PhD Course in

EARTH SCIENCE, FLUID DYNAMICS AND MATHEMATICS. INTERACTIONS AND METHODS

2019-20 Courses

Course: ICE SHEETS AND GLACIERS IN THE CLIMATE SYSTEM
SSD: GEO/02
15+15 hours, 3+3 ECTS
Lecturer/s: A. Camerlenghi (OGS), R. Colucci (ISMAR, CNR), L. De Santis (OGS), E. Forte (Univ. Trieste), R. Francese (OGS), R. G. Lucchi (OGS), F. Pettenati (OGS), M. Rebesco (OGS), F. Colleoni (CMCC), B. Stenni (Univ. Ca' Foscari)

Aims: The course aims to give a current review of modern research into processes and dynamics of the global cryosphere (Glaciers, ice sheets, permafrost) and their connections with climate.

Syllabus:
Lectures will cover arguments linked to glacial dynamics both in the temperate (e.g. the European Alps glaciers) and the cold domains (e.g. Polar cryosphere). A considerable insight into the response of glaciers to climate change and the challenges of predicting future directions in glacier mass balance and dynamics, represents also part of the course. A specific focus is also given to periglacial environments and permafrost. The course will focus both on polar and alpine landscapes, introducing general concepts in regards to glacial and periglacial geomorphology, meteorological and climatological control on the distribution of the cryosphere, ice coring and paleoclimate, ice sheets modelling, polar marine depositional system, and geophysical methods used on ice.

Teaching methods: lectures
Assessment methods: oral/written exam
Other information: the course is delivered in English; it consists of two parts: part 1) Geophysical-geological approach and case studies, resp. Dr. Renata G. Lucchi; part 2) Ice sheets and glaciers in the climate system: Data-model inter-comparison and case studies, resp. Dr. Florence Colleoni.

Course: THE KARST PROCESS: GENESIS, EVOLUTION AND IMPACT IN THE HUMAN LIFE
SSD: GEO/05
30 hours, 6 ECTS
Lecturer: C. Calligaris

Aims: introduce students to the world of karst through the study of geomorphology and hydrogeology

Syllabus:

1.- The Karst process. Definitions. The karst process in the evaporites, in halite, in gypsum, in siliceous rocks, in carbonate rocks. The role of CO_2 in the karst process. Temperature, pressure, mixing.
2.- Karst geomorphology: epigean, marine and hypogean karst features. Sinkholes vs dolines, poljes, caves, springs, mixed origin karst forms. Karst, hyperkarst, parakarst areas in the world.
3.- Karst landscapes and geosystems. The importance of speleology: history, evolution and scientific research.
4.- Modern speleogenesis: history and factors influencing speleogenesis: geographical, geological, physical or hydraulical, climatic and biological. Evolution of karst systems. The role of condensation. The role of sea and thermal waters.
5.- Sedimentation, erosion and paragenesis. Chemical deposits and spelothems in caves.
6.- Structure and morphology of karst systems. Adaptations and changes over time.
7.- Cave explorations, mapping and monitoring.
8.- Karst aquifers. Monitoring karst aquifers. Natural and artificial tracers.
9.- Show caves, human impact, hazard and vulnerability in karst.

Teaching methods: lectures/exercises/surveys
Assessment methods: 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: 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:

<u>Brittle deformation</u>
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
<u>Friction and earthquakes</u>
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
<u>Earthquake Mechanics</u>
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
<u>Viscoelasticity</u>
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
<u>Active deformation</u>
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: EARTH MONITORING WITH SPACE GEODETIC INTERFEROMETRY
SSD: GEO/10
25 hours, 5 ECTS
Lecturer/s: C. Braitenberg
Aims: The Sentinel 1 satellite offers enhanced technology for observing the static and dynamic earth surface. The course aims at achieving a review on the applications in which the observations can be used, discuss the break through achievements and limiting factors compared to other competing methods.

Syllabus:

- 1) The Sentinel 1 satellite. Orbit and coverage, revisit time.
- 2) Sentinel 1 compared to previous satellites. Spatial resolution, time coverage, revisit time.
- 3) Interferograms construction, the role of a good topography model.
- 4) The problem of atmospheric noise on the observations. Atmospheric noise correlation with topography
- 5) Phase unwrapping techniques
- 6) Time series construction with SBAS
- 7) Time series construction with PS
- 8) Common Scene Stacking (CSS) method
- 9) Coseismic deformation
- 10) Postseismic deformation
- 11) Interseismic deformation
- 12) Post-seismic relaxation mechanisms: semi-analytic models of afterslip, poroelastic rebound and viscoelastic flow

Teaching methods: lectures/ reading sessions
Assessment methods: Exposition in the reading sessions
Other information: the course is delivered in English. Basic knowledge in Remote sensing and INAR is required.

