MSc Applied Earth Sciences

The MSc programme of Applied Earth Sciences at TU Delft concerns the part of the Earth system that interacts strongly with society, namely the upper crust from a few kilometres depth up to the lower atmosphere. Graduates of this programme will develop scientific approaches and engineering solutions to understand, monitor and predict processes within the Earth system and to utilize Earth's finite natural resources (including energy, materials, air, water, surface and subsurface space) in a responsible and sustainable way.

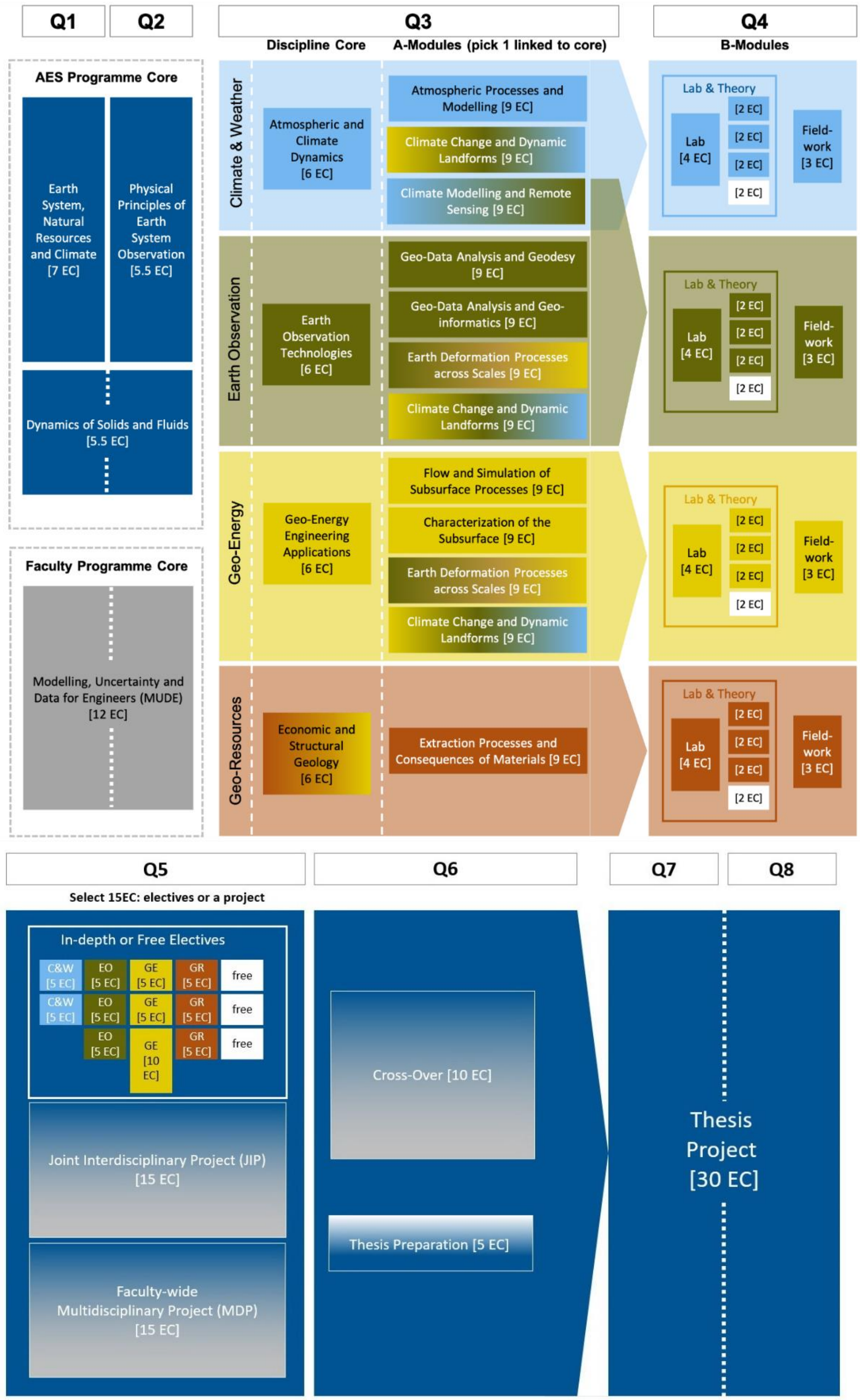
The field of Applied Earth Sciences includes the upper crust layer, which hosts the largest part of our resources (from underground space, water and energy carriers to ore minerals) and supports an increasing number of infrastructural interventions. In this domain, sedimentological, tectonic, and other natural processes have a profound impact on engineered and other anthropogenic structures. In the coupled atmosphere, oceans, and land system a wide variety of phenomena take place that have a strong impact on daily life. Weather phenomena such as (oceanic) storms, gustiness, heat waves and cold spells, droughts and extreme precipitation, (river) flooding, and sea-level rise can be devastating to society. At the same time, weather, winds, and rivers mark an increasingly important part of our natural resources such as solar and wind energy, hydropower, and water.

The MSc programme AES equips students with a combination of highly sophisticated observation and modelling skills together with a profound understanding of the phenomena and processes involved to manage this delicate part of the Earth system in a responsible and sustainable way. Exploration, exploitation, processing, storage, and production of terrestrial materials require the ability to develop and employ prudent and environmentally responsible engineering approaches to the use of the Earth and its finite subsurface resources. Students develop skills to build accurate models and observing systems that can help society to monitor, understand and predict the effects of the ongoing human generated changes in the coupled Earth system. These capabilities will contribute to and mitigate climate change, to help secure water resources and to facilitate the energy transition that makes optimal use of the finite natural resources.

This document presents an overview of the learning objectives, curriculum and module descriptions (of year 1). **Please note**: these are preliminary descriptions of the year 1 AES programme modules. The modules are still being developed, so these descriptions can still be subject to (small) changes [30-11-2021].

Contents

Curriculum overview



Intended Learning Outcomes (final attainments)

The student is able to…

A. Observe, characterise and explain Earth system processes.
B. Develop and apply data processing and analysis techniques to analyse Earth system processes.
C. Model and predict Earth system processes and their variability, and assess the influence of natural and anthropogenic factors.
D. Develop novel engineering solutions to facilitate the exploitation and/or management of Earth's natural resources in a responsible and sustainable way.
E. Formulate a research question, perform a literature, and research study, and build on existing technologies from different disciplines needed for an Applied Earth Sciences solution.
F. Challenge existing knowledge, show a critical attitude, and produce creative, constructive and novel solutions, and exercise independent judgement and uphold ethical standards.
G. Use written and oral communication skills to effectively exchange results and opinions with researchers, engineers, and Applied Earth Sciences stakeholders.
H. Set up, plan and monitor a project, dealing with a deadline and requirements set by Applied Earth sciences stakeholders.
I. Work effectively in a team of diverse talents, skills, characters, and cultures to solve an Applied Earth Sciences challenge.
J. Design and execute a fieldwork campaign for the application and/or Earth system processes to be studied.

Descriptions of the disciplines

Climate & Weather

In this discipline, students learn to quantify physical phenomena in the atmosphere, ocean and over land that act from short time scales (weather) to long time scales (climate). Students are trained to analyse the behavior of complex, non-linear natural systems and to develop modelling and observational techniques to solve quantitative problems. They learn to use those techniques to monitor, understand and predict climate and weather phenomena that have a strong impact on daily life, that set our future climate, that influence the energy transition, and that are the basis for one of the largest challenges faced by our society: to adapt to and mitigate climate change.

Earth Observation

In this discipline, students develop i) a solid technical understanding of the measurement principles, sensors, and data acquisition techniques essential to observe the Earth system and its processes, ii) the skills required to process, analyse, interpret, assess, and visualize the data and results and their quality, iii) the capability to design and apply data analysis methods, and exploit the data to address key scientific and societal challenges in Applied Earth Sciences. Techniques of interest include imaging radar (including interferometry), optical and multi-spectral imaging, gravimetry, radiometry, altimetry, LiDAR, sonar, GNSS, electromagnetic exploration methods, and seismic exploration methods.

Students will apply these techniques to detect, monitor and study phenomena essential to address societal challenges of climate change (e.g., multi-scale transport processes in the hydrosphere, atmosphere and cryosphere), energy transition (e.g., atmospheric circulation, clouds, land deformation), natural hazards (e.g., droughts, extreme weather events, tectonic activity), natural resources (e.g., land deformation, lake & river water levels, groundwater).

Geo-Energy Engineering

The Geo-Energy Engineering discipline will educate engineers who are fully equipped to play a substantial role in the global energy transition towards a more sustainable use of deep subsurface geo-resources. Geo-Energy Engineers will therefore learn to characterise, monitor, and predict the architecture, properties, and behaviour of energy-related subsurface use and the environmental response to subsurface engineering activities. They will be known for their interdisciplinary approach to responsibly apply their creativity and find innovative solutions.

The design of new and innovative solutions for sustainable energy are expected to be initiated where various disciplines intersect. In the learning line, we link the available expertise in geology, petroleum engineering, geothermal engineering, geophysics, and petro-physics into integrated modules. At the same time the students have the possibility to expand their expertise with modules focused on the domains of Earth observation, climate & weather, geotechnical engineering, geo-resource engineering, hydrology, hydraulics, environmental engineering. The learning line envisages to also create a link with programmes in other Delft faculties by using their expertise in the field of e.g., computational physics and optimisation (EEMCS), fluid dynamics, signal processing and imaging (AS and AE), environmental regulation, and project management (TPM).

Geo-Resource Engineering

This discipline includes the environmental and societal aspects to enable the development of innovative management of geo-resources with the objective of (zero) waste extraction and mitigating associated adverse impacts. Students develop i) a solid technical understanding of the characteristics, abundance, distribution and origin of primary and secondary solid raw materials, ii) the skills required to acquire relevant data, to quantitatively model, critically assess and analyse occurrences of primary and secondary solid raw materials, iii) the knowledge required to be environmentally aware of the necessity, utilisation and impact of primary and secondary solid/mineral raw materials. Focus areas will include Critical Raw Materials (CRM) with particular emphasis in the EU region and minerals containing energy transition minerals.

Students are trained to apply appropriate geo-statistical modelling and evaluation techniques to mitigate the effects of uncertainty associated with these variable systems and associated incomplete data. Furthermore, they are trained to manage and optimize extraction and utilization of primary and secondary solid raw materials. Students will be capable of environmental assessment of mine waste generation and its implications to mitigate the associated risks. The goal is to address societal challenges of Resource Efficiency and Raw Materials (e.g., sourcing minerals to a low-carbon future) and Environment (e.g., zero waste mining). Graduates will be qualified engineers for the sustainable and responsible management of primary and secondary solid/mineral raw materials.

Module descriptions: AES programme core

Module formats of:

- Earth system, natural resources and climate
- Physical principles of Earth system observation
- Dynamics of solids and fluids

Module	**Earth System, Natural Resources & Climate**
Learning objectives module	After completing this module, students will be able to: 1. Analyse the different components of the Earth system and the processes and time and spatial scales on which the different components of the Earth system interact. 2. Examine the processes that generate and deplete the availability of natural resources. 3. Distinguish the processes that play a role in the Earth's energy (im)balance and calculate their impact on climate. 4. Identify the processes that underlie impacts of anthropogenic activities on the Earth System. 5. Reflect on social and ethical implications of human interventions in the Earth System.
Module content	In this module, students will first be introduced to the Earth System and human interventions in the Earth System, including the exploitation of natural resources and greenhouse-gas emissions that caused climate change, and the societal challenge of moving towards a carbon-neutral world. Through three narratives, students will study through which processes and on what temporal and spatial scales the different Earth system components interact. **The first story line is named Solid Earth & Resources** and looks at the deep level dynamic processes that make the Earth a unique body in the solar system. These processes will be outlined in terms of the plate tectonic theory which provides a unified framework for the evolution of the solid Earth. We will examine how these processes have evolved through time and how they have been responsible for the distribution of the continents and the formation of mountain belts, volcanoes and the evolution of our natural resources. **The second story line is named Source to Sink** and starts at mountains and follows the pathway of water and sediment towards the river, delta and coastal-oceanic basins. Along the way we will investigate formation of sediment, the water cycle, formation of stratigraphy, vegetation and land use changes, and how all this is affected by the past and current climate and weather. **The third story line is named the Climate System**, in which students will gain a basic understanding of the Earth's energy budget and the natural and anthropogenic influences on past (paleo-)climates and our current and future climate. They will be familiarized with the carbon cycle and study the role of the global atmospheric and oceanic circulation in setting climate zones and weather. Finally, students will appraise and reflect on the societal and ethical implications of past or future human interventions related to resources and the climate of the Earth System.

<table>
<tr><th>Module</th><th>Physical Principles in Earth System Observation</th></tr>
<tr><td>Learning objectives module</td><td>After completing this module, students will be able to:

1. Characterize electromagnetic waves and describe mathematically the effects associated to their propagation through the different components of the Earth system (atmosphere, surface and subsurface).
2. Describe the interaction of optical-infrared waves with the Earth’s atmosphere and surface, and apply radiative transfer models to simulate their propagation and interactions.
3. Assess the potential value and limitations of optical/infrared remote sensing in determining geophysical variables.
4. Describe microwave scattering in the Earth’s atmosphere and at the Earth’s surface, and analyse the fundamental sensitivity to geophysical variables of interest.
5. Describe the emission of thermal waves and microwaves from the Earth’s atmosphere and surface, and apply radiative transfer models to simulate their propagation and interactions.
6. Assess the potential value and limitations of microwave remote sensing in determining geophysical variables.
7. Explain mathematically how the elastodynamic wave equation is derived, characterize elastic waves, and explain their sensitivity to contrast parameters.
8. Establish the linearized relationship between an observable and a given representation of the potential field, and synthesize the potential from functionals given on the surface of a sphere.
9. Critically discuss the potential value and limitations of different types of measurements (I.e., different bands of the EM spectrum and EMR/seismic/potential field) and propose and defend a type of measurement to observe certain geophysical variables.</td></tr>
<tr><td>Module content</td><td>Measuring is essential to characterize and explain processes in the Earth system, and a first step to assess, model and predict natural processes and human activities in and their impact on the Earth system. Electromagnetic, seismic and gravity potential-field observations inform us about a wide range of phenomena in the ocean, atmosphere, land surface, cryosphere and sub-surface. The measurements can be acquired from spaceborne, airborne, surface and sub-surface-based sensors.
This programme core module aims to enable students i) to explain and apply the physical principles underlying the measurements, and ii) to assess what type of measurement could be used best to determine certain geophysical variables. For example, students will learn how electromagnetic theory allows to use the intensity of radar echoes to yield information about rain rate, soil moisture, ocean roughness, or the layering of the subsurface. Similarly, they will learn how potential field theory can be applied to quantify mass changes of, e.g., the ice sheets. Students will be able to weigh the advantages and disadvantages of, for example, microwave versus visible and near-infrared observations for monitoring the Earth surface, and seismic and electromagnetic imaging in mapping the subsurface.

