Master Degree programme in
Physics of the Earth's Interior, Ocean and Atmosphere

TEACHING PLAN

FIRST YEAR (60 CFU) [*three alternative paths - 60 CFU each*]

Path A: Meteorology and Physics of the Atmosphere (60 CFU)

A.1 Compulsory Courses (24 CFU)	**Semester**	**SSD**	**CFU**
ATMOSPHERIC PHYSICS AND METEOROLOGY	1	FIS/06	6
ATMOSPHERIC CHEMISTRY	1	CHIM/12	6
DYNAMIC METEOROLOGY	2	FIS/06	6
ATMOSPHERIC RADIATION: THEORY AND MODELLING	2	FIS/06	6
A.2 Elective Courses (18 CFU)	**Semester**	**SSD**	**CFU**
MICROPHYSICAL PROCESSES	1	FIS/06	6
CLIMATOLOGY	2	FIS/06	6
LABORATORY OF ATMOSPHERIC MEASUREMENTS AND OBSERVATIONS	2	FIS/06	6
DATA ASSIMILATION FOR DYNAMICAL SYSTEMS	1	FIS/06	6
A.3 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
EARTH OBSERVATION FOR CLIMATE SCIENCE	1	FIS/06	6
MODELS AND NUMERICAL METHODS IN PHYSICS	2	MAT/07	6
INVERSION OF GEOPHYSICAL DATA	1	GEO/10	6
A.4 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/03 - PHYSICS OF MATTER	-	FIS/03	6
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/04 - NUCLEAR AND SUBNUCLEAR PHYSICS	-	FIS/04	6
A.5 Free-choice Learning Activities (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered in our University (010)	-	-	6

Path B: Geophysics of the Solid Earth (60 CFU)

B.1 Compulsory Courses (24 CFU)	**Semester**	**SSD**	**CFU**
FOUNDATIONS OF GEOPHYSICS 1: SOLIDS	1	GEO/10	6
SEISMOLOGY	1	GEO/10	6
EARTH SYSTEM INTERACTIONS	2	GEO/10	6
FOUNDATIONS OF GEOPHYSICS 2: FLUIDS	2	GEO/10	6
B.2 Elective Courses (18 CFU)	**Semester**	**SSD**	**CFU**
LABORATORY OF SEISMOLOGY	1	GEO/10	6
LABORATORY OF NUMERICAL GEOPHYSICS	1	GEO/10	6
LABORATORY OF GEOPHYSICS	2	GEO/10	6
GEOPHYSICAL GEODESY	2	GEO/10	6
TECTONOPHYSICS	2	GEO/10	6
B.3 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
TIME SERIES ANALYSIS AND SIGNAL PROCESSING	2	GEO/10	6
INVERSION OF GEOPHYSICAL DATA	1	GEO/10	6
B.4 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/03 - PHYSICS OF MATTER	-	FIS/03	6
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/04 - NUCLEAR AND SUBNUCLEAR PHYSICS	-	FIS/04	6
B.5 Free-choice Learning Activities (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered in our University (010)	-	-	6

Path C: Physics of the Earth System (60 CFU)

C.1 Compulsory Courses (24 CFU)	**Semester**	**SSD**	**CFU**
PHYSICAL OCEANOGRAPHY	2	GEO/12	6
ATMOSPHERIC PHYSICS AND METEOROLOGY	1	FIS/06	6
FOUNDATIONS OF GEOPHYSICS 1: SOLIDS	1	GEO/10	6
FOUNDATIONS OF GEOPHYSICS 2: FLUIDS	2	GEO/10	6
C.2 Elective Courses (12 CFU)	**Semester**	**SSD**	**CFU**
ATMOSPHERIC RADIATION: THEORY AND MODELLING	2	FIS/06	6
GEOPHYSICAL GEODESY	2	GEO/10	6
CLIMATOLOGY	2	FIS/06	6
DYNAMIC METEOROLOGY	2	FIS/06	6
C.3 Elective Courses (12 CFU)	**Semester**	**SSD**	**CFU**
EARTH SYSTEM INTERACTIONS	2	GEO/10	6
ATMOSPHERIC CHEMISTRY	1	CHIM/12	6
TIME SERIES ANALYSIS AND SIGNAL PROCESSING	2	GEO/10	6
INVERSION OF GEOPHYSICAL DATA	1	GEO/10	6
MODELS AND NUMERICAL METHODS IN PHYSICS	2	MAT/07	6
C.4 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/03 - PHYSICS OF MATTER	-	FIS/03	6
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/04 - NUCLEAR AND SUBNUCLEAR PHYSICS	-	FIS/04	6
C.5 Free-choice Learning Activities (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered in our University (010)	-	-	6

SECOND YEAR (60 CFU) [*three alternative paths for 18 CFU each + 42 CFU in common*]

Path A: Meteorology and Physics of the Atmosphere (18 CFU)

A.6 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
COMPLEX TERRAIN METEOROLOGY	1	FIS/06	6
PLANETARY BOUNDARY LAYER AND TURBULENT DISPERSION	1	FIS/06	6
NUMERICAL LABORATORY OF THE ATMOSPHERE AND THE OCEAN	1	FIS/06	6
A.7 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/01 - EXPERIMENTAL PHYSICS	-	FIS/01	6
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/07 - APPLIED PHYSICS	-	FIS/07	6
A.8 Free-choice Learning Activities (6-6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered in our University (010)	-	-	6

Path B: Geophysics of the Solid Earth (18 CFU)

B.6 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
PHYSICS OF VOLCANISM	1	GEO/10	6
Any activity offered by M.Sc. PHYSICS OF THE EARTH'S INTERIOR, OCEAN AND ATMOSPHERE in the sector GEO/10 - SOLID EARTH GEOPHYSICS	-	GEO/10	6
B.7 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/01 - EXPERIMENTAL PHYSICS	-	FIS/01	6
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/07 - APPLIED PHYSICS	-	FIS/07	6
B.8 Free-choice Learning Activities (6-6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered in our University (010)	-	-	6

Path C: Physics of the Earth System (18 CFU)

C.6 Elective Courses (6 CFU)	Semester	SSD	CFU
COASTAL OCEANOGRAPHY	1	GEO/12	6
PHYSICS OF VOLCANISM	1	GEO/10	6
NUMERICAL LABORATORY OF THE ATMOSPHERE AND THE OCEAN	1	FIS/06	6
C.7 Elective Courses (6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/01 - EXPERIMENTAL PHYSICS	-	FIS/01	6
Any activity offered by M.Sc. 6695 - PHYSICS in the sector FIS/07 - APPLIED PHYSICS	-	FIS/07	6
C.8 Free-choice Learning Activities (6-6 CFU)	**Semester**	**SSD**	**CFU**
Any activity offered in our University (010)	-	-	6

Other Activities for All Students (42 CFU)

9. Professional Skills (6 CFU)	Semester	SSD	CFU
TRANSVERSAL PROFESSIONAL SKILLS	E	-	5
SCRITTURA SCIENTIFICA E TECNICA	2	-	1
10. In preparation for the Final Examination (12 CFU)	**Semester**	**SSD**	**CFU**
INTERNSHIP (12 CFU)	1	-	12
INTERNSHIP 1 (6 CFU)	1	-	6
INTERNSHIP 2 (6 CFU)	1	-	6
PREPARATION ABROAD FOR THE FINAL EXAMINATION	1	-	12
11. Final Examination (24 CFU)	**Semester**	**SSD**	**CFU**
FINAL EXAMINATION	2	-	24

SYLLABUS

Learning activity **ATMOSPHERIC CHEMISTRY**

Areas	
Learning outcomes	At the end of the course, students will get an appropriate understanding of the chemical and physico-chemical processes occurring in the atmosphere and on the causes and consequences of changes in atmospheric chemical composition from the global to the local scale. Special focus will be given to problems related to the stratospheric ozone layer, the greenhouse effect and tropospheric pollution both in the gaseous and in the heterogeneous phases (aerosol). In particular, students will gain the basic knowledge necessary to set up experimental design in the various compositional atmospheric problems (monitoring, trend and time series analysis, processes related to aerosol, outdoor and indoor environments); will possess the mathematical and informatic tools used in investigation methods; will acquire chemical and physical concepts needed to carry out qualitative and quantitative evaluations of the impact of processes induced by anthropogenic activities on the atmosphere by means of receptor-models and source-apportionment techniques. Students will be also capable of communicating about atmospheric chemistry and air pollution using the proper technical terminology.
Course contents	This course provides a detailed overview of the chemical composition of the atmosphere with emphasis on key trace species responsible for air quality and climate change problems. The course includes two modules. Beside introducing the importance of trace species, the evolution of their concentration in time and space at short, medium and large scale is explained together with the experimental tools which make these observations available (detection and measurement). *Composition of the atmosphere under natural and polluted conditions*. The concepts of secondary pollutants and atmospheric lifetime of chemical species in the atmosphere are provided in connection with atmospheric transport and their impacts on the environment, health and climate Photochemistry and other relevant chemical processes will be introduced to explain classical and photosmog basics; stratospheric ozone depletion; oxidation chemistry of the troposphere; sources and sinks of greenhouse gases and other climate forcers. A specific section of the course is devoted to aerosol chemistry and physical chemistry including sources and sinks, classification by size, composition and morphology, concept of primary and secondary aerosol, aerosol metrics, aerosol sampling and measurements, air quality and climate involvements of aerosol *Receptor modeling and source apportionment techniques*, complementary to dispersion models treated in other courses. The course will introduce the main characteristics, the hypotheses and the requisites to be satisfied, the considerations and the analyses to be carried out prior to the development of the proper receptor model. After that, the main typologies of receptor models will be illustrated, with a special focus on some specific models with examples also practical. Finally, hybrid models, adding also dynamical knowledge on wind and/or back-trajectories to further support the results of receptor modeling will be introduced. The module includes the numerical solutions of

	case studies and problems.
Readings/Bibliography	Lecture notes and slides. Jeremy Colls, Abhishek Tiwary: Air Pollution: Measurement, Modelling and Mitigation, Third Edition, 2009, CRC Press. John H. Seinfeld, Spyros N. Pandis : Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, 2nd Edition, John Wiley & Sons, Dec 18, 2012. Mircea, M., Calori, G., Pirovano, G. and Belis, C., European guide on air pollution source apportionment for particulate matter with source oriented models and their combined use with receptor models, EUR 30082 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-10698-2, doi:10.2760/470628, JRC119067.
Teaching methods	The theoretical content of the course will be illustrated by means of slides and the blackboard. Support for the study will be given through additional textbooks, recent publications and reports to check and consolidate topics explained in the lectures. The course also includes some examples from direct research experience in the field and classwork solving receptor modeling problems
Assessment methods	The assessment of the student's learning is conducted by means of an oral test on three questions covering the whole program of the course. Two questions will cover the topics of Module 1, and one question will cover the topics of Module 2. The student is given the opportunity to choose a topic of his/her choice in Module 1 to begin the exam.
Teaching tools	The following items will be available to the Students: * Lectures notes (in pdf format). * Scientific articles and references useful to integrate the material illustrated in the classes * Datasets and specific software for exercitations and solution of specific source apportionment problems

