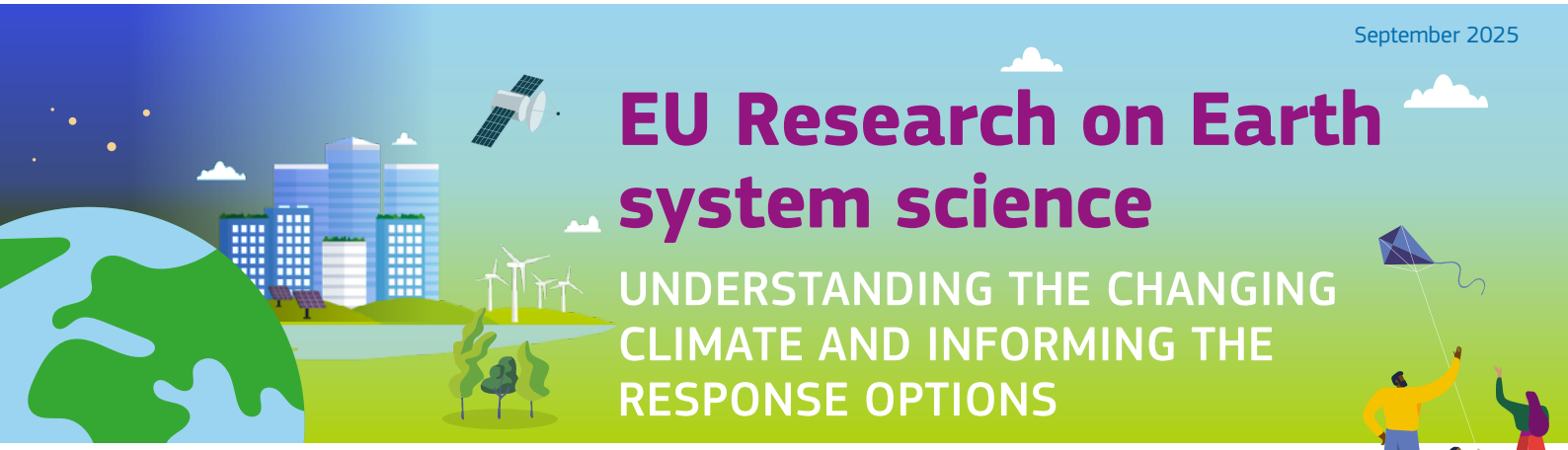
European Commission

European Climate, Infrastructure and Environment Executive Agency



September 2025

EU Research on Earth system science

UNDERSTANDING THE CHANGING CLIMATE AND INFORMING THE RESPONSE OPTIONS

Earth system science studies our planet as an interconnected system, encompassing the atmosphere, oceans, land, cryosphere and biosphere together with the human influence. It explores the dynamics, feedbacks and interactions that shape weather and climate including ocean and atmospheric circulation, melting ice-sheets, greenhouse gas effects and potential climate tipping points.

Through Horizon Europe projects, scientists combine evidence from past climates, modern observations and advanced computer models to improve climate predictions, assess risks and reduce uncertainty. This research underpins European Union's strategies for climate neutrality and resilience as set out in the European Climate Law and the European Green Deal.

Earth system science is integral to the European Union's research agenda, contributing to the 35% of Horizon Europe's budget for climate action. Its results feed into the Intergovernmental Panel on Climate Change (IPCC) assessments and provide the data, tools and actionable knowledge Europe needs to strengthen climate change mitigation, resilience and long-term prosperity.

FUNDAMENTAL UNDERSTANDING OF THE CLIMATE SYSTEM

P2F

P2F integrates paleoclimate proxy data with Earth system models (ESMs) to reconstruct abrupt climate transitions and tipping points from Earth's past to improve future projections. It uses documented past events to test and validate models beyond the period of recorded weather and climate data (instrumental period). The project creates a portfolio of plausible future climate scenarios based directly on past critical transitions, producing fully paleo-informed ESMs for more robust projections of tipping risks.

Project information

OptimESM

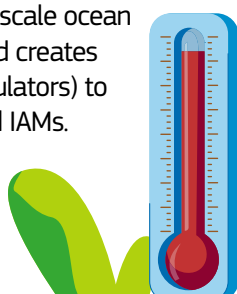
OptimESM develops high-resolution ESMs capable of simulating processes that drive regional climate impacts, extreme events and rapid Earth system changes. It integrates simulations with novel emission scenarios from Integrated Assessment Models (IAMs) and applies methods (e.g. model hierarchies and emulators) to produce tailored risk assessments. OptimESM explicitly supports European regions by providing actionable climate information on variability, extremes and compound risks.