- Review basics of electromagnetic (EM) waves (propagation, polarization, spectra, Doppler, etc.) and propagation effects (attenuation, refraction, dispersion, polarimetric effects)
- Optical-infrared scattering and propagation (different reflection types, albedo, effect of wavelength, BRDF, Radiative transfer modelling of optical EM waves).</td></tr>
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	- Physical principles and limitations of VNIR/SWIR sensing systems (photographic systems, LiDAR, spectral systems including TIR) in terms of spatial and spectral resolution, sensitivity, atmospheric disturbances and corrections. - Microwave scattering and propagation (Rayleigh, Mie scattering, rough surface, volume scattering, clear air, radiative transfer modelling of microwave scattering in the atmosphere and at the land surface). - Radiometry (Radiometric Quantities and Units, Blackbody Radiation, emissivity at different frequencies). Radiative transfer modelling in passive microwave remote sensing of the Earth's atmosphere and surface. - Physical principles and limitations of microwave sensing systems (radiometer, non-imaging radar, imaging radar, ground-penetrating radar) in terms of spatial and spectral resolution, sensitivity, atmospheric propagation effects and corrections, radar range equation - Seismic (including acoustic) waves (Newton's second law, stress tensor, equation of motion, elasto-dynamic wave equation, Plane P- and S-waves, spatial and temporal resolution) - Potential fields (gravity, magnetic and electric fields) and their relationship to physical properties of a medium (Gauss law and its applications, Newtonian/Magnetic Potential, Laplace equation and harmonic functions, representation of potential fields, spherical harmonics) - Choose an approach for the observation and measurement of a geophysical variable.

Module	**Dynamics of Solids and Fluids**
Learning objectives module	After completing this module, students will be able to: 1. Distinguish flows and deformation in different parts of the Earth system (atmosphere, ocean and solid Earth) 2. Perform dimensional analysis of flows in different media and explain appropriate approximations to the equation of motion. 3. Characterise and derive the physical equations that underlie advection, diffusion, convection, conduction, elasticity, brittle and ductile deformation, and consider their application in models of Earth System components. 4. Apply the physical equations to examples of flow and deformation in different media using python notebooks 5. Analyse and compare the behaviour of flow and deformation phenomena in the Earth System using simple python models.
Module content	This course provides students with an understanding of basic concepts and mathematical solutions of fluid and solid dynamics with applications to atmosphere, oceans and the Solid Earth, preparing them for in-depth study of processes in specific Earth components. Students will learn how to derive the governing equations of fluid dynamics and solid dynamics, to explain how these are applied and simplified for flow and solid dynamics in the atmosphere, ocean and the solid Earth. Students will also carry out exercises as group assignments using python notebooks and model codes that exemplify simple models built on these governing equations. The topics covered are:

	Fluid dynamics: Governing Physical Equations • Conservation of Momentum: equations of motion in an inertial frame and a rotating frame, Cartesian and spherical coordinates, advection, Eulerian and Lagrangian derivatives, vorticity equation, vorticity and circulation theorems, vorticity equation in a rotating frame • Dimensional analysis and dimension-less numbers (Reynolds, Rossby, Prandtl, Froude, Peclet) • Conservation of Mass: compressible and incompressible flows • Equation of state, thermodynamic equations for ideal gases and for liquids and mixtures (first and second law of thermodynamics, Dalton's law, phase behaviour). • Buoyancy and thermal (static) stability • Laminar versus turbulent flows and diffusion (as proxy of turbulence) Fluid dynamics: Applications to ocean and atmosphere • Examples of flow in the atmosphere and oceans: geostrophic flows, convection, turbulence • Boussinesq and anelastic approximation, vertical (pressure) coordinates, Hydrostatic balance. • Primitive equations as basis of atmosphere and ocean circulation models. Fluid dynamics: Application to Flow in Porous Media • Single-phase flow in porous media (Porosity, Permeability, Darcy's law, Gov eq., solving potential, pressure & velocity) • Single-phase heat-mass transfer in porous media (conduction and convection) • Upscaling (heterogeneities, anisotropic) • Diffusion/dispersion in porous media • Introduction to multiphase flow in porous media (gov. equations, basics of kr & pc); • Rock-fluid interaction. Solid Dynamics • Solid Mechanics: elasticity, material strength, brittle to ductile deformation, effect of conditions (temperature, pressure, material properties). • Applications to rock deformation in shallow and deep Earth, and ice flow.

Module description: faculty core MUDE

Module	**Modelling, uncertainty, and data for Engineers (MUDE)**
Learning objectives module	After completion of this module the students are able: *General* 1. Is able to **describe and formulate a research question** (or alternatively, **design requirements**) given a set problem and select appropriate methodology and tools 2. Can **demonstrate awareness** of environmental and societal impacts and legal boundaries. (Ethics) 3. Is able to **present a fitting work plan to investigate a set of research questions or design requirements** 4. Is able **to compose a technical document** using appropriate academic language and citations, and describe the work in a **technical presentation** 5. Is able to work in a **collaborative group environment** effectively 6. **able to code** according to **basic coding standards** (e.g., consistency, readability, conciseness, structure, etc.) and **collaborate** with peers via distributed control software (e.g., git) 7. Can **illustrate the end-to-end procedure** of gathering, processing, and extracting knowledge from data using **modelling** and **uncertainty** methods 8. Can **collect and process data from different sources** and **perform** spatial / temporal / multivariate **analysis** to expose underlying relationships using **modelling** and **uncertainty** methods 9. Can **develop suitable data-driven modelling approaches** and present the results via an appropriate choice of metrics, **uncertainty** quantification methods and visualization *Data* 1. Can **identify variables of interest**, **describe the functioning of** common field/remote **sensors** used for **measuring** them, and **explain resolution implications** in space and time 2. Can **draft a suitable campaign** for monitoring processes of interest in space and time including an appropriate infrastructure for data collection 3. Is able to **estimate variables of interest** from observations and perform a quality assessment *Modelling* 1. **Can design a modelling framework** (from problem conceptualization to governing equation setup) for a physical/engineering process 2. **Can translate** the modelling framework into a set of equations or a program code 3. Can mathematically formulate and solve an **optimization problem** and discuss its properties 4. Can assess optimisation and simulation **models' performance** using a set of indicators 5. **Can assess the robustness** of stochastic optimization and simulation models *Uncertainty* 1. **Can derive relevant models and calculate basic probability and statistic problems** for faculty-wide applications using concepts such as: moments, total probability, Bayes' rule, set theory, continuous and discrete distributions, covariance and correlation, etc.

	2. **Can construct relevant models** for probabilistic dependence, for example using bivariate distributions or discrete Bayesian Networks 3. Use **deterministic models with probabilistic inputs** to evaluate engineering questions, describe processes, process-structure interaction, error propagation and similar problems to quantify model output uncertainty (in time and/or space) 4. Use **risk and reliability analyses** concepts to describe systems, their characteristics and behaviour in time and space to support risk and reliability evaluation and decision making under uncertainty
Professional and personal skills[3]	Communication and responsiveness, scientific writing and presentation, time management and anticipation, application of theory to new situations using the relevant equations, presenting, academic reading, writing, referencing, information collection and evaluation, inquiry thinking, critical thinking and teamwork.
Module Content	<u>Goal:</u> all students have common needs at the start of their programme to further develop knowledge and skills to meet the standards of the TU Delft and its research- and design-oriented MSc programmes. The MUDE is one integrated module in which topics related to data, modelling and uncertainty quantification are applied to real engineering challenges. This module comprises two interlinked parts. The **Theory, Application and Coding part** focuses on teaching and applying the fundamental concepts on modelling, uncertainty and data, as well as coding skills. In the **Project part** students work on examples and applications at the interface areas where the three topics overlap, creating opportunities for more integrated applications and the ability to focus on fields of interest per programme (when needed) while satisfying the same set of learning objectives. A gradually increasing complexity and openness of inquiry will be applied. **MUDE: Theory, Application and Coding** Topics Q1: - Fundamentals of Probability theory - Fundamentals of Mathematical modelling - Introduction to simulation - Observation Theory - Error / probabilistic uncertainty propagation (Monte Carlo Simulations) Topics Q2: - Stochastic Processes - Numerical Methods - Optimization - Risk & Reliability - Discrete simulation & Heuristics - Signal analysis & learning Topics related to coding: - Python refresher - Visualization in python - Data management and pre-processing in Pandas - Object Oriented Programming in Python - Code vectorization, algorithms, and complexity - FAIR data and Ethics

	MUDE: Project Links to all learning objectives of the module Student groups will work on a research or design challenge following the Process Oriented Guided Inquiry Learning (POGIL, https://www.pogil.org/) approach. Each group will have a member of the CEG academic staff as coach/client. There will be two stages (Stages 1 & 2), progressing from simple/closed problem solving (level 2 inquiry-based) to complex/open problem solving (level 3 inquiry-based). Q1, stage 1: Students will work on a series of structured projects, aligned with the topics from Theory, Application and Coding. A set of semi-open problems within a theme that support the Theory, Application and Coding activities. Example: Fitting different functions to a given dataset using least squares, or numerical convolution. Students start literature study, defining state of the art, make an initial work plan and by the end of this stage should define their own research questions or design requirements. Q2, stage 2: Each group will work on a different open-ended problem which builds upon the Q1 project. Analysis of complex/open problem is begun with a reduction to smaller problems with associated analytical or numerical solutions. Guided open inquiry is used to solve complex/open problems, leading finally to the integration of partial problem solutions and evaluation of robustness/uncertainty of solutions. The coach/client ensures that the partial problems considered by each group include a minimum number of topics listed in the Theory, Application and Coding part, which may be tailored to a specific programme or track. The project will be defined in the Terms of Reference, for which a template and criteria are provided in Annex I. Topics related to coding covered in the Project: - Selection of suitable visualization; - Coding standards and structured coding in Python; - Git & Github; - Result reproducibility These coding topics emphasize presentation, group work, versioning and collaboration.

Module descriptions: discipline cores

Module formats of:

- DC-CW: Atmosphere and Climate Dynamics
- DC-EO: Earth Observation Technologies
- DC-GE: Geo-Energy Engineering Applications
- DC-GR: Economic and Structural Geology

Module	**DC-CW: Atmosphere and Climate Dynamics**
Learning objectives module	After completing this module, students will be able to: 1. Analyse data of the horizontal and vertical structure of the atmosphere to explain features of the mean planetary circulation and of climate zones 2. Analyse thermodynamic profiles and perform stability analyses to identify the presence of convection 3. Assess the role of the boundary layer in the coupling of the atmosphere to the surface on short- and long-time scales 4. Apply conservation of heat, moisture and momentum to explain the origin and features of tropical, midlatitude and polar storm systems 5. Analyse and evaluate the sensitivity of circulations to changes in atmospheric parameters by running experiments with idealized models 6. Design a hypothetical laboratory experiment to explain the change in atmospheric circulation on climate time scales in response to external forcing 7. Discuss why similar or different processes cause uncertainty in weather prediction and climate prediction
Module content	The core module of the Climate & Weather discipline will provide students with the deeper physical understanding to comprehend and study the complex atmospheric flows that define climate and weather. The module is organized in seven themes: 1_Planetary circulation, 2_Baroclinic instability and planetary waves, 3_Tropical dynamics, 4_Planetary boundary layer, 5_Coupled surface-atmosphere dynamics, 6_From simplified theoretical models to general circulation models and 7_Grand challenges in weather and climate prediction. Throughout the module, observations and laboratory experiments (a rotating tank) serve as a starting point to describe the complex flows in our atmosphere. Building on the AES core modules, students will learn to explain what they observe by applying the laws of fluid dynamics, thermodynamics and radiation. The module will introduce advanced dynamical principles to explain planetary flows and instabilities and it will provide the students with idealized models to analyse and explain the sensitivity of atmospheric circulations.

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<tr><th>Module</th><th>DC-EO: Earth Observation Technologies</th></tr>
<tr><td>Learning objectives module</td><td>After completing this module, students will be able to:
Formulate user requirements that can be assessed based on parameter estimation
Evaluate the principles and limitations of generic classes of observation techniques, observation platforms, and data processing techniques
Analyse third-party user requirements and translate these into system requirements of an observational system (mathematical and physical)
Design an observational mission to gather the requested observations
Analyse results from an observation mission by estimating the parameters of interest, including quality assessment
Reflect on the analysis results in relation to third-party stakeholders
Contribute to effective group work and communicate orally and in written form on the project results at an academic level</td></tr>
<tr><td>Module Content</td><td>The goal of this module is to familiarize students with the process of specifying and designing an observational mission/campaign (e.g., a new satellite mission or a ground measurement campaign). This process includes the interpretation and analysis of user needs and their translation to observational requirements, the high-level design of possible technical solutions, and the evaluation of the expected observational performance with respect to user requirements.

The module will adopt an inquiry-based learning strategy, where groups of 4-5 students will work throughout the module on an observational mission/campaign motivated by topical scientific or societal issues. Each group of students will be mentored by a domain expert to guide their exploration of available and emerging EO technologies, potential trade-offs in mission/campaign design, the availability of suitable forward and inverse models, etc.

