Solid Earth Discuss.,
https://doi.org/10.5194/se-2020-160-AC1, 2021




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

**Nikita Afonin et al.**

nikita.afonin@oulu.fi

Received and published: 14 January 2021

Author response to the interactive comment posted by Yunhuo Zhang (Referee)

Referee: I have gone through the entire pre-print. It is an interesting study and useful reference. It can be considered for publication, provided some areas can be improved. Please refer below for your consideration: The title of the paper highlights the 'advanced method', which is the SNRS algorithm to estimate the green's function from diffusive ambient noise field. However, the SNRS is just referred to the author's earlier paper, without any elaboration. This makes the title not reflects the content correspondingly. Since the SNRS algorithm is already published and discussed earlier, it is suggested to amend the title accordingly, either highlighting the case study, or the attempts to characterize the noise field of the sites, etc.

Authors: The title of the manuscript has been changed by removing words "advanced method". The new title is "Near surface structure of Sodankylä area in Finland, obtained by passive seismic interferometry".

Referee: Section 4, several synthetic models are created to characterize the noise field of the site, taking into consideration of the nearby major activities. It is quite interesting and worth expanding. The assumptions of major sources need more explanation.

Authors: The assumption about major sources was made based on analysis of spectra, presented in the Section 3, and knowledge about locations of industrial objects, roads and other human activities. Moreover, we consider the universal source – plane wave, which is an approximation of any source located in the far field area. The corresponding text has been corrected.

Referee: The key message of creating the synthetic models are to support the claim that the noise field of site is diffusive. However, it is very common in elsewhere, too. Therefore, it would be better to draw some more novel conclusions from the synthetic models.

Authors: The main goal, except of supporting the claim that analyzed wavefield is diffuse, was also to understand how relatively high-frequency wave (dozens of Hz) may produce low-frequency (about 5-20 Hz) wavefield during scattering on heterogeneities. In our opinion, the previous synthetic modelling efforts published in literature were mainly focusing on scattering of waves from controlled sources (see, for example, Gritto et. al., 1995, Bohlen et al., 2003). In our modelling we were interested to see scattered wavefield from various types of sources, including plane wave from sources located in far field zone. In our modelling we also followed propagation of wave from these sources during time intervals that are longer than those typical for data acquisition in controlled source experiments. Spectral analysis of scattering arrivals (figure 5) shows that the plane wave with frequency of 40 Hz produces surface waves with frequencies of about 7-20 Hz during scattering. The corresponding text has been corrected.

Referee: Noted that each synthetic model is to simulate one type of sources. Would it better to create an overall model that combines all possible noise sources. If this one can be done, the authors may explore full waveform inversion of passive seismic waves.

Authors: It was shown in numerous studies (for example Wapenaar et al., 2004; Mulargia, 2012, etc.), that diffused wavefield is usually produced by the superposition of waves of numerous sources and scatterings on heterogeneities. We included these studies to the list of references. Nevertheless, our goal was to study the nature of low frequency wavefield, when all possible sources have relatively high frequencies.

Referee: It is essential to beef up the field acquisition in more and clearer details, e.g., the field plan out, geophone type and corner frequency, sampling rate, source signature and location for active testing, etc.

Authors: The chapter 2 (experiment description) has been revised and more details concerning experiment were added.

Referee: Figure 1 is not clear where are the blue/black lines. It is also difficult for the readers who are not familiar with Finland geology without necessary introduction.

Authors: The figure 1 has been changed

Referee: The quality of Figure 2 needs to be improved to meet the criteria of publication.

Authors: The figure 2 has been modified.

Referee: It is not clear about the caption of Figure 5 (a) that what is the distance of 2000m referring to. Figure 5(b) horizontal axis and color bar scale seem not correct, if it is a dispersion image.

Authors: Figure caption has been changed

Referee: Figure 6 (b) and 6 (c) are very interesting. It is worth expanding the explanation why these 2 directions are so different, whereby 6(b) can't see surface wave and 6 (c) can see surface wave clearly.

Authors: The synthetic model shows that the wave propagating from the considered source (blasts) inside the model that contains numerous irregular heterogeineities, produced only Love surface waves. In this modelling, the main objective was to clarify the absence of Rayleigh waves on seismograms, produced by blasts. The explanation of this phenomenon is not simple and might be the topic for another research and more enhanced modelling.

Referee: Figure 7 shows the source is mainly in 10-40 Hz, which is quite high. Please explain how such high frequency source can illuminate to 300 m below ground.

