Stochastic modeling of coupled climate variables and ice volume over Late Pleistocene glacial cycles

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Understanding the interactions between ice sheets and global climate forcings over geological timescales is essential for projecting their future. Previous studies have highlighted the role of ice dynamics and climate interactions in establishing the 100,000-year glacial cycles, particularly regarding the growth of the North American ice sheet. In recent years, researchers have reconstructed consistent time series of ice volume, temperature, and carbon dioxide by applying inverse forward modeling to benthic oxygen isotope records. Here, we model the stochastic behavior of paleoclimate time series to evaluate the coupling among climate variables during Late Pleistocene glacial cycles. We quantify the behavior of these time series using multifractal time-weighted detrended fluctuation analysis, which differentiates between near-red-noise and white-noise behavior below and above the 100,000-year glacial cycle, respectively, in all records. This study builds upon the work of Keyes et al. [Chaos **33**, 093132 (2023)] by incorporating ice volume into a five-variable model that includes carbon dioxide, methane, nitrous oxide, and temperature, along with intervariable coupling terms to capture potential relationships among these variables. To test our model, we compute response functions for each pair of variables and compare them with empirical data, confirming our predictions regarding inter-variable causal relations.

Keywords: Paleoclimatology, stochastic modeling, glacial cycles, ice volume

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