The required theoretical background will be provided through a combination of classroom lectures and digital learning. This allows the students to acquire a broad foundation and deepen their knowledge on topics most relevant to their observational mission/campaign.

Students will begin by formulating, consolidating, and prioritizing user requirements and translating those to mission/campaign requirements. Students will draw on their prior/existing understanding of the underlying physical principles to select a suitable observation technique to observe the variable(s) of interest. Students will develop a preliminary design for an observational mission/campaign that reconciles user requirements with the capabilities of the selected techniques.

Where appropriate, students will be provided with real or synthetic observation data that they will analyse to characterize the observations obtained from “their mission/campaign”, perform a quality assessment, estimate the parameters of interest and reflect on the ability of the mission/campaign to meet the user requirements. Mission/campaign proposals will be presented in a written report (proposal) and orally (pitch).</td></tr>
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Module	**DC-GE: Geo-Energy Engineering Applications**
Learning objectives module	After completing this module, students will be able to: 1. Explain what the field of Geo-Energy entails, how the subsurface can be utilised and what its role is in the energy transition. 2. Analyse the basic concepts of single-phase flow and reservoir characterization in relation to geothermal energy, subsurface storage, petroleum exploration and production applications and the effects of engineering in this subsurface 3. Evaluate how single-phase flow and subsurface characterisation interact at different temporal and spatial scales 4. Develop a conceptual plan that compares and integrates the different applications utilizing the subsurface for the energy demand towards the future. Quantify the components of the conceptual plan using the physic principles that describe subsurface phenomena. Test this problem towards the sensitivity of different components/issues (flow, mechanics, heterogeneity) 5. Use written and oral communication skills to effectively exchange results and opinions with researchers, engineers, and Applied Earth Sciences stakeholders.
Module content	This module will provide a general overview of the application areas of geothermal energy, petroleum exploration and production, and energy storage in the subsurface. The students will learn in this core module how these geo-energy application areas contribute to the energy demand of the world, in what way they can contribute to the transition towards a carbon-neutral world, what the opportunities, boundary conditions and consequences are of these applications. The students will learn the basic techniques and principles of reservoir characterization and single phase flow. This core module consists of the following components: • Basic principles of reservoir characterization and of single phase flow and how these two complement/interact with each other • Introduction into energy transition towards a CO_2 neutral future energy production, what is the role of the subsurface. Demand, potential and requirements • Basic principles governing and applications of Geothermal Energy (geothermal potential, flow and heat in the subsurface), include role of reservoir characterization and flow • Basic principles governing and applications of Subsurface Storage (storage of CO_2, energy carriers, boundaries of safe operations, cyclic storage), include role of reservoir characterization and flow • Basic principles governing and applications of Petroleum Exploration and Productions, include role of reservoir characterization and flow • Basic principles governing and applications of the Effects of Subsurface Engineering (Subsidence, seismicity, changes to reservoir) The course will be a mixture of lectures and assignments to determine the role of the three applications for energy production and how they play a role in for filling demand for energy towards the future. The effect of those operations are included. By doing those individual assignments a conceptual plan will be build that provides the students with an integrated approach to the use of the subsurface for the world's future energy demand.

Module	DC-GE: Economic and Structural Geology
Learning objectives module	After completing this module, students will be able to: 1. Classify the variety of mineral resource commodities of primary/secondary origin and discuss the relevance to society. 2. Illustrate the spatial and temporal distribution of mineral resources in the Earth crust by means of specific examples (Precious metals, base metals, ferrous metals, non-metallics, secondaries). 3. Compare evolutionary concepts about the origin of mineral deposits by means of specific examples (Precious metals, base metals, ferrous metals, non-metallics, secondaries). 4. Classify different mineral deposit styles based on geological features. 5. Relate different processes that give rise to different ore deposit styles to their genetic classification based on the observed geological features. 6. Define rock stress and strength and how rocks respond to different styles of deformation. 7. Reconstruct the structural evolution of multiscale rock bodies on the basis of documents such as stress-strain diagrams, seismic sections and outcrop data. 8. Appraise the significant processes that lead to formation of an ore deposit during structural deformation. 9. Work effectively in a team to define, plan and execute a project assignment and to report the outcomes by means of oral presentation and written report.
Module content	This module will equip students with the theory and knowledge to understand the nature, origin and factors controlling primary solid/mineral raw materials in order to understand the physical and chemical characteristics that influence and control the behaviour in terms of recovery of value and utilisation. It consists of two units: 1. Economic Geology in which the characteristics of different ore body styles of mineralisation, the origin, controls, formation mechanisms and abundance of primary and secondary raw materials are explained. 2. Geomechanics and structural geology where the role of structural geology and its significance for the formation of ore bodies are presented.
Unit 1	Economic Geology
Learning objectives unit	After completing this unit, students will be able to: • List the variety of mineral resource commodities of primary/secondary origin and discuss the relevance to society. • Illustrate the spatial and temporal distribution of mineral resources in the Earth crust by means of specific examples (Precious metals, base metals, ferrous metals, non-metallics, secondaries). • Explain evolutionary concepts about the origin of mineral deposits by means of specific examples (Precious metals, base metals, ferrous metals, non-metallics, secondaries). • Classify different mineral deposit styles based on geological features. • Describe different processes that give rise to different ore deposit styles and relate these processes to their genetic classification based on the observed geological features.

Content unit	This unit provides a brief introduction to the different types of mineral deposits. These include both the commodities and the geology of the deposits. The evolutionary concepts about the origin of mineral deposits are described. Ore-forming processes (magmatic, sedimentary, hydrothermal, and metamorphic) are explained. The focus of the Module Unit is on metalliferous deposits (encompassing the following commodities: iron, base metals, precious metals, light metals, and minor and specialty metals) as one of the most economically and societally important groups of mineral commodities. From a geological point of view, a simple genetic classification of mineral deposits encompasses four main groups: magmatic, hydrothermal, sedimentary, and metamorphic/ metamorphosed, each of them with several types and subtypes. In more detail: Mineral deposits: Types and Geology o Basic vocabulary. o Evolutionary concepts about the origin of mineral deposits. o Criteria for the Classification of Mineral Deposits. o Ore-Forming Processes. ▪ Magmatic, metamorphic, sedimentary and hydrothermal processes. o Mineral resource commodities ▪ Metals o Genetic classification of mineral deposits ▪ Magmatic, metamorphic and metamorphosed, sedimentary and hydrothermal mineral deposits.
Unit 2	Geomechanics and Structural Geology
Learning objectives unit	After completing this unit, students will be able to: • Apply stress and strain concepts and explain the factors controlling spatial and temporal changes in the state of stress and strain in the Earth on a variety of scales • Evaluate and quantify rock mechanical behaviour of rock materials and explain and predict its changes in time (diagenesis) and space (heterogeneities) at the different scales • Discriminate the different ways rocks have to accommodate deformation (fracturing, folding, faulting and compaction) and the conditions leading to one or the other. • Reconstruct the structural evolution of multiscale rock bodies on the basis of documents such as stress-strain diagrams, seismic sections, outcrop data and geodetic observations • Appraise the learned concepts to sub-surface geo-engineering activities thereby predicting subsurface responses
Content unit	Concepts of stress and strain – rheology Multiscale description of the state of stress in the Earth (inclusive of the effect of fluid pressures) The properties of semi-lithified to lithified sediments (including compaction) Rheology of semi-lithified to lithified sediments: an experimental approach Geological deformation structures 1: low-strain features (mode I, mode II fractures, pressure solution) Geological deformation structures 2: high strain geological structures (faults, and folds) How those structures and deformation processes are formed, expressed, measured and predicted in boreholes and on the surface of the Earth.

Module descriptions: A-modules

Student selects an A-module connected to (one of) the discipline core(s).

Module formats of:

- A-CW: Atmospheric Processes and Modelling
- A-EO1: Geo-data analysis and Geodesy
- A-EO2: Geo-data analysis and Geo-informatics
- A-GE1: Multi Phase Flow and Simulation of the Subsurface Processes
- A-GE2: Characterization of the Subsurface
- A-GR: Extraction Processes and Consequences of Solid/Mineral Raw Materials
- A-CW-EO: Climate Modelling & Remote Sensing
- A-EO-GE: Earth Deformation Processes across Scales
- A-CW-EO-GE: Climate change and dynamic landforms

An overview of all units is presented in the table below:

Discipline	Units	EC	A-CW	A-CW-EO	A-CW-EO-GE	A-EO1	A-EO2	A-EO-GE	A-GE1	A-GE2	A-GR	Remarks
C&W	Climate modelling and prediction	3										
	Water in the atmosphere	3										
	Land-atmosphere interactions	3										
EO	Earth observation technologies	6										this is the DC-EO
	Statistical geo-data analysis	3										
	Fourier analysis in Earth sciences	3										
	Geodesy and geodynamics	3										
	Geo-informatics	3										
GE	Numerical methods for subsurface geoscience simulations	3										
	Multiphase flow in porous rocks	3										
	Simulation and building of stratigraphy	3										
	Geomechanics and Structural Geology	3										also part of DC-GR
	Surface Morphodynamics and Sedimentation	3										
GR	Extraction methodologies	3										
	Residual materials from post extraction processing	3										
	Impact of of waste and raw material flows on the environment	3										

Module	A-CW: Atmospheric Processes and Modelling
Learning objectives module	After completing this module, students will be able to: 1. Explain the physics and dynamics of the transport of energy, water and momentum between the surface, the atmospheric boundary layer and the broader atmospheric circulation 2. Apply simplified models of turbulence and energy and water exchange, including convection and clouds 3. Reflect on the parameterization and coupling of atmospheric processes in general circulation models and their role in current uncertainties in climate prediction 4. Analyse climate simulations for the purpose of process understanding as well as assessment of climate change impacts and mitigation/adaptation policies 5. Assess the influence of land-atmosphere coupling, turbulence, convection and clouds on large-scale circulations (weather) and climate. 6. Hypothesize how land-atmosphere coupling, turbulence and convection and clouds are influenced by changes in weather and climate
Module content	This module is aimed at students with an interest in the field of applied meteorology (such as wind and solar energy prediction or climate impacts on land use), and in the design, analysis and assessment of weather and climate models. As such, this module has a stronger emphasis on analytical and numerical modeling than other modules, although observations are still used to study atmospheric processes. The main objective of the module is to provide students with a solid understanding of atmospheric processes that play a key role in climate and that have a strong impact on daily life: winds, clouds and radiation, storms and precipitation. These processes tend to be strongly coupled to the underlying surface and take place in the lower few kilometers of the atmosphere. They comprise the physics and dynamics of 1) land-atmosphere interactions, 2) boundary layer turbulence and convection and 3) clouds, including precipitation. These are processes that tend to take place on relatively small scales compared to the planetary-scale circulations that define Earth's climate zones (covered in the C&W core module) and form the dynamical core of general circulation models. This module will explain students how these small-scale processes are coupled to large scale circulations, and why their formulation in GCM's is particularly important for climate prediction and pressing uncertainties. The module comprises two units that focus on deepening process knowledge and analytical thinking in the field of land-atmosphere interactions and convection & clouds. Together, they cover atmospheric processes strongly linked to turbulence and radiative transfer across all scales that are not explicitly represented in general circulation models. The third unit – climate modeling and prediction - is shared with other modules and provides students with hands-on experience in the use and application of state-of-the-art general circulation models, including an assessment of the uncertainties in current climate projections.

Unit 1	Land-Atmosphere Interactions
Learning objectives unit	After completing this unit, students will be able to: • Apply principles of energy and mass conservation and set up a surface energy and water balance. • Explain and quantify the interaction between radiation, the Earth's atmosphere, the geometric properties of the natural environment and the radiative budget at the surface. • Explain and mathematically describe heat transport through the vegetation-soil continuum and the effect of soil moisture on the effectivity of heat transport. • Summarize observational techniques (with 'pro and cons') used to probe and quantify temperature dynamics and heat transport in the soil and atmospheric turbulence • Apply statistical methods to describe and quantify turbulent transport in the atmospheric boundary layer being aware of the underlying assumptions. • Explain how and under which assumptions turbulent exchange can be parameterized using K-diffusion analogies. • Explain and apply MO similarity theory also to quantify the effect of atmospheric stability on turbulent exchange. • apply different methods of evaporation estimation, ranging from Penman-Monteith to simplified approaches such as Makkink. • Explain how energy balance methods can be combined with turbulence descriptions as to quantify evapotranspiration in a natural environment. • Analyse a complex realistic case which integrates the different processes at play within the vegetation-soil-atmosphere continuum.
Content	Central topic of the unit is the scientific analysis of the natural environment near the atmosphere-surface interface. We aim to understand the interactions between the soil-vegetation system and the overlying atmosphere and also to assess how this effects the local microclimate. Special emphasis is given to quantification of thermodynamic processes, such as radiative, convective and conductive heat transport and to turbulent air flow over vegetated surfaces. After this course the student is able to approach complex natural systems and able to distil the essence of the problem (using general principles such as budget analysis). Next, he/she is able to simplify the system and to describe and analyse it in terms of simple mathematical models. Finally, the student is able to reflect, in a critical manner, on the obtained answer in relation to the specific methodology chosen. The theoretical unit connects with short practical demonstrations, which illustrates the various physical principles through simple hands-on experiments. This facilitates students to develop scientific intuition for the processes at hand. Topics per week include: 1. Introduction and basic concepts 2. Radiative processes I 3. Radiative processes II 4. Soil-vegetation transport processes 5. Turbulent transport I 6. Turbulent transport II 7. Evaporation and integrated methods

