Climate Dynamics of a (Near-)Snowball Earth

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Abstract:

This project studies the climate dynamics of pan-glaciated Snwoball Earth states, focusing on factors that stabilize or destabilize low-latitude ice edges and influence the Jormungand hysteresis.

The pan-glaciations of the Neoproterozoic era (1000-541 Million years before present) are among the most extreme and most exciting climates in the history of Earth (Hoffman et. Al, 1998; Pierrehumbert et al., 2010). The Neoproterozoic geology provides ample evidence for two million-year long glaciations during which tropical continents were covered by widespread glaciers that reached down to sea level. The classical Snowball Earth theory posits that this can only be explained if one assumes that the oceans were completely covered by sea ice. In 2011, however, the PI together with colleagues from the University of Chicago proposed the alternative Jormungand hypothesis (Abbot et al., 2011). As the Snowball Earth theory the Jormungand hypothesis can explain the Neoproterozoic geology and offers a scenario for an entire lifecycle of the pan-glaciations. In contrast to the Snowball Earth theory, however, the Jormungand hypothesis allows for a small strip of open equatorial ocean, because of which it can much more easily explain how life survived these extreme climates.

The Jormungand hypothesis, and the hysteresis associated with it are created by fundamental dynamics of the atmosphere and the impact of the Hadley circulation on the subtropical hydrological cycle and sea-ice albedo. The Jormungand hypothesis has been successfully demonstrated in energy balance models as well as global climate model simulations in aquaplanet setup without ocean and sea-ice dynamics. Yet, in order to assess whether the Jormungand hypothesis can in fact be a viable alternative to the Snowball Earth theory, climate model simulations in realistic model setups are needed. The project therefore aims to study the Jormungand hypothesis through simulations with the global coupled climate model ICON. The simulations will take a hierarchical approach to investigate the impact of continents, subtropical wind-driven ocean cells, and ocean and sea-ice dynamics in general. Four questions will be addressed: 1) Is the Jormungand hypothesis a robust model feature of idealized aquaplanet setups? 2.) How do continents and their geometry affect the Jormungand hypothesis? 3.) How does ocean energy transport affect the Jormungand hypothesis, and does this depend on continents? 4.) Can we demonstrate the Jormungand hypothesis in a coupled atmosphere-ocean model with realistic Neoproterozoic continents, ocean dynamics, and sea-ice dynamics, and if so what determines the magnitude of Jormungand hysteresis?

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