

# Syllabus

## Course title

### Fundamentals of Climate System Dynamics and Modelling

#### General information

*General description of the required education/training, outlining the main objectives and providing an explanation of the need for training at the organization/country/region level*

The course “Fundamentals of Climate System Dynamics and Modelling” occupies an important place in the training of master’s students in the field of climate services, as climate is a fundamental physical factor of life on Earth and has a significant impact on human activity. Climate change, which people experience through persistent changes in weather patterns, requires the implementation of various measures for adaptation and mitigation of its impacts on human life. Therefore, the study of climate and its dynamics has become one of the most relevant areas of scientific research, aimed at providing answers regarding possible scenarios of the future state of the Earth’s climate and the consequences of potential climate changes for the biosphere and human civilization.

The aim of the course is to develop in students a system of knowledge about the external and internal mechanisms that determine the functioning and interaction of the components of the climate system, as well as the triggers that cause climate change. Particular attention is paid to the direct impact of human activity on the climate system and the feedback effects of climate change on the socio-economic life of humanity.

The course will contribute to the training of qualified specialists in the field of climate services who possess the necessary theoretical foundations in climate science for the development and advancement of the climate services system in Ukraine and its further improvement. Given the challenges facing the country not only in addressing climate change but also in dealing with the consequences of war and post-war recovery, climate services in Ukraine are gaining particular importance.

#### Audience

*Main audience of the course and any secondary audience that may influence decisions regarding the structure or content of the course.*

*Expected level of knowledge and skills of the main audience (current or minimum required), as well as other factors (e.g., cultural characteristics, level of technical training, access to the internet) that should be considered when designing the course, as they may influence the choice of teaching methods, materials, and approaches to learner interaction.*

Main audience – master’s students of Ukrainian higher education institutions studying in the field of climate services..

#### **1. Level of knowledge and skills of the main audience:**

##### Basic academic background:

The main audience of the course consists of students or professionals with fundamental knowledge in natural sciences such as physics, geography, biology, chemistry, and meteorology. Prior familiarity with the components of the climate system is desirable.

Mathematical background:

Participants should have basic knowledge of mathematical analysis (differential equations, integral calculus), as well as basic statistical skills for analyzing climate data.

Technical preparation:

Participants should possess basic computer and internet skills and be familiar with tools used to access interactive learning platforms (e.g., Moodle). It is desirable that learners have basic skills in data analysis and working with presentations.

Participants are also expected to have skills in using computers, including basic programming (Python, R, MATLAB) and the use of GIS or similar tools.

English language level:

An intermediate level of English (B1 or higher) is recommended for working with international research, reports, and economic models.

**2. Other factors influencing course design:**

Inclusivity and accessibility:

During instruction, different ways of presenting material will be used (text, audio, video, interactive tasks). Learning materials will be provided in accessible formats such as large-print text, audio files, or files compatible with screen reader software.

Students will be given a choice of learning methods that best suit their individual needs.

Internet access:

The course includes online components; however, all materials will be available for download and offline use due to possible limitations in internet access.

## Competences

*Training needs at the individual level or at the level of organization/country/region, as well as a description of how these needs were identified and recognized as relevant.*

*Competences targeted by the training.*

- C1. Identify and analyze the causes of climate change and Earth system tipping points as an integrated system in order to quantitatively assess the contribution of climate change and human activity to the socio-economic system.
- C3. Develop and interpret various climate products for different geographical regions and time periods using all modern tools and techniques to provide high-quality information adapted to user needs, including explanations of their possible applications.

## Learning outcomes and effectiveness criteria

*Learning outcomes and effectiveness criteria formulated with consideration of the knowledge and skills to be acquired during the learning process.*

**Performance criterion:**

PC1. Identify and determine all factors influencing the climate of a selected region that should be considered when addressing a specific problem.

**Learning outcomes**

- LO1. Describe the fundamental concepts of atmospheric processes, weather systems, and climate, including the nature and causes of climate variability and change.
- LO2. Understand key processes driving climate dynamics, such as radiative forcing, greenhouse gas concentrations, ocean currents, atmospheric circulation, and feedback mechanisms.
- LO3. Describe teleconnections between patterns of sea surface temperature distribution and seasonal changes in precipitation and other climate conditions for the studied region.
- LO4. Distinguish natural climate variability from anthropogenic influences and analyze the causes and consequences of fluctuations and long-term changes in the climate system.
- LO5. Understand how changes in one component of the climate system can lead to cascade effects and feedbacks, considering the complexity of Earth's climate dynamics.
- LO6. Work with climate models to produce sub-seasonal, seasonal, and long-term climate forecasts under different climate scenarios, assessing their quality and uncertainty.