Authors: We show by synthetic modelling, how high-frequency waves are converted to low-frequency wavefield when scattering on heterogeneities (for example, we show that the plane wave with frequency of 50 Hz during scattering produce wavefield with frequency of 7-20 Hz (Fig.5)). By using the SNRS algorithm, we select these scattered low-frequency waves and then analyze them.

Referee: Figure 11 (a), the 2D profile needs to be further tuned to avoid abrupt change in Vs.

Authors: We used only three 1D models to obtain the 2D model. We cannot smooth this model more.

Referee: Figure 12, the data quality of the real data is not good, even though it is acquired in a quiet environment. The green's function is really quite contaminated; therefore, the dispersion image is not clear. Nevertheless, understand the green's function is retrieved from the SNRS algorithm. It would be interesting to compare the green's function and dispersion image retrieved by conventional method. From there,





Printer-friendly version

Discussion paper

readers would have a more explicit sense of the advantage of SNRS, if any.

Authors: It was the topic of our previous research and one of the reasons for development SNRS algorithm. As we showed earlier (Afonin et al., 2019), conventional methods of stacking EGFs in passive seismic interferometry are not working in the seismically quiet areas of Finland where industrial activity is practically absent and sources of seismic noise with high frequency (higher than 1 Hz) 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. Therefore in our case, the signal and the dispersion curve presented in Figure 12, have relatively high quality. Conventional passive seismic interferometry not allowed evaluating EGF's.

Referee: Figure 13, there are some differences of the results from the proposed method and the conventional active method. Which one would be closer to real situation? A more discussion would be expected.

Authors: Figure 13 does not present results of comparison of models obtained by conventional analysis of surface waves from active sources (like MASW) with the model obtained by our method. Such comparison is not possible because vibrator does not produce Rayleigh waves of low frequencies (see Fig. 14, this is Fig. 15 in the revised manuscript). Figure 13 (Figure 14 in the revised manuscript) shows comparison of velocity models, obtained by analysis of wavefield produced by scattering of signal of vibrator (Fig. 13 (b)) with the wavefield produced by scattering of waves of unknown source (Fig. 13 (a)). That is why in our study we compared them not to each other, but to a priori geological information. Both of them do not contradict the geological information. 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: Same comments to Figure 12 applies for Figure 16. Figure 17, is it have an figure or table to validate or compare with the 2D profile with existing wells?

Authors: Unfortunately, there are too few data from wells in the studied area available for comparison. The wells drilled by Geological Survey of Finland does not penetrate deep, and the data of wells drilled by exploration companies are not available for research organisations. We compared our results with geological information (boundaries of geological units) and with the data about rock properties and composition in XSoDEx area summarized by Leväniemi et al. (2018). In this study no direct measurements of S-wave velocities were made. The presented results are the first detailed information about shear wave seismic velocities in the subsurface for the studied area.

Refernces Afonin, N., Kozlovskaya, E., Nevalainen, J., Narkilahti, J.: Improving the quality of empirical Green's functions, obtained by cross-correlation of high-frequency ambient seismic noise, Solid Earth, 10(5), 1621-1634, https://doi.org/10.5194/se-10-1621-2019, 2019 Bohlen, T., Mueller, Ch. And Milkereit, B.: Elastic Seismic Wave Scattering from Massive Sulfide Orebodies. On the role of Composition and Shape. In: Eaton, D.W., Milkereit, B., and Salisbury, M. Hardrock Seismic Exploration. Geophysical Developments No. 10, Society of Exploration Geophysics, pp. 70-89, 2003. Gritto, R., Korneev, V. A., & Johnson, L. R. (1995). Low-frequency elastic-wave scattering by an inclusion: limits of applications. Geophysical Journal International, 120(3), 677-692. Leväniemi, H., Melamies, M., Mertanen, S., Heinonen, S., Karinen, T.: Petrophysical measurements to support interpretation of geophysical data in Sodankylä, northern Finland, Geological Survey of Finland Open File Work Report 25/2018, 2018 Mulargia, F. (2012). The seismic noise wavefield is not diffuse. The Journal of the Acoustical Society of America, 131(4), 2853-2858. Wapenaar, K.: Retrieving the Elastodynamic Green's Function of an Arbitrary Inhomogeneous Medium by Cross Correlation, Physical review letters, 93(25), 254301, https://link.aps.org/doi/10.1103/PhysRevLett.93.254301, 2004

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2020-160, 2020.