Unit 2	Water in the Atmosphere
Learning objectives unit	After completing this unit, students will be able to: • Explain radiative-convective equilibrium that determines the vertical structure of the atmosphere • Analyse energy and moisture budgets in the clear and cloud boundary layer using simplified bulk models. • Demonstrate and apply the principles of moist atmospheric thermodynamics. • Quantify the cooling and warming radiative effects of clouds and water vapor on the atmosphere. • Determine the precipitation efficiency of clouds based on cloud microphysical principles • Explain how precipitation patterns and clouds will change in a warming climate.
Content	This course describes the role of water in the atmosphere. It provides the physical understanding of the transport of water and energy through the atmosphere by convection, clouds and precipitation: from turbulent plumes and cloud formation processes to deep convective storms and precipitation. It describes how clouds and water vapor warm and cool the atmosphere through their intricate interaction with radiation. The focus is on the physical processes but the coupling of all these processes with the large-scale atmospheric circulation patterns are explained as well as the consequences for these processes in a warming climate: how is precipitation changing and how do clouds feedback to the global warming. Observations, modelling and forecasting tools are used alongside to illustrate theoretical concepts and special attention is paid to simplified statistical descriptions (parameterizations) of clouds, convection and precipitation in weather and climate models.
Unit 3	Climate Modelling and Prediction
Learning objectives unit	After completing this unit, students will be able to: • Explain and discuss state-of-the-art design approaches for climate simulations • Compare different climate models • Identify which type of modelling approach suits different climate modelling applications • Use output of climate models for comparison with observations, input for regional/local modelling of specific Earth processes, examination of theoretical climate dynamics concepts (equilibrium, tipping points, etc), and/or simple studies of climate change impacts and effects of mitigation measures • Identify limitations of models and climate simulations • Evaluate (some aspects of) climate models • Propose improvements for climate models through use of observations and/or inclusion of missing processes
Content	This component explains the numerical, computational and modelling concepts that underlie general circulation models (GCMs) and coupled climate models, which are the primary tool for predicting the dynamics of our current and future climate. The unit reviews the key processes simulated by each climate model component (atmosphere, ocean, land, sea-ice, land-ice) and state-of-the-art approximations/parameterizations, the main strengths and shortcomings of state-of-the-art model components and the way they are coupled (as compared to the real world). The design of climate simulations, covering topics such as model component and coupled model initialization, use of observations for boundary/initial conditions, design of scenarios of anthropogenic forcing,

	simulation of paleoclimates, and evaluation of models with observations and proxies of past climates are reviewed, along with the main applications, perspectives for further applications, and limitations of current simulations. Technical specifications of state-of-the-art coupled models are reviewed, for instance, grids, time-steps, frequency of coupling, computational demand. Students will also acquire the theoretical background for the analysis of climate simulations, from theoretical/fundamental concepts (equilibrium, climate sensitivity, tipping points, irreversibility, etc) to the study of climate change impacts and assessment of mitigation and adaptation measures.

Module	A-EO1: Geo-data analysis and Geodesy
Learning objectives module	After completing this module, students will be able to: 1. Assess the quality of EO data and derived products 2. Design and apply hypothesis testing procedures to select the model which best represents physical reality 3. Apply spectral analysis techniques to extract relevant geophysical information from EO data 4. Apply geodetic observation and analysis techniques to quantify and characterize changes in the shape of the Earth and its gravity field 5. Analyse the link between geodetic observables and the underlying geodynamical processes 6. Present findings in a precise and organized way, both numerically as well as graphically
Module content	This module targets students interested in learning how to rigorously use geo-data to estimate and monitor changes in the shape of the Earth's surface and its gravity field. The signals of interests can be related to local human activities, such as gas or ground-water extraction, or, for example, related to climate change, such as ice-mass losses in Greenland or Antarctica. In this data-oriented module, students will acquire the skills and theoretical background required to process Earth observation data in order to retrieve the signals of interest, in particular by using Fourier analysis methods. A key aspect of this module is dealing with errors in the data and assessing the quality of the input data as well the estimated parameters. Students will learn how to characterize different types of noise, and to make the best possible estimate of the parameters of interest in presence of noise. By learning about hypothesis testing, students will be able to select the model that best fits a set of measurements. Students will also learn to link the estimated parameters (for example, surface deformation rates) to the underlying geodynamical processes. For this purpose, students will learn about some key geophysical processes, such as Earth tides, glacial isostatic adjustment, and tectonics processes, including Earthquakes. Students will follow this module in combination with Earth Observation Technologies, the Earth Observation learning line core. The module includes three units: 1. Statistical geo-data analysis. 2. Signal Processing. 3. Geodesy and Geodynamics
Unit 1	Statistical geo-data analysis
Learning objectives unit	After completing this unit, students will be able to: • Design and apply hypothesis testing procedures to decide which functional or stochastic model best represents physical reality; • Apply tests for the probability distribution of data; • Apply variance component estimation to obtain an appropriate stochastic model; • Assess the quality of Earth observation data sets and derived/estimated parameters in terms of precision, accuracy, significance, reliability and integrity. • Present findings in a precise and organized way, both numerically as well as graphically.

Content unit	Earth observation data and models are the key to modelling and predicting Earth system processes and their variability. In this unit, we will build upon the acquired knowledge on observation theory from the MUDE module and we will treat the statistical concepts and theories needed to be able to further analyse and interpret the estimated parameters. This involves assessing the quality of input and output data, as well as the validity of the underlying models.
Unit 2	Fourier Analysis in Earth Sciences
Learning objectives unit	After completing this unit, students will be able to: • Demonstrate an understanding of Fourier transform and applied Fourier analysis techniques in the multi-dimensional Cartesian and spherical domain. • Analyse multidimensional continuous-time and discrete-time signals using Fourier transform techniques. • Manipulate the spectral content of multi-dimensional signals using linear-shift-invariant systems. • Solve Laplace equation in multi-dimensional Cartesian and spherical domain subject to boundary conditions using Fourier transform techniques. • Explain the concept of stochastic processes and determine covariance and spectral density of stationary random processes. • Estimate covariance and spectral density from realizations of stochastic processes. • Perform minimum mean-square-error estimation of stationary stochastic processes of interest given measurements of related stochastic processes.
Content unit	See learning objectives
Unit 3	Geodesy and Geodynamics
Learning objectives unit	After completing this unit, students will be able to: • Analyse the reference systems used in geodesy in terms of: (i) definition and (ii) the ways they are realized; • Explain how geodynamic processes may affect the Earth's shape and gravity; • Analyse strengths and weaknesses of individual geodetic techniques in relation to the observation of specific geodynamical processes, in terms of signal-to-noise ratio and spatio-temporal resolution; • Quantify the signature of geodynamic processes in temporal variations of the geometry and gravity field of the Earth; • Evaluate how geodetic datasets can be combined in order to better isolate the signature of specific geodynamical processes.
Content unit	This unit focuses on the use of geodetic observations to characterise a number of geophysical processes that affect the Earth's shape and gravity. It aims to provide students interested in fundamental geodetic concepts, such as reference systems and frames, and in geophysical applications of geodesy with the knowledge and the tools they need to contribute to the analysis of both natural and anthropogenic changes. Students will learn about the major geophysical processes involved, such as Earth tides, glacial isostatic adjustment, and tectonics processes, including Earthquakes. They will also learn how those processes can be observed by making use of appropriate geodetic techniques, where the choice of a specific technique depends on various natural and practical factors, such as the involved spatial and temporal scales (varying from kilometres to the whole Earth and from seconds to centuries), environmental conditions (e.g., presence of solid ground or vegetation),

	and data availability (e.g., location of ground stations or satellite ground tracks). Moreover, the students will understand the importance of representing geodetic observations relatively to a suitable reference. They will also learn how different techniques can complement each other, provided that they are properly combined. Particular attention will be given to the combination of gravity and geometry measurements, since gravity is the only geodetic observable that is directly related to processes occurring inside the Earth.

Module	**A-EO2: Geo-data analysis and Geo-informatics**
Learning objectives module	After completing this module, students will be able to: 1. Assess the quality of EO data and derived products 2. Design and apply hypothesis testing procedures to select the model which best represents physical reality 3. Apply spectral analysis techniques to extract relevant geophysical information from EO data 4. Model and estimate the spatial and temporal variability of EO data and relate it to the underlying geophysical processes 5. Select and apply appropriate geo-informatics tools to extract, process and communicate information from EO data 6. Present findings in a precise and organized way, both numerically as well as graphically
Module content	This is the module for students interested in exploring, mining and communicating the wealth of relevant information in state-of-the-art geospatial data. Different ways to visualize and process geospatial data, in different formats and projections, on geographic information systems will be explored. It will be discussed how to assess the quality of input Earth observation data, and how this quality propagates through a processing chain towards a quality description of a final product. Methodology will be analysed to assess the spatial-temporal contents of data in terms of repetitive patterns and the scales at which information is present in both the spatial and temporal domain. Finally, it will be discussed how such different information can be extracted from data, and how the significance of the extracted information can be accessed and communicated to different stakeholders in effective and attractive ways.
Unit 1	Statistical geo-data analysis
Learning objectives unit	After completing this unit, students will be able to: • Design and apply hypothesis testing procedures to decide which functional or stochastic model best represents physical reality; • Apply tests for the probability distribution of data; • Apply variance component estimation to obtain an appropriate stochastic model; • Assess the quality of Earth observation data sets and derived/estimated parameters in terms of precision, accuracy, significance, reliability and integrity. • Present findings in a precise and organized way, both numerically as well as graphically.
Content unit	Earth observation data and models are the key to modelling and predicting Earth system processes and their variability. In this unit, we will build upon the acquired knowledge on observation theory from the MUDE module and we will treat the statistical concepts and theories needed to be able to further analyse and interpret the estimated parameters. This involves assessing the quality of input and output data, as well as the validity of the underlying models.

<table>
<tr><th>Unit 2</th><th>Fourier Analysis in Earth Sciences</th></tr>
<tr><td>Learning objectives unit</td><td>After completing this unit, students will be able to:

• Demonstrate an understanding of Fourier transform and applied Fourier analysis techniques in the multi-dimensional Cartesian and spherical domain.
• Analyse multidimensional continuous-time and discrete-time signals using Fourier transform techniques.
• Manipulate the spectral content of multi-dimensional signals using linear-shift-invariant systems.
• Solve Laplace equation in multi-dimensional Cartesian and spherical domain subject to boundary conditions using Fourier transform techniques.
• Explain the concept of stochastic processes and determine covariance and spectral density of stationary random processes.
• Estimate covariance and spectral density from realizations of stochastic processes.
• Perform minimum mean-square-error estimation of stationary stochastic processes of interest given measurements of related stochastic processes.</td></tr>
<tr><td>Content unit</td><td>See learning objectives</td></tr>
<tr><td>Unit 3</td><td>Geo-informatics</td></tr>
<tr><td>Learning objectives unit</td><td>After completing this unit, students will be able to:

• Analyse geospatial data in different formats (data type, coordinate system) on different geospatial processing environments (GUI-, high-level programming and cloud-based)
• Assess the limitations and applicability of different map-projections and coordinate systems, and able to transform data between different systems and projections
• Perform basic image, vector and point cloud operations on spatio-temporal data
• Apply and select basic machine learning techniques for classification of geospatial data
• Design a workflow to extract geophysical parameters from geospatial data and communicate results to stakeholders in an information product (like a map/website/infographic)</td></tr>
<tr><td>Content unit</td><td>This skills-oriented unit will teach how to handle geospatial data acquired by remote sensing systems. Students will learn image processing techniques and will be introduced to information retrieval approaches necessary to extract the desired geophysical information from the measurements. The students will learn the theory and praxis of reference and coordinate systems. In addition, students will learn to effectively visualize data, including the use of map projections. This unit is aimed at students that want to build-up expertise in handling and analysis of geospatial and/or remote sensing data.</td></tr>
</table>

Module	A-GE1: Multi Phase Flow and Simulation of the Subsurface Processes
Learning objectives module	After completing this module, students will be able to: 1. Evaluate how to build process and stochastic reservoir models and choose appropriate rock properties or facies distribution 2. Analyse the physics and develop an analytical model for two-phase flow, thermal processes and poroelasticity through porous media with different assumptions and for different applications 3. Design a stable and consistent numerical method for modelling of flow and transport in porous rocks 4. Implement and create the three model types (reservoir model, analytical two-phase flow, numerical flow model) with geo-energy related software and codes 5. Apply the models to geo-energy related test cases and analyse the solutions with respect to the role of uncertainties, sensitivities, relationships and consequences critically for the different test cases 6. Work as a team on subject related problems and report findings and interpretations, including codes and choices made, in a structured and consistent way.
Module content	In this module, students acquire the necessary tools and knowledge to accurately model the building blocks of subsurface reservoirs and to accurately model flow of fluids/energy through these subsurface reservoirs. The 3 units focus on 1) analyse sedimentary and structural models of how the effective rock properties and the different facies, faults and fractures are distributed in subsurface reservoirs 2) describe, analyse and analytically model flow of fluids and energy through those reservoirs (both single phase as two phase fluids) and 3) describe, analyse and model flow numerically through these subsurface reservoirs. The students develop these models themselves, analyses the outcomes of these models and reflect on sedimentary and structural heterogeneities, variations, and uncertainties in these models. Particular attention will be paid to the role of scale of effective properties in these three approaches and how these units can be used to understand, solve and predict the key issues within geo-energy engineering applications such as geothermal energy, subsurface storage, hydrocarbon production and consequences of subsurface engineering.
Unit 1	Simulation and Building of Stratigraphy
Learning objectives unit	After completing this unit, students will be able to: • Analyse the difference between forward stratigraphic models, fracture models and stochastic models for sedimentary and structural geological aspects. • Choose and justify a model for the characterization of the rock properties or facies distribution in a geo-energy related subsurface reservoir, based on their model objective and data availability. • Select, customize and apply geo-energy related software or provided code and evaluate and use the produced output of these models. • Assess various sources of uncertainty and their effects in applying stratigraphic simulation techniques and how this uncertainty can be reduced.
Content unit	• Process-based and process-imitating forward stratigraphic simulation • Stochastic simulations • Fracture modelling and simulations • Impact to dynamic modelling and uncertainties

