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The role of oceanic heat transport in abrupt millennial-scale climate transitions

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The last glacial period was punctuated by rapid climate shifts, known as Dansgaard-Oeschger events, with strong imprint in the North Atlantic sector suggesting that they were linked with the Atlantic Meridional Overturning Circulation. Here an idealized single-hemisphere three-dimensional ocean-atmosphere-sea ice coupled model is used to explore the possible origin of the instability driving these abrupt events and to provide a plausible explanation for the relative stability of the Holocene. Focusing on the physics of noise-free millennial oscillations under steady external (solar) forcing, we show that cold climates become unstable, that is, exhibit abrupt millennial-scale transitions, for significantly lower freshwater fluxes than warm climates, in agreement with previous studies making use of zonally-averaged coupled models. This fundamental difference is a direct consequence of the weaker temperature stratification of the glacial ocean, mainly caused by upper ocean cooling. With similar overturning strengths between the cold and warm climates, this weaker temperature stratification implies a weaker baroclinic heat transport that ultimately leads to a weaker stabilization of the circulation by the negative temperature advection feedback. Using a two-hemisphere configuration of a coupled climate model of intermediate complexity, we show that this result is robust to the added presence of a bottom water mass of southern origin. The analysis reveals that under particular conditions, a pronounced interdecadal variability develops during warm interstadials, with maximum variance in the northern extension of the western boundary current in the North Atlantic. While the nature of the instability driving the millennial oscillations is identical to that found in ocean models under mixed boundary conditions, these interstadial-interdecadal oscillations share the same characteristics as those previously found in ocean models forced by fixed surface fluxes: they originate from a large-scale baroclinic instability of the meridional flow.