

ACLA COURSE STUDY GUIDE

Climate Science & Systems
Foundations

Build a rock-solid foundation in climate science — from the greenhouse effect to Earth's interconnected systems.

Dr. Aisha Mwangi · Beginner

8 modules · 39 lessons · 8 weeks

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About This Course

Climate Science and Systems Foundations is a comprehensive, self-paced online course designed to give learners a rigorous yet accessible understanding of how Earth's climate system works, the evidence for climate change, and the science behind mitigation and adaptation solutions. The course treats climate not as an isolated phenomenon but as the product of interacting systems the atmosphere, oceans, ice, land, and living organisms, and builds learners' understanding step by step, from foundational concepts through to applied climate solutions. The course is structured around eight modules, each combining focused lessons, a real-world case study, curated video resources, and a 15-question multiple-choice quiz. A comprehensive final assessment of 15 questions draws on material from across the entire course. Learners who achieve an overall passing score of 80% or higher on the final assessment earn a Certificate of Completion.

Course information

Course	Climate Science & Systems Foundations
Instructor	Dr. Aisha Mwangi
Level	Beginner
Structure	8 modules · 39 lessons · 8 weeks
Assessment	Module quizzes (pass mark 60%) and a final test (pass mark 80%). Certificate issued on final success, verifiable at acla.io/verify .

What you will be able to do

1. Explain the difference between weather and climate, and describe Earth as an interconnected system of atmosphere, ocean, ice, land, and life.
2. Describe the physical basis of the greenhouse effect and Earth's energy balance.
3. Explain the carbon cycle and other biogeochemical cycles, and how human activity has altered them.
4. Describe major ocean-atmosphere climate drivers such as ENSO and thermohaline circulation.
5. Summarize the multiple independent lines of evidence for climate change and the methods of attribution science.
6. Identify climate feedback loops and tipping points, and explain why they matter for future risk.
7. Explain how climate models are built, validated, and used to project future scenarios.
8. Distinguish between mitigation and adaptation, and evaluate real-world climate solutions.

How to use this study guide

This guide is the complete companion to the Tapi Learn mobile course. Each chapter corresponds to one course module and reproduces every lesson in full, including the key takeaways. Read a lesson in the app,

then revisit the same text here to revise; the structure and headings match the in-app lesson reader. After finishing a module, take the module quiz in the app (60% to pass), and after all modules, the final test (80% to pass) to earn your verified ACLA certificate of completion.

Module 1: Introduction to Climate Science and Earth Systems

Climate science is the interdisciplinary study of Earth's long-term atmospheric and environmental patterns, and the physical, chemical, and biological processes that shape them....

5 lessons · 10m

1.1 What Is Climate Science?

Climate science is the interdisciplinary study of Earth's long-term atmospheric and environmental patterns, and the physical, chemical, and biological processes that shape them. It draws on physics, chemistry, biology, oceanography, and geology to explain how energy, water, and chemical elements move through the planet's interconnected systems. Unlike meteorology, which focuses on short-term atmospheric conditions, climate science examines patterns that persist over years, decades, and centuries, and investigates how those patterns respond to natural cycles and human activity.

1.2 Weather versus Climate

Weather describes the state of the atmosphere at a specific place and time: today's temperature, humidity, wind, and precipitation. Climate describes the average pattern of weather conditions in a region over an extended period, typically 30 years or more. A useful way to remember the distinction: climate tells you what clothes to own; weather tells you what to wear today. Because climate is a statistical average, a single unusually hot or cold day says little about long-term climate trends, while a sustained shift in average conditions over decades is a meaningful climate signal.

1.3 Earth's System: Five Interacting Spheres

Earth's climate emerges from interactions among five major components, often called "spheres." The atmosphere is the layer of gases surrounding the planet. The hydrosphere includes all liquid water; oceans, lakes, rivers, and groundwater. The cryosphere comprises frozen water: glaciers, ice sheets, sea ice, and permafrost. The lithosphere is the solid crust and upper mantle, including soil and rock. The biosphere encompasses all living organisms, from microbes to forests to humans. These spheres constantly exchange energy, water, and chemical elements. A change in one, such as a shrinking ice sheet in the cryosphere, can ripple through the others, altering ocean circulation, atmospheric temperature, and ecosystems. Understanding climate therefore requires systems thinking rather than viewing any single component in isolation. .