Unit 2	Multiphase Flow in Porous Rock
Learning objectives unit	After completing this unit, students will be able to: • Analyse the governing physics of two-phase flow; • Model two-phase flow and transport through porous media • Formulate relevant transport problems mathematically and analytically solve simple 1D problems with a Python code as a comparative numerical tool • Perform and interpret lab experiments on gravity drainage and segregated flow
Content unit	The main purpose of this unit is to understand the physics and modelling of two-phase flow and transport through porous. The student learns the basics of fluid-phase distributions and transport in porous media. Then how to formulate the relevant transport problems mathematically and finally to solve simple 1-D problems by analytical methods and with Matlab. Lab practical will provide insight in the physics of two-phase flow.
Unit 3	Numerical Methods in Subsurface Geoscience Simulations
Learning objectives unit	After completing this unit, students will be able to: • Develop a consistent and stable numerical method for flow, transport and geomechanical effects in subsurface heterogeneous porous media • Create a modular computer code by implementing convergent numerical methods • Develop a stable nonlinear coupling strategy for a given geoscientific modelling test case • Appraise the solution output for the given test case • Investigate the applicability, and quantify sensitivity and uncertainty of the simulations
Content unit	• Single-phase flow and heat transport in heterogeneous porous media • Two-phase flow and mass transport in heterogeneous porous media • Modeling of geomechanical response of heterogeneous porous reservoirs

Module	A-GE2: Characterization of the Subsurface
Learning objectives module	After completing this module, students will be able to: 1. Evaluate and quantify process controlling spatial and temporal changes in sedimentological and structural properties of sedimentary successions. 2. Evaluate and quantify state of stress in sedimentary basins, the way rocks deform and the mechanic factors controlling their response to geo-energy activities. Predict spatial and temporal changes of stress, strain and mechanic properties in the subsurface. 3. Interpret the various sedimentary successions and structural features from theory, field, seismic and borehole data. 4. Evaluate how to build sedimentary and structural reservoir models and choose appropriate rock properties and property distributions to characterise the model (including sources of uncertainties) 5. Analyse the origin and scales of heterogeneities in sedimentary deposits and structural features and integrate these into representative elementary volumes 6. Appraise the models in geo-energy related test cases and analyse the solution and investigate the role of uncertainties, sensitivities and relationships for the different test cases 7. Work as a team on subject-related assignments and report findings and interpretations, including codes and choices made, in a structured and consistent way.
Module content	This module focusses on the structural and sedimentological architecture of the rocks in the Earth that are important for Geo-Energy Engineering applications. The properties of rocks, as well as their variabilities on all scales, are assessed and quantified. Knowledge of the various processes taking place in the Earth and at the Earth's surface help the students assess and predict subsurface architecture and properties. The units consists of a understanding and modelling of how subsurface reservoirs are build up with respect to reservoir properties and facies distributions. How those changes in properties and distributions can be correlated to variations in sedimentary deposition due to past climate fluctuations within different tectonic settings. How those changes can be complemented within the structural framework in the subsurface (tectonics, deformation, compaction, faulting and folding). Particular attention will be placed to heterogeneity, variations and the issue of scale in subsurface characterization. Furthermore the students will be taught how process based understanding of sedimentary and tectonic processed is used to accurately populate subsurface reservoir models and how to accurately predict variations in these properties (both in space and in time).

Unit 1	Simulation and Building of Stratigraphy
Learning objectives unit	After completing this unit, students will be able to: • Analyse the difference between forward stratigraphic models, fracture models and stochastic models for sedimentary and structural geological aspects. • Choose and justify a model for the characterization of the rock properties or facies distribution in a geo-energy related subsurface reservoir, based on their model objective and data availability. • Select, customize and apply geo-energy related software or provided code and evaluate and use the produced output of these models. • Assess various sources of uncertainty and their effects in applying stratigraphic simulation techniques and how this uncertainty can be reduced.
Content unit	• Process-based and process-imitating forward stratigraphic simulation • Stochastic simulations • Fracture modelling and simulations • Impact to dynamic modelling and uncertainties
Unit 2	Geomechanics and Structural Geology
Learning objectives unit	After completing this unit, students will be able to: • Apply stress and strain concepts and explain the factors controlling spatial and temporal changes in the state of stress and strain in the Earth on a variety of scales • valuate and quantify rock mechanical behaviour of rock materials and explain and predict its changes in time (diagenesis) and space (heterogeneities) at the different scales • Discriminate the different ways rocks have to accommodate deformation (fracturing, folding, faulting and compaction) and the conditions leading to one or the other. • Reconstruct the structural evolution of multiscale rock bodies on the basis of documents such as stress-strain diagrams, seismic sections, outcrop data and geodetic observations • Appraise the learned concepts to sub-surface geo-engineering activities thereby predicting subsurface responses
Content unit	• Concepts of stress and strain – rheology • Multiscale description of the state of stress in the Earth (inclusive of the effect of fluid pressures) • The properties of semi-lithified to lithified sediments (including compaction) • Rheology of semi-lithified to lithified sediments: an experimental approach • Geological deformation structures 1: low-strain features (mode I, mode II fractures, pressure solution) • Geological deformation structures 2: high strain geological structures (faults, and folds) • How those structures and deformation processes are formed, expressed, measured and predicted in boreholes and on the surface of the Earth

<table>
<tr><th>Unit 3</th><th>Surface Morphodynamics and Sedimentation</th></tr>
<tr><td>Learning objectives unit</td><td>After completing this unit, students will be able to:

• Interpret fluvial and deltaic geomorphologies and successions using existing and new techniques from theory, field, and borehole data
• Analyse the origin and scales of heterogeneities in sedimentary deposits and integrate these into representative elementary volumes
• Analyse fluvial and deltaic morphodynamics in relation to tectonic, climate and base-level changes and internal sedimentary dynamics in an integrated source-to-sink perspective
• Explain the principles of fluvial and deltaic sediment preservation into stratigraphy at morphodynamic and geologic time scales
• Validate integrated stratigraphic concepts, including sequence stratigraphy, to geological data</td></tr>
<tr><td>Content unit</td><td>The sediments in the subsurface have been formed by the interaction of sedimentary processes and time-varying boundary conditions like climate, sea level and tectonics. To predict the character, geometry and heterogeneity of the sedimentary subsurface, knowledge is needed concerning the processes that acted on sedimentation and preservation through time. This course allows you to generate knowledge on sedimentary processes that are key to building stratigraphy, on the related spatial heterogeneity and representative elementary volumes, and on geological and geophysical techniques needed to sedimentologically characterize the subsurface:
• Sedimentary Systems, natural drivers and variability with a focus on fluvial and deltaic systems, while reviewing all systems
• Base-level and upstream changes, geological time in stratigraphy, and internal and external controls
• Methods to study sedimentary systems as numerical and analogue modeling, outcrop as analogue, borehole data, seismic data
• Building subsurface stratigraphy including REV determination and incorporating sedimentary geology in the subsurface workflow</td></tr>
</table>

Module	**A-GR: Extraction Processes and Consequences of Solid/Mineral Raw Materials**
Learning objectives module	After completing this module, students will be able to: 1. Explain the environmental and societal implications associated with the mining related processes to enable the development of innovative management strategies for geo-resources. 2. Explain the different extraction methodologies and consequences and implications associated with them. 3. Evaluate the nature of the residual materials from post extraction processing specifically the origin, handling, stacking and storage of mining residues. 4. Explain the physical, chemical and fluid Interactions and dynamics for mining residues. 5. Analyse and interpret appropriate geophysical and InSAR monitoring data to detect anomalies and consequences over different time scales of mining residues. 6. Translate environmental challenges and economic opportunities in solid waste management into scientific research questions and/or engineering opportunities. 7. Design an integrated plan for the extraction, waste storage and handling, targeting minimal waste and mitigation type strategies for risk/hazards associated with mine waste. 8. Consider the UN, ICMM and EU goals and regulations when developing engineering solutions for waste management options. 9. Work effectively in a team to define, plan and execute a project assignment and to report the outcomes structured and consistent by means of oral presentations and written report.
Module content	This module contains three interrelated units namely Extraction Methodologies, Residual Materials from Post Extraction Processing and the Impact of Primary and Secondary Mineral Raw Materials on the environment.
Unit 1	Extraction Methodologies
Learning objectives unit	After completing this unit, students will be able to: • Explain the basic terminology and constraints in mine design for both surface mining, underground mining and mining under water • Perform simple design calculations for ultimate pit definition, stope definition and extraction sequencing • Integrate safety aspects into design choices • Identify stakeholders of a mining project, the impact of the mining project and discuss preliminary solution strategies to mitigate the risk. • Evaluate critical factors impacting major design decisions in surface and Underground mining and derive performance indicators. • Analyse the factors influencing the transition from surface to underground mining
Content unit	Unit 1 of the course will introduce the tasks of mine method selection for surface, sub-marine and underground deposits, equipment selection, mine planning and extraction as an optimization task integrating geology, rock properties, business goals, mining equipment specifications as well as safety, environmental, social and economic considerations and concept of reserves; concept of

	resource efficiency with maximum recovery and minimal waste. It will provide students a general approach to these complex tasks with the priority of safety, health and minimal environmental and social impact. Surface Mining: • Surface mining methods: dragline mining; bucket wheel mining, stripping shovel mining; panel and bench design; stripping and spoiling strategies • Open pit mining: pit geometry and overall layout design principles. • Environmental/social considerations, health and safety. • Reclamation methods and planning; pit closure Transition from surface to underground mining. • Factors influencing the decision. • Environmental/social considerations, health and safety. Underground Mining: • Methods for underground exploitation of metalliferous and other ores and minerals; • Review of methods: Underground mining methods: room-and-pillar, stope-and-pillar, sublevel stoping, shrinkage stoping, cut-and-fill mining, longwall mining, sublevel caving and block caving. • Mine Planning stages and principles. • Environmental impact of underground operations: impact on water table and water quality. Mining under water: • Material characteristics of submarine deposits and implication for extraction methods. • Extraction methods: differences wet versus dry mining. • Operational challenges • Environmental Implications.
Unit 2	Residual Materials from Post Extraction Processing
Learning objectives unit	After completing this unit, students will be able to: • Explain the origins, nature, properties and implications of mine wastes. • Evaluate the data requirements for safe mine waste disposal and storage designs. • Describe impact of physical, chemical and fluid behavior on the stability of mine wastes. • Explain the dynamic processes of solid-fluid interaction in mine residues • Identify and apply relevant standards and legislations for safe storage and disposal of mine wastes. • Explain risk management process and apply risk assessment methodology to assess the risks associated with mine waste storage and disposal. • Describe the aim, the steps and the legal background of an environmental and social impact assessment for mining projects.

	- Explain the advantages and limitations of InSAR monitoring for various geotechnical problems and evaluate the quality of the monitoring data in relation to the application. - Analyse monitoring data to detect anomalies, seasonality, change in trends and noise levels (time series analysis and anomaly detection) - Make simple designs of DC and induced seismicity monitoring campaigns, apply simple processing and interpret the data.
Content unit	This unit will introduce the tasks of designing, planning, managing and closing storage facilities for materials produced as waste products in the process of extraction. It will provide students a general approach to solve these complex tasks with the priority of safety, health and minimal environmental and social impact. The course will include: - Origin, handling, stacking and storing of waste products due to mining. - Tailing dams, mud lakes: design and waste management - Environmental and social impact and mitigating strategies - Rehabilitation and closure - Risk theory and risk management - Applicable standards and legislation - Physical chemical behavior - Physical material properties - Chemical material properties - Fluid particle interaction - The theory of physical and chemical transport phenomena - Modelling dynamic processes of physical, chemical and fluid interactions - Monitoring of impact and consequences over different time scales of mining residues specifically by means of: - the Direct-Current (DC) electrical method - Induced seismicity - InSAR
Unit 3	Impact of Waste and Raw Material flows on the environment
Learning objectives unit	After completing this unit, the students will be able to: - Recognise and quantify properties of the main mining-related solid waste sources - Describe the magnitude and significance of the environmental impacts and hazards of mining-related solid waste sources - Classify and separate mining-related wastes in compliance with UN-, ICMM- guidance and EU-directives - Identify technical routes for the efficient converting revalorisation and remediation of mining waste - Review and discuss hotspots of environmental impacts in the exploration-, extraction- and processing stages of mineral resources - Identify and evaluate possible remedial measures of environmental impacts of solid waste production- and processing

Content unit	Main aim of the module unit is gaining understanding of the solid waste flows resulting from the exploration, the extraction and processing of mineral resources. These wastes are associated with a variety of environmental impacts and potential hazards. This module unit particularly focuses on the following subjects: • Introduction to types, properties and quantities of the main mining-related solid wastes • Environmental impacts and hazard risks of the exploration, extraction and processing stages of mineral resources • Legislative framework and ethical aspects of mining-related waste • Overview of possible remediation measures of environmental impacts related to solid waste production

Module	**A-EO-GE: Earth Deformation Processes across Scales**
Learning objectives module	After completing this module, students will be able to: 1. Design and apply hypothesis testing procedures to select the model which best represents physical reality 2. Use geodetic observation and analysis techniques needed to quantify, characterize and explain changes in the shape of the Earth and its gravity field, and changes and expressions of crustal structures 3. Evaluate the mechanical and deformation response and expressions of rocks to varying stresses within the shallow part of the Earth's crust 4. Analyse the link between geodetic observables and the underlying geodynamical and geomechanical processes from reservoir to global scales, including the effects of subsurface engineering activities 5. Present findings in a precise and organized way, both numerically as well as graphically
Module content	This module provides the knowledge and skills to understand, predict and characterise Earth deformation processes from continental (e.g., glacial isostatic adjustments and tectonics) towards reservoir scales (e.g., folding, faulting and compaction). Geodetic and geophysical observation techniques will be used to quantify these deformation processes, by extracting physical parameters and assessing their uncertaintes. In addition, students will learn to relate the observed movements to subsurface engineering (e.g., resource extraction, storage, tunnelling) or natural processes (e.g., plate tectonics, Earthquakes). The module contains three components, 1) Statistical geo-data analysis, 2) Geodesy and Geodynamics, and 3) Geomechanics and Structural Geology.
Unit 1	Statistical geo-data analysis
Learning objectives unit	After completing this unit, students will be able to: • Design and apply hypothesis testing procedures to decide which functional or stochastic model best represents physical reality; • Apply tests for the probability distribution of data; • Apply variance component estimation to obtain an appropriate stochastic model; • Assess the quality of Earth observation data sets and derived/estimated parameters in terms of precision, accuracy, significance, reliability and integrity. • Present findings in a precise and organized way, both numerically as well as graphically.
Content unit	Earth observation data and models are the key to modelling and predicting Earth system processes and their variability. In this unit, we will build upon the acquired knowledge on observation theory from the MUDE module and we will treat the statistical concepts and theories needed to be able to further analyse and interpret the estimated parameters. This involves assessing the quality of input and output data, as well as the validity of the underlying models.