Learning activity **ATMOSPHERIC PHYSICS AND METEOROLOGY**

Areas	
Learning outcomes	At the end of the course, the student: - applies the knowledge of electromagnetism and quantum physics to the processes of absorption and emission of radiation by solids and gases; - knows the energy balance of the planet, energy exchanges with external space and the measures that are used to determine them, as well as their intrinsic limitations; - knows the conservation laws that underlie the dynamics and thermodynamics of the atmosphere and the main forms of instability; - knows the characteristics and properties of gravity waves, baroclines and Rossby waves; - will know the main types of numerical forecasting models of the weather and the problems related to the parametrizations used; - uses the acquired knowledge to interpret data measured by sensors for the study of the atmosphere and to interpret the output of weather forecasting models ; - uses the lecturer's texts and lecture notes written in English and acquires skills in communication on the subject, becoming aware of the English terminology in use; - develops simple models (thermodynamics, greenhouse effect) during exercises; - prepares a report at the end of the exercises and discuss it during the final test.
Course contents	<u>*Introduction to synoptic meteorology*</u>; <u>*Atmospheric thermodynamics*</u>: hypsometric equation, adiabatic processes and Dry Adiabatic Lapse Rate, wet processes, thermodynamic diagrams, static thermal stratification: neutral, stable and unstable, conditional and convective instability, convective inhibition (CIN), convective Available Potential Energy (CAPE) <u>*Dynamics of synoptic systems*</u>: synoptic systems, equation of motion in vector form and in various coordinate systems, equation of continuity, equation for

	energy, scale analysis of the equations of motion, scale analysis of the continuity equation, vertical motions, equation for pressure tendency, solutions of the equations for the gradient wind; inertial wind; cyclostropic wind, geostrophic approximation; *Elements of synoptic meteorology*: fronts: definition and characteristics, cyclones: definitions and characteristics, extra-tropical cyclones, mediterranean cyclones, time maps and their interpretation. *Radiative transfer in atmosphere - basic definitions*: thermal and chemical structure of the atmosphere, radiatively active gases, electromagnetic spectrum, Sun solid angle, monochromatic and total radiance and irradiance; *The Sun*: Sun luminosity and solar constant, solar spectrum, natural variation of solar total irradiance, insolation; *Black body and thermodynamic equilibrium*: Maxwell Boltzmann's distribution, derivation of the Planck's equation, features of the black body model, local thermodynamic, equilibrium in the atmosphere; *Absorption of radiation in the atmosphere*: the law of absorption, monochromatic transmissivity, absorptivity and reflectivity, measures of solar radiation from the ground: smithsonian method; *Emission of radiation in the atmosphere*: the source function, the Schwarzschild's equation, brightness temperature; *Introduction to scattering*: scattering regimes, a simple scattering model; *Measuring trace gases in the atmosphere*: ozone total column from ground, differential absorption spectroscopy, scattered light DOAS; *Energy balance 1-D models*: radiative heating in the atmosphere, BDRF and spherical albedo, Earth emission, radiative equilibrium of a planet; *Greenhouse effect*: greenhouse parameter, radiative equilibrium in a window black/grey atmospheric model, greenhouse model and climate sensitivity; *Radiation and Temperature profile*: multiple layers window gray model, equilibrium temperature profile, runaway greenhouse; *Climate sensitivity and feedbacks*: climate radiative forcing: external and anthropogenic, equilibrium response to radiative forcing (i.e. Volcanic eruption), equilibrium, climate sensitivity, feedbacks; *Radiative time constant*: Dark side temperature, adiabatic and radiative lapse rate; *Energy balance*: global energy balance and Trenberth plot, cloud forcing and feedback, latitudinal mean distribution of radiative fluxes, mean energy balance at the surface
Readings/Bibliography	The lecture notes (in English) shall be available online. The lecture notes also contain an extensive bibliography. Atmospheric Science, an introductory survey. John M. Wallace and Peter V. Hobbs, second edition Academic Press 2006.
Teaching methods	The lectures will be provided by making extensive use of multimedia materials
Assessment methods	The verification text consists in a single oral examination and covers all the topics of the program.
Teaching tools	PC and video projector. More complex classroom activities can be performed on a PC or with a personal notebook.

Learning activity **ATMOSPHERIC RADIATION: THEORY AND MODELLING**

Areas	
Learning outcomes	At the end of the course the Student: - knows the main physical processes governing the interaction between solar and terrestrial radiation with the atmosphere, aerosols and surfaces; - knows the fundamentals laws of the radiative transfer: learns the phenomenology and equations governing the physics of the radiative energy transfer by electromagnetic waves in a multiple scattering environment; - knows the role of clouds and aerosols and their interaction with shortwave and longwave radiation and is capable to model their radiative processes - is able to apply approximations to the radiative transfer general equation in order to interpret radiance fields in different regimes - is able to implement numerical modelling techniques for radiative transfer algorithm; - knows the basics of the satellite remote sensing and of the inversion techniques based on the optimal estimation; - uses texts and lecture notes written in English and is able to communicate about radiative transfer in atmosphere using the proper terminology

Course contents	*Introduction, basic definitions*: Summary of the basics. Radiometry and Photometry *Spectroscopy*: Molecular energy levels, Electric dipole, Rotational transitions, Vibrational transitions, Line Shapes *Thermodynamic equilibrium*: LTE e NLTE, Schwarzchild equation, Curve of growth, Complex RI *Shortwave RT*: Absorption of sw radiation, Ozone cycle, Heating rates Rayleigh scattering: Overview of scattering , Rayleigh scattering , Airlight *RT equation and Scattering*: RT equation for MS events, The Mie solution, Stokes parameters *Cloud properties*: Single scattering properties of single particles, Particle size distributions, Optical properties of cloud and aerosols, *Reflectance from surface and thin clouds/aerosols*: BDRF, Albedo, Single scattering approximation, aerosols *Polarization and Radar-lidar equation*: Polarization of light, Active sensors, Depolarization ratio *Longwave RT*: IR absorption and weighting functions, LbL computations LW cooling rates, Cooling rates in presence of clouds *Principles of inversion methods*: Direct linear inversion, IR inversion problems, optimal estimation, regularizations *Advanced topics in Radiative Transfer*: General form of the RT equation, Legendre polynomial, Azimuth independent solution , Approximate solutions of the RTE, Two-stream approximation, Similarity principle and δ-function approximation
Readings/Bibliography	* T. Maestri, lectures notes on radiative transfer and remote sensing * K.N.Liou: An introduction to atmospheric radiation. Academic Press * K.N.Liou: Radiation and cloud processes in the atmosphere. Oxford University Press
Teaching methods	The theoretical content of the program will be illustrated using the video projector and the board. Simple problems will be solved during the classes (or suggested as homework) to facilitate the understanding of the theoretical part of the program. A numerical modelling part is also foreseen. In this case the students (in group) will use a personal computer to implement coded algorithms and solve simple radiative transfer equations.
Assessment methods	The assessment of the student's learnings is performed by an oral test which serves to evaluate the achievements of the main objectives of the course: - understanding the fundamental laws regulating the radiative transfer in atmosphere - the ability to implement numerical solution of the proposed problems The test will cover the whole program. The student is given the opportunity to choose a topic of his/her choice with which to begin the exam. The oral test will last at about 50 minutes/1 hour.
Teaching tools	The following items will be available to the students: * Lectures notes (in pdf format). * Scientific articles useful for the investigation of specific lines of research. * Software algorithms (in MATLAB) for the numerical solution of specific problems. * Bibliography and references including web pages

Learning activity **CLIMATOLOGY**

Areas	
Learning outcomes	Upon successful completion of this course, the student knows: -the observed climatology of the Earth's surface and atmosphere; -the phenomenology and models of the general circulation of the atmosphere; -advanced topics of large-scale meteorology and mechanisms of large-scale climate variability. Upon successful completion of this course the student can: use statistical methods used in climate analysis; use the relevant scientific literature; interpret climate data.
Course contents	The course aims to provide knowledge of the physical aspects of the Earth's climate system, of its dynamics and of the factors that determine its variability. The main mechanisms influencing climate will be taught, including interaction between the different components, global balances, and fluxes. The atmosphere and ocean general circulation and their main mechanisms of variability will be reviewed in the framework of climate and climate variability.

	Finally, students are introduced to climate data analysis.
Readings/Bibliography	Introduction to Circulating atmospheres, Ian James Cambridge University Press (1994) Dennis L. Hartmann: Global Physical Climatology ; Academic Press, (2015). 2nd edition, ISBN: 978-0123285317
Teaching methods	Frontal lectures
Assessment methods	The final exam is intended to verify the understanding/comprehension of all phenomenological, mathematical/statistical aspects. The final exam consists in an oral examination during which the student will be asked generally three questions
Teaching tools	PC, PROJECTOR, BLACK BOARD

Learning activity **COASTAL OCEANOGRAPHY**

Areas	
Learning outcomes	At the end of the lecturing period students are acquainted with the theoretical and analytical concept needed to face the study of the coastal ocean dynamics. Particular emphasis is put on: Solid boundaries, Tides, land based mass input. In addition they acquire basic knowledge of the physical processes regulating biological and biogeochemical processes of the coastal ocean.
Course contents	Introduction (main characteristics of the coastal circulation). The wind driven coastal circulation. Coastal upwellings. The benthic boundary layer Tides (theory) The tides forcing on the coastal circulation. Buoyancy effects on coastal circulation. Marine coastal biogeochemical processes and physical dynamics.
Readings/Bibliography	Lecture notes (powerpoint slides) and additional material provided by the teacher.
Teaching methods	Lecturing
Assessment methods	The assessment will be carried out by an oral exam: It is expected that the student discusses 3-4 topics from the course syllabus. The first topic will be chosen by the student. The final score will be based on the student ability to approach in a formal way the problem treated and on his/her ability to discuss from a physical oceanograhy point of view the solution to the problem.
Teaching tools	Lecturing with powerpoint slides.

Learning activity **COMPLEX TERRAIN METEOROLOGY**

Areas	
Learning outcomes	Upon completion of the course, the student will have developed a solid grounding of the physical mechanisms and the governing equations that underlie key atmospheric phenomena in complex terrain. The student will be able to critically explain and analyze the influence of terrain features—such as orography and land cover or land use heterogeneities—on atmospheric processes and the associated circulations at meso- and micro-scales. Moreover, the student will understand how ground-based atmospheric observations are used to characterize boundary layer dynamics over complex terrain, and will be familiar with the main analytical models in the literature, including the simplifications and scaling arguments on which they are based.
Course contents	Starting from a brief review of the fundamental physics laws governing the dynamics and thermodynamics of the atmosphere at the mesoscale, the course will introduce the concept of “complex terrain”, its declinations over different spatial scales (meso- to micro- scale) and geographic conditions, and then deals with specific meteorological phenomena occurring in complex terrain. The course has a major focus on mountain meteorology, but also covers to a minor extend urban meteorology and other advanced topics. Mountain Meteorology: Thermally driven slopes flows: Historical perspective, analytical models and observations. Components, diurnal cycle, and synoptic disturbances of the mountain

	thermally driven circulation. Thermal structure of the valley atmosphere - the topographic amplification factor. Cold-air pool (CAP) Dynamically forced winds over mountains: 2D and 3D obstacle configurations. Downslope windstorms: shallow-water hydraulic theory, vertical propagating wave theory, wave breaking theory Characteristics of the atmospheric boundary layer in complex terrain. Boundary layer observations in mountainous regions: results from major field campaigns, current challenges, and key applications. Additional topics Analysis of the role of thermal and aerodynamic roughness discontinuities and heterogeneities in the formation of internal boundary layers Urban flow patterns from meso- to micro-scale over cities: an introduction to urban meteorology. Thermally driven circulations: the urban heat island circulation; the sea breeze circulation and their interaction.
Readings/Bibliography	Required materials for exam preparation: Lecture notes and slides provided by the instructor during the course, available on the online platform Virtuale. Recommended texts for further reading: Markowski, Paul, and Yvette Richardson. Mesoscale meteorology in midlatitudes. John Wiley & Sons, 2011. Barry, Roger G. Mountain weather and climate. Routledge, 2013. De Wekker, Stephan FJ, and Bradley J. Snyder. Mountain weather research and forecasting: recent progress and current challenges. Ed. Fotini Katopodes Chow. Vol. 750. Berlin: Springer, 2013. Whiteman, C. David. Mountain meteorology: fundamentals and applications. Oxford University Press, 2000. Relevant scientific articles may be suggested by the instructor during the course for in-depth exploration of specific topics.
Teaching methods	Face-to-face lectures, supported by PowerPoint presentations and additional explanations on the whiteboard.
Assessment methods	Learning will be assessed through a final oral examination of the duration of 50-60 minutes composed of three distinct parts: • The first part invites the student to present and discuss a topic of their choice from the material covered during the course. • The second part involves a question selected by the instructor, addressing a specific concept or theme explored in the lectures. • The third part consists of an integrative question designed to evaluate the student’s ability to connect and critically reflect on the main theoretical, analytical, and phenomenological elements addressed throughout the course. Each part of the exam contributes equally (one-third) to the final grade. The final grade will be expressed on a scale of 30, according to the grading criteria outlined below. Preparation on a very limited number of topics covered in the course and analytical skills that emerge only with the instructor's help, overall correct language usage → 18-19; Preparation on a limited number of topics covered in the course, with independent analytical skills limited only to basic or purely procedural matters, expression in correct language → 20-24; Preparation covering a broad range of topics addressed in the course, with the ability to make independent choices in critical analysis and a solid command of subject-specific terminology → 25-29; Thorough and comprehensive preparation on the topics addressed in the

	course, strong independent critical thinking and ability to establish coherent connections within the subject domain, full mastery of specific terminology, ability to formulate well-reasoned scientific arguments → 30-30L
Teaching tools	Lectures will be delivered by the instructor using both a video projector and the blackboard. To support learning, the following materials will be provided: • Lecture notes in PDF format • Selected scientific articles and reference materials to complement and deepen the topics covered in class

