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Modeling of Quaternary glacial cycles

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Numerous paleoclimate records obtained in recent decades indicate that the climate was much more unstable during ice ages as compared to climates of previous warm epochs. The largest portion of climate variability occurred at the orbital (from twenty to one hundred thousand years) and at the millennial time scales. 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.
Here using the Earth system model of intermediate complexity CLIMBER-2 which includes all major components of the Earth system – atmosphere, ocean, land surface, ice sheets, terrestrial biota, eolian dust and marine biogeochemistry – we performed simulations of the Quaternary climate cycles using variations in the Earth's orbital parameters as the only prescribed climatic forcing. In the experiments with constant CO_2 concentration temporal dynamics of the simulated glacial cycles strongly depend on the CO_2 level. For CO_2 concentration about and above preindustrial one, the model simulates only short glacial cycles with precessional and obliquity frequencies. However, for lower CO_2 concentrations 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. Simulated glacial cycles agreed favorably with paleoclimate reconstructions but their amplitude is underestimated compared to results of simulations with time-dependent CO_2 concentration. These results confirm that positive climate-carbon cycle feedback play an important role in amplification of long glacial cycles. 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, the long glacial cycles can not be simulated. In the experiment with interactive carbon cycle, simulated obliquity component becomes dominant, 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. This result can help to understand the nature of the "40-kyr world".