Project information

EERIE

EERIE enhances ESMs by directly representing small- to medium-scale ocean whirlpools (<100 km) which strongly influence climate variability, extreme events and tipping points such as the Atlantic Meridional Overturning Circulation (AMOC). The project conducts coordinated high-resolution simulations with four advanced models and applies tools such as faster computer processors machine learning, reduced-precision computing and new model components to cut computational time and energy use by over 50%. It also develops specialised protocols focused on medium-scale ocean and atmosphere processes and creates simplified model versions (emulators) to support IPCC assessments and IAMs.

Project information



CRYOSPHERE CHANGE

ICELINK

ICELINK bridges climate models, ice-flow models, satellite observations and in-situ measurements to accelerate understanding of how glaciers in Iceland – and by extension the Greenland Ice Sheet – respond to warming, examining surface mass balance, snow dynamics and meltwater runoff. Using Icelandic glaciers as an observational "laboratory" for warmer-world melt behaviour, ICELINK seeks to improve process understanding and support local communities to bolster adaptation and resilience. The knowledge generated will also contribute to Copernicus, IPCC, IPBES, Destination Earth and other related programmes.

Project information

CryoSCOPE

CryoSCOPE investigates physical and chemical processes in the coupled Cryosphere-Atmosphere-Hydrosphere system across cold-region landscapes – including Finnish Lapland, Iceland, the Indian Himalayas, the Swiss Alps, Norway and Svalbard – using in-situ and remote sensing observations, process models, ESMs and AI tools. It produces actionable services such as improved winter mobility in Finland, optimized hydropower operation in Nordic regions and Switzerland, glacial lake outburst flood hazard mapping and drought forecasts in the Himalayas, all tailored through stakeholder collaboration.

Project information

LIQUIDICE

LIQUIDICE reassesses past and future high-impact changes due to climate-driven alterations in the Greenland Ice Sheet and vulnerable cryospheric systems in the Alps, Norway, High Mountain Asia and Svalbard – including permafrost and ecosystem impacts – by combining satellite Earth observation data and ground observations to improve and test glacier and ice-sheet models integrated into ESMs. Key outputs include multi-decade snow water datasets, albedo records, refined freshwater flux projections, hydrological simulations for High Mountain Asia and a new framework for water discharge impact assessment. These advances support water resource planning, hydropower and socio-economic adaptation strategies and resilience in the studied regions.

Project information

CLOUD-AEROSOL INTERACTIONS

CleanCloud

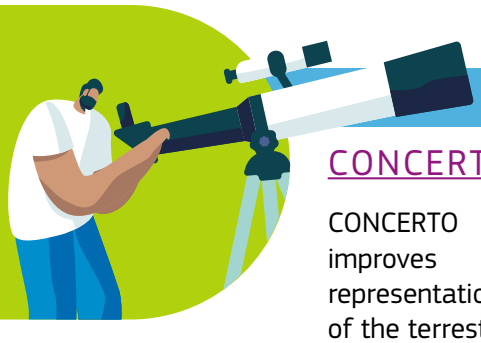
CleanCloud investigates how aerosol–cloud interactions – currently a major climate projection uncertainty – will evolve in a future with drastically reduced anthropogenic aerosols and an increased role of natural particles (e.g., sea spray and dust, for example, from wildfires). It conducts field tests including the CHOPIN and FORTH campaigns in Greece, Arctic spring campaigns in Greenland and PIANO environmental chamber studies at Aarhus University and FORTH (Patras). These efforts are combined with remote sensing, modelling and satellite calibration efforts to improve kilometer-scale and large-scale climate models' representation of convective systems, precipitation formation and aerosol–cloud interactions dynamics.

Project information

CERTAINTY

CERTAINTY aims to reduce uncertainty in how aerosol-cloud-radiation interactions influence weather and climate extremes. It integrates observational, remote sensing and modelling communities – including early adopters of EarthCARE and MetOp-SG satellite retrievals – to improve assimilation methods and model parameterizations across cloud types and key geographic areas. The project strengthens model confidence for weather forecasting, sub-seasonal to decadal predictions and centennial climate projections through Findable, Accessible, Interoperable and Reusable (FAIR) data and open-science infrastructures.

