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Two-way coupled ice sheet–earth system simulations: Consequences of raising CO_2 concentration for Greenland and the interacting climate system

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The observed distinct warming in the Arctic and the northward flow of tropical water masses seem to trigger enhanced melting of the Greenland ice sheet, which adds more fresh water into the ambient ocean. A continuation of the observed accelerated melting during the last decade would stabilize the water column in the adjacent deep water formation sides. With our fully coupled ice sheet-earth system model we approach the questions if this weakens the formation of deep water masses and reduces the thermohaline driven meridional overturning circulation (MOC). We have performed idealized future projections to investigate the response of the interaction under raising atmospheric carbon dioxide concentration with our two-way coupled ice sheet-earth system model system.

We will present the building blocks of our fully coupled system, which includes a physical based calculation of the ice sheet's surface mass balance and ice sheet-ocean interaction; The ESM instead is subject to orographic changes and receives fresh water fluxes, for example. Since the behavior of an ice sheet in the near future is controlled by both the external forcing and by its initial conditions, we have performed Latin Hyper Cube (LHC) simulations with the ice sheet model over more than one glacial-interglacial cycle utilizing standard techniques to obtain a reasonable initial state. According to several quantities the best performing LHC member is exposed afterwards to boundary conditions determined from energy balance calculations again obtained from simulated forcing fields. Finally the fully coupled system is brought into a quasi-equilibrium under pre-industrial conditions before idealized scenarios have been started. In contrast to commonly used strategies, our coupled ice sheet inherits the memory of a glacial cycle simulations obtain exclusively from ESM fields. Furthermore we use a mass conserving scheme, do neither apply flux corrections nor utilize anomaly coupling.

Under different CO_2 forcing scenarios — for example, raising CO_2 by 1%/year until four times the pre-industrial concentration (4xCO_2) has reached, abrupt raise to 4xCO_2 — the response of the coupled system is analyzed. For instance, an abrupt CO_2 forcing leads to an immediate response of the Greenlandic ice sheet. The surface mass balance turns strongly negative within a couple of years, causing skyrocketing melting rates and sea level rise. The contribution of the ocean-ice sheet interaction decreases instead, because the ice sheets retreats from the coast and is therefore less susceptible to an eroding ocean. The additionally released fresh water and the heat both have to potential to stifle the MOC. However sensitivity experiments indicate that the additional fresh water has a negligible influence on the MOC with a time scale of a century or more in our model system.

For the study we have used the current CMIP5 earth system model MPI-ESM that comprises the atmosphere model ECHAM6 (T63L47), the vegetation model JSBACH and the ocean biogeochemical model MPIOM / HAMOCC (GR15L40, nominal horizontal resolution of 1.5° with one pole over Greenland). The ESM is coupled to the Parallel Ice Sheet Model (PISM) covering Greenland, where PISM has a horizontal resolution 10 km.