1.4 A Brief History of Climate Science

The scientific understanding of climate developed over more than 150 years. In the 1820s, Joseph Fourier reasoned that the atmosphere must trap heat to keep Earth warmer than it would otherwise be. In 1856, Eunice Foote conducted experiments showing that carbon dioxide and water vapor absorbed heat more than ordinary air, an early demonstration of what became known as the greenhouse effect. John Tyndall extended this work in the early 1860s by directly measuring the heat-absorbing properties of various gases. In 1896, Svante Arrhenius performed the first calculations estimating how changes in atmospheric carbon dioxide could alter global surface temperature. In the mid-20th century, Guy Callendar compiled early evidence linking rising CO₂ to observed warming. Beginning in 1958, Charles David Keeling established continuous, high-precision measurements of atmospheric CO₂ at the Mauna Loa Observatory in Hawaii, a dataset that continues today and underlies much of modern climate science.

1.5 Why Systems Thinking Matters

Climate is not the product of a single cause acting alone; it is the emergent behaviour of interacting systems with feedbacks, delays, and thresholds. A systems-based foundation helps learners avoid oversimplified explanations and prepares them to critically evaluate evidence, models, and policy debates covered throughout the rest of this course.

Module 2: The Atmosphere and Earth's Energy Balance

Earth's atmosphere is composed mostly of nitrogen (about 78%) and oxygen (about 21%), with argon and trace gases making up the remainder. Among these trace gases are the...

5 lessons · 10m

2.1 Composition of the Atmosphere

Earth's atmosphere is composed mostly of nitrogen (about 78%) and oxygen (about 21%), with argon and trace gases making up the remainder. Among these trace gases are the greenhouse gases; water vapor, carbon dioxide, methane, nitrous oxide, and others — which, despite their small concentrations, have an outsized influence on the planet's temperature because of how they interact with radiation.

2.2 Layers of the Atmosphere

The atmosphere is organized into distinct layers. The troposphere, extending roughly 8 to 15 kilometres above the surface, contains most of the atmosphere's mass and is where nearly all weather occurs. Above it lies the stratosphere, home to the ozone layer, which absorbs harmful ultraviolet radiation. Higher still are the mesosphere, thermosphere, and exosphere, which play smaller direct roles in surface climate but matter for atmospheric chemistry and space weather. .

2.3 Solar Radiation and Planetary Energy Balance

The sun is the fundamental energy source driving Earth's climate. Incoming solar (shortwave) radiation warms the surface, which in turn emits energy back toward space as longwave infrared radiation. When incoming and outgoing energy are equal, the planet is in radiative equilibrium and average temperature remains stable over time. Any factor that changes this balance, more or less incoming sunlight, more or less outgoing heat escaping to space, is called a radiative forcing, and it shifts the equilibrium toward a new average temperature.

2.4 Albedo: Earth's Reflectivity

Albedo is a measure of how much incoming solar radiation a surface reflects rather than absorbs. Fresh snow and ice have very high albedo, reflecting most sunlight back to space, while dark surfaces such as open ocean water or asphalt have low albedo and absorb most incoming energy. Because ice and snow cover changes with temperature, albedo is deeply intertwined with climate feedbacks, a theme explored further in Module 6.

2.5 The Greenhouse Effect

Greenhouse gases are largely transparent to incoming shortwave solar radiation but absorb and re-emit outgoing longwave infrared radiation. This traps heat in the lower atmosphere and warms the surface well above the temperature it would have with no atmosphere at all. This natural greenhouse effect makes Earth habitable; the concern in modern climate science is that human activities are intensifying it by adding extra greenhouse gases, thereby increasing radiative forcing and raising the planet's equilibrium temperature. .

Module 3: The Carbon Cycle and Biogeochemical Systems

Carbon is stored across the planet in several major reservoirs: the atmosphere, oceans, terrestrial vegetation and soils, and rocks and sediments (including fossil fuels). Rocks...

5 lessons · 10m

3.1 Carbon Reservoirs and Fluxes

Carbon is stored across the planet in several major reservoirs: the atmosphere, oceans, terrestrial vegetation and soils, and rocks and sediments (including fossil fuels). Rocks and sediments hold by far the largest quantity of carbon, but it is exchanged only very slowly. The movement of carbon between reservoirs is called a flux, and it is these fluxes, photosynthesis, respiration, ocean-atmosphere exchange, combustion that determine how quickly atmospheric CO₂ concentrations change. .

3.2 The Fast Carbon Cycle

The fast carbon cycle moves carbon between the atmosphere, oceans, vegetation, and soil over timescales of days to centuries. Photosynthesis draws CO₂ out of the atmosphere and converts it into organic matter and oxygen; respiration and decomposition return carbon to the atmosphere as organisms consume that organic matter and break it down. This cycle is the one most immediately affected by human land use and vegetation change.

