Combining terrestrial and marine evidence for state and timescale-dependency of surface climate variability with model constraints

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The power spectrum of surface temperature variability arises from the interactions between the climate system and external forcing. Comparing spectra from observations to that from model simulations with atmosphere-ocean-dynamic vegetation general circulation models (AOGCMs) shows that models simulate appropriate global mean surface temperature (GMST) variability from 1 to 200 years, but fail at the local scale at all timescales beyond the interannual. This uncertainty on regional climate variability hampers projections for short-lived climate extremes. Previously, this lack of variability has been attributed to the reliance on equilibrium simulations, lack of process and component representation and spatial resolution.
Here, we combine a comprehensive set of palaeoclimate reconstructions to establish the first composite spectrum of GMST for the last 2 Million years. The spectrum is largely state-independent, and shows power-law scaling, with a scale-break at millennial scale. Only simulations from AOGCMs with interactive ice sheets and transient volcanic forcing can match reconstructed regional variability in the mid and high latitudes. This points to limitations in state-of-the-art CMIP5/6 simulations and projections, which miss these feedbacks and natural forcing. Moreover, persistent disparities in tropical variability from models and reconstructions highlight gaps in the understanding of tropical climate dynamics. Refining climate models, experiments, and enhancing our comprehension of how the key components of the climate system interact across timescales is required to constrain future temperature variability and appropriate climate action.