Max-Planck-Institut
für Meteorologie

Large-scale projects at MPI-M: co-operations advance climate research

In addition to numerous research projects by various funders, the Max Planck Institute for Meteorology (MPI-M) is involved in three large-scale projects of the German Federal Ministry of Education and Research: HD(CP)^2 (High definition clouds and precipitation for advancing climate prediction), MiKlip (Decadal Climate Prediction) and PalMod (Paleo Modeling). The projects HD(CP)^2 and MiKlip were coordinated at MPI-M, and one of the three speakers in PalMod is from MPI-M.

The MPI-M plays a leading role in these large-scale projects because it advances its own research topics in a way that would not be possible with budget funds from the Max Planck Society alone. The research topics of the projects fit very well with the main topics of MPI-M: Earth system modeling (HD(CP)^2), investigation of climate predictability (MiKlip) and climate changes on long time scales (PalMod). The development of Earth system models is particularly advanced by the large-scale projects and their concrete tasks. A good illustration of this is the HD(CP)^2 project, as ultra-high-resolution versions for regional "hindcasts" were developed, which are retrospective predictions for a past period. In MiKlip the model is adapted to the given tasks, and in PalMod a complete glacial cycle is simulated with the help of complex Earth system models for the first time. In the three projects, simulations with the Earth System models are performed on different time scales and with different resolutions: from a few days to tens of thousands of years and from regional (high) to global (low) resolution.

The cooperation with the research community within the projects is valuable for MPI-M, as all partners benefit from each other and resources can be shared. Through the project partners it is possible to participate in infrastructures or data, such as observations, which MPI-M does not have. HD(CP)^2, for example, uses observational data from the University of Cologne, the German meteorological service (DWD) and the University of Hohenheim, and MiKlip works with an evaluation package from the FU Berlin.

The large-scale projects

HD(CP)2

Clouds and precipitation play a major role in answering the question of how the climate will change as a result of the influence of humans. A lack of understanding of the physical processes and insufficient computer capacity have so far led to the fact that the representation of clouds and precipitation accounts for a large part of the uncertainty in current climate models and their predictions. HD(CP)^2 addressed this problem by combining progress in model development and observations. The project pursued the following overarching objectives: improving climate predictions through better representation of clouds and precipitation in current climate models, quantifying the model uncertainty by assessing the influence of the model errors caused by cloud/precipitation processes, establishing teams of experts, i.e. groups of scientists from different research institutions, who work together on one research question, and increasing the visibility of German research by bundling and focusing existing world-class research.

The ICON model of MPI-M provided ultra-high resolution regional hindcasts for periods and grid spaces that are climatically relevant (resolution: 156 m horizontal, 10-50 m vertical). To evaluate the model on these scales, high-resolution observations are necessary, which were extended to the tropical Atlantic (Barbados) and North Atlantic in the second funding period (observation campaign NARVAL-II with MPI participation). These observations and the ICON model results will be used to answer the current questions regarding clouds and precipitation.

Results:

At the end of the first funding phase, the high-resolution model ICON-LEM was available and the MPI-M played a leading role in its development. It is a community model now, i.e. the scientific community can also use it. The work in the project laid the foundation for MPI-M´s modeling strategy in “Sapphire” (high-resolution modeling of the coupled climate system to explicitly represent convective storms in the tropics and mesoscale ocean eddies in the extratropics) and for the DYAMOND initiative (https://www.esiwace.eu/).

The database SAMD (Standardized Atmospheric Measurement Data archive) at the German Climate Computing Center (DKRZ) is an important tool that HD(CP)^2 has put forth. The aim of this new data archive is to provide both modelers and suppliers of observational data with easy access to an observation data archive. SAMD provides observational data in the Climate Forecast (CF) Conventions format and makes them available to the wider public. The data will be provided in a standardised and validated form, and metadata from different instruments will be made available through open access.

The project´s technically very complex observation campaign HOPE (HD(CP)^2 Observational Prototype Experiment) collected temporally and spatially high-resolution data sets in a two-month field experiment in Jülich and Melpitz, Germany, in 2013. The experiment focused on capturing the formation of clouds and precipitation in the convective atmospheric boundary layer. The data sets were used, among other things, to evaluate the ICON model and to investigate processes between the land surface and the atmospheric boundary layer.

