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Simulation of glacial cycles and abrupt climate changes with a climate-ice sheet model of intermediate complexity

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Simulations of the last eight glacial cycles were performed with the coupled climate-ice sheet model of intermediate complexity CLIMBER-2 using the orbital variations and concentration of greenhouse gases (GHGs) as the only prescribed external forcings. The model reproduces a number of important aspects of glacial climate variability both on orbital and millennial time scales. In particular, simulated temporal dynamics of benthic d18O is in good agreement with Lisiecki and Raymo (2005) stack. Comparison of the experiments with constant and variable GHGs reveals important role of GHGs in amplification of the 100 Kyr cyclicity. The model also simulates numerous abrupt climate changes during each glacial cycle resembling in their temporal and spatial dynamics Dansgaard-Oeschger and Heinrich events. The former are associated with the abrupt transitions of the Atlantic thermohaline circulations between stadial and interstadial modes of operation that cause abrupt (within several decades) air temperature changes of up to 10 C over the northern North Atlantic. Simulated Heinrich events represent episodes of massive iceberg discharge originating predominantly from the Laurentide Ice Sheet with the duration from several hundred to thousand years and typical periodicity of about 7000 years. The Atlantic thermohaline circulation is considerably weakened or completely shut down during Heinrich events. Overall, our modeling results suggest that a considerable portion of glacial climate variability arises from the direct and strongly nonlinear response of the northern hemisphere ice sheets to the variations in Earth's orbital parameters amplified by a number of positive feedbacks and an intrinsic instability of the Atlantic thermohaline circulations and the Northern Hemisphere ice sheets.