Solid Earth Discussions

Solid Earth Discuss., author comment AC1
https://doi.org/10.5194/se-2021-16-AC1, 2021

Reply on RC1

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-AC1, 2021

Reply to review 1

We are grateful to the reviewers for the time that they spent in their review and for their useful and constructive comments, which will greatly help us improve our manuscript.

Generally, I find the method interesting; however, I am sceptical about its overall usefulness. Without a clear understanding/quantification of resolutions in these tomography models, I don't see why we need data compression techniques to decompose and then reconstruct the original tomography models (by considering some principal components). This may remove real signals from some tomography models (as only a limited number of components are considered). I understand that these methods, in general, can help to reduce the noise, but this requires a very good understanding of the resolution, as stated before. Nevertheless, this method can be used as a complementary method to other existing methods (such as k-mean clustering). On some existing platforms (e.g., SubMachine or IRIS EMC), different models are comparable by being projected on the same grid and corrected for different background models. Probably taking all these methods together will help us to better understand and compare these models.

We thank the reviewer for their comment, which made us realise that we did not explain well the whole purpose of the method. We do not consider varimax as a useful representation of the tomography models to be used instead of, e.g., the spline functions that were employed in the construction of some of the models. This would be useless. We rather see it as a diagnostic tool, allowing us to quantify the level of independent information in the tomography models and to compare the models more easily. Hence, we do not need a clear quantification of the resolution of the tomography models to perform the analysis.

We agree with the reviewer that the method is not the only one that can be used for this purpose, being complementary to existing methods and with the following advantages:

- Being data-based, it is neutral concerning the assumptions made in the model's construction (and, thus, we re-emphasise that we do not need to keep 100% of the information to perform the analysis). For example, our simultaneous multi-model

varimax analysis allows the comparison of the various tomography models on a neutral set of modes, determined by the level of compression fixed by the user.
- Based on the vertical consistency between the various tomography models, it provides a set of data-based vertical distribution functions. Those functions represent the information present in the model's reconstruction, and how the models relate to each other.
- It is fast and simple to implement, and, as we maximize the captured variance, the amount of information kept is larger for a given number of components/depths than would be required by other methods such as k-mean, for example (Figure 2).
- As the truncation level is a free parameter of the method, the user controls the amount of signal suppressed from the compression to an arbitrary level.
- As shown in the paper, it allows recovering all the Earth features discussed in the literature, allowing us to compare how each model captures and represents those features.

We will modify our manuscript to make all these points clearer.

Specific comments

- I am worried that the couple of [%] which are not captured by the PCA/Varimax method contain crucial information and are not simply noise (e.g. L. 195). In my option, the small scale (and intermediate) structures/features are the interesting parts of the models to investigate. Hence, the method is suitable for looking into the large and intermediate scales but then why not "simply compare the models" to account for the small scale features? I'd appreciate that if the authors can explain this in the manuscript. This will significantly help the readers to understand the usefulness of the proposed method.

The scale is not relevant for the varimax PCA method. It is only based on the vertical covariance. Considering the low amount of variance lost in the reconstruction (Figure 4) and the spectrum shown in the Supplementary Online Material, we capture most of the information, and we do not change the spectrum of the signal. So the method is valid for any scale, as long as the signal is robust. In the varimax comparison, what is called noise is not the small-scale features, but rather the part of the models that is not covariant vertically. We will clarify this in the revised manuscript and hence that the analysis should not be removing any "crucial information".

Of course, comparing the raw models would also be an option, but one has to determine which reconstruction (number of layers) is relevant for comparison. It is easier to compare 15 varimax components than e.g. more than 20 layers. In addition, the varimax method projects the models on a set of independent vertical profiles – which implies an optimal representation for a given number of layers (number of components) or a given amount of information (captured variance) - determined from the models themselves. This makes the varimax comparison optimal in the sense that you compare the largest amount of information for a given number of maps that are being compared.

