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Interactive comment on "Near surface structure of Sodankylä area in Finland, obtained by advanced method of passive seismic interferometry" *by* Nikita Afonin et al.

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Author response to the interactive comment posted by Anonymous referee #2

First of all, we would like to point out that we use the old figure numbers in our replies. In the revised manuscript one new figure was added and numeration of figures has changed.

Referee: The authors present an application of passive seismic interferometry to image the subsurface of a mineral exploration area in northern Finland (down to 300 m). Passive seismic data were collected in parallel to active reflection/refraction acquisitions (during downtimes) along several linear profiles. The main purpose of the underlying project being active seismic experiments, only a short amount of continuous passive data could be collected (hours/days). The authors try to address the challenging task of retrieving meaningful surface-wave responses from such a short duration dataset. They claim that they could achieve this despite the non-stationary and non-isotropic distribution of noise sources. For that, they used an advanced processing algorithm called SNRS (not described in the work). They also claim (using supporting synthetic modeling) that this achievement was favored by strong local scattering conditions (local scattering helps reaching more diffuse field conditions). Using inversion of the extracted dispersion curves, they provide different 2D sections of shear-wave velocity models and propose some geological interpretations. While I agree that the topic and goals of this work are of high interest, I do not feel at this stage that the claims made by the authors are reliably backed up in the presented work, and I think that many points should be clarified. My major concerns are the following: - I do not understand how the numerical simulations address the problem of nonstationary/ non-isotropic noise sources. The position/angles of the sources have to be clarified, but it seems from the presented configurations that only the "pseudo-1D" case is tackled. By that I mean that the incoming noise horizontal direction seems to match the direction of the profile. This is a very favorable condition that does not address the main challenge of an off-angle dominant source of noise.

Authors: We considered different positions and types of sources (in line with the profile in surface (vibrator, waterpower plant dam and blast), sources out-of-line and also plane wave arriving with different incidence angles). Such positions were selected because in our study area we know positions of vibrator, dam and the active mine. In simulations we were just trying to represent situation with these real noise sources we identify in our experiment areas. In other experiments the sources may have different positions with respect to profiles, of course, but this is out of scope of our case-study paper. Moreover, when we considered a plane wave, which is an approximation of any source in far field area, we tested several incidence angles and azimuths of arrivals.

In all cases, we noticed scattered arrivals with characteristics (polarization, dispersion) of Rayleigh waves and the similar apparent velocities for all considered cases. The similar scattered arrivals we noticed in synthetic seismograms, produced by vibrator, explosive source or dam located in-line with the profile. In the cases when the source was a plane wave or vibrator, we noticed that scattered arrivals have lower frequencies than the source, and that the scattered waves have polarization and apparent velocities typical for Rayleigh waves. Therefore, our modelling suggests that seismic waves from considered sources are converted to diffused wavefield of lower frequencies when scattering. Our modelling is in line with results of previous theoretical studies (for example, Gritto et. al., 1995; Wapenaar, 2004). The analysis of real data recorded in XSoDEx project and presented in our papers proves our suggestions.

Referee: As explained, the passive acquisition was made in parallel to active seismic acquisitions. This is a great opportunity to make detailed comparisons of active vs passive data and benchmark noise correlation/SNRS in a challenging configuration. One convincing comparison example was made for one subsurface model (Figure 13). This approach could be generalized to compare: EGFs to "active" surface-waves, dispersion curves, and other subsurface models. In my opinion, this would make a much more compelling case for the passive approach than the numerical modeling invoked above.

Authors: Direct comparison of the results from the proposed method and from the conventional methods based on surface wave analysis from active sources (like MASW, for example) is impossible because vibrator does not produce Rayleigh waves of low frequencies that we used in our method (Fig. 14). We pointed out on this in the text of Section 3 and this was the main motivation for our synthetic modelling. Figure 13 shows comparison of velocity models obtained by analysis of wavefield produced by scattering of signal from vibrator (Fig. 13 (b)) with the model obtained using scattering of waves of unknown source (Fig. 13 (a)). Therefore, in both cases, the scattering field is used and we applied our method in both cases in order to obtain EGFs. That is why neither of the models can be considered as a benchmark. We compare both models mainly to geological information and we find no contradiction. From Figure 12 (b) one can see that the width of error bars of dispersion curves are about 500 m/s. Differences in velocities between two 2D models (Figure 13) are within these limits.

Referee: The title and paper stress-out the importance of using the advanced SNRS algorithm. However, this algorithm is not described at all in the present work. Additionally, to ensure that SNRS is actually required here, a comparison with traditional ambient noise correlation processing could be a great addition (comparing EGFs with active data for example).

Authors: It was the topic of our previous research and one of the reasons for development SNRS algorithm. The detailed description of the algorithm and results of its testing with real data in two different areas with different type of ambient noise sources are already published in the paper by Afonin et al. (2019). As we showed in this previous study, using of conventional passive seismic interferometry for extracting empirical Green's functions from seismic noise of high frequency (higher than 1 Hz) is practically impossible in seismically quiet areas of Finland where significant industrial activity is absent and sources of seismic noise with high frequency are rare, irregular and have low energy. In addition, high frequency noise from these sporadic sources attenuates rapidly and do not propagate to large distances, so simple noise crosscorrelation does not work. Concerning comparison with the active data, see our reply to the question above.

Referee: In the abstract, the passive dataset is said to contain only several hours of data. In the text, several days of acquisitions are mentioned. The exact record duration(s) should be mentioned as this is a key aspect of this work.

Authors: We used data intervals with durations varying from several hours to couple of days (it was the period when vibrator was in reparation). When we analyzed parts of records with vibrosource in Section 6 it was one day of continuous data. When we

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analyzed passive seismic data without vibrator, it was a couple of days. Nevertheless, we analyzed continuous seismic data without selecting parts of records with signal of vibrator. The SNRS method is selecting automatically parts of the record for retrieving EGFs.

Referee: The workflow from dispersion curves to subsurface models could be explained in more details.

Authors: The main steps of data processing are described in Section 5. They are well known (MASW for obtaining dispersion curves, inversion of dispersion curves using Geopsy). References and a new figure (Figure 10) describing the workflow is added to the text.

Referee: Why not comparing the resulting models with the results of the main project (reflection/ refraction models)?

Authors: To the moment, detailed models from analysis of reflected and refracted P-waves are still not published in regular papers. That is why we decided not to include any preliminary results of these studies into our paper that concentrates mainly on analysis of S-wave velocities down to 300 m. We compared our results mainly with petrophysical and geological information.

Referee: The matching or lack of matching between model and boundary of geological units is not clearly discussed (Fig. 17).

Authors: The XSoDEx study is the first one, where upper subsurface of this area was studied in such details. Our study reveals boundaries between major lithological units in the area. However, it is necessary to take into account that the boundaries of geological units in this area are known with certain precision, depending on density of points for geological sampling. That is why certain discrepancy between previously defined boundaries of geological units and geophysical information is possible. Geologists need input from geophysical studies in order to upgrade their knowledge.

Referee: The quality of the figures should be improved, as well as the quality of the language.

Authors: The quality of the figures has been improved and we made additional work on language.

Referee: Some detailed comments are provided in the attached annotated pdf. Please also note the supplement to this comment: https://se.copernicus.org/preprints/se-2020-160/se-2020-160-RC2-supplement.pdf

Authors: Replies to these comment provided in attached.

References

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Please also note the supplement to this comment:
https://se.copernicus.org/preprints/se-2020-160/se-2020-160-AC2-supplement.pdf

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