Solid Earth Discussions

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Reply on RC2

Olivier de Viron et al.

Author comment on "Comparing global seismic tomography models using varimax principal component analysis" by Olivier de Viron et al., Solid Earth Discuss., https://doi.org/10.5194/se-2021-16-AC2, 2021

This manuscript applies principal component analysis (PCA) to identify and analyze patterns of structure found in global, seismic tomography models. The work presents a potentially useful tool to analyze commonalities and differences among the plethora of tomographic models that have been published over the years.

We thank the reviewer for the comments and suggestion for an improved manuscript.

- The use of PCA to identify main patterns of velocity variations in tomographic models is not entirely new (see Ritsema and Lekic, 2020), and I think the reader would benefit from an explicit comparison of the differences and similarities between this and past work.

We thank the reviewer for pointing us to the Ritsema and Lekic, 2020 study, we were not aware of it. To the best of our knowledge, that is the only previous study that used PCA to interpret tomography models, and we have now modified our manuscript to refer to it. Moreover, we also added some text discussing the differences and similarities between our analysis and that of Ritsema and Lekic, 2020 (see lines 34; 179-183 of the revised manuscript).

Such a comparison between k-mean, PCA and varimax was already present in the paper, in Section 4 and Figure 2. We discuss this comparison further in the new version of the paper and we now refer to Ritsema & Lekic (2020); see also our answer to comment 4.

- Nevertheless, this manuscript is complementary to and moves beyond this previous work in that it redistributes the principal components in a manner that concentrates them in-depth, using the varimax rotation. This is a clever and creative choice, which allows the method to identify patterns that can more directly be related to specific structures/target regions. Another interesting contribution is that the authors explore variations across tomographic models using a common set of PCs.

While a comparison of global tomographic models is a great place to start, I think the true power of this method might end up being in the analysis of local and regional tomographic models, which tend to use more diverse underlying datasets, and have highly variable spatial resolutions that could be revealed effectively by the type of PCA proposed here.

We thank the reviewer for their constructive and positive comments. We agree that while comparing global tomography models is the best point to start, ultimately our method may indeed be useful for the interpretation and comparison of local and regional models. While such applications are beyond the scope of this study, which is already quite extensive, given that we are freely providing the codes used for the analysis, future analyses using local and regional models (as well as, e.g., geodynamical models) will be straightforward. We modified to text to explain this (see lines 465-468 of the modified manuscript).

- The authors point out that the number of PCs needed to explain nearly all (97.3%) of the variance in the tomographic models is always smaller than the number of splines/layers in the parameterization. Is this really surprising? After all, there is inherent smoothing of the retrieved structures due to both explicit regularization and data sensitivity. You write that "the splines or boxes seem to over-sample the available information" as if that is a bad thing. However, overparameterizing tomographic models and stabilizing the inversion through regularization has been advocated by some (e.g. Trampert and Snieder, 1996). It would be interesting to see which models and at what depths show the largest differences between the underlying parameterization width and that of the PCs.

We agree that the fact that the number of PCs required is smaller than the number of splines is not a surprise. As they are based on splines or boxes, there are always fewer PCs than splines or boxes by construction. We did not mean the over-sample as a bad thing; rather, we want to point out that the PCA objectifies the number of layers/splines required considering the information at hand.

We compare the splines and varimax-PCs in Figure 5 of the submitted manuscript (Figure 3 of the new version). We can see that except for the boxes from SAVANI, which have no relations with the PCs, all the models have a few splines that roughly coincide with PCs, and a majority of PCs seemingly independent from the splines. The PCs close to splines are located in the upper part of the lower mantle. This is discussed in line 230-235 (or 247-251 in the new version). But, we agree that the use of the expression "over-sample" in the conclusion is confusing.

Instead of "...where the splines or boxes over-sample the available information", we wrote: "where the information is recovered by fewer PCs than the number of spline functions or boxes" (see lines 265 of the revised manuscript).