3.3 The Slow Carbon Cycle

The slow carbon cycle operates over thousands to millions of years and involves processes such as rock weathering, sediment burial, and the formation of fossil fuels. When humans extract and burn coal, oil, and natural gas, they release carbon that had been locked away by the slow cycle for millions of years, injecting it rapidly back into the fast cycle, a mismatch in timescales that is central to understanding modern climate change.

3.4 The Ocean Carbon Sink and Acidification

The ocean has absorbed roughly a quarter to a third of human CO₂ emissions since the industrial era began, acting as an important carbon sink that has slowed the pace of atmospheric warming. However, this absorption comes at a cost: dissolved CO₂ reacts with seawater to form carbonic acid, lowering ocean pH in a process known as ocean acidification. This reduces the availability of carbonate ions that marine organisms such as corals, mollusks, and some plankton need to build calcium carbonate shells and skeletons.

3.5 Other Biogeochemical Cycles

Carbon does not move alone. The nitrogen and water cycles are also central to Earth systems and interact with the carbon cycle in important ways. Agricultural fertilizer use, for example, has substantially altered the natural nitrogen cycle, contributing nitrous oxide — a potent greenhouse gas — to the atmosphere. Understanding these interconnections reinforces the systems-thinking approach introduced in Module 1.

Module 4: Ocean-Atmosphere Interactions and Climate Drivers

The ocean and atmosphere are tightly linked: the ocean absorbs vast amounts of heat and moisture, while the atmosphere redistributes that heat around the globe through wind...

4 lessons · 8m

4.1 The Ocean and Atmosphere as a Coupled System

The ocean and atmosphere are tightly linked: the ocean absorbs vast amounts of heat and moisture, while the atmosphere redistributes that heat around the globe through wind patterns. Changes in sea surface temperature influence air pressure and wind, and changes in wind influence ocean currents and upwelling in turn. This two-way relationship, called ocean-atmosphere coupling, is responsible for many of the climate patterns that shape regional weather over months to years.

4.2 El Niño-Southern Oscillation (ENSO)

ENSO is the most influential year-to-year climate driver on the planet. During El Niño, the warm phase, trade winds weaken and warm water that is normally piled up in the western Pacific spreads eastward, raising sea surface temperatures in the central and eastern tropical Pacific. This shifts rainfall patterns, often bringing drought to parts of Southeast Asia and Australia while increasing rainfall in parts of the Americas. La Niña, the cool phase, produces roughly opposite effects. ENSO events recur irregularly, on average every two to seven years, and each phase typically persists for nine to twelve months. .

4.3 Thermohaline Circulation and the AMOC

Beyond ENSO, a slower global system of deep ocean currents, called thermohaline circulation, is driven by differences in water temperature and salinity, which together determine water density. Dense, cold, salty water sinks in the North Atlantic and flows along the ocean floor toward the Southern Hemisphere, while warmer surface water flows northward to replace it. The Atlantic branch of this system, the Atlantic Meridional Overturning Circulation (AMOC), transports enormous amounts of heat toward the North Atlantic and helps keep Western Europe milder than other regions at similar latitudes.

4.4 Monsoons and Jet Streams

Monsoons are seasonal reversals of wind direction, often associated with dramatic shifts in rainfall, most notably across South and Southeast Asia. Jet streams are fast-flowing, narrow currents of air in the upper atmosphere that steer weather systems and separate air masses of different temperatures. Both phenomena are sensitive to broader shifts in ocean temperature and atmospheric circulation, linking them closely to the climate drivers discussed throughout this module.

Module 5: Evidence and Causes of Climate Change

Climate scientists do not rely on a single dataset to establish that the climate is changing. Instead, they draw on multiple independent lines of evidence, including the...

5 lessons · 10m

5.1 Multiple Lines of Evidence

Climate scientists do not rely on a single dataset to establish that the climate is changing. Instead, they draw on multiple independent lines of evidence, including the instrumental temperature record, satellite measurements, rising sea levels, shrinking ice sheets and glaciers, warming oceans, and shifts in species ranges and seasonal timing. The instrumental record — direct measurements from thermometers and other instruments is generally considered reliable from roughly the mid-to-late 1800s onward.

