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Simulation and understanding the nature of Quaternary glacial cycles

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Although it is generally accepted that, as postulated by the Milankovitch theory, Earth's orbital variations play an important role in Quaternary climate dynamics, the mechanism of glacial cycles still remains poorly understood. Among remaining scientific challenges are an understanding of the nature of 100 kyr cycles that dominated global ice volume and climate variability over the late part of Quaternary and the causes of the transition from the "40 kyr world" to the "100 kyr world" around one million years ago.
Using the Earth system model of intermediate complexity CLIMBER-2, we demonstrate that both strong 100 kyr periodicity in the ice volume variations and the timing of glacial terminations during past 800 kyr can be successfully simulated as direct, strong nonlinear responses of the climate-cryosphere system to orbital forcing alone. We show that the sharp 100 kyr peak in the power spectrum of ice volume results from the phase locking of the long glacial cycles to the corresponding eccentricity cycles. Variations in obliquity and CO_2 concentration are not required to simulate strong 100 kyr cyclicity if the atmospheric CO_2 concentration stays below its typical interglacial value. The existence of long glacial cycles is primarily attributed to the North American ice sheet and it requires the presence of a large continental area with exposed rocks. In case when the continents are completely covered by a thick sediment layer, for the realistic range of CO_2 concentrations (180-300 ppm), the long glacial cycles can not be simulated. In the experiment with fixed CO_2 concentration, ice volume variations contain both strong precessional and obliquity cycles, which apparently is in odd with empirical data that suggest complete dominance of the obliquity cycle. However, in the experiments with interactive carbon cycle, simulated obliquity component becomes much stronger, especially, in the deep ocean temperature. This is explained by the direct and indirect (via the carbon cycle feedback) effects of the obliquity component of the orbital forcing on the deep ocean temperature. When assuming that before development of the long glacial cycles the benthic delta-18-oxygen concentration was dominated by the deep ocean temperature variations, this result can help to understand the nature of the "40-kyr world".