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Constraining ocean circulation at the Last Glacial Maximum: a model-data comparison study

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During the Last Glacial Maximum (LGM, $\sim 21,000$ years before present), atmospheric CO_2 was $\sim$ 90 ppmv lower compared to that of the pre-industrial state. Changes in ocean circulation, as well as its interplay with ocean carbon cycle, has been suggested to be crucial for the glacial CO_2 drawdown. However, quantitative understanding for mechanisms governing the sequestration of atmospheric CO_2 in the glacial ocean is still limited. One major challenge comes from the fact that the glacial ocean circulation remains not well constrained.

The aim of this study is to constrain the LGM ocean circulation via a model-data comparison approach. Specifically, we use Max Planck Institute Earth System Model (MPI-ESM), including carbon isotopes tracers, to run LGM simulations of different ocean circulation states, followed by a comparison between the corresponding distributions of carbon isotopic ratios and proxy data. We have conducted reference simulations for pre-industrial and for LGM, respectively. In the latter, the LGM orbital parameters, land-sea mask, topography, ice sheets and an atmospheric CO_2 concentration of 190 ppm are used. In our LGM reference run, the Atlantic Meridional Overturning Circulation (AMOC) is stronger and has a deeper boundary ($\sim$ 4400 m at 30 $^\circ$N) between its upper North Atlantic Deep Water (NADW) cell and the lower Antarctic Bottom Water (AABW) cell compared to the pre-industrial AMOC. However, the proxy data suggest a shallower boundary between the NADW and AABW cell of the LGM AMOC. Previous studies with MPI-ESM suggested that the brine release during sea-ice formation and shelf convection in the Southern Ocean are the key processes for the shoaling of NADW cell. Thus, we carry out two series of simulations to simulate different glacial AMOC states. First we apply an extra freshwater flux at the ocean surface to increase the shelf convection in the Southern Ocean. Specifically, freshwater is removed in the shelf region (here defined as the area between the coast and the 1000 m isobath) in the Weddell Sea and the same amount of freshwater is added in the North Atlantic between $50-80\,^\circ$N. In the second series of simulations, we will apply an extra heat fluxes at the ocean surface to increase sea-ice formation in the Southern Ocean.

Regarding the first series of simulations, we conduct four runs with constant freshwater flux of 0.2, 0.25, 0.3 and 0.4 Sv, respectively. Preliminary results show that the boundary between the NADW and AABW cell of the LGM AMOC shoals to $\sim$ 2200 m (at 30 $^\circ$N) when the freshwater flux is increased to 0.3 Sv. In this simulation, the $\delta^{13}C_{DIC}$ pattern is in better agreement with proxy data compared to the LGM reference run.