Modeling of water stable isotopes in the fully coupled Earth system model MPI-ESM: current status and perspectives

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Context and motivation

Water stable isotopes ($H_2{}^{16}O$, $H_2{}^{18}O$, $HD^{16}O$) are integrated tracers of climate processes occurring in various branches of the hydrological cycle. The explicit modeling of these isotopes in GCMs allows to evaluate their performance and to study the past and present-day hydrological cycle evolutions. Here we present the first results, under pre-industrial (PI), Mid-Holocene (6k) and Last Glacial Maximum (LGM) conditions, of the ongoing implementation of water stable isotopes in the fully coupled Earth system model MPI-ESM (release 1.2.01 "CMIP6"), called hereafter MPI-ESM-wiso. It includes the atmospheric model ECHAM6, the dynamic vegetation module JSBACH and the ocean/sea-ice module MPIOM.

Methodology: MPI-ESM-wiso and data used

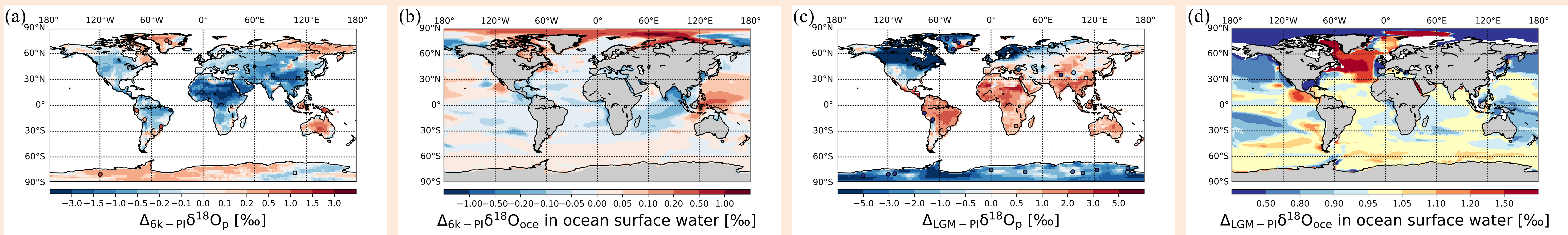
For this study, MPI-ESM has been continued from simulations without isotopes included, which have been run into equilibrium using identical boundary conditions. We have performed PI, 6k and LGM simulations of 200 years each in T63/GR15 configuration (horizontal resolution of 1.88° and 1.5° for the atmosphere and the ocean respectively) and consider here the last 100 model years for our analyses. All our simulations follow the PMIP4 protocol.

For the validation of MPI-ESM-wiso, we compare model values to several available observational dataset (GNIP and GISS database, ice core and calcite speleothem data).