- Doesn't the normalization applied to the velocity variations (standardization at each depth) skew the analysis toward the large mid-mantle areas in which velocity variations are quite small and often poorly resolved? Relatedly, the power in each component seems to be much smaller in this study than in Ritsema and Lekic (2020). Could this be because they did not normalize by depth?

The normalization does affect the result, giving more weight to the areas with smaller variations than what one would get without normalization. On the other hand, without normalization, most of the modes focus on the upper mantle, where the variations are larger. This is probably the case for the Fig. 4 of Ritsema and Lekic (2020) (R&L):

1) For both models tested in R&L, their first PC is driven by the shallowest zone (tectonic pattern), while in our analysis (e.g., S40RTS) the 1st PC is driven by the LLSVPs (Fig. 2 in our original ms);

2) Due to the absence of normalization, even the three other PCs of R&L contain a lot of energy in the shallowest zone, while our normalization allows keeping the tectonic-driven zone in essentially two components out of 6 (#4 capturing 7.6% of the variance and #5

capturing 6.2% on our Fig 2, in the top panels corresponding to PCA). When working without normalization, as in Ritsema & Lkic (2020), all our 6 eigenvectors show a strong contribution from the shallowest mantle (< 250 km), where most of the variance is located.

Considering the uncertainties about the middle mantle, we consider it interesting to have a fair amount of modes in that region, allowing a better model comparison and more readability.

These points and the effect of using a normalization are clarified in the new version of the manuscript (see lines 179-186).

- The authors identify differences in the number of PCs that are required to compress tomographic models, and attribute them to differences in regularization. That is certainly a key parameter, but another difference among the models that is worth discussing pertains to what kind of data are included in the analysis. For example, if the model does not include constraints from overtones, structures in the transition zone and mid-mantle might not be well-retrieved. Treatment of discontinuity topography can also matter because neglecting this topography can map directly into isotropic wave speed variations in the mid-mantle.

We fully agree with this suggestion and have now modified the discussion in the manuscript accounting for the kinds of data used to build the different models (see the text in lines 270-273 of the modified manuscript).

- I would prefer to see a summary figure of some kind, that synthesizes the information that is currently presented across many panels. I was keen to look at all the panels, but most readers might not be, and they would certainly appreciate a figure that eliminates the need for them to make comparisons between panels on their own. Overall, the number of figures/panels in this manuscript can be overwhelming.

We do not think that the existing figures can be further compressed without a (considerable) loss of readability. Nevertheless, considering that the number of figures might jeopardize the manuscript's legibility, we moved some figures to the supplementary material:

- Figure 1, which summarizes published information;
- Figure 4, as the explanation in the main text seems sufficient to make our point.
- Figure 8, as the previous figures on the isotropic models, are sufficient to illustrate the relevance of the varimax method, considering that the result with the anisotropic method is not very convincing.

This increases the number of figures in the supplementary information, but we prefer to keep all that information for completeness and reproducibility of our work. This limits the figures in the main paper to five, making it more concise and hopefully more pleasant to read.

- I also had some minor questions and comments that the authors might wish to respond to and address:

- If the goal is compression, why use the varimax rotation? It is my understanding that the original PCs would always provide better compression.

The compression is exactly the same for varimax and PCs, whereas the PCs have several drawbacks, as explained in the paper.

We added a sentence to clarify this point (see lines 138-144; 148-150). See also our answer to Reviewer 1 where we provide some more details on the main rationale for applying the varimax method.

- When discussing the patterns of heterogeneity, I kept thinking back to the term "heterosphere" introduced in Dziewonski et al. (2010) to describe the strong seismic heterogeneity in the tectonic uppermost 250 km of global tomographic models.

We thank the reviewer for this useful point and we now refer to the "heterosphere" in the manuscript (see lines 287-288)

- The 1D reference model for S362WMANI+M should be the STW105 model of Kustowski et al. 2008.

We thank the reviewer for spotting this mistake, which is now corrected.

- When comparing countable quantities (like the number of PCs), you should use the word "fewer" rather than "less", etc.

Corrected.