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Robustness of Quaternary glacial cycles

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In spite of significant progress in paleoclimate reconstructions and modeling some aspects of Quaternary climate cycles are still poorly understood. Among them is the question of whether glacial cycles are deterministic and solely externally forced or, at least partially, they are stochastic. The answer to this question can only be obtained using a comprehensive Earth system models which incorporates all major components of the Earth system – atmosphere, ocean, land surface, northern hemisphere ice sheets, terrestrial biota and soil carbon, aeolian dust and marine biogeochemistry. Here, we used the Earth system model of intermediate complexity CLIMBER-2. The model was optimally tuned to reproduce climate, ice volume and CO_2 variability for the last 0.8 million years. Using the same model version, we performed a large set of simulations covering the entire Quaternary (3 million years). By starting the model at different times (with the time step of 100,000 years) and using identical initial conditions we run the model for 500,000 years using the Earth's orbital variations as the only prescribed radiative forcing. We show that within less than 100,000 years after the beginning of each experiment the modeling results converge to the same solution which depends only on the orbital forcing and boundary conditions, such as topography and terrestrial sediment thickness for the ice sheets or volcanic CO_2 outgassing for the carbon cycle. By using only several sets of the Northern Hemisphere orography and sediment thickness which represent different stages of landscape evolution during Quaternary, we are able to reproduce all major regimes of Quaternary long-term climate variability. Our results thus strongly support the notion that Quaternary glacial cycles are deterministic and externally forced.