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Marine Isotope Stage 3 in a three-dimensional coupled earth system model: equilibrium climate simulations reveal the importance of freshwater forcing

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Abrupt climate fluctuations known as Dansgaard-Oeschger (D/O) cycles occurred most frequently during the period between 60 and 30ka BP, called Marine Isotope Stage 3 (MIS 3). Proxy climate records recovered from ice, marine and terrestrial cores from the North Atlantic region show clear evidence for these D/O cycles. They consist of a strong and abrupt warming during the transition from colder episodes (stadials) to warmer intervals (interstadials), followed by a gradual cooling phase leading to a return to stadial conditions, forming a saw tooth pattern. Changes in the strength of the oceanic meridional overturning circulation (MOC) induced by changes in buoyancy are believed to be the cause of D/O events, with an MOC onset resulting in increased heat advection to the North Atlantic and Nordic Seas. A weakened or shutdown MOC – for instance following a Heinrich Event – would be responsible for the colder conditions of the stadial climate.

So far, most modelling efforts to reproduce D/O events consisted of experiments run from present-day/pre-industrial or Last Glacial Maximum (LGM) conditions, mostly with relatively simple models (less than three-dimensional). We present the results of MIS 3 equilibrium climate simulations computed with the three-dimensional coupled earth system model of intermediate complexity LOVECLIM. These experiments were run with constant MIS 3 values for the main climate forcings, being atmospheric greenhouse gas (GHG) and dust concentrations, insolation, land-sea mask, and ice sheet extent and topography changes. Two types of experiments were performed: with GHG and dust concentrations typical of (1) stadial and (2) interstadial periods.

Both setups induce a background climate warmer – (1) 13.2˚C, (2) 13.6˚C – than at LGM – (3) 11.5˚C – and colder than at pre-industrial times – (4) 15.9˚C – for the global mean annual temperature or for Europe and the North Atlantic (1) 0.8˚C, (2) 1.6˚C, (3) -4.6˚C and (4) 7.9˚C. Sea-ice and continental ice cover changes best reflect the temperature differences by decreased/increased surface albedo compared to LGM/pre-industrial times. Although some significant cooling of -0.8˚C over Europe and the North Atlantic occurs in experiments forced with stadial GHG and dust concentrations compared to interstadial, the temperature reductions are not sufficient to resemble the stadial climate recorded in proxy data. A third equilibrium experiment with stadial GHG and dust forcings and additional freshwater forcing of 0.30Sv in the North Atlantic is run to simulate a shutdown of the MOC. The outcome is a stadial climate that corresponds much better with the data with a mean annual temperature of -6.1˚C over Europe and the North Atlantic. We thus believe that MOC fluctuations through buoyancy changes could be a necessary mechanism to explain D/O cycles.

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