Learning activity **DATA ASSIMILATION FOR DYNAMICAL SYSTEMS**

Areas	
Learning outcomes	The course aims at introducing the foundation of data assimilation, the term used in geoscience to refer to state estimation theory. Data assimilation encompasses the entire sequence of operations that, starting from the observations of a system, and from additional statistical and/or dynamical information (such as an evolution model), provides an estimate of its state. It is common practice in numerical weather prediction, but its application is becoming widespread in many other areas of climate, atmosphere, ocean and environment modelling. The course will provide first the formulation of the problem from a Bayesian perspective and will then present the two popular families of Gaussian based approaches, the Kalman-filter/-smoother and the variational methods. Ensemble based methods will then be considered, starting from the well-known Ensemble Kalman filter, in its stochastic and deterministic formulations, and then the state-of-the-art ensemble-variational methods, as well as particle filters. The course will focus on the specific challenges that data assimilation has encountered to deal with high-dimensional chaotic systems, such as the atmosphere and ocean, and the countermeasures that have been taken and which have driven the recent dramatic development of the field. An overview of the nowadays and near future challenges for the discipline will conclude the course, with a focus on modern supervised machine learning methods and their use in numerical weather predictions and data assimilation.
Course contents	○ Outlook on Probability theory and stochastic processes ● The inference problem under a Baysiean framework ○ Representation of the physical and of the observational systems ○ The three estimation problems: Prediction, Filter and Smoother ○ Statistical interpolation ● Linear estimation theory ○ Gauss-Markov Models ○ Observability and controllability ○ Minimum variance formulation - Kalman filter and smoother ○ Maximum a-posteriori formulation - Variational formalism ○ Joint state-parameter estimation ○ Filtering versus smoothing ○ Expectation maximization ● Nonlinear estimation theory: the ensemble Kalman filter and 4DVar ○ Minimum Variance approaches: ● The extended Kalman filter ● The ensemble Kalman filter and smoother ● Stochastic and Deterministic EnKF ● Filter stability and divergence ● Making the EnKF works: Inflation and localization ● Nonlinear least squares ○ Gauss-Newton ○ Adjoint-based minimization ○ 3D- and 4D-Var ○ Hybrid ensemble-variational techniques and other iterative methods ● Fully Bayesian estimation: Particle filters ● Data assimilation and Chaos ● Data assimilation and machine learning similarities and key differences

	○ Estimating a model using ML ○ Estimating a model using DA ● Combining DA and ML
Readings/Bibliography	The lecture notes (in English) shall be available online. The lecture notes also contain an extensive bibliography. Suggested readings: https://wires.onlinelibrary.wiley.com/doi/abs/10.1002/wcc.535 https://epubs.siam.org/doi/book/10.1137/1.9781611974546
Teaching methods	Lectures are given in person in the classroom using slides as well as the blackboard. The course includes up to 3 seminars given by scientists working on data assimilation or related.
Assessment methods	The final assessment will be under the form of an oral exam (~45 mins) where the student will be posed a number of questions aimed at inspecting the student's degree of understanding of the concepts, methods, and problems explained in the course.
Teaching tools	Blackboard, projected slides and computer simulations.

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Learning activity **DYNAMIC METEOROLOGY**

Areas	
Learning outcomes	The purpose of the course of Dynamic Meteorology is to provide a deeper learning of the basic dynamical processes underlying the general atmospheric circulation and its variability on relatively short time scales, with the approach of Physics. Such variability is associated with the evolution of meteorological phenomena and with the practical problem of short and medium range weather forecasting and its applications. The main topics of dynamic meteorology are treated, regarding the general circulation and the synoptic scale and mesoscale phenomena. The equations of motion, their properties and analytical or numerical solutions are analyzed, including waves, instability processes, linear and nonlinear effects and the fundaments of meteorological modelling. The presentation of various theoretical aspects having didactical relevance is conducted in parallel with the examination of the properties revealed by the analysis of observational data.
Course contents	The course is made of two parts: the first one is theoretical and the second one is based on Laboratory experiences: The syllabus of theoretical part is: Historical elements on the development of main ideas and methods in Dynamic Meteorology and numerical weather forecasting, both deterministic and probabilistic. Overall phenomenological characteristics of the global circulation, defined on the basis of numerical model reanalyses, and their physical interpretation. Principal phenomena of the atmospheric circulation, structural and spectral analysis and classification on the basis of the various space-time scales of motion. Effects induced by the seasonal cycle. Comparison of quasi-periodic and chaotic phenomena of the general cicrculation. Derivation of the equations of motions of the atmosphere in spherical geometry and related appropriate scaling Coordinate transformations and equations of motions in isentropic coordinates Derivation of the Ertel's theorem and conservation of potential vorticity Circulation and related theorems (Kelvin, Bierknes); circulation and vorticity Dynamical and diagnostic applications of potential vorticity. Principle of invertibility of potential vorticity Atmospheric wave dynamics and identification of basic modes in simplified cases. Sound, gravity waves, Rossby waves, free and forced by the earth orography and distribution of thermal sources). Atmospheric flows over topography, in two and three dimensions. Properties of orographic waves and of different flow regimes over orography Derivation of the quasi-geostrophic approximation and properties of the simplified set of equations. Application to the Rossby wave dynamics. Rossby's problem of geostrophic adjustment. Variability of the extra-tropical atmospheric circulation. Baroclinic instability and the Eady model. Properties of the neutral and unstable baroclinic modes. Detailed syllabus of the experience part:

	Four experiences devoted to the use of Weather Research and Forecasting (WRF) model to simulate and analyse characteristic phenomena studied in the theoretical part. Students will be introduced to numerical modelling and the modelling approach of WRF. Then, the model will be set up to run a didactic test case. Finally, students will be asked to run their own simulations on a case study of their choice. Lab1: Introduction to atmospheric modelling using WRF. Topic: Introduction to basic concepts of atmospheric numerical modelling and description of WRF. Insight into the modelling approach of WRF and verification of the correct installation of WRF. Lab2: Setup of WRF simulations and Run a test case Topic: Practical setup of the operational domain grid and model configuration. Preparation of the static data from the GEOGRID module for an example study domain and download the initial and boundary conditions for it. Prepare the input data and configure the WRF name-list for the simulation. Run WRF. Lab3: Analysis of the simulation and recognition of the theoretical aspects. Topic: Visualization of the simulation results. Data management and computation of the graphical results. Data analysis using the simulation results to compute quantities of physical interests. Evaluate the physical and theoretical aspects from a practical application. Lab4: Build your own case study Topic: Hints on possible atmospheric phenomena to be simulated using WRF. Setup and simulation of case studies selected by the students.
Readings/Bibliography	- suggested textbooks: J. Holton: Introduction to Dynamic Meteorology - 3rd Ed. (Academic Press). H.B. Bluestein: Synoptic-Dynamic Meteorology in midlatitudes (2 vol., Oxford Univ. Press). E. Kalnay: Atmospheric modeling, data assimilation and predictability (Cambridge U. Press). - additional textbooks for further consultation: M. Satoh: Atmospheric Circulation Dynamics and General Circulation Models (Springer). J. Pedloski: Geophysical Fluid Dynamics (Springer-Verlag); R. A. Houze: Cloud Dynamics (Academic Press). R.A. Pielke, 2002: Mesoscale Meteorological Modeling. 2nd Edition (Academic Press). J. E. Martin, 2006: Mid-Latitude Atmospheric Dynamics - A First Course (Wiley). H. Lynch, J. J. Cassano, 2006: Atmospheric Dynamics(Wiley). Y.L. Lin, 2007: Mesoscale Dynamics (Cambridge U. Press).
Teaching methods	The theoretical part is based on traditional teaching using slides and the blackboard. The lectures are complemented with some forecasts from typical weather forecasting models to illustrate specifc features. The experience part in based on numerical experiments run at the PC. Students will use the informatic Lab for this part.
Assessment methods	The verification is based on the final oral exam valid for both parts. It is based on three main questions. The first question is based on the Lab experience, the second question is a topic that the student can choose from those treated during the course. The third question is a more comprehensive question aimed at assessing the learning and understanding, by the student, of the conceptual, analytical and phenomenological elements treated in the course lectures. The final mark is made by 1/3 for the first question, 1/3 for the second and 1/3 for the third.
Teaching tools	PC and media tools. Blackboard

Learning activity **EARTH OBSERVATION FOR CLIMATE SCIENCE**

Areas	
Learning outcomes	Satellite Earth observation is an essential tool that allows a global and integrated view of the whole earth system, allowing quantitative measurements of a large number of relevant geophysical parameters including essential climate variables. In this courses, the students will learn the main capabilities of current satellite earth observing system and the main techniques used for the derivation of key products concerning the earth's atmosphere and surface properties. Practical exercises on satellite data

	analysis will be proposed during the classes.
Course contents	1 Satellite measurements of LW and SW radiance fields (2h: theory) •Introduction to satellite measurements and retrieval •Effective Bi-Directional Reflectance Function •Surface spectral signatures at sw •Brightness temperature •Surface emissivity at lw •The 4 microns band 2 Multi Spectral Radiometers: Detection of snow and vegetation (4h: theory and practice) •AVHRR, ABI, SEVIRI and MODIS •Normalized difference snow index•Fractional snow cover •Ice surface emissivity and temperature •Vegetation index •Leaf Area index and Enhanced VI •Atmospheric perturbations on snow and vegetation index 3 Sea surface temperature (2h: theory and practice) •Absorption and emission of radiation by sea water •Sea Surface temperature from infrared radiometers 4 Fire detection (2h: theory and practice) •Fire Radiative power T •Physical rationale: Temperature sensitivity •Multichannel threshold and contextual algorithms •Normalized burn ratio 5 Water Vapor and Land Surface temperature •Precipitable water vapor from sw channels •Split window techniques: Land surface temperature 6 RGB techniques (2h: theory and practice) •The process of creating RGB: examples • Meteosat RGBs: natural, airmass, dust 7 Detection of aerosols from passive methods (2h: theory and practice) •Radiative transfer equation in single scattering approximation •Aerosol reflectance over black and reflective surfaces •Global aerosol optical depth 8 Detection of clouds from passive measurements (4h: theory and practice) •The full radiative transfer equation and the cloud parameters •Detection of thin cirrus clouds •Cloud phase derivation: techniques •Cloud altitude: co2 slicing and sorting •Nakajima-King method for cloud OD and Reff 9 Sounder data (4h: theory) •The information content in the high spectral resolution measurements•Inversion techniques for derivation of gas and temperature profile •Optimal estimation, the role of the a-priori information •Detection of volcanic ash and outgas •Examples from IASI Basics of satellite orbits and sensor parameters: Geostationary and low Earth orbits Parameters: Pixel, Field of view, dwell time Scanning techniques: whiskbroom and pushbroom sensors Sensor noise: NeSR, NeDT, SNR Resolution: temporal, spatial, spectral, radiometric Dataset and products: Climate Data Records, Copernicus Services The Earth's atmosphere and surface in the microwave spectrum: RTE in the microwave, Absorption and emission of gases, Properties of water vapour and particles,Surface emissivity; Microwave active sensors: radar equation, ground based and space-borne systems; Techniques to estimate precipitation rates with passive sensors: The GPM constellation, Statistical and physical methods, Blended techniques; Techniques to estimate snow/ice parameters: microwave emission from snow and glacier ice Techniques to estimate soil moisture: microwave emission from wet soil, space gravimetry Validation of satellite products
Readings/Bibliography	Lecture notes and selected articles and documents
Teaching methods	The Teachers will develop the course content (6 ects) by using both the blackboard and the video projector. The topics comprise a theoretical part (front lecture) followed by application and exercises using simple software tools (in MATLAB) for the visualisation and analysis of satellite data.
Assessment methods	The assessment of the student's learnings is obtained by means of an oral test which serves to evaluate the achievements of the main objectives of the course: *) understanding the fundamental laws regulating the radiative transfer in atmosphere and their application to measurements *) understanding the main satellite measurements' methods *) the ability to interpret satellite remote sensing data and products of atmosphere and surface Students should demonstrate to be familiar and have a good understanding of the different subjects. The organization of the presentation and a rigorous scientific language will be

	also considered for the formulation of the final grade. The oral test will last at about 1 hour. A final grade (out of 30) is foreseen. The “cum laude” honor is granted to students who demonstrate a personal and critical rethinking of the subject
Teaching tools	The following items will be made available to Students: * Lectures notes (in pdf format). * Scientific articles useful for the investigation of specific lines of research. * A data analysis software kit (in MATLAB) and satellite data * Bibliography and references

