Reply to editor and reviewers

Dear Juliane Dannberg and Shije Zhong,

Herewith we resubmit our revised manuscript entitled "Coupled dynamics and evolution of primordial and recycled heterogeneity in Earth's lower mantle" for *EGU: Solid Earth*. We thank Shije Zhong for his final comments regarding our resolution tests. We have addressed the two points raised by the reviewer in the final version of our manuscript and in the detailed responses below. Moreover, in this final manuscript, we have decided to move our extensive Appendix to a separate file (Supplement), to be downloaded separately, rather than being attached to the main paper as a very long Appendix.

We appreciate your efforts and hope that you will find that the revised manuscript properly accommodates the two points raised, and is suitable to feature in *EGU: Solid Earth*.

Yours sincerely,

Anna Gülcher, Maxim Ballmer, and Paul Tackley.

Response to points raised by reviewer #2 – Shije Zhong

The authors made significant effort in revising the manuscript and I am satisfied with all the responses except that I think that the response to resolution issue needs some more clarification. The newly added appendix B on resolution tests is helpful. The authors used 3 diagnoses for resolution tests: relative volumes of primitive material and ROC in the lower mantle and RMS velocity, v_RMS (Fig. B1). The authors concluded that their results are qualitatively unchanged for different resolutions, which I agree and was what I suspected in my original review.

However, two issues need to be clarified and acknowledged:

1) v_RMS (Fig. B1c) shows some modest resolution dependence even at the highest resolution (~15% change when the resolution is doubled, which is not insignificant, in my view).

Response: thank you for pointing this out. Indeed, the largest v_RMS change between 512x96 and 1024x192 resolution models is approximately -11% for the models MdD30 and MdD300. Note that for our reference model MdD100 (black icons), this is not the case. We have added a few sentences highlighting the v_RMS trends in lines 46-48 in the Supplement, to avoid any misunderstanding that v_RMS is completely insensitive to resolution.

2) The relative volumes in the lower mantle are different from entrainment which often measures the change of mass or volume for a chemical reservoir or domain with time in previous studies (e.g., Zhong and Hager, 2003) and is probably more sensitive to resolution. Perhaps, in using the relative volumes in the lower mantle, the small drips of entrained materials are also included, thus making relative volumes in the lower mantle less sensitive to resolution. An extreme case is to compute the relative volume for the whole mantle, in which case the relative volume is a measure of the total conservation of composition. I am sorry if I sound somewhat insistent on this issue, as I have seen over the years that the calculations of entrainment or preservation of chemical reservoirs (e.g., LLSVP) in numerical models are over-simplified. I think that it would be helpful for the authors to acknowledge these two points in the paper to avoid misunderstanding.

Response: We respectfully insist that the quantities currently shown (vol% of chemical reservoirs Xsi_LM_prim and Xsi_LM_bs in the lower mantle are key quantities to show for several reasons. First, these parameters are extensively used in the main text and Figures and they could, for example, be used for comparisons. We also link these quantities with the different styles of heterogeneity preservations throughout the manuscript. Moreover, in our numerical models, it is difficult to quantify entrainment rates in the mantle in the same way as is done in e.g. Zhong and Hager, 2003, or really in any way (see below). In our models, the bulk composition of the convecting mantle changes as a function of time due to upper-mantle processing (i.e., melting) of primordial material, technically reflected as a conversion of a tracer from primordial to harzburgite-basalt space (see Methods section). Therefore, there is no true "conservation of total composition" and entrainment rate as calculated in other papers is not straightforward.

Primordial material is entrained by the convecting mantle at the margins of blobs with high primordial-material content, but then remains floating in the mantle for several cycles before being processed. After having made several tests (inspired by the reviewer's comment), we conclude that the Xsi_LM_prim is an appropriate quantity that reflects the integrated entrainment of primordial material over time.

Similarly, basaltic materials are entrained from thermochemical piles in the lower mantle, but they also keep on being added to the piles by segregation of basalt from harzburgite. Again, it is difficult to isolate the effects of entrainment of basalt in our models without detailed analysis that goes far beyond the scope of the resolution test. Nevertheless, Xsi_LM_bs is a relevant quantity that reflects both entrainment and segregation of basalt over time. Both are expected to be resolution dependent, but we demonstrate that the net effect does not change our conclusions.

We now better clarify this in the Supplement, and have added additional lines #55-58 and #60-62 of the Supplement. We hope you agree with our statements.