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. The programme enables them to master new knowledge throughout their professional life either in research or engineering applications. They will learn to think and operate at a high academic level and they will develop skills to build solutions in the field of AES.

This document presents an overview of the learning objectives, curriculum and module descriptions (of year 1).

INTENDED LEARNING OUTCOMES

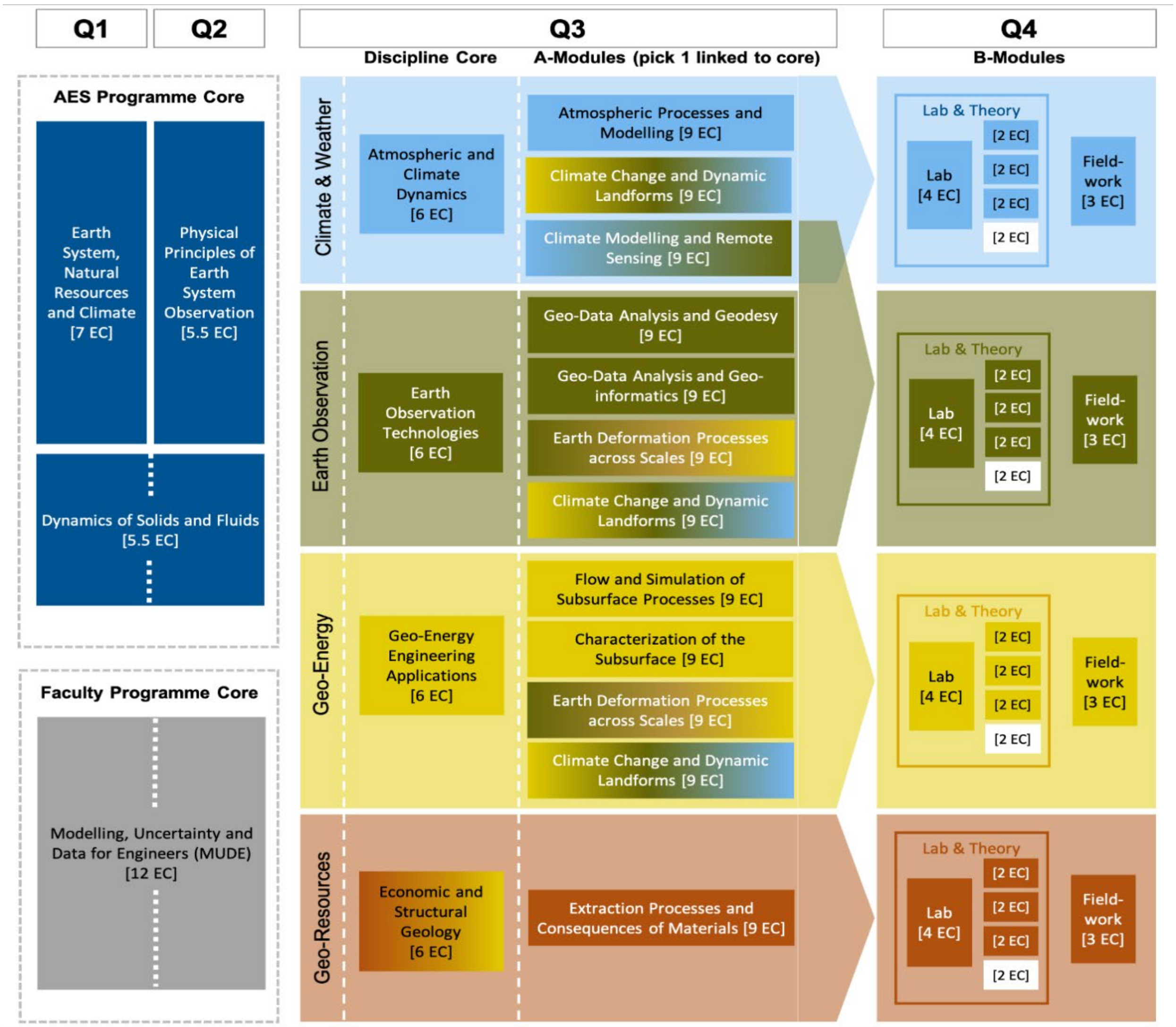
The student is able to…

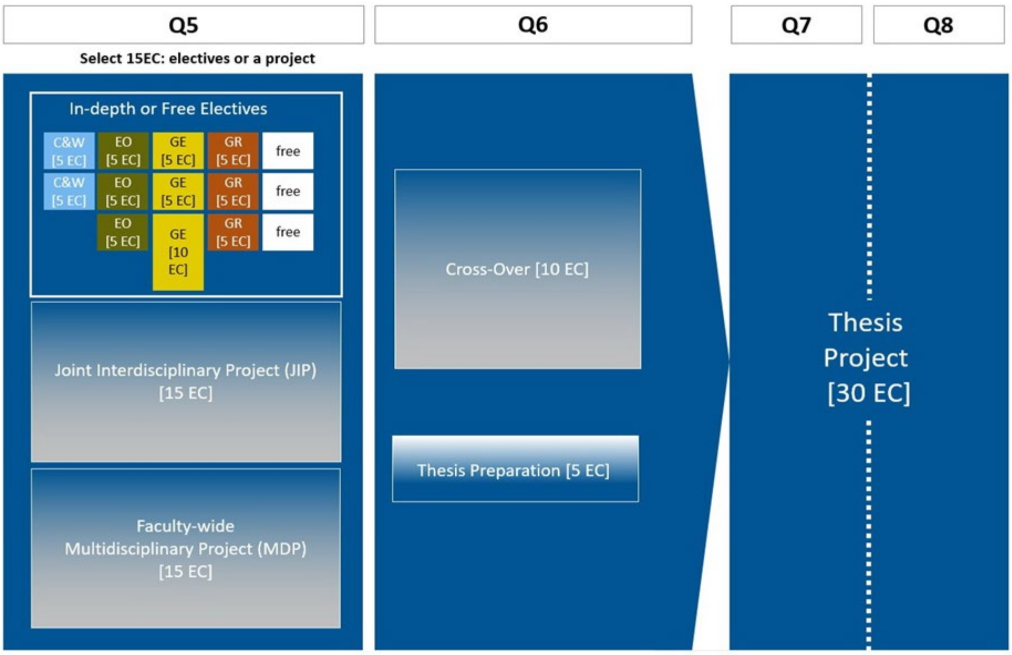
A. Observe, characterise and explain Earth system processes.
B. Develop and apply data processing and analysis techniques to analyse Earth system processes.
C. Model and predict Earth system processes and their variability and assess the influence of natural and anthropogenic factors.