5.2 Paleoclimate Proxy Records

To understand climate before instrumental records existed, scientists use proxy records, natural archives that preserve indirect evidence of past conditions. Tree rings reveal year-by-year growing conditions; coral growth bands record ocean temperature and chemistry; and ice cores, drilled from ice sheets in Antarctica and Greenland, trap tiny bubbles of ancient air that can be directly analysed for past atmospheric composition, alongside chemical signatures that indicate past temperature. Long ice core records, such as those from Vostok and EPICA in Antarctica, extend the climate record back roughly 800,000 years.

5.3 What the Long Record Shows

These proxy records reveal a striking, long-standing correlation: atmospheric CO₂ concentration and global temperature have tracked one another closely across multiple glacial and interglacial cycles. What distinguishes the current period is the rate of change, modern increases in CO₂ and temperature are occurring far faster than the natural transitions recorded in ice cores, a pace that is difficult to explain through natural drivers alone.

5.4 Attribution Science

Attribution science aims to determine how much of an observed climate change or extreme event can be attributed to human activity versus natural variability. Techniques include comparing observed warming patterns to climate model simulations run with and without human greenhouse gas emissions, analysing the isotopic signature of atmospheric carbon (which points to a fossil fuel origin for much of the recent CO₂ increase), and identifying "fingerprint" patterns, for example, warming in the troposphere occurring alongside cooling in the stratosphere, that are consistent with a greenhouse-gas-driven mechanism rather than purely natural causes such as solar variability.

5.5 The Scientific Consensus

Assessments compiled by the Intergovernmental Panel on Climate Change (IPCC), which synthesizes published research from scientists around the world, conclude with high confidence that human activities, primarily the emission of greenhouse gases through fossil fuel combustion, deforestation, and industrial processes are the dominant cause of the rapid warming observed since the mid-20th century, during which global average surface temperature has risen by approximately 1.1 to 1.5 degrees Celsius above pre-industrial levels.

Module 6: Climate Feedback Loops and Tipping Points

A feedback loop occurs when a change in the climate system triggers a secondary effect that influences the original change. A positive feedback amplifies the initial change,...

5 lessons · 10m

6.1 Positive and Negative Feedback Loops

A feedback loop occurs when a change in the climate system triggers a secondary effect that influences the original change. A positive feedback amplifies the initial change, pushing the system further in the same direction. A negative feedback counteracts the initial change, helping stabilize the system. Both types of feedback operate simultaneously throughout the climate system, and their net balance strongly influences how sensitive global temperature is to a given change in greenhouse gas concentrations.

6.2 The Ice-Albedo Feedback

The ice-albedo feedback is one of the clearest examples of a positive feedback. As rising temperatures melt reflective ice and snow, they expose darker ocean water or land underneath. Because dark surfaces absorb more solar energy than ice does, this exposed surface warms further, driving additional melting, a self-reinforcing cycle that is especially pronounced in the Arctic, a region warming several times faster than the global average. .

6.3 The Water Vapor Feedback

Warmer air can hold more water vapor. Since water vapor is itself a potent greenhouse gas, an initial warming trend increases atmospheric humidity, which in turn traps more heat and reinforces the warming, another significant positive feedback that amplifies the effect of other climate forcings.

6.4 Tipping Points and Tipping Elements

A tipping point marks a threshold beyond which a system shifts, potentially abruptly, to a qualitatively different state, and may be difficult or impossible to reverse on human timescales. Climate scientists have identified several large-scale "tipping elements" of particular concern, including the Greenland and West Antarctic ice sheets, the Atlantic Meridional Overturning Circulation, Arctic permafrost, and the Amazon rainforest. Each involves feedbacks that could, beyond a certain threshold of warming, accelerate change independently of further emissions.

6.5 Cascading Risks

A growing area of research examines whether crossing one tipping point could increase the likelihood of triggering others, for example, ice sheet melt altering ocean circulation, which in turn affects regional climates and ecosystems elsewhere. This possibility of cascading, interconnected thresholds is a central reason many scientists emphasize limiting warming as early as possible, since the risks associated with these systems are not necessarily smooth or fully predictable.

Module 7: Climate Modelling and Future Projections

Global Climate Models (also called General Circulation Models, or GCMs) simulate the climate system by dividing the Earth's surface and atmosphere into a three-dimensional grid of...

5 lessons · 10m

7.1 How Climate Models Work

Global Climate Models (also called General Circulation Models, or GCMs) simulate the climate system by dividing the Earth's surface and atmosphere into a three-dimensional grid of cells. Within each cell, the model applies fundamental physical equations governing fluid motion, energy transfer, and chemistry to calculate how conditions such as temperature, pressure, humidity, and wind evolve over time, exchanging information with neighbouring cells at each time step. The finer the grid, the higher the model's resolution, the more detail the model can represent, at the cost of greater computing power. .