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 effect 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.
9. 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: 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: THERMODYNAMICS AND PHYSICS OF THE ATMOSPHERE
SSD: GEO/12
60 hours, 12 ECTS
Lecturer/s: A. Tompkins

Aims: introduce students to thermodynamics and physics of the atmosphere

Syllabus:

1.Dry Thermodynamics
Kinetic theory of heat, Equation of state: The ideal gas law, The first law of thermodynamics, Rules for differentiating , Enthalpy and specific heat, Hydrostatic balance , Special processes , Adiabatic Processes, Potential Temperature, Entropy, Thermodynamic charts

2 Moist Thermodynamics
Saturation Other measures of water vapour Water variables in the liquid and ice state Specific heat of moist air Ways of reaching saturation

3 Atmospheric Convection
Introducing dynamics ,Buoyancy force ,Introduction to convection ,Atmospheric stability ,Convection in the atmospheric boundary Layer ,Single cell deep convection ,Key convective parameters ,Convective triggering ,Mid-tropospheric convection ,Trigger Temperature ,Updraught structure and entrainment ,Downdraughts ,Organised deep convection

4 Cloud Physics
Cloud drop formation , The energy barrier and Kelvin's equation , Diffusional growth , Terminal velocity of particles , Collision and coalescence , Ice crystal nucleation , Ice saturation , Ice nucleation mechanisms , Homogenous nucleation from the liquid phase , Ice crystal growth , Competition between ice nucleation mechanisms , Aggregation , Riming , Ice particle fall-speeds , Ice multiplicationy

5 Radiation
Definitions of the radiative field , Energy balance models of the atmosphere , Sun and Earth Geometry , Radiation interactions with a slab , Direct Radiation , Scattering from other directions , Absorption by atmospheric gases , Scattering

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

Course: ATMOSPHERIC DYNAMICS
SSD: GEO/12
24 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 The General Circulation; Hadley Cell; Ferrell Cell
Lecture 9 Tropical zonal and meridional circulations; Walker circulation; Sverdrup balance
Lecture 10 Energetics of the General Circulation; Lorenz' energy cycle
Lecture 11 and 12 Analysis of climate Variability; EOF analysis, PCA analysis

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

Course: PHYSICS AND DYNAMICS OF THE OCEAN
SSD: GEO/12
60 hours, 12 ECTS
Lecturer/s: R. Farneti, A. Crise, M. Gacic

Aims: introduce students to the main topics of the physics of the ocean

Syllabus:

1. 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.

Suggested readings:
- Benoit Cushman Roisin, 1994: Introduction to Geophysical fluid Dynamics, 320 pp., Prentice Hall, Englewood Cliffs, New Jersey 07632.
- Robert H. Stewart, 2000: Introduction to Physical Oceanography, Dept. Of Oceanography, Texas A&M University, 343 pp.
- Matthias Tomczak, 2002: An Introduction to Physical Oceanography, Flinders University of South Australia in Adelaide, 13 lectures.

(http://www.mt-oceanography.info/IntroOc/newstart.html)

2. 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)

Suggested readings:
- Chapter 1. Data Acquisition and Recording

Data Analysis Methods in Physical Oceanography
W. J. Emery & R. E. Thomson, Elsevier
- Oceanographic Instrumentation

An Introduction to Physical Oceanography (M. Tomczak)
http://www.mt-oceanography.info/IntroOc/lecture13.html
- Underwater gliders for ocean research

http://pordlabs.ucsd.edu/rdavis/publications/MTS_Glider.pdf

3. Dynamics of the Ocean
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: OCEAN DYNAMICS
SSD: GEO/12
24 hours, 5 ECTS
Lecturer/s: R. Farneti, A. Crise

Aims: introduce students to the ocean dynamics

Syllabus:

- Fundamentals: Geostrophy, Thermal Wind and Hydrostasy.
- Ekman Dynamics: the introduction of friction
- Wind-Driven Gyres: The Stommel model
- Wind-Driven Gyres: The Munk model
- Wind-Driven Gyres: Topographic effects
- Thermocline Dynamics
- Meridional Overturning Circulation: Buoyancy driven Overturning
- Meridional Overturning Circulation: Wind-driven Overturning
- The role of the ocean in the global carbon cycle
- Passive tracer transport fundamentals
- The carbon flux and the horizontal ocean
- The carbon flux and the vertical ocean