Learning activity **EARTH SYSTEM INTERACTIONS**

Areas	
Learning outcomes	The student learns how to evaluate and model some of the interactions between the Solid Earth and other components of the Earth system, such as the Hydrosphere and the Cryosphere, which give rise, on various time scales, to global phenomena that can be measured using techniques geophysical and geodetic and cannot be fully understood through a sectorial approach.
Course contents	The first part of the course will examine the data and observations that highlight the interactions between the Solid Earth and other components of the Earth System, on various space and time scales. Geophysical evidence will be considered, linked for example to global geodynamics, variations in the volume of the oceans, deformations of the earth's crust caused by variations in the mass of continental ice, the temporal evolution of the cryosphere, isostatic phenomena, etc. In the second part, the theories and physical models useful for the quantitative description of the phenomena arising from the interactions highlighted in the first part will be described. Various topics will be touched, including the shape of the Earth, the gravity field and its variations, the rheology of geophysical materials, the response of the Earth to redistributions of mass at its surface, the rotation of the Earth, the Sea Level Equation, etc. Finally, in the third part of the course, exercises based on open source numerical calculation codes, easy to use and well documented, will be proposed, which describe the interaction between Solid Earth, Oceans and Cryosphere, developed by the teacher over the years. In this way, students will have the opportunity to directly compare the model predictions with the available geophysical and geodetic observations.
Readings/Bibliography	The slides can be used as study texts, if accompanied by in-depth readings progressively recommended by the teacher. Texts and online resources will be suggested (texts, scientific papers, tools and web sites of interest for understanding the interactions between the Solid Earth and the various components of the Earth System), useful as a complement to the lessons lecture notes.
Teaching methods	Classroom lessons and seminars in which students actively participate, intervening with monographic reports or participating into discussions.
Assessment methods	The verification consists of a final oral exam. The student will be asked to discuss three topics among those covered in the course. The student will be able to prepare one of the three topics in the form of a short-written dissertation.
Teaching tools	Computer, beamer and blackboard

Learning activity **FINAL EXAMINATION**

Areas	
Learning outcomes	At the end of the final examination, the student presents a written dissertation on topics related to the physics of the atmosphere, the ocean, and the Earth's interior, as well as their mutual interactions. In preparation for the final exam, the student carries out a high-level educational activity, which involves scientific research and/or technological development work at national or international laboratories or research institutions, under the guidance of a supervisor. The student addresses a cutting-edge topic within the chosen specialization. The work can be theoretical, computational, and/or experimental, constituting an in-depth study in the selected field.

	In particular, the student applies and develops models for optimizing experiments or interpreting observed phenomena, solving them using analytical or computational methods. Within these activities, the student: • Demonstrates an advanced application of investigative methodologies in the chosen field; • Is able to perform productive work as part of a well-coordinated team; • Is capable of organizing, presenting, and discussing the work in the final dissertation.
Course contents	-
Readings/Bibliography	-
Teaching methods	-
Assessment methods	-
Teaching tools	-

Learning activity **FOUNDATIONS OF GEOPHYSICS 1: SOLIDS**

Areas	
Learning outcomes	At the end of the course, the student has the fundamental concepts of continuum mechanics, the basic concepts of tensor algebra, stress and strain tensors, constitutive relations for elastic and poroelastic materials, the state of stress in the Earth, faulting and intrusion phenomena. In particular, the student is able to: - distinguish and characterize the various stress regimes present in the Earth; - solve some equilibrium problems in elastic media; - solve elementary dislocation problems.
Course contents	Mechanics of continuum media. Stress and strain. Conservation laws. Thermo-Elastic materials. Elastic and adiabatic moduli. Isotropic elastic media. Constraints on elastic moduli. Equations of motion (Cauchy-Navier). Elastic waves: polarization, boundary conditions at a free surface, a compositional interface, a solid-fluid interface. Stress within the Earth, uniaxial and plane configurations, tectonic environments, theories of faulting. Elastostatic plane problems in a half-space: the Airy stress function. Potentials in the theory of elasticity. Solution of elastostatic problems: pressurized spherical shell, response to a point force in a full space (Somigliana tensor). Elastic dislocations and their representation. Darcy's law and poroelasticity.
Readings/Bibliography	Lecture notes (Proff. Maurizio Bonafede, M.E. Belardinelli) which will be available online (on Virtuale platform).
Teaching methods	Classroom lectures using slides.
Assessment methods	Oral examination: typically 3 questions are proposed to assess the student's theoretical knowledge of the Mechanics of elastic solids and its application to the study of the interior of the Earth. The duration of the examination is about 1 hour. The candidate is likely to be requested both to prove the main theoretical results and to estimate some of the physical parameters of the Earth interior.
Teaching tools	Slides will be available online (on Virtuale platform). Students with DSA or temporary or permanent disabilities: it is recommended to contact the responsible University office in good time (https://site.unibo.it/studenti-con-disabilita-e-dsa/it): it will be their responsibility to propose any adaptations to the students concerned, which must however be submitted, 15 days in advance, to the approval of the teacher, who will evaluate the opportunity also in relation to the educational objectives of the course.

Learning activity **FOUNDATIONS OF GEOPHYSICS 2: FLUIDS**

Areas	
Learning outcomes	The student will acquire the fundamental theoretical concepts of fluid dynamics mainly for Newtonian rheologies, with some hints also on non-

	Newtonian rheologies, with a constant attention paid to problems of geophysical interest. In particular, the student will be able to: - characterize the different regimes of propagation of gravity waves in homogeneous as well as in stratified fluids; - quantify the conditions for the onset of instabilities due to differences in velocity, angular velocity, temperature; - understand the key concepts of turbulence.
Course contents	*General introduction*: Recap on continuum mechanics: the fundamental tensors used in fluid dynamics and the constitutive relations, Newtonian fluids, Conservation laws, the Navier-Stokes equations, laws of thermodynamics, Laminar flows and transition to turbulence: the Reynolds number, Hints on non-Newtonian fluids, Equations in a rotating planet: the vorticity equation, The Boussinesq approximation; *Waves in fluids*: Gravity waves at the free surface of a fluid layer, shallow water and deep water approximations, Surface tension and capillary waves, Stationary waves, Internal waves in stratified fluids; *Instability*: Kelvin-Helmholtz instability, Rayleigh-Taylor instability, Rayleigh-Bénard natural convection, convection in internally heated fluids; *Introduction to the theory of turbulence*: Reynolds decomposition, Equations governing turbulent flows, Energy balance for the average flow and for the turbulent flow, Cascade turbulence production, the Kolmogorov micro-scale, the Kolmogorov spectrum in the sub-inertial range
Readings/Bibliography	Lecture notes provided by the teacher at https://virtuale.unibo.it after each lecture. Most of the topics presented during the course can be found in: Pijush Kundu, Ira Cohen, David Dowling: Fluid Mechanics - Academic Press. The most recent edition is the sixth, published in 2015. Donald Turcotte, Gerald Schubert: Geodynamics - Cambridge University Press, 3rd Edition, 2014. Etienne Guyon, Jean-Pierre Hulin, Luc Petit, Catalin D. Mitescu: Physical Hydrodynamics (2nd Ed.) - Oxford University Press, 2015. Some papers on specific topics will be made available in Virtuale: the students may optionally read them to get a bit more into the details of those topics.
Teaching methods	Classroom lectures using the video projector and the board. Attending the lessons is not compulsory, but it is warmly recommended for the learning process.
Assessment methods	The learning assessment consists of an oral examination based on which a mark will be proposed. The examination, which usually foresees three questions on different topics, aims at evaluating the knowledge of the student and her/his independence in reasoning. The exam does NOT foresee any written report to be delivered by the student before the exam. The exam duration is about one hour on average.
Teaching tools	In addition to the material taught during the lessons in pptx and pdf formats, the teacher will upload on the "Virtuale" platform few simple codes allowing the students to become acquainted through a "hands on" approach with some of the theoretical concepts illustrated during the lessons. The teacher will also provide a list of web links related to topics of interest to the course.

Learning activity **GEOPHYSICAL GEODESY**

Areas	
Learning outcomes	At the end of the course the students will have learned the basic concepts related to modern geodesy. In addition, they will be able to appreciate, through case studies, the role that this discipline plays on knowledge in various fields of geophysics and in particular in the context of Earth System Physics.
Course contents	Introduction to Geodesy. Mathematical foundations and harmonic functions. Mass distributions. Newton's Law. The Earth's gravity field and the geoid. Motion of satellites in a non-central field. Global gravity field models. Satellite methods. Undulations of the geoid. Isostasy. Tides. Love numbers. Harmonic expansion of the gravitational field. The Earth’s movements. Reference systems. Geodesy and climate change. Case studies. Space geodetic techniques and their applications in the study of the Earth system, with a particular focus on the Global Navigation Satellite System (GNSS). The course covers GNSS data processing methods, procedures for

	generating coordinate time series, and methods to analyze noise and geophysical signals within these series. Students will learn techniques for estimating displacement velocities and deformation rates, as well as for computing, visualizing, and interpreting these quantities. This part includes case study analysis in the fields of seismotectonics (plate tectonics and the seismic cycle) and environmental geodesy (hydrology and land subsidence). Learning will be supported using collaborative computational tools, enabling students to explore some of the studied topics using real or synthetic data and to develop their analytical and problem-solving skills.
Readings/Bibliography	Torge W, e Müller J. Geodesy. Walter de Gruyter, 2012; Lambeck K. Geophysical geodesy, Oxford: Clarendon, 1988; Hofmann-Wellenhof B, e Moritz H. Physical geodesy. Springer, 2006; Wahr J. Geodesy and Gravity (class notes), Samizdat Press, 1996.
Teaching methods	Classroom lessons and seminars in which students actively participate, intervening with monographic reports or participating into discussions. Python notebook and/or Matlab codes.
Assessment methods	Oral exam
Teaching tools	Computer, beamer and blackboard

Learning activity **INTERNSHIP (12 CFU)**

Areas	
Learning outcomes	In preparation for the final exam, through direct experience at highly specialized research institutions, either external or internal to the University, with controlled observation activities or hands-on experiences, the student has tested the application of theoretical concepts and foundational knowledge to solve practical problems, gaining familiarity with the techniques required in research.
Course contents	-
Readings/Bibliography	-
Teaching methods	-
Assessment methods	-
Teaching tools	-

Learning activity **INTERNSHIP 1 (6 CFU)**

Areas	
Learning outcomes	In preparation for the final exam, through direct experience at highly specialized research institutions, either external or internal to the University, with controlled observation activities or hands-on experiences, the student has tested the application of theoretical concepts and foundational knowledge to solve practical problems, gaining familiarity with the techniques required in research.
Course contents	-
Readings/Bibliography	-
Teaching methods	-
Assessment methods	-
Teaching tools	-

Learning activity **INTERNSHIP 2 (6 CFU)**

Areas	
Learning outcomes	In preparation for the final exam, through direct experience at highly specialized research institutions, either external or internal to the University, with controlled observation activities or hands-on experiences, the student has tested the application of theoretical concepts and foundational knowledge to solve practical problems, gaining familiarity with the techniques required in research.

Course contents	-
Readings/Bibliography	-
Teaching methods	-
Assessment methods	-
Teaching tools	-