Unit 2	Geodesy and Geodynamics
Learning objectives unit	After completing this unit, students will be able to: • Analyse the reference systems used in geodesy in terms of: (i) definition and (ii) the ways they are realized; • Explain how geodynamic processes may affect the Earth's shape and gravity; • Analyse strengths and weaknesses of individual geodetic techniques in relation to the observation of specific geodynamical processes, in terms of signal-to-noise ratio and spatio-temporal resolution; • Quantify the signature of geodynamic processes in temporal variations of the geometry and gravity field of the Earth; • Evaluate how geodetic datasets can be combined in order to better isolate the signature of specific geodynamical processes.
Content unit	This unit focuses on the use of geodetic observations to characterise a number of geophysical processes that affect the Earth's shape and gravity. It aims to provide students interested in fundamental geodetic concepts, such as reference systems and frames, and in geophysical applications of geodesy with the knowledge and the tools they need to contribute to the analysis of both natural and anthropogenic changes. Students will learn about the major geophysical processes involved, such as Earth tides, glacial isostatic adjustment, and tectonics processes, including Earthquakes. They will also learn how those processes can be observed by making use of appropriate geodetic techniques, where the choice of a specific technique depends on various natural and practical factors, such as the involved spatial and temporal scales (varying from kilometres to the whole Earth and from seconds to centuries), environmental conditions (e.g., presence of solid ground or vegetation), and data availability (e.g., location of ground stations or satellite ground tracks). Moreover, the students will understand the importance of representing geodetic observations relatively to a suitable reference. They will also learn how different techniques can complement each other, provided that they are properly combined. Particular attention will be given to the combination of gravity and geometry measurements, since gravity is the only geodetic observable that is directly related to processes occurring inside the Earth.
Unit 3	Geomechanics and Structural Geology
Learning objectives unit	After completing this unit, students will be able to: • Apply stress and strain concepts and explain the factors controlling spatial and temporal changes in the state of stress and strain in the Earth on a variety of scales • Evaluate and quantify rock mechanical behaviour of rock materials and explain and predict its changes in time (diagenesis) and space (heterogeneities) at the different scales • Discriminate the different ways rocks have to accommodate deformation (fracturing, folding, faulting and compaction) and the conditions leading to one or the other. • Reconstruct the structural evolution of multiscale rock bodies on the basis of documents such as stress-strain diagrams, seismic sections, outcrop data and geodetic observations • Appraise the learned concepts to sub-surface geo-engineering activities thereby predicting subsurface responses

Content unit	• Concepts of stress and strain – rheology • Multiscale description of the state of stress in the Earth (inclusive of the effect of fluid pressures) • The properties of semi-lithified to lithified sediments (including compaction) • Rheology of semi-lithified to lithified sediments: an experimental approach • Geological deformation structures 1: low-strain features (mode I, mode II fractures, pressure solution) • Geological deformation structures 2: high strain geological structures (faults, and folds) • How those structures and deformation processes are formed, expressed, measured and predicted in boreholes and on the surface of the Earth

Module	A-CW-EO: Climate Modelling & Remote Sensing
Learning objectives module	After completing this module, students will be able to: 1. Formulate, consolidate, and prioritize remote sensing data requirements to study processes in the coupled climate system and validate and inform their parametrization in climate models 2. Select a suitable observation technique to observe the variable(s) of interest, drawing on their prior/existing understanding of the underlying physical principles 3. Characterize real or synthetic observation data, perform a quality assessment, estimate the parameters of interest and reflect on the ability of the available data to meet their requirements. 4. Construct (simplified) models of climate variables and evaluate these with remote sensing data. 5. Analyse climate simulations for the purpose of process understanding (climate science) as well as for the interpretation of remote sensing data records. 6. Reflect on how integration of remote sensing data in climate modelling may improve our understanding and prediction of climate variables.
Module content	This module complements the Climate & Weather core module. It is aimed at students from the Climate & Weather learning line who are interested in the synergy offered by the combination of remote sensing and climate models to understand, predict and model the wide range of processes governing our present-day coupled climate system. The objective of this module is to provide students with a physical understanding of these processes and the skills needed to observe and assess those processes using ground-based and space-borne observations, and coupled global models. Ultimately, the student will be able to understand and analyse both one specific component of the climate system (e.g. cryosphere, terrestrial water cycle, ocean), and on a broader level, the interactions between them using a combination of observations and modelling. Students will learn how to formulate, consolidate, and prioritize their data needs, and will draw on their prior/existing understanding of the underlying physical principles to select a suitable observation technique to observe the variable(s) of interest. By developing a preliminary design for an observational mission/campaign they will become familiar with the trade-offs commonly made to reconcile requirements from a modeler's perspective with the capabilities of the selected techniques. They will analyse real or synthetic observation data, perform a quality assessment, estimate the parameters of interest and reflect on the ability of the mission/campaign to meet their needs in terms of parameterizing processes of interest, constraining models and improving predictions. The module comprises two units that, together, offer the students a thorough understanding of how large-scale climate processes can be observed and modelled. Earth Observation Technologies (6 EC) consists of the core module of the Earth Observation learning line and familiarizes students with the process of specifying and designing an observational mission/campaign (e.g., a new satellite mission or a ground measurement campaign). This process includes the interpretation and analysis of user needs and their translation to observational requirements, the high-level design of possible technical solutions, and the evaluation of the expected observational performance with respect to user requirements.

	The unit Climate Modeling and Prediction (3 EC) from the Climate & Weather learning line is shared with other modules and provides students with hands-on experience in the use and application of stat-of-the-art general circulation models, including an assessment of the uncertainties in current climate projections.
Unit 1	Climate Modelling and Prediction
Learning objectives unit	After completing this unit, students will be able to: • Explain and discuss state-of-the-art design approaches for climate simulations • Compare different climate models • Identify which type of modelling approach suits different climate modelling applications • Use output of climate models for comparison with observations, input for regional/local modelling of specific Earth processes, examination of theoretical climate dynamics concepts (equilibrium, tipping points, etc), and/or simple studies of climate change impacts and effects of mitigation measures • Identify limitations of models and climate simulations • Evaluate (some aspects of) climate models • Propose improvements for climate models through use of observations and/or inclusion of missing processes
Content	This component explains the numerical, computational and modelling concepts that underlie general circulation models (GCMs) and coupled climate models, which are the primary tool for predicting the dynamics of our current and future climate. The unit reviews the key processes simulated by each climate model component (atmosphere, ocean, land, sea-ice, land-ice) and state-of-the-art approximations/parameterizations, the main strengths and shortcomings of state-of-the-art model components and the way they are coupled (as compared to the real world). The design of climate simulations, covering topics such as model component and coupled model initialization, use of observations for boundary/initial conditions, design of scenarios of anthropogenic forcing, simulation of paleoclimates, and evaluation of models with observations and proxies of past climates are reviewed, along with the main applications, perspectives for further applications, and limitations of current simulations. Technical specifications of state-of-the-art coupled models are reviewed, for instance, grids, time-steps, frequency of coupling, computational demand. Students will also acquire the theoretical background for the analysis of climate simulations, from theoretical/fundamental concepts (equilibrium, climate sensitivity, tipping points, irreversibility, etc) to the study of climate change impacts and assessment of mitigation and adaptation measures.

Unit 2	Earth Observation Technologies (DC EO)
Learning objectives module	After completing this unit, students will be able to: • Formulate user requirements that can be assessed based on parameter estimation • Evaluate the principles and limitations of generic classes of observation techniques and observation platforms, and data processing techniques; • Analyse third-party user requirements and translate these into system requirements of an observational system (mathematical and physical); • Design an observational mission to gather the requested observations; • Analyse results from an observation mission by estimating the parameters of interest, including quality assessment; • Reflect on the analysis results in relation to third-party stakeholders; • Contribute to effective group work and communicate orally and in written form on the project results at an academic level.
Content	The goal of this unit is to familiarize students with the process of specifying and designing an observational mission/campaign (e.g., a new satellite mission or a ground measurement campaign). This process includes the interpretation and analysis of user needs and their translation to observational requirements, the high-level design of possible technical solutions, and the evaluation of the expected observational performance with respect to user requirements. The unit will adopt an inquiry-based learning strategy, where groups of 5-6 students will work throughout the module on an observational mission/campaign motivated by topical scientific or societal issues. Each group of students will be mentored by a domain expert to guide their exploration of available and emerging EO technologies, potential trade-offs in mission/campaign design, the availability of suitable forward and inverse models, etc. The required theoretical background will be provided through a combination of classroom lectures and digital learning. This allows the students to acquire a broad foundation and deepen their knowledge on topics most relevant to their observational mission/campaign. Students will begin by formulating, consolidating, and prioritizing user requirements and translating those to mission/campaign requirements. Students will draw on their prior/existing understanding of the underlying physical principles to select a suitable observation technique to observe the variable(s) of interest. Students will develop a preliminary design for an observational mission/campaign that reconciles user requirements with the capabilities of the selected techniques. Where appropriate, students will be provided with real or synthetic observation data that they will analyse to characterize the observations obtained from “their mission/campaign”, perform a quality assessment, estimate the parameters of interest and reflect on the ability of the mission/campaign to meet the user requirements. Mission/campaign proposals will be presented in a written report (proposal) and orally (pitch).

Module	**A-CW-EO-GE: Climate change and dynamic landforms**
Learning objectives module	After completing this module, students will be able to: 1. Analyse the interaction between climate change and the solid Earth's surface, with particular attention to the timescales involved. 2. Explain the origin of present-day morphodynamic features by integrating geological and geospatial data. 3. Analyse climate simulations for the purpose of understanding the driving physical processes. 4. Analyse source-to-sink sedimentary systems and records in relation to tectonics and climate amongst other parameters. 5. Extract geophysical parameters from geospatial data. 6. Present findings in a precise and organized way, both numerically as well as graphically
Module content	This module is aimed at students with an interest in the physics of climate change, its effects on the natural environment and how those can be analysed through geospatial data. In the climate modelling unit, student will learn about the numerical, computational and modelling concepts than underlie general circulation models and coupled climate models, which are the primary tools for predicting the dynamics of past and future climate. The natural environment is here represented by rivers and deltas, which provide an instructive and societal-relevant study case to learn about the interaction between climate change and the surface of the solid Earth. Finally, the Earth observation unit has a strong hands-on identity, which complements the geological characterization of landforms by teaching how to deliver remote sensing products that can be used in geophysical studies. This module will fit into a study-route that addresses how the natural environment is affected by past and future climate change at decadal to secular scales, by using numerical models of the driving physical processes as well as geological and instrumental observations.
Unit 1	Geo-informatics
Learning objectives unit	After this unit students are able to: • Analyse geospatial data in different formats (data type, coordinate system) on different geospatial processing environments (GUI-, high-level programming and cloud-based) • Assess the limitations and applicability of different map-projections and coordinate systems, and able to transform data between different systems and projections • Perform basic image, vector and point cloud operations on spatio-temporal data • Apply and select basic machine learning techniques for classification of geospatial data • Design a workflow to extract geophysical parameters from geospatial data and communicate results to stakeholders in an information product (like a map/website/infographic)

Content unit	This skills-oriented unit will teach how to handle geospatial data acquired by remote sensing systems. Students will learn image processing techniques and will be introduced to information retrieval approaches necessary to extract the desired geophysical information from the measurements. The students will learn the theory and praxis of reference and coordinate systems. In addition, students will learn to effectively visualize data, including the use of map projections. This unit is aimed at all students that want to work with analyse geospatial data and/or remote sensing data.
Unit 2	Surface Morphodynamics and Sedimentation
Learning objectives unit	After this unit students are able to: • Interpret fluvial and deltaic geomorphologies and successions using existing and new techniques from theory, field, and borehole data • Analyse the origin and scales of heterogeneities in sedimentary deposits and integrate these into representative elementary volumes • Analyse fluvial and deltaic morphodynamics in relation to tectonic, climate and base-level changes and internal sedimentary dynamics in an integrated source-to-sink perspective • Explain the principles of fluvial and deltaic sediment preservation into stratigraphy at morphodynamic and geologic time scales • Validate integrated stratigraphic concepts, including sequence stratigraphy, to geological data
Content unit	The sediments in the subsurface have been formed by the interaction of sedimentary processes and time-varying boundary conditions like climate, sea level and tectonics. To predict the character, geometry and heterogeneity of the sedimentary subsurface, knowledge is needed concerning the processes that acted on sedimentation and preservation through time. This course allows you to generate knowledge on sedimentary processes that are key to building stratigraphy, on the related spatial heterogeneity and representative elementary volumes, and on geological and geophysical techniques needed to sedimentologically characterize the subsurface: • Sedimentary Systems, natural drivers and variability with a focus on fluvial and deltaic systems, while reviewing all systems • Base-level and upstream changes, geological time in stratigraphy, and internal and external controls • Methods to study sedimentary systems as numerical and analogue modeling, outcrop as analogue, borehole data, seismic data • Building subsurface stratigraphy including REV determination and incorporating sedimentary geology in the subsurface workflow

Unit 3	Climate Modelling and Prediction
Learning objectives unit	After this unit students are able to: • Explain and discuss state-of-the-art design approaches for climate simulations • Compare different climate models • Identify which type of modelling approach suits different climate modelling applications • Use output of climate models for comparison with observations, input for regional/local modelling of specific Earth processes, examination of theoretical climate dynamics concepts (equilibrium, tipping points, etc), and/or simple studies of climate change impacts and effects of mitigation measures • Identify limitations of models and climate simulations • Evaluate (some aspects of) climate models • Propose improvements for climate models through use of observations and/or inclusion of missing processes
Content	This component explains the numerical, computational and modelling concepts that underlie general circulation models (GCMs) and coupled climate models, which are the primary tool for predicting the dynamics of our current and future climate. The unit reviews the key processes simulated by each climate model component (atmosphere, ocean, land, sea-ice, land-ice) and state-of-the-art approximations/ parameterizations, the main strengths and shortcomings of state-of-the-art model components and the way they are coupled (as compared to the real world). The design of climate simulations, covering topics such as model component and coupled model initialization, use of observations for boundary/initial conditions, design of scenarios of anthropogenic forcing, simulation of paleoclimates, and evaluation of models with observations and proxies of past climates are reviewed, along with the main applications, perspectives for further applications, and limitations of current simulations. Technical specifications of state-of-the-art coupled models are reviewed, for instance, grids, time-steps, frequency of coupling, computational demand. Students will also acquire the theoretical background for the analysis of climate simulations, from theoretical/fundamental concepts (equilibrium, climate sensitivity, tipping points, irreversibility, etc) to the study of climate change impacts and assessment of mitigation and adaptation measures.

