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Climate of the Past Discussions



# *Interactive comment on* "Initiation of a Marinoan Snowball Earth in a state-of-the-art atmosphere-ocean general circulation model" *by* A. Voigt et al.

**Anonymous Referee #1**

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This paper presents atmosphere-ocean general circulation model (GCM) results targeted at determining the threshold for global sea-ice cover during the Marinoan, ∼635 Ma. A series of experiments with varying solar flux and atmospheric pCO2 are described. In addition to the GCM results, an analysis using a 0-D energy balance model is performed to identify the cause, of the GCM temperature response. The conclusions of the paper are (i) that global sea-ice cover, in the ECHAM5/MPI-OM model, occurs at 94% of the modern solar irradiance, a value higher than in previous ocean-atmosphere GCM studies, and (ii) that low-latitude continents cause cooling through a reduction in surface albedo.

The strategy and modeling technique used in the paper are mostly well designed and straightforward. The results from the ECHAM5/MPI-OM model are interesting and, importantly, increase the number of coupled ocean-atmosphere GCMs used to test snowball Earth initiation. The manuscript should be published after some revision. Nonetheless, the paper is disappointing on several accounts and could be substantially improved:

(i) The paper is polemic. It sets up the notion that climate modeling studies have determined that the snowball Earth hypothesis is implausible, and then aggressively refutes this strawman argument. Of course this is not quite the state of snowball Earth modeling. Since the original 1-D EBMs, a hierarchy of models has been used to test the idea of a snowball Earth. These models have obtained different solutions, but the important contribution is that through these studies a much richer understanding of the dynamics and physics has surfaced, including the roles of sea ice and sea glacier dynamics, ice albedo, ocean dynamics, Hadley circulation, and clouds. In addition, many previous snowball Earth studies have carefully pointed out that large uncertainties remain in components of the climate system that may be important to snowball Earth simulation.

(ii) This study does not contribute substantially to our understanding of the dynamics and physics of snowball Earth initiation, and fails to indicate why this particular model simulates global sea-ice cover at 94%. What is happening at the sea-ice line that causes it to advance in the Marinoan case relative to the pre-industrial case? This is the salient problem. The global energy balance analysis using a 0-D EBM does not speak to this issue, consumes too much of the paper, and provides little insight into the GCM behavior. What is it about the ECHAM/MPI-OM model that facilitates snowball Earth simulation? The fact that it is a “state-of-the-art” model is not sufficient explanation.

(iii) The authors conclude that low-latitude continents cause cooling (and facilitate global sea-ice cover) due to an increase in surface albedo. This is rather obvious. Of course surface albedo will be greater in the Marinoan case than the pre-industrial



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case because the sea ice area is larger. As in (ii), the important question is why the sea-ice expansion is greater with low-latitude continents. The paper doesn't address this.

Some minor points/corrections. 1. p. 1862. T should be used for surface temperature, rather than $\tau$. Later in the paper, T is used for ocean potential temperature and $\tau$ is a time constant. Please make these symbols consistent throughout.

2. p. 1863. "...effective emissivity decreases...due to larger longwave cloud radiative forcing (not shown)..." The authors should expand and explain this point. How are the clouds changing? Which clouds?

3. p. 1872. "...we point out that not only ocean dynamics and sea-ice and snow albedo parameterizations but also differences in the simulation of the atmospheric circulation and clouds must contribute..." Where? Other snowball Earth studies have done this and should be cited here, but this is exactly what's missing from this study.

4. p. 1865. "the sea-ice line has stabilized at 30N...." Previous studies have indicated that the sea-ice line de-stabilizes once it enters the Hadley realm. ECHAM seems to show a similar behavior.

5. p. 1872, 1874. Discussion of land glaciers on a slushball Earth. Pollard and Kasting (2004) have shown that the simulation of land glaciers is sensitive to details of continental paleogeography.

6. Not all of the figures are necessary. The land/ocean mask in Fig. 1 can be seen in Fig. 7. The horizontal grid distance in Fig. 3, while an interesting technical point, is not necessary. Fig. 8 is also unnecessary, and can be described in the text. These figures could be replaced with figures that show the surface temperature of the open ocean for the MAR and PI case. In addition, figures should be added to address points (ii) and (iii) above.

Interactive comment on Clim. Past Discuss., 6, 1853, 2010.