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Influence of LGM boundary conditions on the global water isotope distribution in an atmospheric general circulation model

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Because of differences in the saturation vapor pressures between the isotopic forms of the water molecule ($H_2^{16}O$, $H_2^{18}O$, HDO), an isotopic fractionation occurs during any phase transition such as evaporation or condensation. This is a temperature-dependent process, which causes the ratios of the heavier to the lighter isotopes in different reservoirs of the hydrological cycle to vary depending on the atmospheric conditions in the source region or along the way. So the isotopic information may be utilized to make inferences about climate change.

The Last Glacial Maximum (LGM, around 21,000 years B.P) represents the largest change in climate during the last 100,000 years. A strong cooling in both hemispheres is recorded in many proxy records. We conducted a series of experiments using a water isotope tracers-enabled atmospheric general circulation model (Community Atmosphere Model version 3.0, CAM3.0-Iso), by changing the individual boundary conditions (greenhouse gases (GHG), albedo, topography and ice sheets) each at a time to LGM values. In addition, we carried out a combined simulation with all the boundary conditions being set to the values at the LGM. A pre-industrial (PI) simulation with boundary conditions taken according to the PMIP (Paleoclimate Modelling Intercomparison Project) protocol was performed as the control experiment. The experiments are designed in order to analyze the temporal and spatial variations of the isotope distribution with the change of the individual climate factors and to verify the isotope proxy records for LGM.

In agreement with previous studies, the experiments show that at high latitudes δ^{18}O in precipitation ($\delta^{18}O_{precip}$) is strongly correlated with the local surface temperature, while in the tropics $\delta^{18}O_{precip}$ is strongly correlated with the amount of precipitation. Furthermore, a strong seasonality in the global distribution of $\delta^{18}O_{precip}$ is observed. The change in topography (due to the change in land-ice cover) plays a significant role in reducing the surface temperature and $\delta^{18}O_{precip}$ over North America. Exposed shelf areas and their related surface albedo, combined with the LGM vegetation and surface type distribution, reduce the Northern Hemisphere surface temperature and $\delta^{18}O_{precip}$ further. A global mean cooling of 4.1°C is observed in the simulation with complete LGM boundary conditions compared to the control simulation, which is in agreement with previous experiments using the fully coupled community Climate System Model (CCSM3.0). Large reductions in $\delta^{18}O_{precip}$ over the LGM ice sheets are highly correlated with the temperature decrease over them.

Our results show that the change in ice-sheet topography has the largest effect in lowering the surface temperature and precipitation hence $\delta^{18}O_{precip}$ in the northern hemisphere during the LGM. The reductions in surface temperature and $\delta^{18}O_{precip}$ values in the GHG experiment are low in comparison with the localized and prominent reductions in the surface temperature and $\delta^{18}O_{precip}$ concentration of topography and albedo experiments, even though the reduced GHG bring about lowered surface temperature all over the globe. The lack of an active ocean component and hence positive ocean-atmosphere feedback mechanisms in the model is expected to have minimized the effect of the reduction of GHG concentrations to LGM levels on climate in the GHG experiment.