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# Modeling glacial millennial-scale climate variability as related to the Atlantic Meridional Overturning Circulation

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Millennial-scale climate variability during glacial epochs such as Marine Isotopic Stage 3 is documented in many climate archives: ocean sediments, ice cores, pollen, etc. We consider its modeling to be an important way to improve our understanding of the underlying processes and a severe test for climate models. However, while the global climatic signature of Heinrich events can be plausibly ascribed to freshwater discharge from the Laurentide ice-sheet to the North Atlantic Ocean, the existence of a triggering mechanism is elusive as far as Dansgaard-Oeschger-type variability is concerned. The majority of modeling attempts has assumed it to be linked to abrupt variations in the Atlantic Meridional Overturning Circulation.

In this review, we therefore first focus on the theoretical basis of most of this modeling work: the possible existence of multiple equilibrium states (stable and unstable) in the climate system, in particular the ocean. We also discuss the imprint of these states on the surface climate. Then, we present mechanisms for the response of the climate system to perturbations of the surface freshwater balance of the North Atlantic Ocean under present-day and glacial boundary conditions. Finally, we address problems which are associated with comparing model output to paleodata.

In order to rigorously compare several types of numerical experiments (equilibrium vs. transient, pre-industrial vs. glacial boundary conditions), we carried out a number of dedicated simulations with two earth-system models of intermediate complexity (UVic and LOVECLIM) under strictly the same boundary conditions. Here we can go beyond the physical part of the climate system (as evident in the surface air temperature, sea-surface and deep-ocean temperature as well as the meridional overturning circulation) and also show the response of vegetation to abrupt climate change. We compare our results to paleo-sea surface temperature and pollen data.