Through close communication, HD(CP)^2 has improved the network between the communities of modelers and observers.

MiKlip

There is a growing need for reliable information on trends in climate for time periods of years to decades, mainly because the planning horizon of the economy, but also of politics and society, is in the order of ten years. Such predictions are the essential prerequisite for improving society´s adaptability to the future climate and for sustainable economic development in line with the United Nations´ sustainability goals. The MiKlip project met these challenges, with a particular focus on creating the scientific basis and developing a pre-operational prediction system for decadal climate predictions.

On time scales ranging from a few years to decades, the distribution of climate parameters depends not only on anthropogenic greenhouse gas concentrations in the atmosphere but also on the natural variability of the climate system. The natural variability is based on external drivers such as fluctuations in incident solar radiation or volcanoes as well as the internal variability of the coupled climate system. The internal variability is predominantly chaotic, but in the decadal time dimension there are clear indications of a longer-term “memory” of individual internal processes. Decadal climate prediction tries to exploit the memory of these slow processes. The inertia of the ocean and its key processes are of central importance here. For this reason, information such as temperatures and salinity of the ocean are prescribed and used for the predictions. These initial conditions are crucial for decadal climate predictions; for long-term projections, they are largely irrelevant.

Before MiKlip began, promising scientific papers have been published in individual fields of decadal climate prediction, but these were focused on individual aspects of the research groups involved. Altogether there were no more than three publications, so that a targeted synthesis of such important questions as initialisation, evaluation and process reference was not possible. MiKlip addressed this problem and developed a coordinated programme for the systematic development and evaluation of a national decadal climate system at a global and regional level for an operational application.

The research questions in MiKlip were roughly assigned to four major challenges: initialization and provision of an ensemble of decadal climate predictions, increasing the understanding of processes relevant for a time horizon of 10 years (important for the decadal predictability of the climate), regionalization of decadal climate forecasts, evaluation and verification of the decadal climate predictions. A synthesis bundles the knowledge gained into the development of a central prediction and evaluation system.

In the first phase, MiKlip made important contributions to investigate the fundamentals of decadal predictability and developed an internationally competitive decadal climate prediction system. Based on these results, the overall objective for the second funding phase of MiKlip (MiKlip II) was not only to improve the decadal climate prediction system but also to prepare it for the operational use. The results of this second phase will be the focus in the following.

Results:

The basis of the climate prediction system is the coupled Earth System Model of the MPI-M (MPI-ESM). It considers not only the classical climate components atmosphere-ocean-sea ice but also other Earth system components such as ocean-land biochemistry and is coupled to a 5-layer land component. MiKlip II developed a high-resolution version of the MPI-ESM (MPI-ESM-HR) for the decadal climate predictions and is used, besides a lower resolution of the MPI-ESM, as a basis model for the Climate Model Intercomparison Project Phase 6 (CMIP6) and the WCRP DCPP (World Climate Research Program Decadal Climate Prediction Panel). Compared to its predecessors, MPI-ESM-HR is characterized by a doubling of the resolution of the atmosphere (~100 km). This further development improves key processes in the mid-latitudes, such as blocking weather conditions and the formation and strengthening of storm tracks, and significantly increases their prediction quality on decadal time scales.

The decadal climate predictions of the MiKlip system show a significant improvement of the predictions compared to climatology, e.g. for surface temperatures. Although this improvement is still characterised by the general rise in temperature, the appropriate initialisation of the natural climate variability can lead to a significant regional improvement in the quality of the prediction. A clear improvement is to be found over the North Atlantic and also for the European continental climate. However, further progress in prediction has also been made for other parameters: precipitation and droughts, key dynamic parameters such as storm tracks over Europe, the quasi-biennial oscillation in the Tropics and parameters relevant to the Earth system such as ocean carbon uptake. Furthermore, the first successes in predicting extreme temperature events over Europe have been recorded. The forecasts have been published on the MiKlip project page since 2017 (https://www.fona-miklip.de/decadal-forecast/forecasts-archive/decadal-forecast-for-2018-2027/).

