

## *Preface*

# Modelling Late Quaternary Climate

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## 1 Introduction

A robust simulation of the present-day climate does not guarantee an accurate simulation of a different climate, such as that in the future. Models, therefore, need to be tested on historical climate conditions that are different from the present but, unlike the future climate, can be compared with observational data. Suitable climates can be found in the Quaternary, where glacial and interglacial periods succeed each other in a more or less regular way. The Paleoclimate Modelling Intercomparison Project, PMIP (Joussaume and Taylor, 1995) focused on two very different periods of the late Quaternary: the Last Glacial Maximum (LGM), 21 ka Before Present (BP), and the mid-Holocene, 6 ka BP. Data syntheses were conducted in parallel with the modelling efforts for the same periods which has made it possible to explore the realism of the simulations. The models used during this first stage of PMIP were atmospheric General Circulation Models (GCMs). With the second phase, PMIP2 (Braconnot et al., 2007, part 1), it has become feasible to run a coupled ocean-atmosphere GCM for the same periods. In fact, a large range of different models are now available, ranging from intermediate complexity models, able to simulate transient climate over long periods, through ocean-atmosphere coupled GCMs, to Earth system models, which are able to take into account an increasing number of components such as the biosphere, land ice and carbon cycle. From the point of view of data, new syntheses are also available to validate climate models and to identify key forcings and feedbacks within the climatic system for each time period. This special issue is dedicated to research dealing with the understanding of late Quaternary climate variations on time-scales ranging from Milankovitch to millennial and related to various forcings. Most papers are based on presentations made at the “late

Quaternary” session at the EGU General Assembly in 2006 and several papers use model results from PMIP2. All aim to understand the climatic and oceanic dynamics recorded by the paleodata during the last glacial-interglacial cycle.

## 2 Overview of the papers

### 2.1 Coupled atmosphere and ocean

An overview of PMIP2 is presented by Braconnot et al. (2007, part 1 and 2) for the LGM and the mid-Holocene. They compare a set of coupled ocean-atmosphere simulations from PMIP2 to those of the atmospheric models from the first phase of PMIP (PMIP1). In part one, they describe the details of the PMIP2 protocol and present the large-scale features of climatic changes. In particular, they show that systematic differences between PMIP1 and PMIP2 simulations are due to the ocean (interactive in PMIP2 and prescribed in PMIP1). The inclusion of an interactive ocean amplifies the African monsoon at Mid-Holocene and the mid-latitude precipitation at the LGM. Benchmark model data comparisons show that PMIP2 simulations are generally in better agreement with data than are PMIP1 simulations in the tropical regions. In part two, Braconnot et al. (2007) show that the ITCZ shift was limited for the LGM, whereas a northward shift and an increase of precipitation are well depicted for mid-Holocene in continental regions affected by monsoon precipitation. For both periods the feedback from snow and sea-ice in mid and high latitudes is quantified, and some of the open questions requiring further research are identified.

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Renssen et al. (2006) performed two simulations with long spin-up times from different initial conditions plus an additional experiment run with time varying forcing for the Mid-Holocene (6 ka) climate with the ECBilt-CLIO-VECODE coupled atmosphere-ocean-vegetation model. The results suggest that, with a spin-up phase long enough (at least 550 years) to allow the deep ocean to adjust to the change in forcings, models run with the PMIP2 protocol should produce valid results.

Brewer et al. (2007) present a comparison between the outputs of a set of 25 climate models run for the mid-Holocene period (6 ka BP) with a set of paleoclimate reconstructions of Europe, using a statistical method. The conclusion is that, whilst the models are unable to reproduce the exact patterns of change, they all produce the correct direction of change for the mid-Holocene.

Yanase and Abe-Ouchi (2007) investigate the surface climate and atmospheric circulation over East Asia and the North Pacific at the LGM using the outputs from several PMIP2 simulations. In boreal summer, weakening of high pressure over the North Pacific and decrease of precipitation over East Asia are obtained by most models. These changes explain why the change in water vapour over East Asia is not simply related to reduced evaporation. In boreal winter, the mean feature is the intensification of the Aleutian low and southward shift of the upper-level jet.

Using the earth system model of intermediate complexity GENIE-1 over the last 30 ka years, Lunt et al. (2006) compare a transient simulation to snapshot simulations made every 3 ka years and including LGM (21 ka BP), mid-Holocene (6 ka BP) and pre-industrial periods. The close agreement between the transient run and the snapshots indicates that over the last 30 ka years, the model's ocean-atmosphere system is close to equilibrium with its boundary conditions. The effect on the results of using several different acceleration factors is also discussed, and the results suggest that the Southern Ocean is most affected by the acceleration while the Northern Hemisphere is relatively unaffected, even with a higher vertical resolution in the ocean.

## 2.2 Ocean thermohaline circulation

The simulation of the thermohaline circulation (THC) during the LGM, and specifically the Atlantic Meridional Overturning (AMOC), provides an important benchmark for models used to predict future climatic changes. Weber et al. (2007) have compared in this respect nine PMIP simulations, which show widely varying AMOC responses. They found that a major controlling factor for the LGM AMOC is the density contrast between Antarctic Bottom Water and North Atlantic Deep Water during the LGM as compared to the modern climate.