Learning activity **INVERSION OF GEOPHYSICAL DATA**

Areas	
Learning outcomes	At the end of the course, students acquire mathematical and computational skills to utilise atmospheric and solid Earth data to obtain information on the physical processes that generate them.
Course contents	Inverse Problems are the fundamental tool through which, given theory and experimental data, we can reconstruct the parameters that controlled the data. This means being able to reconstruct parameters, such as temperature or wave velocity, that explain how the deep Earth, the atmosphere, and the interface between the two work. The course is structured within the framework of Bayesian approaches to find solutions to physical problems and estimate the uncertainties of the parameters that control them in a computationally efficient manner. Theoretical lectures will be followed by practical exercises with applications to the fields of Solid Earth Physics, Atmospheric Physics, Oceanography, and Medical Physics. Topics covered: Definition of Inverse Problems: Data, model parameters, and exact physical theories, with references to non-uniqueness. Bayesian Inferences and Monte Carlo Methods: Probabilistic information states and the solution of probabilistic inverse problems with corresponding search methods. Linear Problems: Least-squares methods with concepts of resolution and stability, using a priori information and Tikhonov Theory to address the lack of observations. Weakly Nonlinear Problems: Backus-Gilbert and optimization using linearization methods, gradient-guided searches, and Newton methods. Adjoint Methods and Nonlinear Problem Solution: Discrete and continuous methods applied to the wave equation, including misfit and sensitivity kernel calculations. Inverse Problem Solutions: Analytical and computational solutions, including advanced topics.
Readings/Bibliography	Menke W., Geophysical Data Analysis: Discrete Inverse Theory – Matlab edition, Academic Press, Elsevier, 2012. Tarantola A., Inverse problem theory, SIAM, 2005. Jaynes, E. T., Probability theory: the logic of Science, Cambridge University Press, 2003. Fichtner A., Lecture Notes on Inverse Theory https://www.cambridge.org/engage/coe/article-details/60e6a70d609d0d7fa3d893a7 Lecturer notes and suggestions for additional content provided on the Virtuale platform.
Teaching methods	To the cycle of frontal lessons, in which student participation is stimulated through questions and discussions of modern lines of research, analyzes and solutions of practical cases within the Physics of the Atmosphere, the Solid Earth and their interface are added. The course includes several computational exercises carried out in Matlab, Python and Julia environments, which allow students to be introduced to standard codes for the Geophysics and Atmospheric Physics community. In the final exercises, students will develop small applications related to their chosen curriculum, with the aim of contributing to the learning necessary for the thesis. Non-attending students are encouraged to contact the instructor, who will suggest a path based on the Menke content and exercises. The instructor will record the lectures upon request.
Assessment methods	The assessment test is oral and will consist of an interview lasting a maximum of 30 minutes. It will start from an initial topic and continue with two other course topics, according to the teachers' requests. The commission will ensure that the student has well understood the

	principles and methods underlying the solution of inverse problems in Geophysics and the limits and fields of application of the different methods studied through comments and questions that test the student's understanding and help the student reconnect the conversation. Application topics will be covered, with questions on the examples covered in class. The criteria used for the evaluation of the oral test will refer to the following indicators: 1. ability to analyze a topic in a way that is relevant to the questions, well organized, concise and exhaustive; 2. ability to clearly express theoretical themes, connecting equations and physical theories in a conceptual way using the specific language of the discipline; 3. ability to critically re-elaborate and discuss any variations with respect to the reasoning proposed in lessons and comments by the commission.
Teaching tools	The frontal lessons use visual aids such as PowerPoint, teacher handouts, and videos, which will be partially uploaded to the site. The course includes activities that directly involve students, who will be asked to solve theoretical and computational exercises. Optional seminar activities are held by researchers from other Research Institutes affiliated to the Department who are invited to present their recent research/publications.

Learning activity **LABORATORY OF ATMOSPHERIC MEASUREMENTS AND OBSERVATIONS**

Areas	
Learning outcomes	Upon completion of the course, the student will have acquired an advanced understanding of experimental techniques employed for the 'in-situ' measurement of key atmospheric variables. The course covers both conventional sensors used in operational meteorology and advanced instruments employed in atmospheric physics research. Students will develop a thorough comprehension of the physical principles underlying each measurement technique, along with their respective advantages and limitations. In cases where multiple methods are available for measuring the same atmospheric parameter, students will be equipped with the critical judgment required to identify the most appropriate technique based on the specific experimental context. Furthermore, students will be able to compare and validate measurements obtained from different instruments and will be capable of designing and implementing basic measurement campaigns, both in laboratory settings and in the field. The practical components of the course are designed to enhance students' data analysis skills and to provide hands-on experience with instrumentation
Course contents	The course provides integrated theoretical and experimental training on atmospheric physical measurements, with a focus on both instrumentation and the analysis of observational data. First part • Operating principles, static and dynamic response, and calibration methods of conventional instruments for atmospheric measurements; WMO standards. • Surface measurement of key meteorological variables (pressure, temperature, humidity, solar radiation, precipitation intensity, wind direction and speed) using conventional and research-grade instrumentation, with critical evaluation of the instruments' performance in terms of uncertainty, temporal resolution, robustness, cost-effectiveness, and suitability for different observational contexts. An introduction to remote sensing potential is also provided.

	- World Meteorological Organization (WMO) guidelines for the siting and exposure of surface meteorological stations. - Procedures for the validation and processing of atmospheric data (visualization, descriptive statistics, quality checks, consistency tests, and management of systematic errors). - Development of basic data analysis and processing routines using computational tools. Second part - Basic aerosol properties and measurement of particle size. Aerosol size distribution, main fashions and their sources and sinks. Method of moments for analyzing distributions and its application in atmospheric aerosol analysis. Notes on light scattering by aerosol particles. - Measurement techniques, principles of operation, limitations and efficiency of atmospheric aerosol measuring instruments: impactors, cyclones, optical particle counters. - Comparison of atmospheric aerosol data obtained from different instrumental algorithms and in different neighborhoods of the real urban environment. Development of routines for atmospheric aerosol data analysis collected by a portable optical particle counter. - Principles of thermography and its application in the atmospheric field. Use of thermal imaging camera for atmospheric applications. Development of simple routines for analysis of images and data collected by a thermal imaging camera. **Proposed laboratory/field activities:** 1. Validation and analysis of meteorological data from automatic stations and regional and/or global observation networks (e.g., ARPAE, WMO networks). [Part 1] 2. Acquisition and analysis of a three-dimensional wind dataset using a 3D sonic anemometer. [Part 1] 3. Use of an optical particle counter and analysis of the resulting dataset. [Part 2] 4. Acquisition and analysis of a dataset using a thermal imaging camera. [Part 2]
Readings/Bibliography	**Required materials for exam preparation:** Lecture notes and slides provided by the instructor during the course, available on the online platform *Virtuale*. **Recommended texts for further reading:** - F.V. Brock, S.J. Richardson, *Meteorological Measurement Systems*, Oxford University Press, 290 pp., 2001.

	• WMO-No. 8: *Guide to Meteorological Instruments and Methods of Observation*. • WMO-No. 100: *Guide to Climatological Practices*. • WMO-No. 485: *Guide to the Global Observing System (GOS)*. • W. Hinds, *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*, John Wiley & Sons, 504 pp., 1999. **Further resources:** Selected chapters from the above texts and relevant scientific articles may be suggested by the instructor during the course for in-depth exploration of specific topics.
Teaching methods	The theoretical content will be delivered through face-to-face lectures, supported by PowerPoint presentations and additional explanations on the whiteboard. The practical activities, conducted in the laboratory and in the field for both parts, will be carried out in groups of 2 or 3 students. *Due to the types of activities and teaching methods adopted in this course, it is mandatory that all students take the E-learning Modules 1 and 2 on general health and safety training, as well as **Module 3** on specific health and safety training in studying places. Please visit the Degree Programme website to find out the dates and enrollment instructions for Module 3*
Assessment methods	The final examination covers the content of both parts and consists of two components: 1. **Laboratory Reports:** Students will work in groups of two or three. For each laboratory session, a report must be prepared by the group and submitted within two weeks of the activity. The reports will be evaluated by the instructor. The average grade of all reports will account for **50% of the final mark**. 2. **Individual Oral Exam:** The oral exam, approximately 30-40 minutes in duration, includes two main questions: critical discussion of data, elaborations, or results obtained during the practical activities; in-depth discussion of theoretical topics covered in class. The oral exam will contribute the remaining **50% of the final mark**. The final grade will be expressed on a scale of 30, as the arithmetic mean of the scores obtained from the laboratory reports (50%) and the oral exam (50%). **Grading Criteria (for both the reports and the oral exam)** • Limited understanding of the topics or data discussed; analysis is only partially independent and requires significant

	guidance from the instructor. Expression is correct but simplified. Reports are essential and lack depth.-->18-19 • Adequate knowledge of a limited number of topics. Independent analysis is generally correct, though focused on procedural aspects. Appropriate technical language. Reports are structured but not always comprehensive.-->20-24 • Good understanding of a wide range of topics, with the ability to conduct independent and critical analysis, draw theoretical-practical connections, and use technical terminology accurately. Reports are complete, well-structured, and show good interpretation of results.-->25-29 • Full mastery of the course content; strong critical thinking, synthesis, and ability to connect theoretical and practical aspects. Arguments are rigorous, independent, and well-justified. Technical language is precise and fluent. Reports are outstanding in clarity, scientific accuracy, and depth.-->30-30L
Teaching tools	Lectures will be delivered by the instructor using a video projector and blackboard. During the practical sessions, students will have access to the following resources: • PCs equipped with Windows operating system and software tools for data processing; • A variety of sensors installed in the laboratory and/or outdoors at the Department of Physics and Astronomy, including DAVIS weather stations, a three-dimensional sonic anemometer with Campbell Scientific data acquisition system, optical particle counters, thermal camera; • Datasets acquired using state-of-the-art atmospheric instruments, including both research-grade and low-cost devices; • Reference materials and scientific literature to support the practical activities.

Learning activity **LABORATORY OF GEOPHYSICS**

Areas	
Learning outcomes	By the end of the course students get theoretical and practical basic knowledge about some geophysical prospecting methods and to use them to interpret key features of surface geology. In particular, students understand from the physical point of view, plan and carry out surveys in the field, and interpret in the lab results obtained through the following methods of geophysical prospecting: Georesistivity, seismic refraction, seismic surface waves.

Course contents	*General introduction to seismic waves*: P waves, S waves, plain and inhomogeneous waves, Rayleigh waves, Love waves. *Seismic waves attenuation*: quality factor, gain and attenuation unity of measure, P and S waves attenuation. *Fundamentals of georesistivity methods*. Concept of apparent resistivity. Vertical and horizontal electric soundings. Experiments in the field: planning, acquisition and processing of data from electrical resistivity surveys. Hints on the inverse problem. *Seismic refraction* *Surface wave methods* (H/V), Surface wave methods (dispersion curves) Each exploration method (georesistivity, seismic refraction, surface waves methods) will be introduced by means of laboratory experiments and field surveys.
Readings/Bibliography	The slides presented during the lectures and some material related to the lab experiences will be uploaded to the "Virtuale" web platform. Different textbooks and papers, some of which will be uploaded to Virtuale, can be used to go into detail in the topics presented during the course. Fowler, C.M.R. (2004). The solid Earth: an introduction to global geophysics. Cambridge University Press, 2nd edition). Burger, H.R., Sheehan, A.F., Jones, C.H. (2023). Introduction to Applied Geophysics: Exploring the Shallow Subsurface. Cambridge University Press. Binley, A. and Slater, L. (2020). Resistivity and Induced Polarization - Theory and Application to the Near Surface Earth. Cambridge University Press. Everett, M.E. (2013). Near surface applied geophysics. Cambridge University Press. Kearey, Brooks, Hill (2002). An introduction to geophysical exploration. Blackwell Publishing.
Teaching methods	Lessons, laboratory experiments and field surveys. Laboratory and field surveys require the student to be physically present. The attendance of the lessons in the classroom is not compulsory, but it is highly recommended for the learning process and for its tight connection to the lab experiences. Some lessons for will be recorded and made available to students attending the classes. As concerns the teaching methods of this course unit, all students must attend in advance Module 1, 2 of the formation course on health and safety (to be attended online) Module 3 in presence, based on a schedule that will be timely announced by the Department of Physics and Astronomy. For further information, please consult the web site: https://site.unibo.it/tutela-promozione-salute-sicurezza/it/corsi-di-formazione/formazione-obbligatoria-su-sicurezza-e-salute-per-svolgimento-di-tirocinio-tesi-laboratorio
Assessment methods	At the end of the laboratory activities, students must complete three separate written reports for georesistivity refraction seismics surface waves methods. The reports must be delivered and sent to the lecturers no later than 15 days after the end of the course, and anyway before the exam. The reports will not get a separate mark, but the discussion on them will be part of the exam. The final test has the aim of ascertaining that the formation objectives are achieved and consists of a single oral examination, concerning theory as well as the experimental tests carried out in the laboratory and in the field. The typical exam duration is between one hour and one hour and a half.
Teaching tools	Slides projected in the classroom, laboratory computer with data analysis software. All lessons related to Seismic refraction and Surface waves methods will be recorded and made available online to students attending the classes.

Learning activity **LABORATORY OF NUMERICAL GEOPHYSICS**

Areas	
Learning outcomes	At the end of the course, students will possess basic knowledge of the main numerical techniques used for solving ordinary differential equations (ODEs) and partial differential equations (PDEs), identifying and understanding the conditions for which numerical instabilities may arise. They will be also able to implement these methods in numerical codes, personally developed in MATLAB environment.
Course contents	Discretization methods for ordinary differential equations (ODE) based on finite-difference schemes. Implicit and explicit multi-step methods. Runge-Kutta methods. Accuracy. Partial differential equations (PDE). Parabolic and hyperbolic systems. Transport equation. Method of characteristics. Discrete differential operators. Stability analysis. Equation of heat transfer. Equation of waves propagation. Design and implementation of numerical algorithms for: - Generic ODEs, using multi-step and Runge-Kutta methods - PDEs describing specific geophysical problems (transport equation, heat equation, wave equation) The students will develop the numerical codes on their own PC (or on a computer provided in the lab, if available) and will verify their stability conditions and accuracy by comparing them with the corresponding analytical solutions. This activity will be carried out using MATLAB software.
Readings/Bibliography	Slides presented during the lectures. Outlines of the exercises performed in the laboratory.
Teaching methods	Classroom lectures, projection of slides. Laboratory exercises carried out on own computer. Attendance of this training activity requires the prior participation of all students to modules 1 and 2 of training on safety in the places of study, through e-learning mode (see the link https://corsi.unibo.it/magistrale/FisicaSistemaTerra/formazione-obbligatoria-su-sicurezza-e-salute).
Assessment methods	The final test is joint, exclusively oral, with duration ranging between an hour and an hour and a half. It will concern the theory as well as the numerical tests carried out in the laboratory. The examinee will be asked to show, discuss and run the numerical codes solving the differential equations developed in the laboratory.
Teaching tools	Projector; PC and MATLAB (or Octave).