6k and LGM changes in $\delta^{18}O$ signals

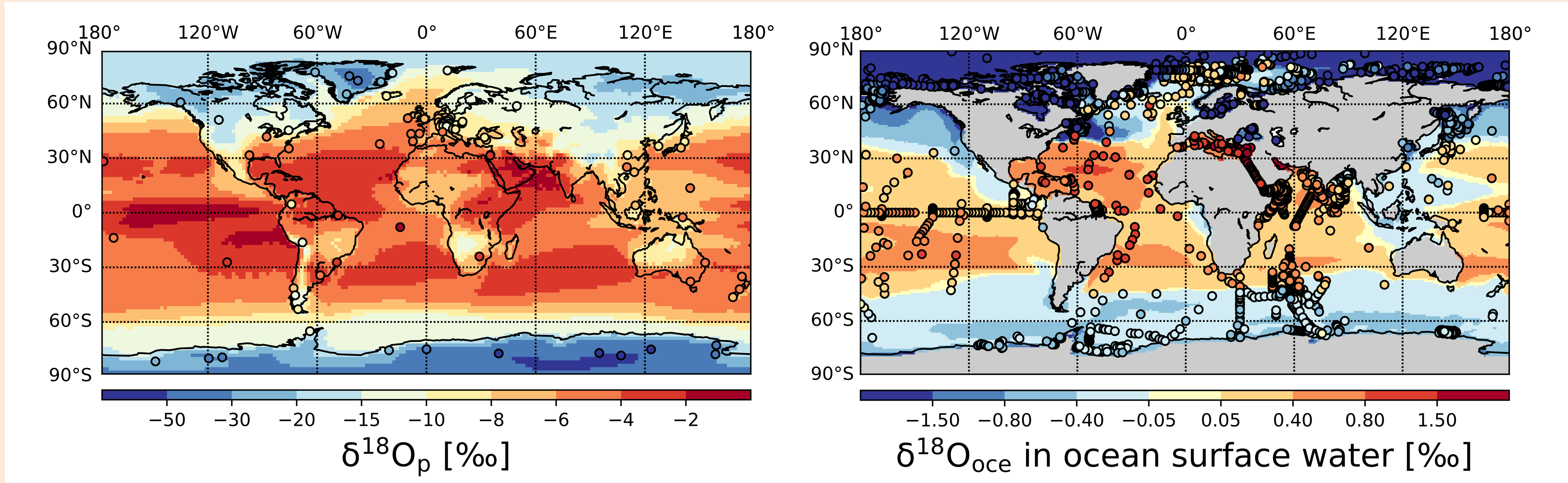
The 6k simulation is as the PI simulation, but with Mid-Holocene orbital and radiative active trace gas forcing. For the LGM simulation, the isotopic results are preliminary and we prescribed an oceanic glacial increase in $\delta^{18}O$ of +1‰.

Simulated global pattern of annual mean $\delta^{18}O$ changes in precipitation between (a) the Mid-Holocene and PI climate and (c) the LGM and PI climate. Reconstructed $\delta^{18}O$ changes in ice cores and in calcite speleothems are shown as colored symbols. Simulated global pattern of annual mean $\delta^{18}O$ changes in ocean surface waters between (b) the Mid-Holocene and PI climate and (d) the LGM and PI climate.



$\delta^{18}O$ in precipitation and in ocean surface water under PI conditions

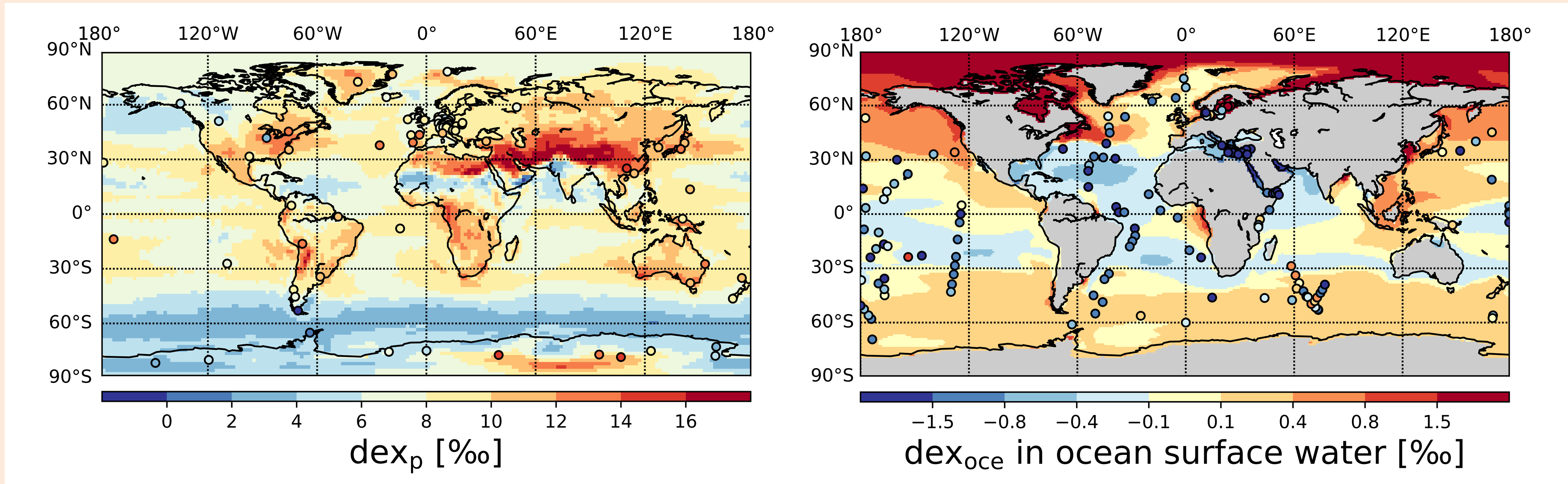
Global distribution of simulated and observed annual mean $\delta^{18}O$ values in precipitation (left) and in ocean surface waters (right).



