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# 100 kyr World: the role of carbon dioxide, regolith and eolian dust

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It is generally accepted that, as postulated by the Milankovitch theory, the Earth's orbital variations play a fundamental role in driving glacial cycles. However, many aspects of glacial cycles, such as strongly-nonlinear response of the ice sheets to orbital forcing and the role of carbon-dioxide climate ice-sheet feedback, still remain poorly understood. In recent years, it became increasingly clear that solving of the glacial cycles problem requires application of comprehensive Earth system models.

To address the issue of glacial climate variability, we developed the comprehensive and computationally efficient Earth system model of intermediate complexity CLIMBER-2. The model includes the most essential components of the climate system: atmosphere, ocean, sea ice, land surface, terrestrial biosphere, dust cycle and ice sheets. The later is represented by the high-resolution 3-dimensional polythermal ice sheet model SICOPOLIS.

The CLIMBER-2 model was first applied to simulate the last eight glacial cycles forced by variations of the Earth orbital parameters and prescribed temporal variability of the major greenhouse gases derived from Antarctic ice cores. Simulated temporal dynamics of the ice sheets agree favorably with paleoclimate reconstructions both in respect of the magnitude and temporal dynamics of glacial cycles. In addition, we performed two sets of experiments with different (fixed) levels of atmospheric CO2 concentration ranging from 180 to 320 ppm. In the first set of experiments, we used a realistic distribution of the area covered by thick terrestrial sediments, while in the second one all continents of the Northern Hemisphere were covered by terrestrial sediments. For the modeling setups with CO2 concentrations below 300 ppm pronounced Northern Hemisphere ice-volume variations with obliquity and precessional frequencies are simulated. In the experiments with completely sediment covered continents this regime of ice-volume variability was simulated for the entire range of CO2 concentration. At the same time, in the experiment with realistic sediment distribution, a pronounced 100 kyr cyclicity appeared also for CO2 concentration below ca. 260 ppm. Simulated 100 kyr cycles with fixed CO2 are coherent with those simulated with prescribed time-dependent CO2 concentration and have a pronounced asymmetry with slow growing phases and abrupt terminations. The presence of a 400 kyr signal in the simulated ice volume clearly indicates its eccentricity origin. Analysis of modeling results reveals the important role of the glaciogenic dust in the termination of glacial cycles.

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.