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Northern Hemisphere millennial-scale ice discharges as a response to oceanic forcing simulated with a hybrid ice-sheet/ice-shelf model

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Marine and continental records and ice core data have revealed the existence of pronounced millennial time-scale climate variability during the last glacial cycle. Greenland ice core records show abrupt transitions known as Dansgaard-Oeschger (DO) events within decades from cold (stadial) to relatively warm (interstadial) conditions, followed by slow cooling that lasts several centuries and more rapid cooling through stadial conditions. Two types of explanation have been suggested: periodic external forcing and internal oscillations in the climate system, for which ocean circulation is the main candidate. On the other hand, six periods of extreme cooling registered in the Northern Hemisphere, known as Heinrich events, have been found to be coeval with increased deposition of ice-rafted debris, which is interpreted as enhanced discharge of icebergs into the North Atlantic Ocean. Recently, the coupled effects between ocean circulation and ice-sheets dynamics have been suggested to play a major role in triggering Heinrich events. This interpretation of Heinrich events responding to changes in the oceanic patterns (or at least not being purely internal and spontaneous manifestations of ice sheets), allows the possibility to provide an explicit relationship between DO events and the periodic iceberg surges.

Here this hypothesis is reassessed within a more realistic modeling framework by forcing a 3D state-of-the-art ice-sheet model with the output of abrupt climate change simulations carried out with a coupled climate model of intermediate complexity. These show the main expected characteristics of such events: an abrupt warming of the North Atlantic and Atlantic Meridional Overturning Circulation (AMOC) intensification followed by a progressive cooling and AMOC reduction, as well as a more drastic fall into a stadial condition. Interestingly, stadial periods are characterized by the occurrence of subsurface oceanic warming of up to 3 K in regions where deep water formation takes place (Nordic and Labrador Seas). We show that subsurface warming is a crucial mechanism to destabilize the Labrador Sea ice shelves favoring the acceleration of the Laurentide ice streams. Iceberg production is then enhanced during stadial periods. However, this pattern is not monotonically present through all DO events: the combination of both a characteristic ice-shelf break-up and re-developing time larger than the DO forcing period and the fact that ice-streams need to flow extremely fast to create major calving rates explains the different magnitude of iceberg discharge during different stadial periods. Finally, when applying a time-evolving basal melt rate of the Labrador ice shelf calibrated (in anti-phase) against the GRIP curve, the ice sheet models produces ice discharges that compare well with ice rafted debris records. These results suggest that oceanic forcing can be considered as a sufficient condition for triggering the observed millennial-scale ice discharges, including Heinrich events.