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Multi-proxy constraints on Atlantic circulation dynamics since the Last Glacial Maximum

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Uncertainties persist in the understanding of the Atlantic Meridional Overturning Circulation (AMOC) and its response to external perturbations such as freshwater or radiative forcing. Abrupt reduction of the AMOC is considered a climate tipping point that may have been crossed when Earth's climate was propelled out of the last ice age. However, the evolution of the AMOC since the Last Glacial Maximum (LGM) remains insufficiently constrained due to model and proxy limitations. Here we leverage information from both multi-proxy data and climate model simulations of the Bern3D model to constrain the Atlantic circulation over the past 20,000 years. This is facilitated by the explicit implementation of the four major isotope-based ocean proxies $\Delta^{14}C$, $\delta^{13}C$, εNd, and $^{231}Pa/^{230}Th$ in our model, allowing for direct model-data comparisons. By varying formation rates of northern- and southern-sourced waters in a model set up with realistic glacial boundary conditions we explore a wide range of circulation states and test their ability to reproduce the spatial patterns of newly compiled proxy data of the LGM. We find a coherent picture of a shallow and weak AMOC during the LGM that reconciles long-standing apparently conflicting proxy evidence. Model-data comparison of the last deglaciation, with fully transient simulations starting from this new, multiply constrained LGM state, indicate a muted AMOC response during Heinrich Stadial 1. The relatively small changes from the LGM to the Heinrich Stadial 1 in AMOC are therefore in conflict with the proposal that an AMOC collapse triggered the early deglacial rise in atmospheric CO2 and instead favor mechanisms associated with the Southern Ocean/Pacific. We further find that the water mass geometry did not fully adjust to the strong AMOC reduction during the comparably short Younger Dryas period. This demonstrates that the relationship between freshwater forcing and Atlantic overturning strength is strongly dependent on the climatic and oceanic background state.