Module descriptions: B-modules

Module formats of:

- B-CW: Climate & Weather
- B-EO: Earth observation
- B-GE: Geo-energy engineering
- B-GR: Geo-resource engineering

Module name	**B-CW: Climate & Weather**
Learning objectives module	General learning objectives for theory, labs and fieldwork. After completing the module students will be able to: ***General***: 1. Identify open issues in the processing and/or interpretation of Earth system data records based on the outcomes of the lab project and design a development roadmap to address them. 2. Present analyses, interpretations and conclusions, as well as ethical implications, of the Lab and Fieldwork projects in a clear and convincing manner, both orally and written. **Theory/Lab (module specific):** 3. Explain which techniques are needed to measure or model specific geophysical parameters governing the processes relevant to a societal challenge. 4. Evaluate the temporal and spatial requirements for measurements or models to monitor and predict these processes. 5. Combine and analyse data records to understand processes and their relationships on relevant scales 6. Distinguish the different sources of uncertainty in observational and in model data. 7. Analyse the skills and errors of a model by comparing with observations. 8. Evaluate the sensitivity of geophysical models to key parameters and boundary conditions. 9. Analyse, visualize and interpret and present findings in a clear and convincing manner. **Fieldwork**: 10. Plan and design a field campaign that is appropriate for the physical process to be measured. 11. Collect data in the field using different measurement techniques. 12. Explain and quantify the error sources associated with the field measurements. 13. Process and analyse the data collected in the field to give meaningful constraints on the physical process. 14. Effectively communicate with peers, assessors and clients. 15. Contribute to a project as a team player and to the overall project management.
Module content	The lab and the theory part of the B-module are connected and inquiry-based. **Theory (8EC)**

From the table below students need to choose a societal challenge, 2EC (Climate Data Analysis) is compulsory, 2EC to be selected from subset 1, remaining 4EC to be selected from subsets 1 and 2.

Each theory component in the table is 2EC.
A description of each theory component is provided later in this document.

	Geohazards lab	**Climate impacts lab**	**Energy transition lab**
Compul-sory	Climate data analysis	Climate data analysis	Climate data analysis
Subset 1: Choose at least 2EC	Remote Sensing of Precipitation	Remote Sensing of Precipitation	Remote Sensing of Precipitation
	Multi-Sensor Cloud and Atmospheric Observation	(Multi-Sensor Cloud and Atmospheric Observation	Multi-Sensor Cloud and Atmospheric Observation
	Sea level change and floods	Cryosphere Dynamics	Production science and technology
		Sea level change and floods	
Subset 2:	Time series analysis	Time series analysis	Time series analysis
	GNSS	GNSS	
	(In)SAR	(In)SAR	
	Optical remote sensing	Optical remote sensing	

Lab (4EC)

Individual or groups of max. 4 students
The lab has a central place in the module, triggering the inquiries and as the place where the students apply the theory to a challenge related to monitoring and/or prediction of climate impacts or geohazards. The student (team) defines a topic related to the challenge within a predefined theme that they will work on during the Lab. They collect analyse and interpret data to address or solve their posed topic. The lab includes an ethical reflection (0.5 EC) on the specific challenge and approach.

Fieldwork (3EC)
Group size: 3 - 5

During the fieldwork, students will work in teams to define an objective related to the understanding of a phenomenon/process in weather and climate relevant to a societal challenge. Students start with a project planning phase (0.5EC), in which they receive instruction, and they design a measurement experiment, which will be reviewed. In a second phase they will implement the measurements, collect data and process the data (1.5EC). Thereafter they will analyse and interpret the data, present their findings and provide recommendations for future work (1EC).

Module name	B-EO: Earth Observation
Learning objectives module	General learning objectives for theory, labs and fieldwork. After completing the module students will be able to: General: 1. Identify open issues in the processing and/or interpretation of Earth system data records based on the outcomes of the lab project and design a development roadmap to address them. 2. Present analyses, interpretations and conclusions, as well as ethical implications, of the Lab and Fieldwork projects in a clear and convincing manner, both orally and written. Theory/Lab (module specific): 3. Assess the value and limitations of Earth observation data in addressing a societal challenge related to geohazards or climate impacts. 4. Select Earth observation data suitable for the study of a phenomenon of interest. 5. Design, implement and validate a workflow to derive/extract geophysical parameters from Earth observation data. 6. Quantify and assess the input data uncertainties and the quality of the results. 7. Characterize temporal or spatial variations of geophysical parameters using Earth observation data. 8. Analyse, visualize and interpret findings in a clear and convincing manner. Fieldwork: 9. Plan and design a field campaign that is appropriate for the physical process to be measured. 10. Collect data in the field using different measurement techniques. 11. Explain and quantify the error sources associated with the field measurements. 12. Process and analyse the data collected in the field to give meaningful constraints on the physical process. 13. Effectively communicate with peers, assessors and clients. 14. Contribute to a project as a team player and to the overall project management.
Module content	The lab and the theory part of the B-module are connected and inquiry-based. **Theory (8EC)** From the table below students need to choose one of the labs; 2EC (Time series analysis) is compulsory, 4EC to be selected from subset 1, 2EC to be selected from subset 2. Each theory component in the table is 2EC. A description of each theory component is provided later in this document.

	Geohazards lab	Climate impacts lab
Compul-sory	Time series analysis	Time series analysis
Subset 1: Choose 4EC	GNSS	GNSS
	(In)SAR	(In)SAR
	Optical remote sensing	Optical remote sensing
	Geostatistical data analysis	Climate data analysis
Subset 2: Choose 2EC	Climate data analysis	Geostatistical data analysis
	Remote Sensing of Precipitation	Remote Sensing of Precipitation
	Multi-Sensor Cloud and Atmospheric Observation	Multi-Sensor Cloud and Atmospheric Observation
	Geological interpretation of geophysical data	Cryosphere Dynamics
	Geophysical prospecting	Sea level change and floods
	Induced seismicity	

Lab (4EC)
Individual or groups of max. 4 students
The lab has a central place in the module, triggering the inquiries and as the place where the students apply the theory to a challenge related to monitoring and/or prediction of climate impacts or geohazards. The student (team) defines a topic related to the challenge within a predefined theme that they will work on during the Lab. They collect, analyse and interpret data to address or solve their posed topic. The lab includes an ethical reflection (0.5 EC) on the specific challenge and approach.

Fieldwork (3EC)
Group size: 5-8
Phase 1: project planning (0.5EC)
Teams receive the terms of reference as defined by a (virtual) client, with the aim to analyse local to regional deformations and/or mass displacements due to various natural and/or human-induced causes. They need to design a fieldwork campaign accordingly; the design will be reviewed during the project planning review.

Phase 2: data collection & processing (1.5EC)
Data collection in field and processing of historical and newly acquired data.

Phase 3: analysis & interpretation (1EC)
Data analysis and interpretation, answering the questions from the terms of reference, reporting in form of final presentation.

Module name	**B-GE: Geo-Energy Engineering**
Learning objectives module	General learning objectives for theory, labs and fieldwork. After completing the module students will be able to: General: 1. Identify open issues in the processing and/or interpretation of Earth system data records based on the outcomes of the lab project and design a development roadmap to address them. 2. Present analyses, interpretations and conclusions, as well as ethical implications, of the Lab and Fieldwork projects in a clear and convincing manner, both orally and written. Energy Transition and Geohazards Lab + Theory 3. Define and solve a research topic related to the Energy Transition or Geohazards challenge. 4. Analyse Earth system processes through a combination of data, observations and model outputs (geophysical data, subsurface data, petrophysical data, and monitoring data). 5. Extract subsurface characteristics and evaluate the options and limitations of data types for present-day and future societal challenges in Energy Transition or Geohazards. 6. Present analyses, interpretations and conclusions, as well as ethical implications, of the Lab project in a clearly written and convincing manner. Fieldwork: 7. Design and execute a fieldwork campaign appropriate for the Earth system processes and/or applications to be studied. 8. Describe, identify and measure sedimentary heterogeneities, faults, fractures, folds, and 2D rock property trends at different scales (10-1 to 103m) and qualitatively predict their architecture and their potential impact on dynamic behaviour. 9. Link field observations of rock property trends at different sub-seismic scales to geophysical data and include the impact of scale to model uncertainty. 10. Extract subsurface characteristics and evaluate the options and limitations of data types for present-day and future societal challenges in Energy Transition and Geohazards. 11. Present analyses, interpretations and conclusions of the Fieldlab project in a clearly written and convincing manner. 12. Contribute to a project as a team player and to the overall project management.
Module content	The lab and the theory part of the B-module are connected and inquiry-based. **Theory (8EC)** From the table below students need to choose a societal challenge, 2EC (Induced seismicity) is compulsory, 4EC to be selected additionally from subset 1, remaining 2EC to be selected from subsets 1 and 2. Each theory component in the table is 2EC. A description of each theory component is provided later in this document.

	Geohazards lab	Energy transition lab
Compul-sory	Induced seismicity	Induced seismicity
Subset 1: Choose at least 4EC	Geological interpretation of geophysical data	Geological interpretation of geophysical data
	Geophysical prospecting	Geophysical prospecting
	Production science and technology	Production science and technology
Subset 2:	Geostatistical data analysis	Geostatistical data analysis
	Exploration tools and methods	Exploration tools and methods
	Advanced Resource Modelling	Advanced Resource Modelling
	Time series analysis	Time series analysis
	(In)SAR	(In)SAR
	Optical remote sensing	Optical remote sensing
	Climate data analysis	Climate data analysis
	Sea level change and floods	Sea level change and floods

Lab (4EC)
Group size: 2-3
The lab has a central place in the module, triggering the inquiries and as the place where the students apply the theory to a given challenge related to energy transition or geohazards. The student team defines a topic related to the challenge within a predefined theme that they will work on during the Lab. They collect, analyse and interpret data to address or solve their posed topic. The lab includes an ethical reflection (0.5 EC) on the specific challenge.

Fieldwork (3EC)
Group size: 2-3
Part 1 (0.5EC): preparation
Prepare for the assignment in a team. Discussion of the main scientific and technical challenges related to energy transition and/or geohazards. Read literature on the geological objects investigated. Define the data needed and the strategy to collect them, preparing the necessary (digital) platforms.

Part 2 (1.5EC): the field trip
In the various outcrops visited, student groups will collect the data necessary to address the questions defined in part I.
Preliminary data processing will be performed during the late afternoon/evening together with the definition of activities needed for the coming day.

Part 3 (1EC): reporting
The 3rd part is dedicated to the final processing of the acquired data and the preparation of a schematic report on the first-order questions posed in part II.

Module name	B-module Geo-Resource Engineering
Learning objectives module	After completing the module students will be able to: General: 1. Identify open issues in the processing and/or interpretation of Earth system data records based on the outcomes of the lab project and design a development roadmap to address them. 2. Analyse, visualize and interpret findings in a clear and convincing manner. 3. Present analyses, interpretations and conclusions, as well as ethical implications, of the Lab and Fieldwork projects in a clear and convincing manner, both orally and written. Theory/Lab (module specific): 4. Assess the value and limitations of mineral exploration data in addressing a societal challenge related to resource efficiency and responsible sourcing of mineral resources for a green future. 5. Select appropriate exploration tools and methods and design a workflow to acquire the necessary data for mineral resource characterisation and modelling in order to select a suitable extraction method. 6. Analyse and manipulate data to assess the degree of spatial continuity and use deterministic and/or geostatistical interpolation methods to estimate unknown variables of interest. 7. Model the data using advanced geostatistical techniques to define a quantified mineral resource incorporating an estimation of the associated degree of confidence and uncertainty in compliance with international reporting standards (e.g. JORC, PERC). Fieldwork: 8. plan a field campaign that is appropriate for a selected deposit style and environmental impact to be measured. 9. collect data in the field using different measurement tools and techniques. 10. explain and quantify the error sources and uncertainties associated with the field measurements. 11. identify and justify the choice of the selection of extraction methods. 12. process and analyse the data collected in the field to assess possible environmental consequences. 13. effectively communicate with peers, assessors and clients. 14. contribute to a project as a team player and to the overall project management.
Module content	The lab and the theory part of the B-module are connected and inquiry-based. **Theory (8EC)** From the table below students need to choose a societal challenge, 6EC is compulsory, 2EC to be selected from subset 1. Each theory component in the table is 2EC. A description of each theory component is provided later in this document.