Learning activity **LABORATORY OF SEISMOLOGY**

Areas	
Learning outcomes	At the end of the course, students will gain scientific and practical knowledge on some aspects of experimental methods and statistical techniques used in seismology and in the assessment of seismic hazard. In particular, students will: - understand the operating principles of mechanical and electromagnetic seismometers and to carry out experiments to quantify the fundamental characteristics of an electromagnetic seismometer; - read and interpret the fundamental aspects of seismograms and to use them to localize earthquake; - apply statistical and probabilistic methods to assess the statistical properties of occurrence of earthquakes, to make deterministic forecasts and to assess seismic hazard and risk
Course contents	Seismic source: magnitude, focal mechanisms, macroseismology. Statistical seismology: statistical properties of occurrence, maximum likelihood methods. Earthquake prediction: deterministic prediction, seismic hazard and risk. Lab exercises.
Readings/Bibliography	The set of files, divided into chapters, contains a comprehensive exposition of

	the program and can act as a text for the study of the subject. The files in PowerPoint and pdf format are available on the Virtuale web site. If students wish to delve deeper into the topics covered in the course, they consult the following texts: Havskov, J. and Alguacil., G. (2016). Instrumentation in Earthquake Seismology, 2nd Ed., Springer. Havskov, J., Bormann, P., Schweitzer, J. (2011). Seismic source location. https://gfzpublic.gfz-potsdam.de/rest/items/item_43361/component/file_816919/content
Teaching methods	Lectures will be held in the classroom. Experiments will be carried out in the laboratory. The attendance of the lessons in the classroom is not compulsory, but it is highly recommended for the learning process and for its tight connection to the lab experiences. The laboratory experiments are compulsory: the lecturer will collect the students' signatures at the beginning of each turn. As concerns the teaching methods of this course unit, all students must attend in advance Module 1, 2 of the formation course on health and safety (to be attended online) Module 3 in presence, based on a schedule that will be timely announced by the Department of Physics and Astronomy. For further information, please consult the web site: https://site.unibo.it/tutela-promozione-salute-sicurezza/it/corsi-di-formazione/formazione-obbligatoria-su-sicurezza-e-salute-per-svolgimento-di-tirocinio-tesi-laboratorio
Assessment methods	Students, possibly organised in groups, will be asked to prepare two different written reports on the lab experiences connected respectively to seismometry and earthquake location. The two reports must be sent to the teacher within 15 days after the end of the course and anyway before taking the final exam. The discussion of the reports is part of the final exam in oral form and with a typical duration of 50-60 minutes.
Teaching tools	In the room: projector. In the lab: two PCs with free and commercial software for data modelling and visualization; two vertical, long period electromagnetic seismometers; data acquisition hardware.

Learning activity **MICROPHYSICAL PROCESSES**

Areas	
Learning outcomes	The objective of this course is to introduce students to the fundamental microphysical processes that occur in the atmosphere and affect the formation, structure, and dynamics of clouds and precipitation. The mechanisms of the water phase transition and the role of aerosol particles will be studied, as well as the mechanical properties of particulate matter and hydrometeors. We will also examine the primary techniques for measuring and estimating the quantities that describe the processes under consideration.
Course contents	1. Introduction of microphysical processes in the atmosphere; 2. Basics of thermodynamics: water in the atmosphere; 3. Homogeneous nucleation; 4. Heterogeneous nucleation; 5. Aerosol's mechanics; 6. Warm clouds formation and growth; 7. Cold clouds' structure;

	8. Precipitation; 9. Hydrodynamics of cloud and precipitation particles; 10. Precipitation structure; 11. Measurements; 12. Charge separation and lightening.
Readings/Bibliography	• notes of the teacher; • Pruppacher and Klett, 1997, Microphysics of clouds and precipitation, Kluwer Academic Publishers, pp. 954. • Wang, P.K., 2014, Physics and Dynamics of Clouds and Precipitation, Cambridge University Press, pp 451 • Houze, R.H., 2014, Cloud Dynamics, Elsevier, pp. 496
Teaching methods	Blackboard lectures with use of video projector, when needed.
Assessment methods	The assessment will be a 50 min oral interview on the course topics. the student, if he/she wishes, can present the contents of a scientific article proposed by the teacher
Teaching tools	Blackboard and videoprojector

Learning activity **MODELS AND NUMERICAL METHODS IN PHYSICS**

Areas	
Learning outcomes	By the end of the course, the student will have acquired the theoretical and numerical skills for the study of entropic properties of datasets, more or less structured. Theoretical skills will be acquired in the area of intersection between Complex Dynamical Systems Theory, Information Theory and Statistical Mechanics. Please refer to the syllabus for detailed topics. As far as numerical skills are concerned, the student will experiment with Python the numerical implementation of algorithms for the estimation of entropy, relative entropy and entropic production for stochastic processes on finite alphabets. Some applications in the area of natural language, gene sequences and (time permitting) in the area of human mobility data will be explored.
Course contents	"..*a large Language Model is just something that compress part of the Internet ....and then it dreams about*...." (Andrej Karpathy, https://youtu.be/zjkBMFhNj_g?si=_CjyJdSOKhvyVZXk) Entropy and Diffusion in Physics: Theory and Applications The course will focus on developing the mathematical and computational tools for understanding two main concepts in Physics, along with their applications: 1. Entropy: We will explore the close relationship between Entropy, Information, and Compression, starting from stochastic processes over finite alphabets. 2. Diffusion: We will introduce and explore diffusive processes in physics and their recent remarkable applications in the so-called Probabilistic Diffusion Models (e.g., stable diffusion). Methods and techniques lie at the intersection of Dynamical Systems, Statistical Mechanics, and Information Theory. The course will combine traditional lectures with numerical investigations (in Python). This course is a natural extension of the Complex Systems Physics course, sharing approaches, techniques, and results. This course will start by recalling the main definitions and results about “Entropy and Information” developed in the course Complex System Physics. This online program will be refined over time, but here is a preliminary list of topics: · Entropy, Information and Coding: recall of basic notions from Complex Systems Physics course · Coding and Entropy: Recall of the main notions of entropy for processes over finite alphabet. Introduction to Lempel-Ziv algorithms for parsing and coding, highlighting their relation to entropy and information theory(8h) · From Compression to Embedding: Introduction to Variational Auto-Encoders (VAE): Introduction to modern techniques in data compression and representation, specifically focusing on Variational Auto-Encoders and their applications.(8h) · Numerical Methods (16h):

	I. Numerical schemes to integrate ODE: the properties of Runge-Kutta schemes. (2h) II. Symplectic numerical schemes to integrate Hamiltonian system: expected error for integrable and chaotic systems, properties of symplectic maps (2h). III. Numerical schemes for dynamical systems on Lie groups with applications (2h). IV. Chaotic systems and definition of Ljapunov exponents: numerical scheme to evaluate Ljapunov exponents with applications (2h). V. Numerical integration of stochastic differential equations: Wiener process and Ito integral definition, Ito formula and stochastic equivalence of stochastic process (4h). VI. Fokker-Planck equation: properties and numerical integration (2h). VII. Introduction to stochastic processes on manifolds (2h) · Introduction to Diffusion Models in Physics: Comprehensive introduction to diffusion models in physics, covering Langevin dynamics, Fokker-Planck equations, and diffusion phenomena. This section will also include an exploration of random walks and random processes on graphs or networks, providing a deeper understanding of the mathematical and physical principles behind diffusion. (8h) · Probabilistic Diffusion Models: Examination of the theoretical foundations of probabilistic diffusion models, their implementation, and applications in Artificial Intelligence. We will explore the generative methods based on diffusion, focusing on canonical examples for image generation conditioned on text, and more recent applications to urban data. (8h)
Readings/Bibliography	Here just the basic reference books used in the course. All sources, books and papers, will be available to students in digital format: Notes "Entropy. Information and Large Language Models", M.- Degli Esposti (2024) Cover, M.T., and Thomas, A.J.: Elements of Information Theory. John Wiley & and Sons,1991. Andrej Karpathy's Lecture (YouTube)
Teaching methods	Lectures and Numerical Simulations (with Python)
Assessment methods	to be defined
Teaching tools	Blackboard and Python

Learning activity **NUMERICAL LABORATORY OF THE ATMOSPHERE AND THE OCEAN**

Areas	
Learning outcomes	Upon successful completion of this course, the student knows: the formulation of general circulation models and climate models; -numerical methods employed in atmospheric and oceanic sciences; -methodologies to solve numerically chaotic, multi-scale systems of PDEs. Upon successful completion of this course, the student is able to: run and interpret simple numerical simulations for the atmosphere and ocean; use large datasets in self-describing, array-oriented formats; work in UNIX-like shell and HPC environment. Ability to write numerical codes to integrate hyperbolic conservation laws in one and multiple dimensions. Basic knowledge of a UNIX-like shell and job submission in a HPC environment. Compiling and running a model, design and implementation of a numerical simulation. Interpretation and use of a self-describing, array-oriented data format. Expertise with analysis and post-processing of model outputs and simple strategies to handle large datasets. Interpretation of model results in view of governing equations.
Course contents	*Atmosphere* -Introduction Overview of the course, History and development of Atmospheric General Circulation Models, global and mesoscale numerical weather predictions, climate models. -Numerical Methods I Classification of PDEs, consistency and stability analysis, semi-lagrangian schemes, spectral methods, grids -Hands-on Session: Numerical Integration of the Lorenz 63 system Deriving the Lorenz system, the coding environment, writing the code for the integration, exercises on fundamentals of chaotic systems, conceptual example of an ensemble forecast. -Hands-on Session: Numerical integration of the barotropic vorticity equation Implementation of a code to solve the barotropic vorticity equation, filtering approximations, recreation of the

	pioneering numerical weather prediction made by Charney, Fjörtoff and von Neumann. -Hands-on Session: Simulations with an atmospheric General Circulation Model Vertical coordinates in AGCMs, subgrid-scale processes, overview of model dynamical core and parameterizations. Computation of the model climatology, a sensitivity simulation. What is a weather forecast system, the example of the ECMWF Integrated Forecast System, forecast and discussion of a case study. *Ocean* Introduction: The governing equations and a short history about ocean models. Here we review the equation of state, the Navier-Stokes equation, the approximations (Hydrostatic, Boussinesq), and consequences to derive the Primitive Equations. Brief history of oceanographic modelling. Review and classification of different ocean models Lecture 2: Finite difference Method. Taylor series and finite difference. How to find solution for 1st and 2nd derivatives. Low order and high orders schemes. Overview of the different possibilities and implications (Backward, centered and forward). Examples applied to the heat equation. Lecture 3: Numerical dispersion and diffusivity. Overview of the advection schemes. Lecture 4: SGS processes. Horizontal and vertical diffusion & viscosity. Lateral Open boundary conditions and nested grids (time-permitting). Hands-on Session: Introduction to the NEMO code. Preparing the environment. Getting familiar with bash/Fortran. Overview of the code, its structure, the modules. Modularity and choices to be done. Hands-on Session: Available options for the momentum equation (flux vs vorticity / baroclinic and barotropic). Surface and lateral boundary conditions. Execute the code (pre-defined test cases). Check results and diagnostic files. Hands-on Session: Create your own model configuration: Definition of the problem. Run the Experiments. Study and understand the model results and output. Hands-on Session: Sensitivity tests. Study and understand the model results and output (comparison).
Readings/Bibliography	Lecture notes and slides Atmospheric Modeling, Data Assimilation and Predictability, E. Kalnay, Cambridge university press Haidvogel and Beckmann, Numerical Ocean Circulation Modeling, Imperial College Press, 1999 Benoit Cushman-Roisin and Jean-Marie Becker. Introduction to Geophysical Fluid Dynamics. Physical and Numerical Aspects. Academic Press F. Mesinger, A. Arakawa, Numerical Methods Used in Atmospheric Models, GARP Publ. Ser. No. 17, vol. 1, WMO, Geneva, 1976
Teaching methods	Classroom lectures and hands-on sessions with numerical simulations. *Mandatory Lab safety training to be completed in advance: Moduli 1 e 2 di formazione sulla sicurezza nei luoghi di studio, [https://elearning-sicurezza.unibo.it/] are required (E-Learning).*
Assessment methods	Reports developed during the course are evaluated but do not directly influence the final mark. The final mark is determined with an oral examination focused on the theoretical part of the lectures and on the discussion of the reports. The examination is done with 3 questions and at least 1 question both for the Atmosphere and the Ocean part. The duration of the exam is about 35 minutes.
Teaching tools	Slide projector and computer laboratory.