D. Develop novel 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.

DISCIPLINES

Climate & Weather   Earth Observation   Geo-Energy Engineering   Geo-Resources Engineering

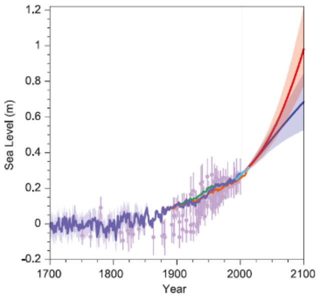
APPLIED EARTH SCIENCES - PROGRAMME OVERVIEW





COMPULSORY COURSES

EARTH SYSTEM, NATURAL RESOURCES & CLIMATE (7 EC)

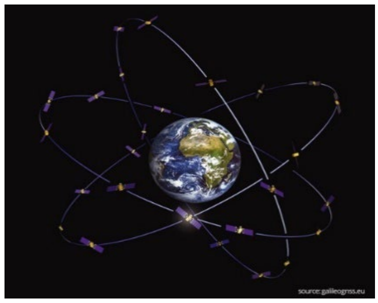


In this module, students will first be introduced to the Earth System and human interventions in the Earth System, including the exploitation of natural resources and greenhouse-gas emissions that caused climate change, and the societal challenge of moving towards a carbon-neutral world. Through three narratives, students will study through which processes and on what temporal and spatial scales the different Earth system components interact.