7.2 From Simple to Complex Models

Climate models range enormously in complexity. Energy Balance Models (EBMs) are relatively simple, calculating only the balance between incoming and outgoing energy to estimate surface temperature; some can run on a basic spreadsheet. At the other end of the spectrum, modern Earth System Models couple the atmosphere, ocean, ice, land surface, and even biogeochemical cycles into a single integrated simulation.

7.3 Emissions Scenarios: Shared Socioeconomic Pathways

Because future greenhouse gas emissions depend on human choices, climate models are typically run under a range of Shared Socioeconomic Pathways (SSPs), which represent different plausible storylines for future population, economic development, energy use, and policy. Comparing model outputs across these different pathways allows scientists to illustrate how future warming and its impacts depend heavily on the emissions choices made in the coming decades, rather than being predetermined.

7.4 Validating Climate Models

Climate models are tested and refined by checking whether they can reproduce observed historical climate patterns, including the response to real-world events such as volcanic eruptions. International efforts such as the Coupled Model Intercomparison Project (CMIP) coordinate standardized experiments across dozens of independent modelling groups worldwide, allowing scientists to compare results, identify areas of agreement, and better characterize uncertainty by examining the spread across a multi-model ensemble.

7.5 Understanding Uncertainty

Uncertainty in climate projections comes from several distinct sources: uncertainty about future human emissions choices, natural internal variability in the climate system (such as ENSO cycles), and differences between models in how they represent complex processes like cloud formation. Presenting projections as a range rather than a single number is not a sign of weak science, it is an honest reflection of these compounding, well-understood sources of uncertainty.

Module 8: Climate Mitigation, Adaptation, and Solutions

Climate mitigation refers to actions that reduce or prevent greenhouse gas emissions, addressing the root cause of climate change, for example, transitioning power grids from...

5 lessons · 10m

8.1 Mitigation versus Adaptation

Climate mitigation refers to actions that reduce or prevent greenhouse gas emissions, addressing the root cause of climate change, for example, transitioning power grids from fossil fuels to renewable energy. Climate adaptation refers to adjusting systems, infrastructure, and behaviour to reduce vulnerability to climate impacts that are already occurring or unavoidable, for example, building early warning systems for extreme heat or designing infrastructure to withstand more intense storms. Effective climate policy generally requires both strategies working together, since some warming and its associated impacts are already locked in by past emissions. .

8.2 International Policy: The Paris Agreement

Adopted in 2015, the Paris Agreement is the primary international framework for coordinating climate action, with the central goal of limiting global warming to well below 2 degrees Celsius above pre-industrial levels, while pursuing efforts to limit the increase to 1.5 degrees Celsius. Countries submit nationally determined contributions outlining their emissions reduction commitments, which are reviewed and strengthened periodically.

8.3 Net-Zero Emissions and Decarbonization

"Net-zero emissions" means balancing the amount of greenhouse gases emitted with an equivalent amount removed from the atmosphere, rather than eliminating all emissions in every sector. Decarbonization — the process of reducing the carbon intensity of energy systems, is central to reaching this goal, and typically involves shifting electricity generation toward renewable sources such as solar and wind, electrifying transportation and heating, and improving energy efficiency across the economy.

8.4 Carbon Removal and Nature-Based Solutions

Alongside reducing emissions, some strategies focus on removing existing CO₂ from the atmosphere. Carbon capture and storage (CCS) technologies capture emissions at their source, such as power plants, and store them underground. Nature-based solutions, including reforestation and wetland restoration, work by enhancing natural carbon sinks like those discussed in Module 3, while also often providing co-benefits for biodiversity and local communities.

8.5 Adaptation in Practice

Adaptation measures span many sectors: developing drought-resistant crop varieties for agriculture, building sea walls and elevating infrastructure in coastal cities, improving early warning systems for extreme heat and storms, and diversifying water supplies in drought-prone regions. Because climate impacts vary greatly by location, effective adaptation is often highly context-specific, requiring close attention to local vulnerabilities and resources.

Final Assessment & Certificate

The final test draws on questions from every module. The pass mark is 80%. When you pass, Tapi Learn issues a certificate of completion bearing your name, the course title, your final score, a unique certificate number and the signature of the CEO of the Pan African Network for Climate Action (PANFCA). Each certificate carries a verification URL (acla.io/verify/<number>) so employers and partners can confirm its authenticity. You can download the certificate as a PDF directly from the app at any time, and your progress and certificates are backed up to the cloud under your email address.

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