### *Course content*

*Provide a content plan aligned with the objectives and learning outcomes. This may be a course outline as it will be presented to students, but it does not need to be a full syllabus.*

*Include a general list of all topics you consider necessary to cover. If you think it will help clarify the scope, indicate what will NOT be covered.*

**Module 1: Introduction. Climate system and atmospheric processes.** The Earth system: atmosphere, hydrosphere, biosphere, cryosphere, lithosphere. Atmospheric and ocean dynamics. Effects of Earth's rotation. The role of atmospheric processes in climate formation.

**Module 2: Climate dynamics and key driving processes.** Solar radiation, albedo, greenhouse effect. Energy exchange between components of the climate system.

**Module 3: Teleconnections and variability of regional climate and hydrological conditions.** Climate variability and climate change. Influence of climate oscillations on regional climate. ENSO, NAO, PDO, IOD. Mechanisms of impact on regional climate.

**Module 4: Natural and anthropogenic drivers of climate change.** Solar activity, volcanic activity. Long-term climate cycles (Milankovitch cycles). Greenhouse gas emissions, land-use changes. Role of industry, energy, and agriculture.

**Module 5: Feedbacks in the climate system.** Ice–albedo feedback, water vapor, clouds, biogeochemical cycles. Consequences of amplification or mitigation of changes. Climate regimes, tipping points. Scenarios of abrupt climate change.

**Module 6: Climate modelling and forecasting.** Energy balance models, regional models, and general circulation models. Initial and boundary conditions. Parameterization. CMIP6, SSP scenarios, model intercomparison.

### *Learning solutions and methods of implementation*

*List the learning solutions (teaching methods) that will be used and explain why you have chosen them. For example: classroom learning, online learning, blended learning, workplace learning, online resources for self-study, coaching, or mentoring, etc.*

For the implementation of the course “**Climate System Dynamics and Modelling**,” a combination of several learning solutions will be used to effectively integrate students’ theoretical preparation with the development of analytical and research skills. This approach ensures flexibility in the learning process and adaptability to different learning conditions.

**Classroom-based learning** will be used to explain fundamental theoretical concepts related to the functioning of the climate system, atmospheric and ocean dynamics, climate variability, and mechanisms of climate change. In-person classes enable a structured presentation of complex scientific concepts, direct interaction between the instructor and students, and immediate response to questions arising during the learning process.

**Blended learning** will combine traditional instruction with the use of digital educational resources. Part of the learning materials, including additional explanations, scientific articles, presentations, and instructional videos, will be made available to students via an online platform. This format allows students to work with materials at their own pace and revisit complex topics for further study.

**Online self-study resources** will be used to deepen knowledge and develop skills in working with modern climate data and scientific tools. Students will have access to open educational resources, climate databases, interactive learning platforms, and scientific repositories. This supports the development of independent information-search skills, critical analysis of scientific sources, and the use of modern digital tools in climate research.

**Independent student work** is an important component of the learning process and includes studying academic literature, analyzing scientific materials, preparing for discussions, and completing analytical tasks. This format fosters autonomy, critical thinking, and the ability to systematize complex scientific information.

**Consultations and mentoring support** will be used to guide the learning process and assist students in completing complex analytical tasks. During consultations, students will be able to clarify difficult topics, discuss their progress, and receive recommendations for further study.

The combination of these learning solutions creates a flexible and effective learning environment that integrates traditional academic approaches with modern educational technologies and supports the development of competencies required for professional work in climate research and climate services.

### *Learning strategies*

*Consider which learning strategies you will use. Provide justification for why you want to apply them, including reasons why they will help participants achieve the planned learning outcomes.*

*Combine different learning strategies to create a diverse learning environment that meets the different learning styles of participants. This will increase the effectiveness of learning and help achieve the planned learning outcomes. In this section, there is no need to describe specific activities in detail.*

During the learning process, the following learning strategies will be used:

Lecture-based learning and reading resources (lectures and available online resources will help students acquire the necessary scientific knowledge about the structure of the climate system, the mechanisms of its functioning, the main processes of atmospheric and ocean dynamics, and the causes of climate variability and climate change. They will also support the understanding of concepts such as radiative balance, atmospheric and ocean circulation, teleconnections, natural and anthropogenic drivers of climate change, feedback mechanisms, and the basics of climate modelling. This strategy forms a fundamental theoretical

basis required for further analysis of climate processes and understanding the principles of climate system modelling);