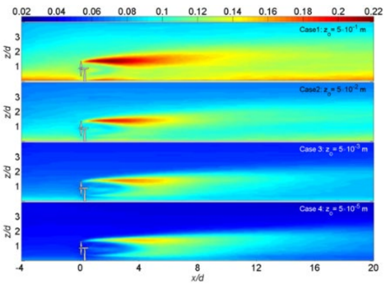
The storylines are: Solid Earth & Resources, looking at deep-level dynamic processes, outlined in terms of the plate tectonic theory; Source to Sink, which investigates the formation of sediment, the water cycle, formation of stratigraphy, vegetation and land use changes, and how all this is affected by the past and current climate and weather and 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.

PHYSICAL PRINCIPLES IN EARTH SYSTEM OBSERVATION (5.5 EC)

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.



DYNAMICS OF SOLIDS AND FLUIDS (5.5 EC)



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.

FACULTY CORE: MODELLING, UNCERTAINTY, AND DATA FOR ENGINEERS (MUDE) (12 EC)

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.

CLIMATE AND WEATHER

Atmospheric and Climate Dynamics [6 EC]

Atmospheric Processes and Modelling [9 EC]

Climate Change and Dynamic Landforms [9 EC]

Climate Modelling and Remote Sensing [9 EC]

ATMOSPHERIC AND CLIMATE DYNAMICS (DISCIPLINE CORE)

The core module of the Climate & Weather discipline will provide students with a deeper physical understanding to comprehend and study the complex atmospheric flows that define climate and weather. The module is organized into seven themes: Planetary circulation, Baroclinic instability and planetary waves, Tropical dynamics, Planetary boundary layer, Coupled surface-atmosphere dynamics, From simplified theoretical models to general circulation models and 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.

ATMOSPHERIC PROCESSES AND MODELLING (A-MODULE)

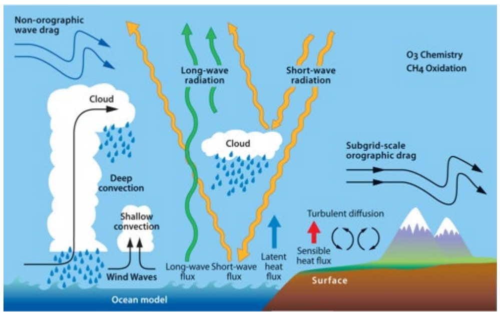
AESM301A
Atmospheric Processes and Modelling

- Climate Modeling
- Water in the atmosphere
- Land-Atmosphere Interactions

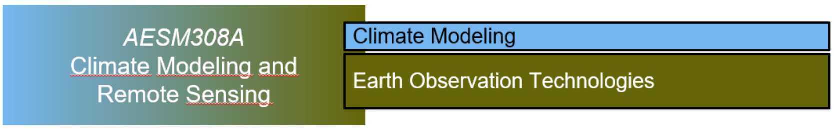
This module is aimed at students with an interest in the field of applied meteorology (such as wind and solar energy prediction or climate impacts on land use), and in the design, analysis and assessment of weather and climate models. As such, this module has a stronger emphasis on analytical and numerical modelling 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.

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 to students how these small-scale processes are coupled to large-scale circulations, and why their formulation in GCMs is particularly important for climate prediction and pressing uncertainties.

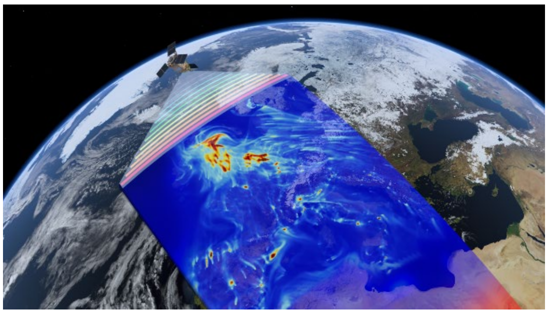
The module comprises two units that focus on deepening process knowledge and analytical thinking in the field of land-atmosphere interactions and convection & clouds. Together, they cover atmospheric processes strongly linked to turbulence and radiative transfer across all scales that are not explicitly represented in general circulation models. The third unit – climate modelling 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.



