



EGUsphere, referee comment RC1
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Comment on egusphere-2022-418

Anonymous Referee #1

Referee comment on "Influence of heterogeneous thermal conductivity on the long-term evolution of the lower-mantle thermochemical structure: implications for primordial reservoirs" by Joshua Martin Guerrero et al., EGU sphere,
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This study uses mantle convection simulations to address the influence of pressure-, temperature- and composition-dependence of thermal conductivity on the fate of a dense primitive layer sitting at the bottom of the mantle, mimicking the LL(S)VPs on the Earth. While previous studies have investigated the effect of those various dependencies of thermal conductivity have been investigated individually, the novelty of this work is to consider consider the interplay between them in the context of the Earth's lower mantle structure. While I think that the results are worth being published, their presentation in the current manuscript is hard to follow and lacks a clear narrative thread, and more importantly, lacks in interpretation. Therefore, I think the paper would benefit from a thorough re-organization of the results section.

General

The study adopts a rather complex baseline set up (mixed basal + internal heating, phase transition, yield stress) to study the effect of pressure, temperature and composition on thermal conductivity. While my preference goes to simpler models when trying to unravel such systematic trends, one can argue that the current set-up is relevant for an Earth-like case, and I think it is fair.

I find the introduction a bit too light. I would expect some more background on the physics of the various dependencies of thermal conductivity, and in particular that the trends be clearly announced: increase of pressure results in increase of thermal conductivity, increase in temperature results in decrease in thermal conductivity, increase in iron content results in decrease in thermal conductivity (it seems). Also, it seems that considering a variable thermal conductivity is particularly relevant for compressible convection. If this is indeed the case, I would expect more time to be spent discussing why.

In my opinion, the main weakness of the paper in its current state is the lack of apparent organization in its exploration of the parameter space, which makes it pretty confused and fails at highlighting general tendencies in the effect of the different dependences of the thermal conductivity. This is probably due in part to the simultaneous changes in investigated parameters and diagnostic quantities from one section to the other (first time-evolution of the heat flux varying K_C and n , then instantaneous mantle structures varying everything, and finally time-evolution of entrainment again varying K_C and n). While I seem to get the idea in the progression, I had a really hard time getting a clear picture out of this section. Maybe starting by isolating the effect of each dependencies, and then considering their correlations could make things simpler. Maybe also distinguishing more systematically between the effect on mantle flow (pile structure) and on the time-evolution (e.g. of the CMB and surface heat fluxes) could help. Another possibility would be to add dependencies successively to a fiducial model, for which a preferred value of K_D would be selected before considering the effect of n , and in turn a preferred value of n would be selected before adding a third layer with K_C . That could spare some cases of the parameter space if there are reason to think they are less relevant. These are suggestion, hopefully that can help. Anyway, one important thing which is lacking in my opinion is also some theoretical speculation on the expected effect of the parameters that should come before presenting the results, and would help their interpretation (e.g. we expect the effect of increasing K_D to increase the thermal conductivity in the lower mantle and thus to make it more stable to convection (it decreases Ra) by homogenizing its temperature, potentially building heat... etc.). I think it is better for the reader to be incited to think in advance of seeing the results.

Specific

This article will probably mainly be read by people familiar with the equations of mantle convections. Nevertheless, I think it would be beneficial to write down the conservation equations (they are not even in the supplementary materials!), at least the heat conservation where the thermal conductivity appears, as it would make clear where the supplementary mechanism induced by varying thermal conductivity operate.

A plot of the thermal conductivity profile corresponding to the reference state for the various K_D , K_C and n (not all of them but the few most relevant combinations, e.g. the cases presented in Figure 2) would be insightful. It could be a supplementary panel in Figure 1, or a stand-alone figure.

I don't really understand why simulations run until 11 Gyr, but some values are avergaed around 4.5 Gyr. Anyway, the averaged values reported in Table 1 do not seem to be used.

Dimensional and non-dimensional quantities are often mixed, which lacks a bit of rigor.

Technical

L. 48: "compositional- dependent" \square "composition-dependent"

L. 84: "a quadratic that smoothly" \square "a quadratic curve that smoothly"

Figure 1: the markers for "<200 ppm water" are hard to see, please change for a more contrasting colour.

L. 118: "We first defined a purely depth- dependent reference case characterized by depth- dependence, $K_D = 2.5$, with lower mantle conductivities comparable to current estimates" in Figure 1, it seems that $K_D = 10$ is the closest match to lower mantle estimates.

L. 121: "by approximately 75%" it seems less than that in Figure 2.

L. 122: "in agreement with Li et al. (2022) findings" \square "in agreement with Li et al. (2022)'s findings"

L. 150: "We observed that T_{prim} increased with greater temperature dependence (top-to-bottom rows in Figure 3)." I don't see it.

For the snapshot figures, when a parameter is held constant, write it in the caption rather than for each snapshot. That will lighten a bit the figures.

Figure 5: Please alternate colormaps between the different quantities plotted. In particular, don't take a "divergent" colormap for the primordial mantle one which only has two extremal values, which are both very dark and hard to distinguish in the current plot.

L. 172: "and is equivalent to" \square "and which is equivalent to" ?

Figure 6: Same as figure 5: it is very hard to know which colormap corresponds to the snapshot and which corresponds to the time-evolution plots. Also please change colours for the onset of instability (the magenta is pretty hard to see).

L. 189: "may not compensate (or be exceeded) by" "may not compensate (or be exceeded by)"

Supplementary Materials

L. 43: "and the depth variation of thermal expansivity imply a depth average" "and the depth variation of thermal expansivity implies a depth average"

L. 176: "The density anomalies [...] is calculated" "The density anomalies [...] are calculated"

Figure S1: the y-axis is non-dimensional height, not depth.

Figure S4: What do line styles correspond to?