Case-based learning strategies (through the analysis of specific examples and scientific cases, students will develop practical skills in interpreting climate processes, identifying cause-and-effect relationships between components of the climate system, analyzing manifestations of climate variability, and assessing the impact of natural and anthropogenic factors. This approach helps apply theoretical knowledge to explain real climate phenomena, including changes in temperature and precipitation, circulation patterns, teleconnections, and possible climate system development scenarios);

Discussion-based strategies (briefings, discussions, and reflective sessions will help students critically interpret learning material, analyze scientific information, compare different approaches to explaining climate processes, and develop well-argued conclusions. These strategies contribute to the development of scientific thinking, the ability to work with concepts, and the explanation of complex interactions within the climate system);

Project-based learning strategies (project development helps integrate knowledge of climate system dynamics, climate variability, feedback mechanisms, and natural and anthropogenic drivers of climate change. It also develops the ability to independently analyze scientific information, synthesize results, and justify conclusions. The project strategy promotes independence, analytical thinking, and the ability to apply acquired knowledge in research and professional contexts).

The use of these strategies ensures a learning process that meets two key criteria: flexibility (the ability to adapt to different conditions and student needs) and diversity (a combination of theoretical and practice-oriented learning methods).

In addition, all proposed strategies meet both academic and practical criteria, as they contribute to the development of deep knowledge of climate system dynamics, analytical skills, critical thinking, and the ability to apply scientific approaches to explain climate processes and climate change.

## *Learning activities*

*Describe the main learning activities that will be included, such as lectures, readings, case studies, discussions, exercises, practical tasks, simulations, role-playing, etc.*

*Also describe the roles of instructors and students during these activities.*

The learning activities of master's students will consist of lectures, which will account for approximately 20% of the total course time. Practical sessions will be implemented in the form of various practical tasks (20% of the time), case studies (30%), and projects (30%). Case studies and project work will also include discussions, which will be conducted either after task completion or during its implementation. To assess knowledge of course sections, self-assessment tests and final assessment tests will be provided.

Lecture sessions will include the following topics:

Lecture 1. Introduction to the climate system: components and interactions. (LO#1)

Lecture 2. Fundamentals of atmospheric dynamics. (LO#1)

Lecture 3. Radiative balance and energy fluxes. (LO#2)

Lecture 4. Atmospheric and ocean circulation. (LO#2)

Lecture 5. Climate variability: spatio-temporal scales. (LO#3)

Lecture 6. Climate teleconnections. (LO#3)

Lecture 7. Natural drivers of climate change. (LO#4)

Lecture 8. Anthropogenic influences on climate. (LO#4)

Lecture 9. Positive and negative feedbacks. (LO#5)

Lecture 10. Thresholds, nonlinearity, and stability of the climate system. (LO#5)

Lecture 11. Climate models: types and principles of construction. (LO#6)

Lecture 12. Climate forecasting: scenarios, uncertainties, and model applications. (LO#6)

### *Practical assignments*

**Practical assignment: Global Energy Balance Model.** The Climate Modelling and Data Analysis Course includes a section “Global Energy Balance Model,” a simple balanced model in Python/Jupyter with parameterized feedbacks and scenarios. [https://sauterto.github.io/climate\\_modelling/welcome.html](https://sauterto.github.io/climate_modelling/welcome.html)

**Practical assignment: Ice–albedo model.** Simple Climate Model v.2 (UW) – an Excel model used by student groups to study climate sensitivity, feedbacks, and system energy response. It includes a ready-made .climatemodel2.xlsx file and a worksheet for tasks. <https://pcc.uw.edu/education/k-12-educator-resources/classroom-resources/uwhs-atms-211-climate-model/>

**Practical assignment: Impact of ENSO on precipitation and temperature.** Study how the El Niño–Southern Oscillation (ENSO) affects precipitation in a selected region using climate indices (e.g., Niño 3.4 index), observational data, and climate model outputs (CMIP5/6, NOAA, ERA5).  
[https://www.stem.org.uk/resources/elibrary/resource/26878/modelling-climate-change?utm\\_source](https://www.stem.org.uk/resources/elibrary/resource/26878/modelling-climate-change?utm_source)  
[https://colab.research.google.com/github/ClimateMatchAcademy/course-content/blob/main/projects/project-notebooks/ENSO\\_impact\\_on\\_precipitation\\_and\\_temperature.ipynb?utm\\_source](https://colab.research.google.com/github/ClimateMatchAcademy/course-content/blob/main/projects/project-notebooks/ENSO_impact_on_precipitation_and_temperature.ipynb?utm_source)