Project information



CARBON CYCLE AND CLIMATE – ECOSYSTEM FEEDBACKS

CONCERTO

CONCERTO improves representation of the terrestrial carbon cycle by integrating multi-scale models with Earth observation data. It focuses on quantifying carbon fluxes in European ecosystems, enhancing process understanding and model-data fusion to reduce uncertainty in projections. By combining satellite observations, in-situ campaigns and advanced modelling, the project aims to deliver refined datasets and predictive tools for terrestrial carbon dynamics, supporting climate mitigation and policy assessment.

Project information

NextGenCarbon

NextGenCarbon advances terrestrial carbon cycle modelling by assimilating comprehensive in-situ and satellite observations into next-generation ESMs. It develops frameworks to improve carbon flux estimates, evaluate ecosystem responses and produce high-resolution projections for climate impact assessments. The project enhances understanding of carbon-climate feedbacks and delivers data to inform both mitigation strategies and regional climate adaptation policies.

Project information

GreenFeedBack

GreenFeedBack investigates climate feedbacks in terrestrial, freshwater and marine ecosystems with a strong focus on underrepresented high-latitude and high-altitude regions such as sub-Arctic Finland, the Arctic permafrost zones and the Swiss Alps. It combines ecosystem observations, process studies and modelling to quantify greenhouse gas fluxes (carbon dioxide, methane, nitrous oxide) and tipping point risks. The results improve representation of these feedback in ESMs and reduce uncertainty in global climate projections used by the IPCC.

Project information

METHANE AND OTHER SHORT-LIVED CLIMATE FORCERS

IM4CA

IM4CA brings together leading European methane experts to tackle climate forcing from methane by building measurement and modelling capabilities across Europe and tropical Africa. The project seeks to provide actionable, location-specific data on emissions and key drivers, improve monitoring using satellites and land-surface characterization, understand climate feedback from natural methane sources and sinks and resolve causes of recent global methane growth variations to deliver reliable future projections and efficient mitigation scenarios.

Project information

FOCI

The FOCI project examines the influence of short-lived non-CO_2 radiative forcers – including black carbon, methane, tropospheric ozone, hydrocarbons and aerosol-albedo changes – on climate, air quality and health. It assesses where and how these pollutants arise, integrates observational data into Earth system and regional climate models and develops regionally-tuned emission scenarios (for regions like Europe, South Asia, Africa, the Arctic). The project also evaluates mitigation and adaptation strategies, measuring their multi-scale benefits.

Project information

TIPPING POINTS AND OVERSHOOT[1]

ClimTip

ClimTip focuses on quantifying and assessing tipping points in the Earth system, specifically the AMOC, the Greenland and West Antarctic ice sheets and the Amazon rainforest. It combines paleoclimate records, observations and ESM simulations to determine thresholds, reversibility, overshoot risks and cascading impacts. ClimTip develops early-warning indicators, high-resolution climate “storylines” and risk assessments to support European and international climate policy.

Project information

TipESM

TipESM runs coordinated ESM experiments with multiple models to systematically investigate tipping elements including the AMOC, ice sheets, permafrost, vegetation systems and marine biogeochemistry-related. It identifies precursor signals, quantifies likelihoods and irreversibility and analyses cascading effects between tipping elements. TipESM contributes to the Tipping Points Model Intercomparison Project and produces a tipping-point risk register to inform mitigation pathways.

Project information

1 **Tipping point**: A critical threshold beyond which a system reorganizes, often abruptly and/or irreversibly (IPCC, 2022).
Overshoot pathway: Pathways that first exceed a specified concentration, forcing or global warming level and then return to or below that level again before the end of a specified period of time (e.g., before 2100) (IPCC, 2022).

RESCUE

The RESCUE project studies how the Earth system responds to overshoot scenarios, climate neutrality and negative emissions by conducting coordinated simulations with enhanced ESMs. It analyses reversibility and risks of overshooting temperature targets, explores the effectiveness and side effects of carbon dioxide removal and provides datasets and knowledge to constrain uncertainties in overshoot pathways for use in European and international climate strategies.

Project information

CLIMATE AND ATMOSPHERIC FEEDBACKS OF HYDROGEN

HYWAY

HYWAY explores the climate and environmental implications of scaling up a hydrogen economy. The project quantifies the global hydrogen budget – including leakage and soil uptake fluxes – and models hydrogen's indirect effects on atmospheric components such as methane, ozone and stratospheric water vapour. It also develops sectoral and regional hydrogen emission inventories and scenario frameworks, combining field and laboratory measurements with atmospheric modelling to evaluate risks and co-benefits in collaboration with industry through advisory board.