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

Course: EARTH SYSTEM MODELLING
SSD: GEO/12
60 hours, 12 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: F. Kucharski

Aims: introduce students to earth system thermodynamics

Syllabus:

- Thermodynamic state and state variables; extensive, intensive variables; field quantities; energy, first law; Gibbs equation
- Thermodynamics potentials; second law; thermodynamics equilibrium; multicomponent systems; hydrostatic equation
- Application to dry air; ideal gas law; Daltons law; partial pressures; entropy of mixing; dependency of internal energy of Temperature; Potential Temperature; entropy of dry air; specific heat capacities
- Atmospheric convection; stability; Brunt-Vaisala frequency; lapse rate; dry adiabatic lapse rate
- Moist atmospheric thermodynamics; Virtual Temperature; specific heat of moist air; Clausius Claperon Equation; evaporation parameterization; ways to saturation
- Moist stability; moist enthalpy, moist entropy; equivalent potential temperature; moist static stability; moist adiabate
- Some useful energy quantities; dry static energy; moist static energy; CAPE, CIN, Exergy

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

Course: FLUID MECHANICS
SSD: ICAR/01
48 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: Computational fluid dynamics
SSD: ICAR 01
30 hours, 6 ECTS
Lecturer/s: V. Armenio

Aims: to provide students to build up an algorithm and a computer code for the numerical solution of the Navier-Stokes Equations

Syllabus: Concept of consistence and stability of a numerical scheme, finite differences and finite volume methods;
Numerical solution of the advection-diffusion equation using different time schemes and spatial discretization;
Iterative methods for the Poisson equation: Jacobi, Gauss-Seidel and SOR
Fractional method for the time integration of the incompressible NSE
Consistency of the BCs in the fractional method
Development of the computer code and application to a literature case

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

Course: GEOPHYSICAL FLUID DYNAMICS
SSD: ICAR/01, GEO/12
40 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:

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 8-9 Conservation laws IV: Energy and Bernoulli equations
Lecture 10 Dynamic similarity
Lecture 11 Introduction to Geophysical FD: scales of motion, rotation/stratification in atmosphere and ocean
Lecture 12 Rotating frame of reference: Coriolis force, inertial oscillations, acceleration on a 3-D rotating planet
Lecture 13 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 14 Geostrophy: geostrophic flows; Taylor-Proudman theorem; non-geostrophic flows; vorticity dynamics
Lecture 15 Friction and rotation: Ekman layers
Lecture 16-17 Barotropic waves: Kelvin, Poincarè, Rossby, topographic waves and analogies
Lecture 18 Stratification: static stability, Froude number, combination of rotation and stratification
Lecture 19 Mixing 1: mixing of stratified fluids, Kelvin-Helmoltz instability – Instability of a stratified shear flow
Lecture 20 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 AND MODELLING OF TURBULENCE
SSD: ICAR/01
48 hours, 6 ECTS
Lecturer/s: V. Armenio

Aims: introduce students to turbulence.

Syllabus:

1. Introduction to turbulence
2. Statistical description of turbulence
3. Turbulent scales and Energy cascade
4. Equations of turbulent motion (mean momentum and Reynolds stresses transport equations)
5. Free-shear flows
6. Wall bounded turbulence
7. Numerical methods for turbulent flows (DNS and LES)
8. Analysis of complex turbulent fields

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

1. Introduction to statistical machine learning
2. Graphical models and exact inference
3. Approximate inference for models latent variables
4. Sampling methods
5. Bayesian linear regression and classification
6. Kernel based methods and Gaussian Processes
7. 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).
5. Examples from systems biology, epidemiology, performance of computer networks, ecology.

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: ARTIFICIAL INTELLIGENCE
SSD: INF/01
8 hours, 2 ECTS
Lecturer/s: Enrico Franconi

Aims: This course is about the study of the design of intelligent computational agents, and the emergence of Artificial Intelligence (AI) as an integrated science. The focus is on an intelligent agent acting in an environment and searching for solutions to her problem in the best way she can envisage given the context. Search is an important component of problem solving in artificial intelligence and, more generally, in computer science, engineering and operations research. Combinatorial optimization, decision analysis, game playing, learning, language understanding, planning, pattern recognition, robotics and theorem proving are some of the areas in which search algorithms play a key role. We will go through basic search technologies, and we will see their application to different contexts.
Textbook: David Poole and Alan Mackworth: Artificial Intelligence - Foundations of Computational Agents (2nd Edition). Cambridge University Press, 2017.