**Practical assignment: Spectral analysis of a climate time series. Python Climate Analysis Project.** Analysis of temperature and CO<sub>2</sub> trends from 1850 to 2024. [https://github.com/sophiaec/Climate-Analysis-Project?utm\\_source](https://github.com/sophiaec/Climate-Analysis-Project?utm_source)

**Case study: Assessment of climate changes in a selected region based on observational data and climate model outputs.**

**Objective:** To develop students’ ability to analyze long-term regional climate changes using observational data and climate models and interpret their impacts on key sectors (water resources, agriculture, cities).

**Case study: Analysis of climate feedbacks and tipping points – modelling future instability scenarios.**

**Objective:** To develop students’ ability to model climate feedbacks and tipping point scenarios using digital tools and explain potential implications for climate system stability.

### *Assessment of learning*

*Describe the assessment plan for participants before, during, and/or after the course, including tests, exercises, activities, and projects to be assessed.*

*Indicate whether self-assessment or peer assessment will be used. Explain how assessment is linked to learning outcomes.*

Assessment of learning outcomes in the course “Climate System Dynamics and Modelling” will be carried out in a staged manner throughout the entire learning process and will include diagnostic, formative (ongoing), and summative assessment. This approach allows not only the evaluation of knowledge acquisition but also the support of the learning process by providing students with feedback on their progress.

Diagnostic assessment may be conducted at the beginning of the course in the form of a short test or discussion to determine students’ initial level of preparation in climatology, atmospheric physics, and basic mathematical methods. This allows the instructor to adjust subsequent teaching according to the group’s level of preparedness.

Formative (ongoing) assessment will be carried out throughout the course and will include tests, practical exercises, participation in discussions, and analysis of case studies. Tests will be used to assess the understanding of key concepts and theoretical principles, including climate system processes, mechanisms of climate variability, the role of natural and anthropogenic factors, and feedback mechanisms. Practical exercises and analytical tasks will assess students' ability to apply acquired knowledge to explain climate processes and analyze scientific information.

A key component of assessment is the project assignment, which involves a comprehensive analysis of a specific aspect of the climate system or climate change. The project assesses students' ability to integrate theoretical knowledge, work with scientific sources, formulate evidence-based conclusions, and present analytical results.

Summative assessment will be conducted in the form of a final test or examination task that evaluates the level of mastery of key course concepts, understanding of climate system dynamics, and the ability to explain mechanisms of climate change.

Self-assessment and peer-assessment may also be used during the learning process. Self-assessment enables students to reflect on their own progress and identify areas for further improvement. Peer assessment may be used during project presentations or group tasks, contributing to the development of critical thinking, communication skills, and the ability to evaluate scientific results in an informed and reasoned manner.

The proposed assessment system is directly linked to the course learning outcomes. Tests and theoretical tasks assess understanding of fundamental concepts of the climate system and its dynamics, while practical and project-based tasks evaluate students' ability to analyze climate processes, interpret scientific information, and apply acquired knowledge to explain climate change. Thus, the assessment system provides a comprehensive evaluation of both theoretical knowledge and analytical and research skills.

## Learning storyboard (instructional storyboard)

Use this to create a visual scenario of your blended learning activity.