Roche et al. (2007) present here an ensemble of LGM climate simulations obtained with the Earth System model LOVECLIM, including coupled dynamic atmosphere, ocean

and vegetation components. They find that the oceanic circulation obtained resembles that of the present-day, but with increased overturning rates. By performing a comprehensive model-data comparison they argue that, in contrast to the usual paleoceanographic view, the observational data may not be inconsistent with these results.

## 2.3 Cryosphere

By using a time-dependent modelling approach to generate synthetic sediment core records, Ridgwell (2007) find that a close match between predicted and observed down-core changes in sedimentary opal content is achieved when changes in seasonal sea-ice extent are imposed, suggesting that the cryosphere is probably the primary driver of the striking features exhibited by records of the Southern Ocean.

Abe-Ouchi et al. (2007) have examined the ice sheet-climate interaction as well as the climatic response to orbital parameters and atmospheric CO<sub>2</sub> concentration in order to drive an ice sheet model throughout an ice age cycle. Among the proposed processes, the ice albedo feedback, the elevation-mass balance feedback and the desertification effect over the ice sheet were found to be the dominant processes for the ice-sheet mass balance. Careful treatment of climate-ice sheet feedback is essential for a reliable simulation of the ice sheet changes during ice age cycles.

A similar conclusion is drawn by Peyaud et al. (2007). Using an ice-sheet model (GRISLI) forced by the climate generated by an AGCM, they also show the importance of the ice shelves in the inception of ice-sheets. In addition they find that ice-dammed lakes have a substantial impact on the evolution of the ice-sheets, with reduced summer ablation enhancing the ice extent and thickness, and causing the deglaciation to be delayed by 2 ka.

## 2.4 Biosphere and biogeochemical cycles

Zeng (2007) proposes a new mechanism to explain the quasi-100 ka cycle in the paleoclimatic records tested by a fully coupled earth system model with comprehensive carbon cycle and semi-empirical physical climate components. In the proposed theory, deglaciation can be triggered by the ejection of glacial burial carbon and glacial inception by CO<sub>2</sub> draw-down as the land-originated CO<sub>2</sub> invades into deep ocean and to vegetation in the previously ice-covered boreal regions.

The dynamics of the terrestrial biota, climate and the carbon cycle were studied for the Eemian and Holocene (Schurgers et al., 2006), using a coupled earth system model with interactive carbon cycle. Net anomalies in terrestrial carbon storage for the Eemian and Holocene were found to be rather similar, but the processes causing these effects were different for each time period.

Ramstein et al. (2007) study the reasons for the improvement in PMIP2 (compared to PMIP1) of the agreement between the pollen data and model simulations for

winter temperature over Western Europe and the Mediterranean. They show that none of the following advances in the modelling improved this particular model-data discrepancy: increased spatial resolution; inclusion of a vegetation cover compatible with the LGM climate; inclusion of ocean-atmosphere interaction. In addition, accounting for changes in interannual variability in the interpretation of the pollen data did not help. Instead, the improvement in the results in PMIP2 has arisen from a new climate reconstruction based on inverse vegetation modelling, which explicitly accounts for the CO<sub>2</sub> decrease at LGM.

## 2.5 Forcings: orbital forcing and greenhouse gases

Kaspar et al. (2007) have analysed the impact of changes in the orbital configuration on the meridional temperature gradients and on the strength and location of the storm tracks in simulations for the last interglacial (Eemian, 125 ka BP) and the last glacial inception (115 ka BP). Winter storm activity increases over large parts of the North Atlantic in the Eemian, resulting in a precipitation increase for Northern Europe. Opposite but weaker changes are simulated for 115 ka BP.

Tuenter et al. (2007) use transient simulations of the CLIMBER-2 coupled atmosphere-ocean-vegetation earth system model of intermediate complexity to study sub-Milankovitch climate variability. Concentrating on the regions influenced by the African and Asian monsoons they find periodic variations in monsoonal runoff at sub-Milankovitch time-scales, which occur only when vegetation is dynamically coupled in the model. They hypothesize that the sub-Milankovitch variations found in terrestrial and marine records could be related to variations in vegetation, soil characteristics and runoff influencing ocean salinity and circulation.

The relationships between the modelled climate of the LGM and that for doubled atmospheric CO<sub>2</sub> compared to the pre-industrial climate are analysed from an ensemble of runs from the MIROC3.2 GCM (Hargreaves et al., 2007). It is found that improving the modelled LGM climatology in both Antarctica and the tropics should help improve model predictions of future climate. In addition, an asymmetry in climate sensitivity, calculated by decreasing rather than increasing the greenhouse gases, with 80% of the ensemble having a weaker cooling than warming, was found. This could lead to a climate sensitivity estimate from LGM being too low by about half a degree. These results may be highly model dependent and should be investigated with other models.

## 3 Conclusions

These various experiments using models of increasing complexity (from PMIP1 to PMIP2) on specific time-slices, but also using intermediate-complexity models performing experiments over longer time periods, show the value of work-

ing on past periods when the forcings were strongly different to today, and relatively well known. Even though geological data are scarce and not always precise, the climatic signal is often large enough to test the robustness of the models under various conditions. This double approach enables one to show the weakness, not revealed in simulations of the modern climate, of some processes included in the models, to establish a hierarchy among the various forcings and feedbacks, and finally to help to improve the interpretation of the data.

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