EGU22-11090
https://doi.org/10.5194/egusphere-egu22-11090
EGU General Assembly 2022

Tracing the snowball bifurcation of aquaplanets through time reveals a fundamental shift in critical-state dynamics

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The instability with respect to global glaciation is a fundamental property of the climate system caused by the positive ice-albedo feedback. The atmospheric concentration of carbon dioxide (CO_2) at which this Snowball bifurcation occurs changes through Earth's history because of the slowly increasing solar luminosity. Quantifying this critical CO_2concentration is not only interesting from a climate dynamics perspective, but also an important prerequisite for understanding past "snowball Earth" episodes and the conditions for habitability on Earth and other planets. Earlier studies are limited to investigations with very simple climate models for Earth's entire history or studies of individual time slices carried out with a variety of more complex models and for different boundary conditions, making comparisons difficult. Here we use a coupled climate model of intermediate complexity to trace the Snowball bifurcation of an aquaplanet through Earth's history in one consistent model framework. We find that the critical CO_2concentration decreases more or less logarithmically with increasing solar luminosity until about 1 billion years ago, but drops faster in more recent times. Furthermore, there is a fundamental shift in the dynamics of the critical state about 1.8 billion years ago, driven by the interplay of wind-driven sea-ice dynamics and the surface energy balance.