	Resource efficiency lab	Energy transition lab
Compul-sory	Exploration Tools and Methods	Exploration Tools and Methods
	Geostatistical Data Analysis	Geostatistical Data Analysis
	Advanced Resource Modelling	Advanced Resource Modelling
Subset 1: choose 2EC	Geophysical prospecting	Geophysical prospecting
	Optical remote sensing	Optical remote sensing

Lab (4EC)
Individual or groups of max. 3 students
The lab has a central place in the module, triggering the inquiries and as the place where the students apply the theory to a challenge related to charcterisation and modelling of mineral resources in order to maximise resource efficiency and/or resource a green future. The student (team) defines a topic related to the challenge within a predefined theme that they will work on during the Lab. They collect, analyse, model and interpret data to address or solve their posed topic. The lab includes an ethical reflection (0.5 EC) on the specific challenge and approach.

Fieldwork (3EC)
Group size: 3-5
Phase 1: project planning (0.5EC)
Teams receive the terms of reference as defined by a (virtual) client, with the aim to analyse specific topic related to resource efficiency and/or resourcing a green future. They need to design a fieldwork campaign accordingly; the design will be reviewed during the project planning review.

Phase 2: data collection & processing (1.5EC)
Data collection in field and processing of historical and newly acquired data.

Phase 3: analysis & interpretation (1EC)
Data analysis and interpretation, answering the questions from the terms of reference, reporting in form of a final group presentation and a written report.

B-module: Theory components

The table below provides an overview of all theory components, each 2EC. It is indicated which discipline is offering a certain component, as well as in which B-modules the component is compulsory or part of one of the subsets from which students can choose (indicated as elective). Note that these subsets may still depend on the societal challenge selected by a student, as is indicated in the module formats.

Discipline	Theory components (color indicates with discipline offers it)	B-CW	B-EO	B-GE	B-GR
C&W	Climate data analysis	C	E	E	
	Remote sensing of precipitation	E	E		
	Multi-sensor cloud and atmospheric observations	E	E		
	Cryosphere dynamics	E	E		
	Sea level change and floods	E	E	E	
EO	Time series analysis	E	C	E	
	GNSS	E	E		
	(In)SAR	E	E	E	
	Optical remote sensing	E	E	E	E
GE	Induced seismicity		E	C	
	Geophysical prospecting		E	E	E
	Production science and technology	E		E	
	Geological interpretation of geophysical data		E	E	
GR	Exploration tools and methods			E	C
	Advanced resource modelling			E	C
GR + EO	Geostatistical data analysis		E	E	C

C	compulsory
E	elective

Theory components C&W

	Climate Data Analysis
Content	• B*asic concepts and fundamentals:* i. review of most common distributions of climate variables, length/time scales; ii. common pitfalls and misuse of statistical analysis in climate research; iii. commonly used non-parametric alternatives for parametric regression, hypothesis testing, etc.; iv. Origin of auto-/serial correlation in climate data and impact on confidence intervals, bootstrapping, etc. • *Hypothesis testing of climate data:* field significance tests (e.g., Livezey-Chen, FDR methods, one/two-way ANOVA • *Analysis of climate model output*: climate sensitivity, detection and attribution • *Spectral analysis of climate data*: cross-spectra, wavenumber-frequency analysis, wavelet power spectra • *Empirical orthogonal function analysis*: EOF analysis theory, links to SVD, application to point data & field data, sampling variance of eigenvalues and eigenvectors, selection rules, degenerate multiplets, test for significance of EOF loadings vs noise, rotated EOFs, joint analysis of multiple fields • *Statistical forecasts and ensemble forecasts & forecast verification (categorical and quantitative), extreme value analysis*

	Sea Level Change and Floods
Content	• *Drivers of sea level change*: steric changes, ocean dynamics, freshwater fluxes, global and regional sea level budgets. • *Sea level projections*: process-based and semi-empirical, global and regional models. • *Coastal sea level change and solid Earth deformation*: coastal currents, wind and atmospheric pressure effects, river outflow, vertical land motion, glacial isostatic adjustment. • *Tides and sea level records*: origin and propagation of tides, the geological and the instrumental sea level records (proxies, systems and networks). • *Dutch sea level change and the AMOC*: available observations, detection of accelerations, the KNMI scenarios, the role of the Atlantic Meridional Overturning Circulation. • *Sea level reconstructions*: global and regional past sea level change from tide gauge observations. • *Storm surges and floods*: causes, frequency and intensity from records and models, operational forecasting, coastal topography and flood risk. • *Tsunamis*: origin (Earthquakes, landslides), open-ocean propagation, coastal amplification, early warning systems.

	Cryosphere Dynamics
Content	1. *Surface mass balance of glaciers and ice sheets:* contribution of radiative and sensible heat fluxes to melt, precipitation over ice sheets, meltwater refreezing. 2. *Ice sheet flow*: stresses acting on a glacier, Glen's flow law, the Shallow Ice Approximation, Higher Order Approximations to flow 3. *Remote sensing of ice/snow properties*: overview of RS ice/snow variables that can be measured using RS (albedo, melt, grain size, extent, ...) 4. *Remote sensing of ice dynamics:* overview on monitoring mass balance (altimetry, gravimetry, input/output based on velocity data) 5. *Ice sheet modelling*: main equations, types of models, boundary conditions 6. *Climate modelling for ice sheets*: state of the art in regional and global climate modelling with application to the polar regions 7. *Past ice sheets*: ice sheet evolution through glacial and interglacial periods 8. *Contemporary mass budget of ice sheets*: reconstructions from gravimetry/altimetry and the input/output method 9. *Projections of ice sheet change*: state-of-the-art, major certainties and uncertainties, challenges, effect of climate mitigation on ice sheet melt, comparison of scenarios 10. *Sea-ice:* main processes, observation, modelling

	Remote Sensing of Precipitation
Content	This theory component aims at providing state-of-the art knowledge on multi-frequency remote sensing of precipitation. Focus is given on retrieval techniques of precipitation microphysics and precipitation dynamics from weather radar and micro-rain radar, and the validation of radar retrievals using in-situ rain measurements (disdrometers): • Scanning and profiling weather/cloud radars: interpretation of radar reflectivity, polarimetric, Doppler and Doppler power spectra measurements. • Identification and removal of non-hydrometeor data (clutter) • Disentanglement of scattering and propagation variables in cloud radar measurements of rain, spectral polarimetry methodology. Attenuation estimation and correction. • Retrieval techniques for estimates of rainfall, raindrop size distribution and wind.

	Multi-Sensor Cloud and Atmospheric Observation
Content	This unit targets synergetic use of various sensors used at conventional atmospheric and cloud observations that are key to retrieve vertical profiles of atmospheric temperature, water vapor and cloud micro- and macroscopic properties. Topics covered include: • Microwave radiometry for temperature and humidity profiles

	• Cloud remote sensing by lidar • Cloud remote sensing by radar • Synergetic cloud retrievals from radar, lidar and microwave radiometers

Theory components EO

	Time series analysis
Content	Exploring the temporal structure of Earth observation data is one of the key skills of every engineer and scientist. In this component we will familiarize students with the analysis of time series using parametric techniques. They can be applied to both stationary and non-stationary data records, can deal with data gaps and unevenly space data, and abrupt changes in the time series. Moreover, students will learn to deal with different data noise models, assess the uncertainty and significance of estimated model parameters, and decide between competing models. In the Lab students will familiarize themselves with the implementation and application of the techniques for various types of data.

	GNSS
Content	Global Navigation Satellite Systems (GNSS), such as GPS, have revolutionized positioning and navigation, and resulted in novel geoscience applications. Topics: • Fundamental principles of Global Navigation Satellite Systems (GNSS): signals, observables, noise characteristics, error sources; • Methods to improve the accuracy of standard GPS positioning down to the millimeter level. You will discover the techniques that make millimetre GNSS possible: interferometric measurement principle, differential/relative positioning with two (or more) receivers, carrier phase measurement, mathematical models with single- and double-differences, carrier phase ambiguity resolution. • High-precision positioning algorithms and implementation aspects for applications in monitoring and prediction of geohazards and climate impacts. Lab activities: • Assess the value and limitations of GNSS data in addressing a societal challenge related to geohazards or climate impacts • Select a GNSS dataset suitable for the study of a phenomenon of interest • Design, implement and validate a workflow to derive/extract geophysical parameters from the selected GNSS dataset • Quantify input data uncertainties and make a quality assessment of the results • Characterize temporal and spatial variations of geophysical parameters of interest using the GNSS data

	Optical remote sensing
Responsible instructor Proposed instructor(s)	Stef Lhermitte
Content	Topics: Recap of fundamental principles of optical sensors (e.g., multi/hyperspectral, trade-off spatial/temporal/spectral resolution) and signals (e.g., EM interaction with atmosphere/land, noise). Data processing chain to derive/extract geophysical parameters (+uncertainty) from optical remote sensing data: • Error correction and pre-processing (atmospheric/geometric/radiometric correction) • Image enhancement methodologies (e.g., band transformations) • Image regression / classification using: Spectral information, Spatial information, Contextual information, Segmentation (object-based information), Sub-pixel information Lab activities: • Assess the value and limitations of optical remote sensing data in addressing a societal challenge related to geohazards or climate impacts • Select an optical remote sensing dataset suitable for the study of a phenomenon of interest • Design, implement and validate a workflow to derive/extract geophysical parameters from the selected dataset • Quantify input data uncertainties and make a quality assessment of the results • Characterize temporal and spatial variations of geophysical parameters of interest using the optical remote sensing data

	(In)SAR
Content	Synthetic Aperture Radar (SAR) systems provide high-resolution images of the Earth Surface independently of illumination conditions (i.e. day or night, or also during polar winters) and of weather conditions. Aside from being sensitivity to properties of the surface (for example, the backscattered intensity is modulated by soil moisture variations), complex-valued SAR data carry information about the distance between the radar and the object. SAR interferometry (InSAR) exploits this to, for example, observe deformation of the surface, being able to detect deformations rates in the order of millimeter per year. With the guaranteed availability of long-term dense time series of global observations provided by, for example, the Copernicus Sentinel-1 mission, and the emergence of satellite-data providers from the private sector, SAR and InSAR data will continue to consolidate as one of the main sources of reliable information to monitor process related to natural hazards, climate change, or a diversity of human related activities.

	Topics: • Understanding SAR data: observation geometry and radar coordinates, resolution; speckle, radiometric quality, geometric and non-geometric contributions to the phase, etc. • Foundations of InSAR: cross-track InSAR; differential InSAR; coherence and phase quality; atmospheric effects; systematic errors, InSAR processing, phase unwrapping. • Persistent Scatterer Interferometry and InSAR time-series (stacks). Lab activities: • Assess the value and limitations of SAR of InSAR data stacks from different sensors in addressing a societal challenge related to geohazards or climate impacts • Select a SAR data time-series suitable for the study of a phenomenon of interest • Retrieve and process a stack of SAR data using available software tools. • Implement and validate a workflow to perform a time-series analysis to derive/extract geophysical parameters from the SAR/InSAR data stack. • Quantify data uncertainties and make a quality assessment of the results • Characterize temporal and spatial variations of geophysical parameters of interest using the SAR/InSAR data

Theory components GE

	Geological interpretation of geophysical data
Content	Geological interpretation of Geophysical data theory component. • Explain what information is present in geophysical data (images and attributes) and to what extent the data can be reliably used for their geological interpretation and apply this to the geophysical data sets. • Provide a geological interpretation of the structure, the sedimentary environment, and the properties of the rocks imaged in a geophysical data set related to Energy Transition and Geohazard applications.

	Geophysical prospecting
Content	Geophysical prospecting theory component. • Formulate the basic connections between the physical properties of matter and the wave, diffusive and potential field measurements. • Choose and apply the proper method(s) to solve a specific problem related to Energy Transition or Geohazard applications.

	Production science and technology
Content	Production and Science Technology theory component • Explain the differences between production technology in hydrocarbon, geothermal and subsurface-storage industry, and evaluate risks and safety issues of its well drilling and operations. • Evaluate production facilities in terms of production scenarios, well productivity, artificial lift, formation damage, well stimulation (acidizing and fracturing), and well performance.

	Induced seismicity
Content	Induced seismicity theory component • Describe and explain the mechanisms of, and the effects that engineering applications in the subsurface have on the natural and build environment and society, for example induced seismicity, subsidence, and cap rock integrity. • Integrate knowledge of ethical issues, international standards and risk management systems into Energy Transition and Geohazards applications.

Theory components GR

	Exploration Tools and Methods
Content	Topics: • Use of geological mapping, remote sensing, geophysical techniques or mineral exploration. • Surface sampling media for geochemistry (soil, water, stream sediments, rock) • Subsurface sampling (RC drilling, diamond core drilling) • Small scale (hand specimen) spectral mapping (FTIR, Raman, LIBS) • Resulting data outputs. • Precision, accuracy, resolution and limitations of data. Lab activities: • Spectral characterisation of mineralised drill-core and hand specimens • Geophysical characterisation of mineralised drill-core and hand specimens

	Advanced Resource Modelling
Content	Topics: • Introduction to the block model and smallest mining unit (SMU) concepts in the context of mineral resource modelling. • Linear geostatistics (Block Kriging and Indicator Kriging) • Multivariate geostatistics (Collocated Co-Kriging, properties of Co-Kriging, Kriging with External Drift). • Geostatistical Simulation (Conditional simulation). • Dispersion variance (correcting for the support effect). • Conversion of mineral resources to mineral reserves. • Mineral resources reporting standards (e.g. JORC) Lab activities: • Resource modelling and estimation of data from real case studies using Datamine™ software to address the relevant societal challenges.

Theory component GR + EO

	Geostatistical Data Analysis
Content	Topics: • Exploratory data analysis. • Deterministic interpolation methods. • Variography (quantification of the degree of spatial continuity) • Introduction to geostatistics • Linear geostatistical interpolation methods (Simple Kriging, Ordinary Kriging, Universal Kriging) • Multivariate geostatistics (Ordinary Co-Kriging) Lab activities: • Exploratory data analysis via Python using real-world dataset. • Spatial data analysis using Python and/or Datamine™ software.