MPI-ESM-wiso reproduces reasonably well the distribution of annual mean $\delta^{18}O$ in precipitation and in ocean surface water for PI conditions.

deuterium excess in precipitation and in ocean surface water under PI conditions

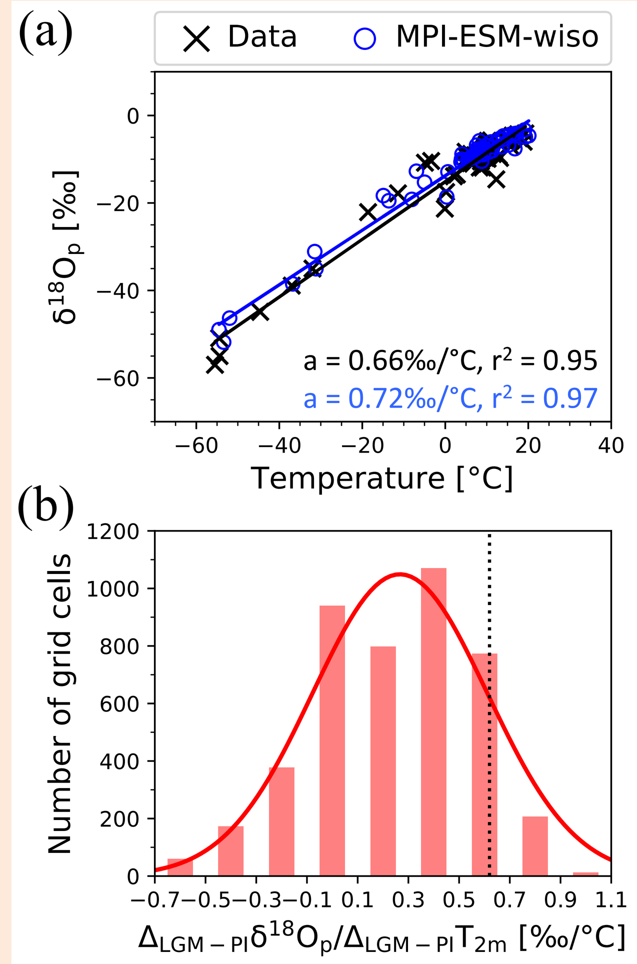
Global distribution of simulated and observed annual mean deuterium excess (dex) values in precipitation (left) and in ocean surface waters (right).



The deuterium excess is defined as $dex = \delta D - 8 \times \delta^{18}O$. This second-order parameter signal of the evaporation flux from the ocean surface is mainly influenced by the relative humidity above the ocean surface and the water temperature during evaporation.

$\delta^{18}O_p$/temperature changes

The spatial $\delta^{18}O_p$/T relationship under PI conditions is very well simulated by MPI-ESM-wiso (a). In most of the grid cells, the simulated temporal LGM-PI $\delta^{18}O_p$/T gradient is below the modern spatial one (b).



Conclusions and Perspectives

The simulations of water isotopes with the new coupled model MPI-ESM-wiso are promising. The next step is to produce long steady-state isotopic climate simulations of the different time periods presented here.

As a part of the PalMod initiative, this work will be an important contribution to the Paleoclimate Modelling Intercomparison Project. Indeed, the models with an explicit water stable isotope diagnostics make it possible to perform direct comparisons, at different time periods, with environmental records and to reduce the uncertainties resulting from the interpretation of these records in terms of climate signals in model-data comparisons.

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