Interactive comment on "Temperatures from Energy Balance Models: the effective heat capacity matters" *by* Gerrit Lohmann

Anonymous Referee #1

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This manuscript revisits the relationship between the (global mean) surface temperature of the Earth and its radiation budget as is frequently used in Energy balance models (EBMs). The main point is, that the effective heat capacity (and its temporal variation over the daily/seasonal cycle) needs to be taken into account when estimating surface temperature from the energy budget. The results of this exercise together with coupled ocean-atmosphere GCM simulations lets the author suggest a potential mechanism for the relatively low equator-to-pole temperature gradient in past warm climates that has been observed in proxy data, but remains difficult to reproduce with GCMs.

The paper includes a very useful discussion about general properties of the energy balance of the Earth and this certainly justifies publication in ESD. However, I have two

main comments to be improved on before I can recommend publication:

1. The theoretical arguments should be much better explained. This holds in particular for sections 2 and 3.

   For example, after or before eq. (4), it should be very explicitly explained which variables become lat-lon dependent, and which not. Otherwise eq. (4) and the analysis that follows is very hard to understand (or reproduce). In my view, if you consider the local energy balance, temperature T, emissivity ϵ and albedo α, should be spatially dependent and therefore this should have consequences for the following integration. If they are not spatially dependent, then it should be clearly stated why not.

   I find it very puzzling that the heat capacity C_p does not explicitly appear in eq. (11), although I clearly see how you get there. A few words of explanation would be very useful to the (less-expert) reader.

   Then, after eq. (12) the reference heat capacity is chosen as the atmospheric heat capacity. Why is that? Above in the text you have said that the heat capacity is manly given by the ocean, so why do you use the atmospheric heat capacity here?

   A bit more explanation and motivation should also enter the fact that in one case in Fig. 5 you use a latitudinal dependent heat capacity (in the text just after eq. (12)). How exactly? And what is the motivation for that?

   On page 6, line 18, the temperatures T1 and T2 remain unexplained!

2. The second point relates to the vertical mixing in the ocean. It is interesting to see how the vertical mixing in the ocean obviously can affect the equator-to-pole surface temperature gradient. However, why should the vertical mixing be so different in the Palaeogene/Neogene before 3 Ma? Tidal dissipation can play a role, but also bathymetry and probably also the number and specific geometry of

the ocean gateways. But so far, this remains very speculative and unmotivated in the manuscript. For example, how does the factor 25 in the vertical mixing coefficient that is used in the GCM simulations relate to expected changes in vertical mixing due to tides and bathymetry?