

# **Explaining the duration and oxygenation of the Sturtian Snowball Earth**

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The Neoproterozoic Snowball Earth glaciations represent some of the most extreme climate events in Earth's history, coinciding with major geochemical and biological transformations. However, recent geologic evidence presents major challenges to the Snowball Earth hypothesis that call into question our understanding of these events. Recent precision geochronology shows that the Sturtian Snowball Earth lasted ~56 million years, an order of magnitude longer than the expected deglaciation timescale due to CO<sub>2</sub> buildup. Additionally, the lack of sulfur mass-independent fractionation (S-MIF) observed during the Sturtian suggests persistent atmospheric oxygenation, implying significant primary production throughout the Snowball.

To address these challenges, we develop a box model of the global carbon and oxygen cycles during a Snowball and explore two scenarios. In the first, a prolonged stable Snowball state is maintained by syn-glacial weathering, with primary production occurring in dust-fed supraglacial cryoconite holes. In the second scenario, the system remains in disequilibrium maintained by enhanced weathering during interglacial intervals, modulating CO<sub>2</sub> and O<sub>2</sub> over multimillion-year timescales. We examine this regime over a wide parameter space to identify key drivers of carbon and oxygen cycle stability, determine the conditions necessary to explain the geologic record, and provide testable predictions for the level of primary production maintained during the Snowball.