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The sensitivity of the AMOC to decreasing greenhouse gas concentrations with glacial and modern ice sheets

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The state of the glacial Atlantic Meridional Overturning Circulation (AMOC) is often inconsistent between different climate models as well as between climate models and proxy-based reconstruction, even though the simulated mean glacial surface climate is usually in reasonable agreement with the reconstructions. We study the equilibrium response of the AMOC to decreasing greenhouse gas (GHG) concentrations and its dependence on the prescribed continental ice sheets in the coupled model MPI-ESM in order to identify the mechanisms which determine the AMOC state in a glacial climate.

In general, a GHG reduction causes a weakening and a shoaling of the upper overturning cell. The response of the overturning strength and geometry is, however, strongly non-linear, depending on the absolute GHG concentrations and the prescribed ice sheets. With prescribed glacial ice sheets, the overturning strength decreases almost linearly with decreasing radiative forcing when the pCO_2 is lower than 284 ppm. Between 353 and 230 ppm, a GHG reduction does not significantly affect the depth of the upper cell; the shoaling occurs only when the pCO_2 is lower than 230 ppm. With prescribed modern ice sheets, there are two distinct AMOC modes; in the first mode the upper cell is strong and deep, and in the second mode it is weak and shallow. The transition between the two modes occurs abruptly between 230 and 185 ppm. In both ice-sheet cases, the key process driving the shoaling of the upper cell is a salinity increase in the Southern Ocean through brine release and shelf convection, which increases the density of Antarctic Bottom Water sufficiently to replace North Atlantic Deep Water in the deep North Atlantic. The weak AMOC mode is not found with prescribed glacial ice sheets. The glacial ice sheets enhance the salt transport into the North Atlantic and increase the density gain in the deep-water formation sites in the North Atlantic, thereby increasing the AMOC strength also at low GHG concentrations. With glacial ice sheets, the AMOC is therefore far away from the bifurcation point beyond which a transition to the weak AMOC mode would occur.