Project information

HYDRA

HYDRA assesses both the benefits and potential climate and safety risks of large-scale hydrogen deployment. It evaluates market and policy scenarios, simulates atmospheric impacts – including changes in radiative forcing due to hydrogen interactions with methane, carbon monoxide, nitrous oxide, ozone and water vapour – and develops a remote-sensing monitoring system to detect hydrogen leaks in large-scale storage facilities. HYDRA couples environmental impact analysis with socio-economic modelling and policy guidance, updating life cycle assessment methodologies to support safe and sustainable hydrogen technologies.

Project information

EMISSION VERIFICATION

AVENGERS

AVENGERS quantifies and verifies European and national greenhouse gas and aerosol emissions by integrating top-down atmospheric measurements – from ground-based monitoring stations and satellite observations – with bottom-up statistical emission inventories. The project reconciles discrepancies between different emission estimates, develops source attribution methodologies and enhances accuracy of emission reporting. Case studies conducted in collaboration with national inventory teams target key sectors including agriculture, transport and energy, addressing uncertainties in sectoral and spatial emission data. Outputs provide actionable knowledge to support implementation of mitigation policies.

Project information

EYE-CLIMA

EYE-CLIMA aims to improve estimates of emissions and removals of key greenhouse gases (carbon dioxide, methane, nitrous oxide) and black carbon across Europe. The project uses high-resolution satellite observations and inverse modelling techniques to monitor emissions from both point sources (such as fossil fuel infrastructure) and diffuse sources (such as agriculture). It collaborates with national inventory agencies through pilot studies to compare these measurements with official emission statistics, producing more accurate data to support European and international climate policy. It also develops interactive data visualization tools to communicate its findings.

Project information

PARIS

PARIS focuses on the process attribution of regional emissions, aiming to enhance the understanding of greenhouse gas emissions in Europe. The project combines bottom-up emission inventories with top-down atmospheric measurements to improve the accuracy of national greenhouse gas inventories. Key activities include the development of sector-level methane emission quantification methods and the separation of biospheric and fossil fuel CO_2 fluxes. The project collaborates with national inventory teams across eight European countries, establishing monitoring and sampling locations to refine emission estimates and support mitigation strategies. The project also contributes to the European Monitoring and Evaluation Programme by providing high-resolution emission data for regional climate modelling.

Project information

ADVANCED ESM DEVELOPMENT AND AI INTEGRATION

AI4PEX

AI4PEX enhances ESMs by fusing Earth observations, AI and machine learning to better represent key processes and uncertainties in land, atmosphere and ocean domains. It develops machine learning -augmented, physics-aware hybrid modelling techniques to advance representation of vegetation responses, cloud feedback at local scales, ocean heat and carbon uptake and extreme climate risks. The project also builds fast, agile workflows for integrating observations and machine learning into ESMs, improving resilience tools and climate projection reliability at regional to global scales.

Project information

EXPECT

EXPECT tackles the challenge that regional climate extremes (particularly European summer extremes) are emerging more rapidly than current models capture. It uses advanced climate model simulations, Earth observations and machine learning to identify and quantify the drivers of regional climate changes over periods from years to decades, strengthening understanding of atmospheric circulation and land–atmosphere feedback. EXPECT builds tools for integrated attribution, prediction and hazard analysis and develops an open science platform to share datasets, code, trained models, benchmarks and evaluation protocols with the wider climate research community, enhancing data science capacity.

Project information

FOCAL

FOCAL aims to develop an open-access platform that merges intelligent workflow management, Earth observations and ESM data with artificial intelligence and high-performance computing to deliver reliable local-level climate impact assessments for urban planning and forestry. The platform will empower non-expert users – such as urban planners and foresters – through co-design of web applications and provide modular services, tools and workflows for easy integration by developers and small and medium-sized enterprises. The project also contributes to enhanced understanding of Earth system processes by combining Earth observation data with data assimilation and modelling, enabling discovery of feedback mechanisms and patterns at local scales, all under an open, interdisciplinary framework.

Project information

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Intergovernmental Panel on Climate Change (IPCC). (2022). *Annex II: Glossary*. In *Climate Change 2022: Impacts, Adaptation and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

FIND OUT MORE

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