Syllabus:

1. Artificial Intelligence and Agents
2. States and Searching
3. Reasoning with Constraints
4. Propositions and Inference
5. Supervised Learning
6. Individuals and Relations
7. Natural Language Understanding

Teaching methods: lectures and some exercises
Assessment: oral exam.
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
1. Numerical Differentiation – Finite Differences
2. Numerical Integration
3. 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: ADVANCED MATHEMATICAL METHODS
SSD: MAT/05
48 hours, 6 ECTS
Lecturer/s: P. Omari, F. Obersnel

Aims: provide students with some tools and methods to analyze basic partial differential equations

Syllabus:

1. Introduction to partial differential equations
2. The linear transport equation
3. The method of characteristics for quasilinear first order equations
4. Scalar conservation laws
5. The diffusion equation
6. The Laplace and the Poisson equations: classical approach
7. Basics on functional analysis and Sobolev spaces
8. Boundary value problems for the Poisson equation: modern approach
9. The wave equation

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

Course: INCOMPRESSIBLE NAVIER STOKES EQUATION
SSD: MAT/05
30 hours, 4 ECTS
Lecturer: S. Cuccagna

Aims: the course introduces some of the basic results of the classical analytic theory of the Navier Stokes equation (NS) in the whole Euclidean space. It is an advanced analysis course aimed at students who know the basics of Functional Analysis, the theory of Distributions and have some at least rudimentary knowledge of the theory of Sobolev Spaces.

Syllabus:

1.- A review of the Fourier transform. The Riesz Thorin interpolation theorem. Heat kernel.
2.- A review of Sobolev Spaces, of the Sobolev Embedding Theorem and some basic notions of Harmonic Analysis
3.- Weak solutions of NS. Energy inequality. Proof of Leray's Theorem of existence of weak solutions in dimension 2 and 3.
4.- Strong solutions of NS in Sobolev spaces.
5.- Uniqueness of weak solutions and energy equality in dimension 2.
6.- Kato spaces Kp(T) and existence of solutions of NS in such spaces. Local well posedness of NS in L^3(R^3).

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

Course: MATHEMATICAL STATISTICS
SSD: MAT/06
30 hours, 6 ECTS
Lecturer: C. Asci

Aims: introduce students to mathematical statistics

Syllabus:

1.- Basics
Populations and samples. Parameter space. Statistics. Average, median, variance, standard deviation, sample moments. Order statistics.
2.- Punctual estimators
Concept of statistical inference. Punctual estimators. Likelihood. Search methods for point estimators: method of moments, method of maximum likelihood. Properties of point estimators: correctness, consistency, efficiency. Distortion. Mean square error. Analysis of variance. Asymptotic normality of the estimators. Fisher information. Sufficient statistics. Exponential models. Bayesian estimators.
3.- Confidence intervals and statistical tests
Confidence intervals and estimate by intervals. Sampling from the normal distribution: confidence intervals for mean and variance. Estimate of a proportion. Statistical tests. Sampling from the normal distribution: test on media and variance. Chi-square test. Test theory.
4.- Linear regression
Linear regression. Multiple linear regression. Prediction and model analysis.

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

Course: PARTIAL DIFFERENTIAL EQUATIONS IN QUANTUM PHYSICS
SSD: MAT/07
8 hours, 1 ECTS
Lecturer: I. M. Sigal

Aims: A review of equations related to the quantum many-body problem, describing origin, physical (and often geometrical) significance, properties and applications. Their origin is in the last fundamental equation of physics - the Schrodinger equation, describing quantum matter such as atoms, molecules, solids and ... stars. Soon after the Schrodinger equation was written it was realized that it is intractable beyond two particle systems and a search for effective approximations began. Some of them will be reviewed in these lectures. I will also review some recent results. The lectures will use only basic results from analysis and geometry and otherwise will be self-contained.

Syllabus:

1. A review of the Hartree and Hartree-Fock equations.
2. A review of the Gross-Pitaevski (or nonlinear Schrodinger) equations.
3. A review of the Kohn-Sham equation (density functional theory)
4. A review of the Ginzburg-Landau equations .
5. A review of the Chern-Simons equations

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

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

Aims: introduce students to the basics of numerical analysis from the computational point of view

Syllabus:

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

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

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

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

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

Syllabus:

A) Finite Difference Methods
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) Finite Element Method (FEM)
Preliminary notions, weak formulation of the Poisson problem, the Galerkin's method, a simple FEM, more general PDEs, Neumann boundary conditions, Inhomogeneus boundary conditions, Robin boundary conditions, curved boundary, higher order finite element spaces, theory of the FEM approximation.

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