Investigating the Equatorial Gaps in Snowball Earth Sea Glaciers on Tidally-Locked Exoplanets around M-stars

[1]Francisco Spaulding-Astudillo, [2]Eli Tziperman, [3]Dorian Abbot

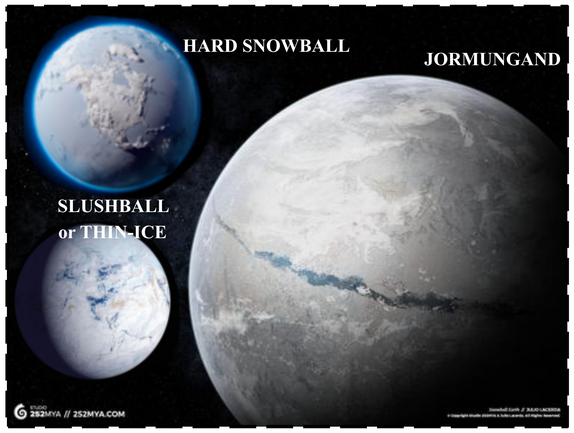
[1]University of California, Los Angeles, [2]Harvard University, [3]University of Chicago

Main Points

- Here, we present the blueprint of a novel 1-D spherical ice flow model that will eventually be asynchronously coupled to 2-D atmospheric and oceanic models.
- The ice flow model allows for gaps in thick ice cover on a Snowball Earth or glaciated planet.
- At the edges of thick ice, dynamic boundary conditions and a parameterization for subgrid-scale advance and retreat was introduced.

The Earth's surface became globally or partially glaciated at least once during the Neoproterozoic by O(km) thick ice sheets.

- observations of vigorous glacial activity in low latitudes.[3]
- survival of photosynthetic, eukaryotic, marine life for millions of years.[1]
- deglacial recovery without *excessive* buildup of atmospheric CO_2 .[3]



Is an open-ocean or thin-ice climate solution viable?

- The form of the operating curve (equilibrium ice-line latitude versus CO_2 is still an open question for Snowball Earth.[3]

There is at least one Earth-sized Planet in the HZ of every M-star. [1]

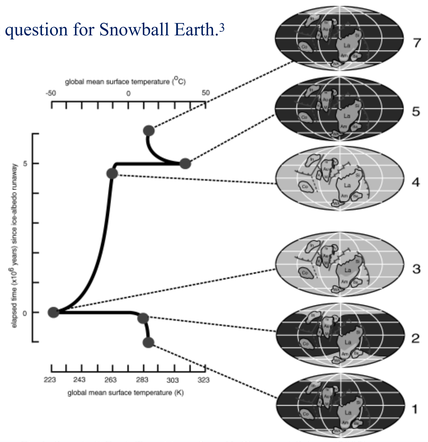


Fig 1: Snowball Earth Transition - from Hoffman and Schrag (2002)

