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Control of rapid glacial climate shifts by variations in intermediate ice-sheet volume

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During glacial periods of the Late Pleistocene, an abundance of proxy data demonstrates the existence of large and repeated, millennial-scale climate changes, known as Dansgaard-Oeschger (DO) events. This ubiquitous feature of rapid glacial climate change can be extended back as far as 800kyr BP in the record and has drawn broad attention from geologists, climatologists, oceanographers and policy makers alike. Many studies have been dedicated to investigating the underlying causes, however a consistent mechanism remains elusive. Here, using a comprehensive fully-coupled model, we show that the non-linear responses of the glacial ocean to Northern Hemisphere Ice Sheets (NHIS) changes in the coupled atmosphere-ocean system explain the occurrence of rapid glacial climate shifts. The global climate response is generally consistent with empirical evidence. A hysteresis analysis with respect to changes of the NHIS suggests that two distinct glacial climate modes coexist at identical intermediate ice sheet volume. Notably, minor changes in global sea level and carbon dioxide can trigger the rapid climate shifts occurring due to local positive atmosphere-ocean-sea ice feedback in the North Atlantic under intermediate ice-sheet volume. The pronounced glacial climate sensitivity to forcing changes is associated with tempo-spatial variations in the internal variability of sea-ice cover and surface air temperature in the northern North Atlantic and Nordic Sea. In conclusion, the hysteresis of the glacial ocean with respect to ice-sheet variation provides a new concept for understanding the recorded millennial-scale variability and abrupt climate changes in the coupled atmosphere-ocean system, as well as their linkages to intermediate ice-sheet volume during glacials.