Learning activity **PHYSICAL OCEANOGRAPHY**

Areas	
Learning outcomes	The student will develop an understanding of the ocean dynamics by solving the classical problems of the wind-driven ocean circulation, with a particular focus on vorticity dynamics and mesoscale variability. They will gain detailed knowledge of planetary gravity waves and Rossby wave motions, as well as a foundational understanding of the ocean's overturning circulation and the processes involved in deep water formation.
Course contents	1. Structure of the ocean general circulation and its variability 2. The forcing of the ocean circulation: wind, heat and water fluxes at the air-

	sea interface 3. Primitive equations for the oceans 4. Reynolds theory of turbulence, parameterizations of turbulence in the ocean 5. Classical viscous solutions and the 'law of the wall' for momentum stress at the air-sea interface 6. Boundary conditions for the ocean primitive equations 7. The planetary turbulent boundary layer: the Ekman currents at the surface and in the bottom boundary layer 8. Ekman dynamics and large scale upwelling/downwelling areas of the ocean (Eastern Boundary Upwelling, Equatorial upwelling, eddy upwelling) 9. Shallow water equations 10. Gravity wave solutions for the shallow water equations: inertial, Poincare', Kelvin waves 11. Equatorial Kelvin waves, Rossby waves 12. Fundamentals of energy and enstrophy cascading: oceanic vortices and quasigeostrophic turbulence 13. The large scale wind driven circulation: Svedrup and Stommel gyre circulation 14. Global Ocean Overturning circulation 15. Deep and intermediate water convection in the ocean
Readings/Bibliography	Talley, L., D., G.L.Pickard, W.J. Emery and J.H. Swift, 2011. Descriptive Physical O Cushman-Roisin, B., Introduction to Geophysical Fluid Dynamics, Academic Press N.Pinardi,2022. Notes in Physical Oceanography
Teaching methods	All lectures and exercises are done in the classroom (all frontal lectures)
Assessment methods	The assessment will be conducted through an oral examination. The student will select the first topic, followed by two additional questions chosen by the instructor. The exam will typically last 45 minutes.
Teaching tools	All material will be distributed from the "Teaching material" web site

Learning activity **PHYSICS OF VOLCANISM**

Areas	
Learning outcomes	At the end of the course, the student: understands the main physical processes governing volcanic activity, including magma generation, ascent, storage, and eruption dynamics; is familiar with the fundamental laws of rock mechanics, fluid dynamics, and thermodynamics as they apply to magmatic and volcanic systems; understands the role of volatiles, crystallization, and phase transitions in controlling eruption styles, and is capable of modelling these processes; - is able to apply physical models and appropriate approximations to describe magma ascent through the lithosphere via porous flow and magma-driven fracturing; - is able to describe the processes occurring in magmas during storage; - is able to apply physical models and approximations to describe volcanic phenomena such as lava flows, pyroclastic density currents, and explosive eruptions; - has a foundational understanding of geophysical monitoring techniques, including seismicity, ground deformation, gravimetry, and satellite-based remote sensing, and how to constrain physical models using these data; - is proficient in using scientific literature and course materials in English, and can communicate effectively about volcanic processes using appropriate technical terminology.
Course contents	*Introduction, basic definitions*: The tectonic contexts of volcanism, The shape of volcanoes and their eruptive style, Iconic volcanoes on Earth and in the Solar System; *Magmas*: The chemical composition of magma, The physical properties of magmas; *Thermodynamics of melting:* Geotherms and the solidus, Melt generation; *Magma ascent*: Magma ascent by porous flow, Magma ascent by fracturing, Modelling the stress state of volcanoes, Geophysical observations of magma

	ascent; *Magma storage*: Chemical changes of magmas during storage, Geophysical observations of magma storage; *Volcano deformation*: The Mogi model, Non-spherical deformation sources, Viscoelasticity and other more complex rheologies; *Effusive eruptions*: Magma flow in near-surface conduits, Lava flows, Dynamics of lava domes, Caldera collapse; *Explosive eruptions*: Phreatic eruptions and hydrothermal systems, Volcanic plumes, Atmospheric ash dispersion, Pyroclastic density currents.
Readings/Bibliography	- Encyclopedia of Volcanoes, Elsevier, 2026. - R. Lopes e T. Gregg, Volcanic Worlds, Springer, 2004. - D. L. Turcotte e G. Schubert, Geodynamics, Cambridge University Press, 2002. - Dobran F (2001) Volcanic Processes: Mechanisms In Material Transport. Kluwer, New York, pp 620 - Fagents S.A., K.P. Gregg, R.M.C. Lopes (Edtrs), Modeling Volcanic Processes, The Physics and Mathematics of Volcanism, Cambridge University Press, 2013. - Gilbert JS, Sparks RSJ (eds) (1998) The Physics of Explosive Volcanism. Special Publication of the Geological
Teaching methods	Theoretical content will be illustrated using the video projector and the board. Simple problems will be solved during the classes (or suggested as homework) to facilitate the understanding of the theoretical aspects. A numerical modelling part is also foreseen. The students (in group) will use a personal computer to implement computer codes and simulate magma ascent or solve simple volcano deformation problems.
Assessment methods	Learning assessment will work by an oral test aimed at evaluating the achievements of the main objectives of the course: - understanding the fundamental laws regulating the generation, ascent, storage and eruption of magmas, - the ability to interpret geophysical and geochemical observations at volcanoes The test will cover the whole program, except for the computer part. The oral exam will last at about 30-45 minutes
Teaching tools	Lectures notes (in pdf format). A few key scientific articles. Computer codes (in MATLAB) for volcano deformation. Bibliography and references including web pages

Learning activity **PLANETARY BOUNDARY LAYER AND TURBULENT DISPERSION**

Areas	
Learning outcomes	At the end of the course, the student knows the fundamentals of the theory of turbulent flows in the atmosphere and of the theory of turbulent dispersion. In particular, the student: - is able to analyze and interpret qualitative and quantitative observations related to the structure of the boundary layer and dispersion; - knows the models of turbulence closure, including large eddy-simulations and its applications; - is able to produce reports and documents at a basic level on issues related to boundary layer problems, air quality; - is able to use simple models related to the dynamics and dispersion in the atmospheric boundary layer; - is able to critically evaluate the characterizing aspects of complex models.
Course contents	Part 1 focuses on theoretical aspects and theory of the atmospheric boundary layer and dispersion. Part 2 will put in practice the learnt concept by using computational fluid dynamics. **Theory of the atmospheric boundary layer and dispersion,** content: 1) Introduction: Definition of atmospheric boundary layer (ABL) - the diurnal cycle of ABL on land - ABL on the sea - measuring the ABL 2) Variables defining the ABL: stochastic variables - probability density function (pdf) - moments, mean value, fluctuations; correlation functions and spectra; from wave numbers to frequency (frozen turbulence hypothesis) 3) Equations (1): the equations for the velocity components and for the passive

	scalar; scale analysis; hydrostatic pressure; potential temperature; geostrophic wind 4) Equations (2): the equations for prime moments; the equations for fluctuations; the equations for the second moments; the equation for turbulent kinetic energy (TKE); the equation for the variance of a scalar; turbulent flows and the mixing length model; horizontal and vertical heat flows 5) Introduction to turbulence: Eulerian and Lagrangian description; universal characteristics of turbulent flows; a fundamental paradigm: Kolmogorov (1941); spectra and structure functions; the pdf of the velocity 6) Horizontally homogeneous ABL on flat ground: observations; equations for mean velocity and mean temperature; internal and external 'scaling'; definition of surface layer (SL) 7) Near neutral ABL (QNBL): Richardson number of flow and Obukhov length; neutral conditions in SL; mean velocity variance profile and TKE dissipation rate; integral scales; the neutral Ekman layer; weakly stratified conditions; average velocity and average temperature profiles; variances; turbulent diffusion coefficients for momentum and heat; 8) The convective boundary layer (CBL): observations; the pdf of the speed; scales for speed and temperature; average velocity and average temperature profiles; second and third order moments; TKE dissipation rate; a model for horizontal heat flows; potential temperature balance and height of the CBL; the encroachment model; more complex models 9) The residual layer (RL): observations; numerical simulations; a simplified model 10) The stable boundary layer (SBL): observations; extension of the definition of ABL under stable conditions; Long-lasting SBL; other types of SBL; transfer of TKE from top to bottom; local similarity theory: the Nieuwstadt model (1984); average quantity profiles in SL; critical Richardson number 11) Similarity functions in SL: nondimensional gradients of average quantities; nondimensional profiles; Richardson numbers of gradient and bulk 12) The flow in a vegetable 'canopy' and in an urban 'canopy' observations of average velocity and second moments; flow above the 'canopy'; flow within the 'canopy layer'; friction due to obstacles, urban canyons 13) Introduction to turbulent dispersion; Fundamental equations and analysis of solutions for different types of sources 14) Large-scale atmospheric dispersion: dispersion in a neutral laboratory boundary layer, dispersion in the CBL, Mikkelsen et al. (1987): horizontal 'meandering' in SL, flow dispersion on topography 15) Simple fluid dynamic models for plumes: case of point source without buoyancy, case of point source with buoyancy 16) Dispersion in an urban environment: Analysis of models and approaches for the analysis of dispersion in urban areas ================= **Practice the learnt concept** by using computational fluid dynamics. 1. Introduction: discussion of the main numerical methods for computational fluid dynamics, Raynolds-Averaged Navier-Stokes (RANS), Large-Eddy Simulation (LES), Direct-Numerical Simulation (DNS) approaches. 2. Turbulence models: presentation and derivation of some of the most used turbulence models. 3. Numerical methods: brief overview of numerical techniques for solving fluid dynamics equations. Algorithms, solution schemes, computational grid. 4. Practical case studies: presentation of case studies for the reproduction of a planetary boundary layer, dispersion of pollutants in an urban environment, ventilation of urban areas. Data analysis and postprocessing techniques. 5. OpenFOAM simulator: computer tools for numerical simulations, C ++ programming languages, OpenFOAM open-source software, customized scripts. 6. Simulation and analysis: simulation case setting, data and statistics
Readings/Bibliography	Lecture notes on the **theory of the atmospheric boundary layer and dispersion** Books: Stull: Introduction to Boundary-Layer Meteorology, 1988; Wyngaard, J. C., 2010. Turbulence in the atmosphere, Cambridge University Press; Csanady, G. T., 1973. Turbulent diffusion in the environment, Reidel Pu. Co., Dordrecht; Seinfeld, J. H. and Pandis, Spyros N., 1998. Atmospheric chemistry and physics, John Wiley and Sons. Kaimal and Finnigan, 1994: “Atmospheric Boundary-Layer Flows” =============

	Lecture notes on **practice the learnt concept** S.B. Pope. Turbulent Flows. Cambridge University Press (2000).
Teaching methods	Frontal teaching and practice in the computer science laboratory where guided excercises will be carried out by the students (second part).
Assessment methods	A single oral examination with 3 questions. The first topic is chosen by the student. During the exams the student will discuss and respond to questions related to the laboratory final report.
Teaching tools	PC, Blackboard Computer science laboratory with computers having UNIX/LINUX operative system

Learning activity **PREPARATION ABROAD FOR THE FINAL EXAMINATION**

Areas	
Learning outcomes	At the end of the activity, carried out in a foreign institution and according to procedures established by the University Regulations and international mobility programs, students: - possess practical knowledge related to hardware or software tools, or bibliographic research (including online resources) that is preparatory to the final dissertation; - are able to better organize their work activity.
Course contents	
Readings/Bibliography	
Teaching methods	
Assessment methods	
Teaching tools	

Learning activity **SCRITTURA SCIENTIFICA E TECNICA**

Areas	
Learning outcomes	Questo corso fornirà una serie di competenze trasversali necessarie per essere pronti alla stesura della tesi e per comunicare Course contents scientifici a un vasto pubblico. Il corso si occuperà di come scrivere un documento tecnico, un articolo scientifico e proposte di progetto.
Course contents	L'iattività (3 lezioni da 2-3 ore) è dedicata allo sviluppo di competenze di scrittura specificamente mirate a documenti tecnici, report scientifici e proposte di progetto in italiano.
Readings/Bibliography	Il materiale didattico viene fornito durante il corso tramite una cartella condivisa.
Teaching methods	Lezioni frontali e attività interattive in aula.
Assessment methods	Soni richieste la frequenza (almeno il 75%).e una relazione in italiano su quanto appreso.
Teaching tools	Presentazioni e materiale di lavoro.