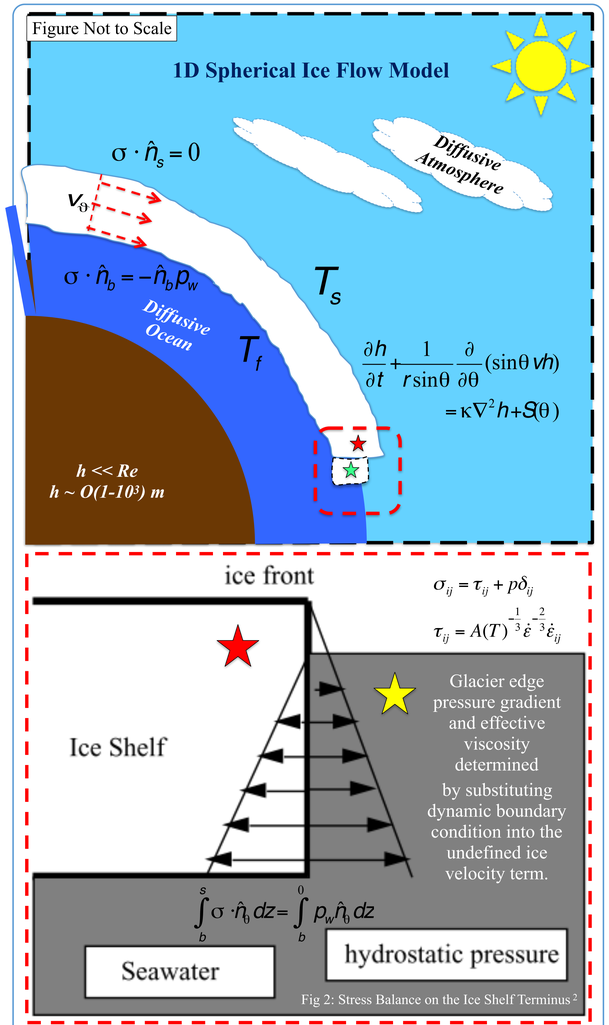
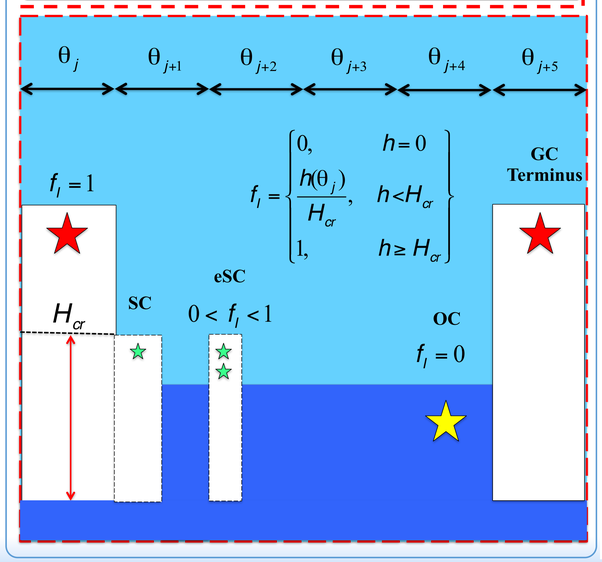
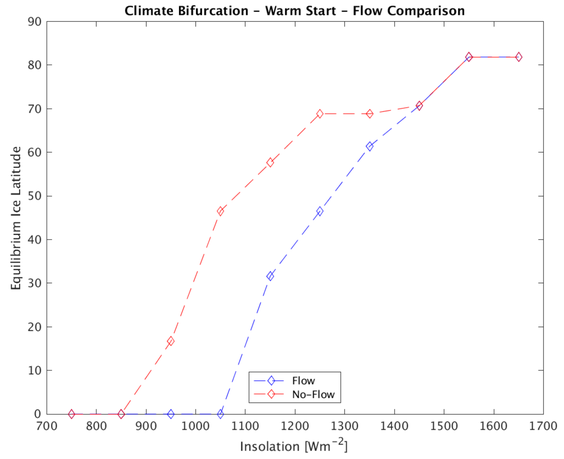
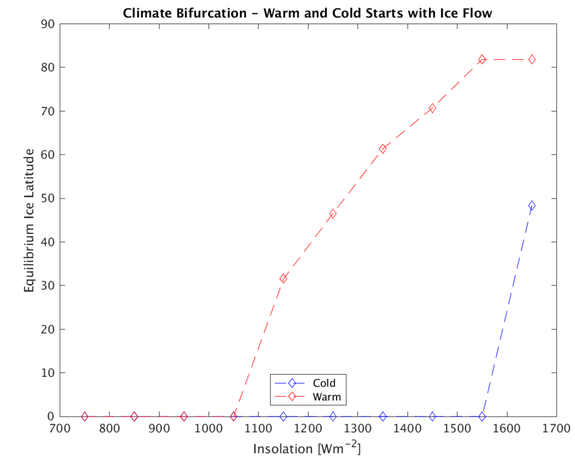


