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# Effect of the Milankovitch cycles on climate multistability for the last 1 Myr

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During the last million years, the growth and retreat of massive ice sheets in North America and Eurasia defined the alternating climate conditions of the glacial-interglacial cycle. The main driver of these climatic oscillations is the combined effect of precession, eccentricity, and obliquity frequency modes (Milankovitch cycles) [1]. However, the climate expected from the Milankovitch cycles does not always align with the records from the Marine Isotope Stages [2].

To address this discrepancy, we test the hypothesis that multiple climatic steady states (attractors) exist for a given $CO_2$ concentration and can be destabilized by different combinations of Milankovitch forcing. We developed a biogeodynamical coupled setup, *biogeodyn-MITgcmUS* [3], which has the MIT general circulation model as its dynamical core, and asynchronously couples hydrology, ice sheets, and vegetation. The results of this new coupled model show that including the long-term dynamics of vegetation and ice sheets is crucial to evaluate past and future climate trajectories.

First, we construct the bifurcation diagram by varying the $CO_2$ concentration between 180 ppm and 320 ppm (i.e., within the observed range over the last 1 Myr). We analyze the stability range of the cold (glacial) and warm (interglacial) attractors, and identify their tipping points at the global scale. Second, we repeat selected simulations with different Milankovitch configurations to evaluate the robustness of the bifurcation structure. Finally, to detect signatures of climate multistability, we compare the simulation outputs with global mean sea level and temperature reconstructions [4], and we discuss preliminary results.

[1] Barker et al. Science 387, eadp3491 (2025)

[2] Past Interglacials Working Group of PAGES, Rev. Geophys. 54, 162–219 (2016)

[3] Moinat et al. EGUsphere [preprint], https://doi.org/10.5194/egusphere-2025-2946 (2025).

[4] Clark et al. Science 390, eadv8389 (2025)