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Assessing the sensitivity of North Atlantic Ocean circulation to freshwater forcing under various glacial boundary conditions

Cedric J. Van Meerbeeck (1), Didier M. Roche (1,2), and Hans Renssen (1)

(1) VU University Amsterdam, Earth Sciences, Amsterdam, Netherlands (cedric.van.meerbeeck@falw.vu.nl, +31 2059 89940), (2) Laboratoire des Sciences du Climat et de l'Environnement (LSCE/IPSL), Laboratoire CEA/INSU-CNRS/UVSQ, Gif-sur-Yvette, France

A striking characteristic of glacial climate in the North Atlantic region is the recurrence of abrupt shifts between cold stadials and mild interstadials. These shifts have been associated with abrupt changes in Atlantic Meridional Overturning Circulation (AMOC) mode, possibly in response to glacial meltwater perturbations. However, it is poorly understood why they were more clearly expressed during Marine Isotope Stage 3 (MIS3, ∼60-27ka BP) than during Termination 1 (T1, ∼18-10ka BP) and especially around the Last Glacial Maximum (LGM, ∼23-19ka BP). One clue may reside in varying climatic boundary conditions, making MIS3 and T1 generally milder than LGM. To investigate this idea, we evaluate in a climate model how ice sheet size, atmospheric greenhouse gas concentration and orbital insolation changes between 56ka BP (=56k), 21k and 12.5k affect the glacial AMOC response to freshwater forcing. We have performed three ensemble simulations with the earth system model LOVECLIM using those forcings. We find that the AMOC mode in the mild glacial climate type (56k and 12.5k), with deep convection in the Labrador Sea and the Nordic Seas, is more sensitive to a constant 0.15Sv freshwater forcing than in the cold type (21k), with deep convection mainly south of Greenland and Iceland. The initial AMOC weakening in response to freshwater forcing is larger in the mild type due to an early shutdown of Labrador Sea deep convection, which is completely absent in the 21k simulation. This causes a larger fraction of the freshwater anomaly to remain at surface in the mild type compared to the cold type. After 200 years, a weak AMOC is established in both climate types, as further freshening is compensated by an anomalous salt advection from the (sub-)tropical North Atlantic. However, the slightly fresher sea surface in the mild type facilitates further weakening of the AMOC, which occurs when a surface salinity threshold is stochastically crossed in the Nordic Seas. While described details are model-specific, our results imply that a more northern location of deep convection sites during milder glacial times may have amplified frequency and amplitude of abrupt climate shifts.