

Interactive comment on “The dynamics of the Snowball Earth Hadley circulation for off-equatorial and seasonally-varying insolation” **by A. Voigt**

Anonymous Referee #1

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In the present paper the author investigates the Hadley cell dynamics of a an ice-covered Snowball Earth simulated by an comprehensive atmospheric general circulation model. The Snowball Earth setup is taken as an example of a dry atmosphere. The paper is an extension of a study focusing on perpetual equinox conditions, and is concerned with the effect of off-equatorial heating and seasonal cycle. Main results are that i) the comprehensive model is in general agreement with conceptual/idealized studies, and ii) the vertical transport of momentum by subgrid-scale processes (dry convection which is parameterized by vertical diffusion) is fundamental for the strength of the Hadley cell. In addition the author gives some implication for Neoproterozoic Snowball Earth climate.

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I think that the paper is well written and presents sufficient interesting results to be published. However, I have some specific remarks/comments/questions the author may address (I'm aware that some of them can only be answered in a speculative way):

Specific

1) The author (et al.) already obtained both results (i and ii from above) in the previous paper concerning the equinox case. Given this and the fact that the underlying physics/equations do not change, one may ask what reasons could cause dry theories not to hold for the off-equatorial case and the author may comment on this in the introduction.

2) The general setup of the experiment is design to study Snowball Earth and not to study a dry atmospheric circulation. Though the obtained climate is almost dry and I have no particular doubt that the main conclusions will also hold for the perfect dry case in general, figure 5 suggests that there is a non-zero effect of latent heat release (stabilizing the profile?). The author may provide some numbers to quantify the effect of the remaining moisture: How large is the global mean diabatic heating by latent heat release (or the surface latent hat flux)? How large is the radiative forcing due to the remaining water vapor? Of course it would be interesting to know how large the difference to a climate of a run with no moisture is (i.e. a run which is initialized without moisture and the surface evaporation is switched off).

3) The vertical diffusion of momentum is related to a loss of kinetic energy. I wonder if and how this energy is given back into the atmosphere in the model (to assure energy conservation). Is this done by diabatic heating? If so, how large is the heating rate, and what is the effect on the (Hadley) circulation? If not, how large is the energy loss and what effect can be expected if energy would be conserved by heating?

4) It seems that transient eddy forcing is weak in the present runs compared to 'normal' Earth conditions. Thus, it is not clear to me how transferable the results are to cases

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with significant eddy contribution. Would vertical diffusion still play a major role there?

5) In chapter 2, the author may briefly note that no orography is present (i.e. there are no stationary waves and no mountain torque which may affect the Hadley cell as well).

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