CLIMATE MODELLING & REMOTE SENSING (A-MODULE) - SHARED WITH EARTH OBSERVATION



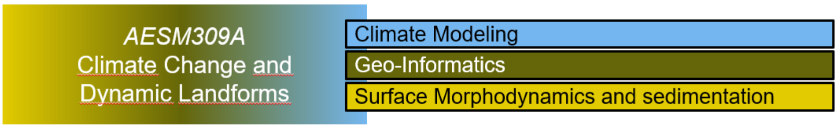
This module complements the Climate & Weather core module. It is aimed at students from the Climate & Weather learning line who are interested in the synergy offered by the combination of remote sensing and climate models to understand, predict and model the wide range of processes governing our present-day 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 modeller'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 the core module of the Earth Observation learning line and the unit Climate Modelling and Prediction (3 EC) from the Climate & Weather learning line.

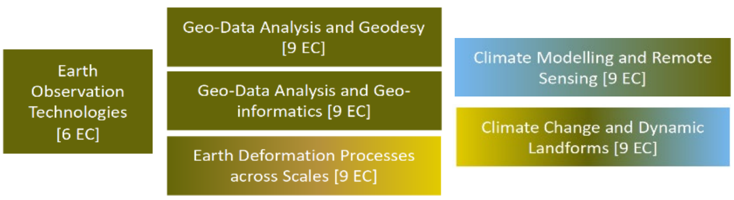
CLIMATE CHANGE AND DYNAMIC LANDFORMS (A-MODULE) - SHARED WITH EO & GE



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, students will learn about the numerical, computational and modelling concepts that 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.

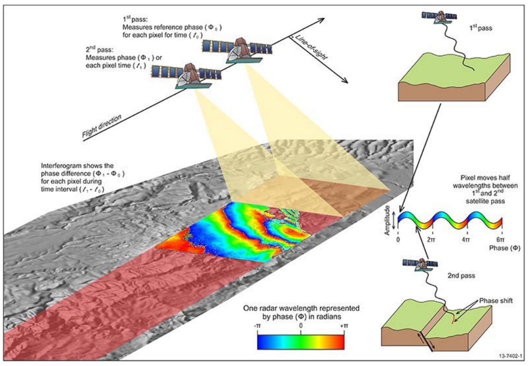
EARTH OBSERVATION



EARTH OBSERVATION TECHNLOGIES (DISCIPLINE CORE)

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.

Groups of 4-6 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.



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.

GEO-DATA ANALYSIS AND GEODESY (A-MODULE)

AESM302A Geo-Data Analysis and Geodesy	Statistical Geo-Data Analysis
	Fourier Analysis in Earth Sciences
	Geodesy and Geodynamics

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. The module includes three units: Statistical geo-data analysis, Signal Processing and Geodesy and Geodynamics.

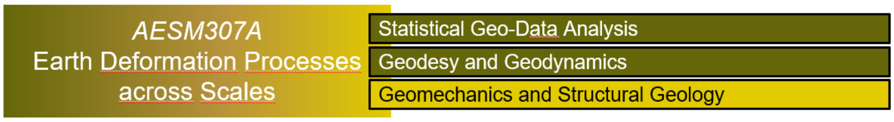
A key aspect of this module is dealing with errors in the data and assessing the quality of the input data as well the estimated parameters. Students will learn how to characterize different types of noise, and to make the best possible estimate of the parameters of interest in presence of noise. By 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.

