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Cooling Induced Instability of the Atlantic Overturning Circulation as a Cause for Rapid Climate Transitions

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Although there is considerable debate about differences between the modern and the glacial Atlantic meridional overturning circulation (AMOC) it is commonly agreed that at peak glacial times the AMOC was characterised by a southward shift of the North Atlantic deep water (NADW) formation sites and a relatively shallow NADW-cell. Recently the Paleoclimate Modelling Inter-comparison Project (PMIP) has shown that state of the art coupled atmosphere-ocean circulation models can successfully reproduce such changes. Interestingly, the AMOC response to glacial conditions in the PMIP has revealed that a southward shift of the downward branch and a shoaling of the NADW overturning cell is accompanied by a reduced overturning.

Here we present a conceptual approach using an interhemipheric box model of the Atlantic overturning circulation. We assume that a completely sea ice covered North Atlantic box would inhibit the formation of NADW by its insulating effect of surface heat fluxes at the ocean surface. Therefore we introduce a dependence of the overturning strength from the sea ice extent in the North Atlantic. This approach can be viewed as a loss of efficiency of the inter-hemispheric density gradient in driving the overturning with cooler climate conditions. Using this concept we show that the transition from a modern climate state to a colder climate forces the system into millennial-scale oscillations at a threshold. The oscillations are activated by a southward migration of the sea-ice cover in the North Atlantic. The southward migration of the sea ice margin also provides a positive feedback on a weakening of the overturning by climate cooling, which leads to the existence of multiple equilibria in an intermediate climate state. The stability behaviour in our model suggests that changes in the North Atlantic sea-ice cover may have played a dominant role for Dansgaard-Oeschger oscillations by determining the available surface area for deep water formation and the location of deep water formation sites.