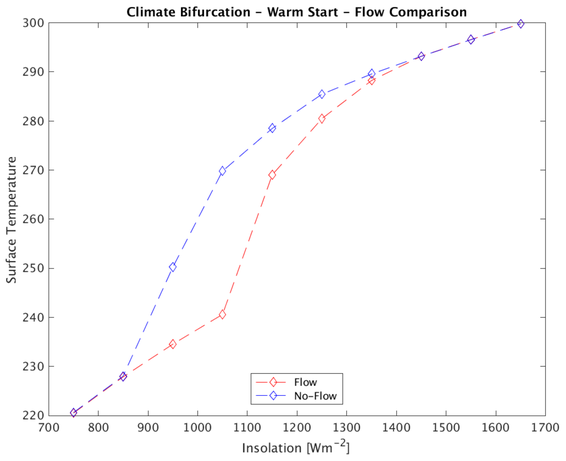
Fig 2: Stress Balance on the Ice Shelf Terminus [2]

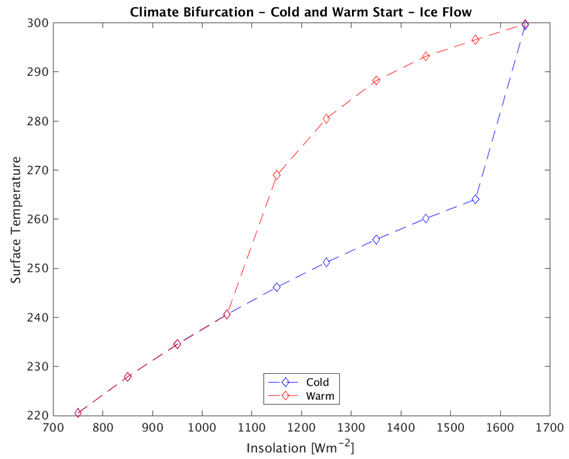


Can gaps in thick, semi-global ice coverage be maintained as open-ocean or thin sea ice at the equator by ocean-ice-atmosphere dynamics?









Results for a Rapidly Rotating Earth-like Planet

A. For warm-starts, ice flow increases hysteresis.

B. The snowball-to-warm transition occurs at high insolation in the presence of ice flow.

C. For warm-starts at a given solar insolation, ice flow reduces global mean surface temperatures.

Next Steps

- Sensitivity testing of artificial variables like the critical height
- Asynchronously coupling ice flow to 2D ocean and atmosphere model
- Apply full model to the research question and its applicable extensions

References

(1) Abbot, D. S., A. Voigt, and D. Koll (2011), The Jormungand global climate state and implications for Neoproterozoic Glaciations, *Journal of Geophysical Research*, *116*, D18103, doi:10.1029/2011JD015927.

(2) MacAyeal, D. (1997), Eismint: Lessons in ice-sheet modeling, technical report, The University of Chicago, Chicago, Ill.

(3) Pollard, D., J. F. Kasting, and M. Zugger (2017), Snowball earth: Asynchronous coupling of sea-glacier flow with a global climate model, *Journal of Geophysical Research: Atmospheres*, *122*.

(4) Tziperman, E., D. S. Abbot, Y. Ashkenazy, H. Gildor, D. Pollard, C. G. Schoof, and D. P. Schrag (2012), Continental constriction and oceanic ice-cover thickness in a snowball-earth scenario, *J Geophys Res*, *117*, C05016, doi:10.1029/2011JC007730.

(5) Albrecht, T., Martin, M., Haseloff, M.,Winkelmann, R., and Lever- mann, A.: Parameterization for subgrid-scale motion of ice-shelf calving fronts, The Cryosphere, 5, 35–44, doi:10.5194/tc-5-35- 2011, 2011.

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