Сторіборд курсу «Основи динаміки та моделювання кліматичної системи»: Баланс змішаного навчання		
	Очне навчання (Синхронно)	Онлайн-навчання (Асинхронно)
 <b>LO1: Фундаментальні концепції</b>	Лекції 1-2, присвячені компонентам земної системи (атмосфера, гідросфера тощо) та основам атмосферної динаміки. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання	Опрацювання наукових статей про будову кліматичної системи та проходження діагностичного тесту для визначення початкового рівня. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання
 <b>LO2: Ключові процеси динаміки</b>	Лекції 3-4 про радіаційний баланс та циркуляцію; практична робота з розробки глобальної енергетичної балансної моделі на Python. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання	Робота з онлайн-ресурсами про енергетичні потоки та проходження тесту за результатами модуля. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання
 <b>LO3: Віддалений зв'язок (Teleconnections)</b>	Лекції 5-6 про кліматичну мілливисть; практичне дослідження впливу явища ENSO на опади та температуру в обраному регіоні. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання	Аналіз даних з глобальних репозиторіїв (ERA5, CRU TS) та участь у дистанційному обговоренні отриманих результатів. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання
 <b>LO4: Природна мінливість vs Антропогенний вплив</b>	Лекції 7-3 про цикли Мілankовича та викиди парникових газів; практична робота: спектральний аналіз кліматичного ряду (1950-2024 рр.). <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання	Кейс-стаді: комплексна оцінка змін кліматичних умов у вибраному регіоні на основі спостережних даних. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання
 <b>LO5: Зворотні зв'язки та каскадні ефекти</b>	Лекції 9-10 про точки неповернення (tipping points); практична робота з Excel-моделлю «лід-альbedo» для вивчення кліматичної чутливості. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання	Кейс-стаді: цифрове моделювання сценаріїв нестабільності та аналіз порогових ефектів у кліматичній системі. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання
 <b>LO6: Моделювання та прогноз</b>	Лекції 11-12 про CMIP6 та SSP-сценарії; презентація та захист фінального дослідницького проєкту перед аудиторією. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання	Опрацювання інструментів аналізу (climate4R, R Shiny) та проходження комплексного підсумкового тестування. <input checked="" type="checkbox"/> Групування <input checked="" type="checkbox"/> Оцінювання

## Learning resources and tools

List the available resources you will use for different types of learning activities and recommend to students.

Describe the technologies that will be used to implement learning solutions, including educational technologies and operational equipment (hardware, software, and collaboration tools).

<http://www.climate.be/textbook/ebook.html>

<https://exchange.iseesystems.com/public/davidbice/earth103-m3q1-4/index.html#page1> **Simple Planetary Climate Model**

<https://www.e-education.psu.edu/earth103/>

<https://nap.nationalacademies.org/read/11175/chapter/3#24>

<https://www.e-education.psu.edu/earth103/node/814>

<https://exchange.iseesystems.com/public/davidbice/earth103-m5-2/index.html#page1>

Data repository for Indicators of Global Climate Change (a data repository containing indicators of global climate change such as temperature anomalies, greenhouse gas emissions, and sea level rise; used in scientific publications from 2024).

[https://github.com/ClimateIndicator/data?utm\\_source](https://github.com/ClimateIndicator/data?utm_source)

Interface for automated downloading of meteorological data from public sources such as NOAA, IMGW, Ogimet, and others. It is convenient for research in R.

[https://github.com/bczernecki/climate?utm\\_source](https://github.com/bczernecki/climate?utm_source)

Climate data visualization – working with the Shiny application.

[https://github.com/TurjyaDataScience/Climate\\_Visualization?utm\\_source](https://github.com/TurjyaDataScience/Climate_Visualization?utm_source)

An R package with modules for downloading, transforming, searching, and visualizing climate data: loaderR, transformeR, downscaleR, and visualizer.

[https://github.com/SantanderMetGroup/climate4R?utm\\_source=chatgpt.com](https://github.com/SantanderMetGroup/climate4R?utm_source=chatgpt.com)

Name	Link	Data
<b>ERA5 (Copernicus Climate Data Store)</b>	<a href="https://cds.climate.copernicus.eu">cds.climate.copernicus.eu</a>	Global data (temperature, precipitation, wind, SST, etc.)
<b>CRU TS</b>	<a href="https://crudata.uea.ac.uk">crudata.uea.ac.uk</a>	Temperature, precipitation (1901–2022), global, 0.5° resolution
<b>NASA GISS GISTEMP</b>	<a href="https://data.giss.nasa.gov/gistemp">data.giss.nasa.gov/gistemp</a>	Temperature anomalies (1880–2024)
<b>NSIDC</b>	<a href="https://nsidc.org">nsidc.org</a>	Ice cover, albedo, permafrost
<b>Carbon Monitor</b>	<a href="https://carbonmonitor.org">carbonmonitor.org</a>	Daily global CO <sub>2</sub> emissions
<b>Berkeley Earth</b>	<a href="https://berkeleyearth.org">berkeleyearth.org</a>	Temperature time series (regional and global)

Name of repository	Theme	Content
<i>tustyanovych/climate-events-dataset-ukr</i>	Ukraine, climate	Research climate data
<i>ClimateIndicator/data</i>	Global climate	IPCC project data (2024)
<i>bczernecki/climate</i>	R tool	Automated meteorological data import
<i>SantanderMetGroup/climate4R</i>	R tool	Full automated pipeline: download → transformation → visualization
<i>TurjyaDataScience/Climate_Visualization</i>	R Shiny	Visualization of climate scenarios