GEO-DATA ANALYSIS AND GEO-INFORMATICS (A-MODULE)

AESM303A Geo-Data Analysis and Geo-informatics	Statistical Geo-Data Analysis
	Fourier Analysis in Earth Sciences
	Geo-Informatics

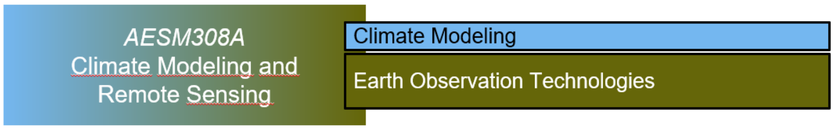
This is the module for students interested in exploring, mining and communicating the wealth of relevant information in state-of-the-art geospatial data. Different ways to visualize and process geospatial data, in different formats and projections, on geographic information systems will be explored. 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.

EARTH DEFORMATION PROCESSES ACROSS SCALES (A-MODULE) – SHARED WITH GEO-ENERGY



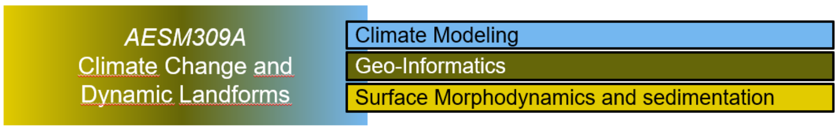
This module provides the knowledge and skills to understand, predict and characterise Earth deformation processes from continental (e.g., glacial isostatic adjustments and tectonics) towards reservoir scales (e.g., folding, faulting and compaction). Geodetic and geophysical observation techniques will be used to quantify these deformation processes, by extracting physical parameters and assessing their uncertainties. 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.

CLIMATE MODELLING & REMOTE SENSING (A-MODULE)



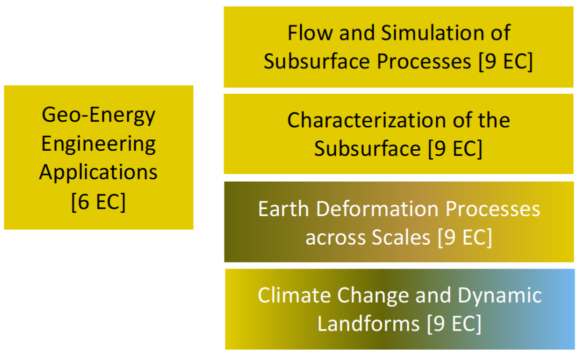
For more information about this A-Module click here.

CLIMATE CHANGE AND DYNAMIC LANDFORMS (A-MODULE)



For more information about this A-Module click here.

GEO-ENERGY



GEO-ENERGY ENGINEERING APPLICATIONS (DISCIPLINE CORE)

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. Some of the topics covered are basic principles of: reservoir characterization and of single phase flow and how these two complement/interact with each other, governing and applications of Geothermal Energy, Subsurface Storage, Petroleum Exploration and Productions, effects of Subsurface Engineering and Introduction into energy transition towards a CO2 neutral future energy production, what is the role of the subsurface.

FLOW AND SIMULATION OF SUBSURFACE PROCESSES (A-MODULE)

AESM304A
Flow and Simulation of Subsurface Processes

- Modelling geological heterogeneities
- Multiphase Flow in Porous Rock
- Num. methods in Subsurface Geoscience Simulations

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.

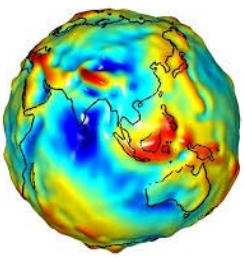
The 3 units focus on 1) analyse sedimentary and structural models of how the effective rock properties and the different facies, faults and fractures are distributed in subsurface reservoirs 2) describe, analyse and analytically model flow of fluids and energy through those reservoirs (both single phase 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.

CHARACTERIZATION OF THE SUBSURFACE (A-MODULE)

AESM305A
Characterization of the Subsurface

- Modelling geological heterogeneities
- Geomechanics and Structural Geology
- Surface Morphodynamics and sedimentation

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 consist 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).