A special, unprecedented result is the successful transfer of the tested forecasting system to Germany´s National Meteorological Service, Deutscher Wetterdienst (DWD), for operational use. It is now part of DWD´s “seamless predictions” strategy, which takes into account both operational climate forecasts in the monthly and seasonal ranges as well as decadal forecasts and climate projections. Furthermore, the decadal climate predictions are now part of an international initiative of the WCRP, the World Meteorological Organization (WMO) and the Global Framework on Climate Service (GFCS) to provide an operational multi-model system for decadal climate predictions.

PalMod

PalMod investigates the climate system and its variability during the last glacial cycle with complex Earth system models. The project aims at simulating a full glacial cycle in transient mode with complex Earth System Models which allow full interactions between the relevant physical and biogeochemical processes of the Earth system, including ice sheets. With the results from the model studies, the robustness of long-term climate projections can be better estimated and the validity of future climate simulations can be improved accordingly.

20,000 years ago, the average global temperature was about four to five degrees colder than today. North America and Scandinavia were covered with gigantic ice sheets, and the sea level was by about 120 m lower than today. Compared to the pre-industrial value, the atmospheric CO_2-concentration was more than a third lower. The massive ice sheets disappeared within 10,000 years and the climate got warmer. The direct calculation of the transition from weather to long term climate fluctuations of many centuries and millennia presents a major challenge to climate modelers. So far, simulations with complex climate models have only been performed for a time range of several centuries, only in very few cases for a couple of millennia.

For longer calculations, the models will have to be made significantly faster. New algorithms need to be developed. The models are lacking potentially important physical and biogeochemical processes. Ice sheets, with their long timescales, are constant by default in conventional simulations. On very long time scales, the variability is amplified by the means of interactive coupling with dynamic ice sheet models, which permits the study of feedbacks between continental ice masses and large-scale ocean circulations in the Earth system models. In addition, current models are lacking important interaction processes of the global carbon cycle, the sea level and ice sheets, which may explain the rapid and asynchronous changes in atmospheric carbon dioxide and methane during abrupt climate changes. The effect of carbon and methane being stored in permafrost on land and as a gas hydrate in marine sediments, which amplifies the climate variability depending on Earth´s orbit, is not included in Earth system models yet.

PalMod is supposed to close these gaps in knowledge and modeling. A period of 10 years is envisaged to achieve these scientific objectives. Currently, the second project phase is beginning.

Results from the first project phase:

In the first four-year project phase, the focus was on technical model development and on deglacification, i.e. the melting of the large land ice masses. A transient deglaciation experiment was carried out as a test case, with some worldwide innovations. The land-sea mask and the river courses were adapted interactively, depending on the topography, the extent of the ice sheets and the sea level change. An interactive methane module with terrestrial methane emissions from a land surface model was integrated. For this purpose, a model for the methane sink was developed jointly with the Max Planck Institute for Chemistry in order to determine the atmospheric methane concentration in transient experiments. The results of this transient experiment have not yet been published, but show some climate characteristics observed in the paleo data, such as the greening of the Sahel/Sahara region in the early Holocene and the doubling of atmospheric methane between the Last Glacial Maximum and pre-industrial times.

Innovations in the Earth System model enabled the scientists to carry out simulations of Heinrich events - climate changes during the ice age. They showed that these events were caused by the succession of the effects of two mechanisms: iceberg calving and ice sheet elevation loss. The iceberg calving affected the ocean circulation, and the elevation loss of the Laurentide Ice Sheet had effects on the atmosphere. Using a novel model setup, the scientists were able to study the relationship between the two individual effects.

In the now beginning second phase of PalMod, the focus will be on the beginning of the glacial. Furthermore, Dansgaard-Oeschger events will be investigated. They are rapid climate changes during the last ice age and are related to the Heinrich events. Another objective is the simulation of the biogeochemistry and the carbon cycle during the deglaciation.

Conclusion

The coordination and participation in large-scale research projects successfully advance MPI-M´s research. Cooperation with other project partners leads to good networking in the research community and benefits all partners. Modelers and observers work more closely together. The model development in the described projects leads to numerous innovations in the Earth System Model of MPI-M. The list of publications below shows impressively the research results achieved.

More information:

Project website HD(CP)²: http://hdcp2.eu/index.php?id=3744
Project website MiKlip: https://www.fona-miklip.de/
Project website PalMod: https://www.palmod.de/home

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