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Interactive comment

Interactive comment on "Crustal structures beneath the Eastern and Southern Alps from ambient noise tomography" *by* Ehsan Qorbani et al.

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Dear Editor,

We are pleased to submit the authors' response of "Crustal structures beneath the Eastern and Southern Alps from ambient noise tomography". We appreciate the time and attention by the editor, associate editor, and referees. The comments and questions were insightful and enabled us to improve the quality of the manuscript.
All points raised by the reviewer2 have been addressed. In the following we list the reviewer's comments in bold face following by the authors' response to each of

comments and questions. As suggested by the reviewer, we modified the text to better explain of the resolution of the model. We updated Figure 6 (of the revised manuscript) to include correlation length in best and the worst directions as well. We also add more equations and explanations to the text to better describe details of the group velocity inversion.

Sincerely,
Ehsan Qorbani on behalf of the co-authors

Referee 2

1) Resolution: My major concern is the resolution analysis. In section 4.1, the authors claim, for instance, that resolution length at 16 s is as low as 8 km. Obviously, this is physically impossible. At 16 s, surface wave velocity is around 3 km/s. Therefore, the wavelength is certainly larger than 50 km. It follows that resolution in this transmission tomography can be at most 50 km at 16 s period. The problem here seems to be that the authors forget the limitations of ray theory. By virtue of the central-slice theorem, ray theory can give infinite resolution, regardless of the frequency content of the waves. In other words, this apparently good resolution is really just an artefact of the ray approximation. Another problem is that resolution length is a quantity that has a direction. Resolution in one direction is generally different from resolution in another one. So, which direction do you consider here?

We thank the reviewer for its comment and we agree with him. The resolution as discussed in the manuscript is indeed not a true resolution but more an estimation of the correlation length or the size of the averaging spot for each cell of the model. We also agreed with the reviewer that the text was misleading, and we therefore have changed the terminology used in the manuscript to better reflect that this measurement is simply a proxy to assess the spatial averaging of the inversion rather than the true resolution of the model. "Resolution length" has been renamed "correlation length", which better explain that this value may be interpreted as the minimum distance at which two delta-shaped input anomalies can be resolved on the tomographic map (Barmin et al., 2001). We would like to point that assessing the "resolution" in the sense of "correlation length" directly from the resolution matrix, as done in the manuscript, is a robust way of quantifying spatial averaging and the size of the "resolution" spots (Barmin et al., 2001; An 2012). Studies combining both resolution matrix analysis and checkerboard tests show similar results in terms of extracted correlation length (e.g., Poli et al., 2013) with more information for the resolution matrix approach (e.g., Barmin et al., 2001; Stehly et al., 2009). As mentioned by the reviewer, the spatial projection of the individual resolution matrices for each cell are not symmetric which allows to look at the different size of the "resolution spot" in the best and worst direction for each cell. In the previous version of the paper, we presented the mean "correlation length" between the best and worst direction. In the updated version of the paper we now include the mean correlation length, the one in the best direction and the one in the worst direction (Fig. 6 in the revised version).

2) Details of the inversion: Some technical details of the inversion procedure could be described better. Especially in the first paragraph of section 4, the authors introduce various parameters that seemly control the regularisation of the inverse problem. Without showing an equation, it is difficult to understand what exactly these parameters are, and how their specific values have been determined.

In the revised manuscript, we add more explanation and include equations for more clarification.

Printer-friendly version

Discussion paper

3) English: The English of the manuscript is good, but can still be improved. For instance, many plural s's are missing. So, I would suggest that a native speaker carefully reads the text.

We will ask a native English speaker to proofread the revised manuscript.

4) Figures: Some of the figures could be improved. Often, the labels are too small and resolution is a bit low.

We improve the quality of the figures and make the labels and titles larger.

The authors' response to the major comments in the supplement by Referee2

1-It is not quite clear why you would need 9. Already the 3 diagonal components would allow you to do this.

To compute the diagonal terms ZZ, TT, and RR of the correlation tensor, the rotation matrix includes ZZ, EE, EN, NE and NN terms. In addition, the RZ and ZR terms also includes Rayleigh waves. Calculating the full tensor therefore allows redundancy in the dispersion measurements which avoid biases due to noise sources distribution.

2-"*In order to select the clearer CC, we picked those that have signal-to-noise ratio (SNR) larger than 4*". This seems to be a very low signal-to-noise ratio.

The selection based on SNR is done at the very beginning of the selection process. At that step, the database is still composed in most of the correlation pairs. This low SNR is simply there to remove the really poor correlation functions. Most of the actual selection is performed by the following selection criteria. To better show the SNR of the final correlations, we added a new figure (Fig. 3 in the revised manuscript) presenting the average SNR as a function of period. This figure clearly shows that the SNR of the correlation entering the inversion is actually good for all periods. The figure is also attached to this letter (see Fig AC1).

3- "*To improve the reliability of Rayleigh wave dispersions measurements we used the redundancy of the correlation tensor by using all components (RR, RZ, ZR, and ZZ) containing Rayleigh waves*". It is not clear that this really brings an improvement. In fact, you silently make the assumption that the Earth is isotropic. In case of azimuthal anisotropy, which surely exists but may be difficult to constrain, you introduce a systematic error, e.g., by having Love waves on the vertical component and vice versa.

The goal of the paper is to present a isotropic velocity model of the Eastern Alps. The combination of the various components containing Rayleigh waves improves the stability of the dispersions measurements by limiting the bias due to the non-uniform noise sources distribution. This type of combination is commonly done in Ambient Noise Tomography to improve the stability of the dispersions measurements.

4-"*These parameters strongly affect the variance reduction of the final model. Stehly et al. (2009) recommended that the correlation length should be at least equal to grid size*". Since you explicitly say that these parameters affect the variance reduction, it is difficult to understand that you just fix them. How did you get to these values? For instance, did you run some kind of L-curve analysis for them?

We selected the inversion best parameters using L-curves analysis . The variations of variance reduction as a function of damping factor and correlation length that are now provided as a new figure in the manuscript. The Figure is also attached to this letter

(Figure AC3).

Figures caption

Figure AC1: Average signal-to-noise ratio (SNR) for Rayleigh and Love waves for all station pairs. Average SNR of ZZ, RR, ZR, and RZ are also shown, which Rayleigh waves are extracted from these 4 inter-components. Average SNR of TT and Love-waves are also represented in the figure. Love waves appears on the TT inter-components.

Figure AC3: Variance reduction as a function of the inversion parameters. a) L-curve analysis for damping factor (alpha) for Rayleigh waves at periods of 5, 10, 20, 30, 40 sec. b) Correlation length (sigma) for Rayleigh waves at the same period range. c, d) Variance reduction vs damping factor and correlation length (sigma) respectively for Love waves at the same period range. The selected parameters are shown by black circles.