EARTH DEFORMATION PROCESSES ACROSS SCALES (A-MODULE)

AESM307A
Earth Deformation Processes across Scales

- Statistical Geo-Data Analysis
- Geodesy and Geodynamics
- Geomechanics and Structural Geology

For more information about this A-Module click here.

CLIMATE CHANGE AND DYNAMIC LANDFORMS (A-MODULE)

AESM309A
Climate Change and Dynamic Landforms

- Climate Modeling
- Geo-Informatics
- Surface Morphodynamics and sedimentation

For more information about this A-Module click here.

GEO-RESOURCES

Economic and Structural Geology [6 EC]

Extraction Processes and Consequences of Materials [9 EC]

ECONOMIC AND STRUCTURAL GEOLOGY (DISCIPLINE CORE)

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: 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

2. Geomechanics and structural geology covers the following topics: 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, low-strain features (mode I, mode II fractures, pressure solution), high strain geological structures (faults, and folds) and How those structures and deformation processes are formed, expressed, measured and predicted in boreholes and on the surface of the Earth.

EXTRACTION PROCESSES AND COSEQUENCES OF MATERIALS (A-MODULE)

AESM306A
Extraction Processes and Consequences of Raw Materials

- Extraction methodologies
- Residual materials from Post Extraction Processing
- Impact of Waste and Raw Material Flows on the Env.

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 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. Unit 2 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. Last Unit's main aim 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.

B-MODULES

- **Theory (8EC)**

From the table below students need to choose a societal challenge, 2EC are compulsory, 2EC to be selected from subset 1, and the remaining 4EC to be selected from subsets 1 and/or 2. Each theory component in the table is 2EC. A description of each theory component is provided later in this document.

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 extremes	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

- **Lab (4EC)**

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 or the energy transition (depending on the learning line). 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)**

During the fieldwork, students will work in teams to define an objective related to their learning line. Students start with a project planning phase (0.5EC), in which they receive instruction, and they design a measurement experiment or a fieldwork capaign, 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 or answer questions in different formats (1EC).

CLIMATE & WEATHER – THEORY COMPONENTS

	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 extremes	Cryosphere Dynamics	Production science and technology
		Sea level change and extremes	
Subset 2:	Time series analysis	Time series analysis	Time series analysis
	GNSS	GNSS	
	(In)SAR	(In)SAR	
	Optical remote sensing	Optical remote sensing	

Climate Data Analysis

- *Basic 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

- *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

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

Remote Sensing of Precipitation

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

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

EARTH OBSERVATION – THEORY COMPONENTS

	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 extremes
	Induced seismicity	

Time series analysis

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

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.

Optical remote sensing

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

(In)SAR

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).

GEO-ENERGY – THEORY COMPONENTS

	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 extremes	Sea level change and extremes

Geological interpretation of geophysical data
• 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
• 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
• 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
• 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.

GEO-RESOURCES – THEORY COMPONENTS

	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

Exploration Tools and Methods
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.
Advanced Resource Modelling
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)

YEAR 2

ELECTIVES

Aerosol and cloud microphysics
Data Assimilation for Geosciences
Climate remote sensing
Microwave remote sensing of surface-atmosphere interactions
Applied space geodesy
Coastal remote sensing
Advanced Numerical Methods and Optimization for Subsurface Geoscience Simulation
Geo-energy integration project
Additional Geo-energy fieldwork
Occupational Health and Safety Management
Project execution and implementation plan
Optimisation of discrete processes
Geo-Resource Research Driven Project

Resilient Delatas under Climate Change / Delta Technology

Engineering for Global Development

Subsurface Storage: Energy and Climate

Data Science and Artificial Intelligence for Engineers

Noise and Vibrations: Generation, Propagation and Effect on Humans and Environment

Advanced Topics in Probability and Statistics in Engineering

Monitoring of Structural Health and Geohazards

Understanding MUD: From Suspended Clay to Soil

Sustainable Cities