- I am not sure I understand the reasoning behind simplifying the tomographic model in the last step/after the inversion. The model is already a smooth/simplified version of the actual Earth structures. I think regularization is a safer method to remove "noise" from tomography models as it is, at least, informed by the measurements. The PCA/Varimax method does this as a "postprocessing". I am wondering why we need this postprocessing step?

As we tried to explain above, the purpose of our study is not to represent or simplify tomography models but rather to provide an alternative, independent method to quantify the level of independent information in the tomography models, and to quantitatively compare different tomography models. With the varimax representation, we quantify the level of vertical independence of the information and how much of it is associated with the parametrization of the model – by comparing the varimax profiles with the splines or boxes of the model, for example. We find that this is a very useful tool to quantitatively compare how a given Earth feature is captured by the different tomography models.

We will modify our manuscript to make this point clearer.

- Maybe the easiest way to show the usefulness of this method is via synthetic tests? e.g., a synthetic global model that consists of large/intermediate-scale features as well as small-scale features. These small-scale features are generated via a stochastic process (noise), or they are real (but again, small-scale) structures. What would different components of PCA show? Can we reconstruct the small-scaled features?

Although we agree that a synthetic test may seem appealing at the first sight, we think that it is not useful for this particular study. If we generate a synthetic 3D global model with vertical consistency and add random noise on it, then the varimax method, being PCA-based, will retrieve the model and diminish the noise, because this is what PCA is good at: separating the covariant part from the non-covariant one. If the noise is not covariant (vertically), it will disappear in the data compression. So, simply adding independent noise will not to teach us something new about the quality of the varimax analysis. Adding real small-scale structures would also not be very useful because, as explained above, the varimax analysis is scale-independent, it depends only on the vertical covariance of the signal.

- (This comment does not require any action/changes for this manuscript.) You describe in L.59 that you did not consider using P-wave models because the agreement is more limited between those models. New global P-wave models have a good agreement with existing S-models, also in the lowermost mantle. Maybe for your next analysis, you could consider including more "agreeable" P-models?

We thank the reviewer for this remark. We will modify the manuscript to explain that future work will expand the analysis to P-wave models, in light of recent work showing a better agreement between P-wave models.

In Figure 2, why does the PCA method show the LLVPs and the Varimax shows ridges and cratons. Why does it not capture structures at the same depth? What is the x-axis?

The PCA captures the most covariant vertical structures in the model, which correspond to the LLSVPs, given that they extend from the lower mantle nearly to 1000 km depth. The varimax keeps the same information as that retrieved by PCA, but it redistributes it between the components with a maximal vertical compacity – the large values of the profiles are limited to as little depth as possible. That is why the two types of analyses capture structures at different depths. Both are valid representation/compression of the dataset, but it has been shown that the PCA presents artefacts from the domain geometry (In Richman review: the topographies of the PCs are primarily determined by the shape of the domain and not by the covariation among the data. In other words, different correlation functions on a geometrically shaped domain have similar EOF patterns in a predictable sequence, which do not reflect the underlying covariation. This is the case of square domains found on meteorological maps, or in our case, the progression of the unrotated PCs patterns is caused by a relationship between EOFs and harmonics). The varimax rotation captures distinct, well-defined depth domains in the mantle, which are easier to interpret physically.

The x-axis, i.e. the amplitude of the vertical eigenvectors, represents the maximum absolute value of the normalized anomaly at a given depth. It must be multiplied by the horizontal loading pattern, which provides normalized loads ranging between -1 and 1.

We will modify our manuscript to clarify this.

- Maybe I missed this part, but how do you handle different background models of the tomography models (e.g., PREM, IASP91, AK135, or even 3D background models)? How does this change PCAs? Is this being taken care of as you normalize the data (remove the mean and divide by standard deviation)?

As explained in lines 81-82 of the manuscript, we converted all the models into perturbations in shear wave speed and radial anisotropy with respect to the 1-D model PREM for fairer comparisons. Moreover, since both the vertical structure and the horizontal patterns are normalized, indeed, the background model does not impact the results. We will add some text to the manuscript to further clarify this point.