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Improving the simulation of the Northern Hemisphere ice-sheet response to millennial-scale climate variability

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Oceanic instabilities are thought to underlie both types of abrupt climatic changes of the last glacial period (LGP), Dansgaard-Oeschger (D/O) and Heinrich (H) events. The role of ice sheets in such instabilities is yet unclear. Meltwater discharge from Northern Hemisphere (NH) ice sheets remains a potential explanation for the density reduction of North Atlantic waters that affects the oceanic circulation. Thus improving our understanding of the response of ice sheets to past millennial-scale climate changes would help to constrain freshwater inputs into the North Atlantic Ocean and thereby contribute to a better understanding of the driving mechanisms of glacial abrupt climate changes. The simplest approach is to use ice-sheet models forced offline by a time-varying climatology. Because of the lack of continuous, accurate proxy data, a synthetic time-varying climatology is often built based on a combination of climate-model and proxy data. Temperature anomalies relative to present are calculated by combining the present-day climatology with a simulated glacial-interglacial climatic anomaly field through a weighting index derived from the Greenland ice-core temperature reconstruction. A similar procedure is applied to precipitation but considering ratios rather than anomalies. Here we illustrate the problems derived from this approach, and propose a new offline climate forcing method that attempts to better represent the characteristic pattern of millennial-scale climate variability by including an additional spatial anomaly field associated with this timescale. Improving the representation of millennial-scale variability alone yields an important increase of ice volume in all NH ice sheets throughout the LGP, but especially in the Fennoscandian ice sheet. Interestingly, ice-volume variations on millennial timescales as indicated by sea-level records are underestimated. This suggests that either the origin of the latter is not the NH or that processes not represented in our study, such as variations in oceanic conditions, need to be invoked to explain millennial-scale ice-volume fluctuations. Our new method provides a more realistic representation of orbital and millennial scale climate variability and opens up the possibility for new inter-comparison exercises involving climate and ice-sheet models in the frame of glacial abrupt climate changes.