

WP2: The Earth System on Long Time Scales (Gerrit Lohmann, Wolfgang Hiller, Eduardo Zorita)

Feedbacks between ice sheets, atmosphere-ocean circulation and carbon cycle in an integrated earth system approach.

Objectives and challenges

It is of vital importance to understand whether increasing human population and industrialization have already caused, or have the potential to induce significant changes in earth's climate. In order to properly address this question, quantitative information is needed regarding the amplitude and rapidity of natural variations in the polar and marine environment. Unfortunately, the type of direct measurement records which would allow to quantify climate changes on a global scale are too short, and they fall already within the period of strong human impact on natural conditions. Information regarding the pre-anthropogenic state of the system can be obtained from simulating climate using comprehensive models under appropriate external forcing changes, in combination with a mechanistic understanding of proxies that record past climate and environmental conditions. This approach provides a synthesis of the regional aspects in the research program, bringing together the expertise from the different disciplines.

Within Topic 4, a three-dimensional climate model will explicitly resolve the atmosphere-ocean dynamics, including climate components such as the cryosphere. The potential vulnerability of the ice sheets under rapid climate change leads to important changes in feedbacks between the climate earth system components. As a further innovative step, the ESM should be capable of simulating biogeochemical cycles, including the carbon cycle and marine sediments, human land use changes, as well as isotopes in the various Earth system components. To this end, well documented and tested model components should be used and adapted for our purposes. One specific aspect will be the link between climate and the biosphere on a wide range of time-scales (decadal to multi-millennial), including satellite data and its relation to the influence of different biotic and abiotic factors, and plankton's functioning in the marine ecosystems and the global carbon cycle. In our finite element ocean model processes are resolved by an appropriate setup, for example coasts, passages and dynamically active regions such as the Gulf Stream. By these means we can focus on coastal and Polar Regions in a global setup.

The studies will focus on

1) Coupling the cryosphere, biogeochemical cycles, and simulated cores

Long-term climate variations and abrupt climate changes are strongly affected by the high-latitude freshwater balances. In order to analyse the special polar influence on global climate, ice sheets will explicitly be incorporated into the ESM. Furthermore, the model shall be capable of simulating the global carbon and other elemental cycles and the distributions of isotopes, including simulated sediment and ice cores. Necessary model parameterizations will be based on process knowledge from observational and experimental approaches in AWI (Topic 3 WP3).

2) Climate simulations: ice sheets, global ocean thermohaline circulation and carbon cycle

The analysis of the glacial-interglacial variability, Holocene variability including the recent period of anthropogenic greenhouse warming and human-induced land use changes, and the next centuries, enables us to compare conditions under natural and anthropogenic conditions. Analysis of large-scale teleconnections and climate variability modes (internal and externally forced) have to be identified on decadal to multi-millennial time-scales, including the Atlantic multidecadal mode linked to the oceanic meridional overturning circulation. This will help to improve our understanding of the mechanisms for natural and anthropogenic climate changes, the predictability of the climate, and provides insights into the response of the earth system under pressure. We will place emphasis on the special role of the high latitudes on long-term climate evolution, associated to ice sheets, the global ocean thermohaline circulation and carbon cycle.

3) Synthesizing data and models

As hypotheses concerning the origin of climate variability and abrupt climate change accumulate, there is an increasing need to synthesize data and to develop methods that may help assess their strengths and inconsistencies. To provide the ability to quantitatively connect the model predictions with data, a data assimilation methodology is applied. Based on a framework of filter algorithms developed at AWI, different methods like ensemble-based Kalman filters will be used, which can be configured for particular observational data sets.

Implementation

In WP2, we bring together earth system modelling, data analyses, as well as conceptual work. The set up of an ESM that includes coupled modules for atmospheric and oceanic circulation, the cryosphere, marine biogeochemistry, sediments, land biosphere, and data assimilation requires a team of climate modellers, people with computational expertise, data and process oriented research. In order to use unstructured grid modelling in our ESM, coupling techniques will be applied to interface unstructured to structured grid model components. As an integrated service optimized solvers have to be provided for the relevant architectures and modelling requirements. Other methodological aspects (model development, data-model comparison, upscaling and downscaling techniques) will be part of the WP and are largely based on the AWI and GKSS expertise. The palaeoclimate records that are obtained in Topic 3 “Lessons from the past” provide an excellent test of our hypotheses as they reveal climate and environmental variations that have actually occurred in the past. The focus will be on long time scales, which is essential to understand past climate, but also to examine the special role of the high latitudes on long-term climate trends beyond the next decades. Feedbacks between the ice sheets, the global ocean thermohaline circulation and carbon cycle are less explored in an integrated earth system approach, and we expect fundamental insights into the coupled climate-biogeochemical system.

Milestones

Set up of an ESM that includes coupled modules for atmospheric and oceanic circulation, the cryosphere, marine biogeochemistry, land biosphere, and sediments (years 1&2).

Coupling of adaptive model components with unstructured grids (year 2).

Model support and optimization of ESM components on high performance computing infrastructure; adaptation of model code to forthcoming multicore parallel architectures with hybrid programming and appropriate numerical solvers. Verification and integration of model components, visualization of high volume modelling data; Integration of parallel filter framework for data assimilation, applications (years 2&3).

Deliverables

Development of model components for elemental cycles, application of data-model comparison tools. Software framework and components for ESM Workbench including pre- and post-processing tools.

Climate Scenarios with a low-resolution model: Holocene, glacial-interglacial, long-term future. Simulation of elemental cycles and the distributions of isotopes, including simulated sediment and ice cores; elaboration of climate modes on decadal to multi-millennial time-scales, including the Atlantic multidecadal mode linked to the oceanic meridional overturning circulation and the cryosphere.

Assessing the role of past and future evolution of sea level and trace gas concentrations; dynamics of polar ice sheets, global ocean circulation and carbon cycle.