Learning activity **SEISMOLOGY**

Areas	
Learning outcomes	At the end of the course, students acquire knowledge about the theoretical, computational, and data-processing aspects of seismology, focusing on the physics of seismic sources and the generation, propagation, and recording of seismic waves.
Course contents	Seismology represents one of the fundamental disciplines in the study of Earth Sciences, as it includes the study of the elastic and inelastic processes that

	characterize the Solid Earth and materials, at time scales ranging from microseconds to years. Topics presented. The seismic source: description of the earthquake as seismic source, the spectrum of seismic waves, magnitude, energy and focal mechanism of earthquakes. Seismic waves: propagation in inhomogeneous media, seismic rays in the Earth, surface waves and dispersion, absorption of seismic waves, elastic reflection and refraction. Effects of earthquakes: the Earth's free oscillations, the change in the Earth's rotation due to earthquakes. Seismic imaging techniques: seismic tomography; use of phase and amplitude information, interferometry and ambient noise tomography. It is assumed that the student has a good preliminary knowledge of the basic concepts of thermodynamics, fluid mechanics and theory of elasticity. The course provides the first elements of data processing and computational analysis of signals to the students of the CdS. The topics covered provide the first skills to work in an applied seismological environment, especially in research institutes and companies interested in the assessment of resources and seismic risk. The course comprises computational laboratories that will provide the first training for students on software and programming languages used by the seismological community.
Readings/Bibliography	Each lesson is delivered by the projection of a file PowerPoint. The collection of files, divided into chapters, contains an exhaustive treatment of the program and can be used as a textbook for the study of the subject. The files in PowerPoint format are available since the beginning of the course and can be reached from the web page of the course. If students wish to go deeper into the topics of the course, they can consult the following textbooks: - K. Aki e P. G. Richards, Quantitative Seismology, 2a edizione, University Science Books, Sausalito CA, 2002. - F. A. Dahlen e J. Tromp, Theoretical Global Seismology, Princeton University Press, Princeton NJ, 1998. - E. Boschi e M. Dragoni, Sismologia, UTET, Torino, 2000. - D. Gubbins, Time Series Analysis and Inverse Theory, Cambride University Press, Cambridge UK, 2004. - T. Lay e T. C. Wallace, Modern Global Seismology, Academic Press, San Diego California US, 1995. The following books are available by request to lecturers: - H. Igel, Computational Seismology, A Practical Introduction, Oxford University Press Books, Oxford UK, 2017.
Teaching methods	The course is presented in the form of a "frontal lectures" accompanied by visual documentation in PowerPoint. The course includes computer exercises with introductory programming in Julia, Matlab, and Python; relative to these methods, active participation is expected from the attending students.
Assessment methods	The exam will be oral and will generally last about 30 minutes. The student will be asked to analyse a portion of the seismogram, describing the components that constitute it and connecting it to the theoretical topics covered in the course. The student will be asked in sequence to illustrate two topics, among those considered in the course. For each topic, the student will be first asked to expose the general framework, then to go into details on some specific aspects. The student will be requested to know the main equations of the physical theories employed and to know how they are derived; to be able to apply them to specific cases; to know the orders of magnitude of the employed physical quantities.
Teaching tools	The course uses presentations that will have connections to online resources, such as seismological databases and codes, which will contribute to the student's computational and data training. The exercises include instructions given in advance for installing codes and downloading datasets on a personal computer, for in-class exercises and, optionally, outside of course time.

Learning activity **TECTONOPHYSICS**

Areas	
Learning outcomes	At the end of the course, the student has advanced knowledge of the evidence and models of geodynamic phenomena in the Earth's lithosphere. In particular, the student is able to interpret the rheological behaviour of the Earth's interior and constrain large-scale processes (compensation of topographic loads, post-glacial 'rebound', subduction zones) also taking into account surface data.
Course contents	Rheological stratification of the Earth. Thermal lithosphere. Effects of the time scale and stress intensity on rock deformation. Microphysical processes underlying the inelastic behavior of rocks. Mobility of lattice defects. Fick's laws of diffusion. Mechanisms underlying linear and nonlinear rheologies. Dominant rheology in the sublithospheric mantle: constraints from data and models. Viscoelastic solids: analogical models. Elasto-plastic rheology. Geotherm in the oceanic lithosphere. Elastic part of the lithosphere. Theory of cylindrical flexure of thin elastic plates. Laccolith mountain. Lithospheric flexure produced by horizontal and vertical loads, applications to deformation near a island chain and subduction zones. Universal flexure profile. Plastic hinge in elastic-plastic transition. Gravitional field equations. Gravity in the interior of a spherical planet with compositional stratification. Measurements of gravity at the Earth surface: variations and corrections. Free-air and Bouguer anomalies. Isostasy: conditions and models. Gravitational effects associated with continental lithospheric flexure: compensation ratio. Isostatic seafloor depth. High-viscosity fluid models. Prandtl number. Lithosphere and asthenosphere. Stress diffusion from a tectonic margin. Estimation of mantle viscosity by studying postglacial deformation. Subduction angle. Fluids and creep in the crust. Fold formation. Estimation of the strength of a tectonic margin. Brittle-ductile transition. Seismic and aseismic creep. Quasi-static problems in viscoelastic Maxwell continuum media: relaxation function and correspondence with elastic solutions.
Readings/Bibliography	-D.L. Turcotte, G. Schubert. Geodynamics. Second or Third Edition, Cambridge University Press. Lecture notes concerning the rheology of the interior of the Earth and Solid-state creep will be available online (Virtuale).
Teaching methods	Lessons in the lecture-hall using slides
Assessment methods	The learning assessment consists of an oral examination in presence of the teacher and another expert person. The examination tends to evaluate the fulfilment of the Course learning outcomes: -Knowledge about the rheology of the Earth interior. -Knowledge of main evidences that allow constraining geodynamic processes and the rheology of the Earth interior. -Knowledge of modelling of geodynamic processes and related inferences about Earth Interior features. The final score of the course of Tectonophysics is determined as the average of the scores obtained by answering three questions about the main Course subjects.
Teaching tools	Slides are available online on the Virtuale platform. Students with DSA or temporary or permanent disabilities: it is recommended to contact the responsible University office in good time (https://site.unibo.it/studenti-con-disabilita-e-dsa/it): it will be their responsibility to propose any adaptations to the students concerned, which must however be submitted, 15 days in advance, to the approval of the teacher, who will evaluate the opportunity also in relation to the educational objectives of the course.

Learning activity **TIME SERIES ANALYSIS AND SIGNAL PROCESSING**

Areas	
Learning outcomes	At the end of the course, students acquire theoretical, computational, and applied skills that prepare them for working with any time-dependent signal produced by the atmosphere, oceans and the solid Earth, as well as in communications or information systems.
Course contents	Time Series Analysis and Signal Processing are the most common ways of representing data and temporal models in Earth and Atmospheric Sciences. The study of physical processes in scientific/engineering fields cannot ignore

	these tools and the statistics that describe them, allowing studies at time scales ranging from microseconds to millions of years. The student will be able to create synthetic signals for the validation of physical theories, distinguish deterministic and stochastic signals with advanced computational and data-processing methods, and inferring the physical processes controlling them. The course provides advanced elements of data processing and computational analysis of signals to students of the Degree Course. The topics covered provide the skills needed to work in Atmospheric and Earth Science, applied physics, and engeeniering environment, like research institutes and companies interested in the assessment of georesources and risk. The course includes computational exercises that will provide core training to students on the software and programming languages used by the scientific and engineering community to process signals. ***Topics covered.*** **Time series analysis:** time series as a mathematical/physical tool for the study of oscillatory and non-oscillatory phenomena; stochastic processes; Fourier and other trasforms applied to Earth and Atmospheric data; spectral and correlation analyses. **Signal processing:** building temporal filters and application to time series produced by physical processes; physics of oscillatory signals and their processing; data collection and processing strategies for Earth, Oceanic, Atmospheric, and Environmental Sciences. **Computation, Visualization and Interpretation:** advanced processing through open-access and propietary software; collaborative coding; visualization in 3D and 4D environment of physical data; interpretation of physical models derived by signal processing. **Applications:** Earth, Ocean, Atmospheric and Environmental Sciences; Topics proposed by students. It is assumed that the student has a good preliminary knowledge of the basic concepts of mathematical methods for physics.
Readings/Bibliography	- Shumway, R. H., & Stoffer, D. S. (2006). *Time series analysis and its applications: with R examples*. New York, NY: Springer New York - Cryer, J. D., & Chan, K. S. (2008). *Time series analysis: with applications in R*. New York, NY: Springer New York. - Vistnes, A. I. (2018). *Physics of Oscillations and Waves: With Use of Matlab and Python*. Springer. - D. Gubbins, (2004) *Time Series Analysis and Inverse Theory*, Cambridge University Press, Cambridge UK. - Thomson, R. E., & Emery, W. J. (2024). *Data analysis methods in physical oceanography*. Elsevier.
Teaching methods	The course is presented in the form of a "frontal lesson" accompanied by visual documentation in PowerPoint. The course includes computer exercises with programming in Julia, Matlab, and Python; with respect to these methods, active participation is expected from the attending students.
Assessment methods	The exam will be oral and will last approximately 45 minutes. It will involve an oral presentation of 15 minutes followed by questions. After the presentation, the student will be asked to illustrate one topic among those covered in the course. The depth and correctness of the answers will also be evaluated in light of practical and computational learning.
Teaching tools	The course uses presentations that will have connections to online resources, such as online databases and codes, which will contribute to the student's computational and data training. The exercises include instructions given in advance for installing codes and downloading datasets on a personal computer, for in-class exercises and, optionally, outside of course time.

Learning activity **TRANSVERSAL PROFESSIONAL SKILLS**

Areas	
Learning outcomes	At the end of the course the student will acquire soft professional skills working in disciplinary themes in physical sciences. In particular he/she will have abilities in: - writing a scientific project; - innovation and entrepreneurship; - scientific communication and journalism;

	- science outreach.
Course contents	Scientific project writing and communication is nowadays an almost daily activity, which is required at every level and grade of one's scientific cAreasr. Project writing has become part of the scientific daily working routine, while the effective and concise conveyance of scientific results, both in written and oral form, is essential to convey the results of one's work in a way that makes an impact in an environment of information overload. All this must be declined from a teamwork perspective: today's problems are complex; hence, solutions need to be achieved by combining knowledge and skills from different people. Aim and structure This extensive course aims to develop scientific and technical writing skills, as well as public speaking ability, through an interactive and team-based approach. The above-mentioned topics are tackled into three different hands-on modules. - Part 1 (10 hours, first period) 3 meeting of 3-4 hours: Technical Writing: this module is devoted to developing writing skills specifically targeted for technical documents, scientific reports and project proposals. Strategies to structure the contents and organise the writing in a collaborative manner will be discussed and applied to the writing of a real project proposal, responding to a real call of the EU programme. Timetable: the class timetable will be agreed with the students according to their teaching commitments. Part 2 (20 hours, second period): introduction (2 hours) + 6 meeting of 3 hours dedicated to seminars devoted to “thesis presentation”: “How to structure a thesis”, “How to structure an oral presentation”, “How to structure a scientific paper”, “How to write a CV”, and individual presentations of the thesis project made by students, to other students. Part 3 (18 hours, second period) 3 meeting of 6 hours with seminars in the morning ad laboratory in the afternoon. Subjects are particularly useful for thesis development: “Bash scripts”, “Plotting con GMT”,” Plotting and creating videos with Paraview”.
Readings/Bibliography	Teaching material is provided during the course via a shared folder. Additional texts: Jalongo, M. R., & Saracho, O. N. (2016). *Writing for publication*. Springer International Publishing. Marques, J., & Dhiman, S. (2017). *Leadership today: Practices for personal and professional performance*. Springer International Publishing Switzerland. Wang, K. C. (2018). *Systems Programming in Unix/Linux* (pp. 1-452). Springer
Teaching methods	Lectures and interactive classroom activities. Individual or group work at home to produce the outcomes required by the selected modules.
Assessment methods	Attendance is required (no less than 75%) Part 1 - evaluation of a research project developed during the course. Part 2 - a powerpoint presentation of the thesis project should be validated by the responsible of the module. Part 3 each laboratory activity aims at producing a specific outcome, that must be submitted and validated by the responsible of the module.
Teaching tools	Presentations, research articles, working material (tutorials, group working sheets, research questionnaires).