Authors response to Reviewers Comments: Anonymous Referee #2
Manuscript **SE-2021-142**

Dear Reviewer,

Thank you for your time and efforts devoted to the evaluation of our manuscript! We appreciate the chance to know your suggestions for improving the processing and future experiments. We are also very grateful for emphasizing the specific nature of our study, and appreciation of the selective stacking processing. In this response letter, your concerns and comments are highlighted in violet color, while our responses are in black. The figure included in this response is exclusively for the review purpose and thus denoted with the letter "R".

The manuscript provides an interesting case study for the application of ambient noise interferometry to a polymetallic mine, with a large N seismic deployment. The key idea of the manuscript is to apply seismic interferometry (SI) selectively to sections of the continuous dataset dominated by body waves to extract a reflection volume. To my knowledge, not many examples exist of selective SI with large N datasets, and even less, if any, applied to a mine setting.

The methodology of the manuscript is robust, in that the authors first study the temporal and spatial distribution of frequency-amplitude within the dataset, followed by examining the directionality and speed of the different seismic arrivals. The authors later apply a selection methodology to extract noise panels dominated by body waves.

The rest of the manuscript deals with computation of virtual source gathers, which has been discussed at length in the literature. The key aspect of this section is the comparison of the virtual gathers that resulted from the selective SI with standard SI gathers (all data in, blind cross-correlation) and more importantly with active source gathers.

Finally the authors discussed their result which in my opinion are acceptable and show evidence of reflected arrivals in both the selective SI and standard SI gathers, specially given the complexity of imaging crystalline targets in which some of them are at near vertical angles.

Overall my recommendation is that the article merits publication.

Thank you for very much for this constructive and positive opinion.

Specific comments:

It is not clear from the data section that the geophones used are vertical component or 3C (etc).

Thank you for this comment. We added explanation to the Data section: "We used 994 vertical-component receiver stations distributed regularly over the 3.5 x 3 km area with 200 m line spacing and 50 m receiver interval (Fig. 1)."

No comments are made about multicomponent processing thus I am assuming that vertical component geophones were used. For future consideration would be to deploy 3C nodes in order to image the PP, PSV, SS wavefields to obtain different illumination zones. Equally interesting would be to explore ambient noise interferometry of a large N array with the different seismic wavefields and a large-N dataset.

Thank you for this comment. Indeed, we used vertical-component geophones. In the same area, single 2-D receiver line consisting of 3C seismometers was deployed, and there is a study investigating the passive and multicomponent imaging capacity, that aims to utilize the benefits of all components in conjunction with seismic interferometry (Väkevä, 2019). It would indeed be very nice to deploy a 3C large-N network, as we agree that it would benefit the imaging and interpretation of subsurface structures.

Employing 3C large N arrays would likely facilitate identification of seismic arrivals (e.g., P or S) and even perhaps help the application of selective SI.

Thank you for this comment. We are grateful for this suggestion and will consider this for the future experiments. Maybe, the alternative and good tradeoff solution would be using 2D line, or sparsely distributed array of seismometers (deployed within the area of the main 1C large-N array), to have the time-parallel data with 3 components, just for the wavefield-identification purposes. Either way, your suggestion would allow to improve the SNR of retrieved arrivals, and probably reduce the processing costs, as some parts of data could be immediately rejected based solely on the type of dominant source acting at the time, which could be identified from the 3C data.

It was not quite clear why Day 6 is not used in the selective SI methodology, it seems to have a large component of body wave energy in it. Perhaps the authors might want to comment on this.

Thank you for this very relevant comment. From the general point of view, and looking just at the beamforming plots, indeed for some applications Day 6 could be better than, for instance, Day 2. However, as we will explain below, for the selective stacking and the case of passive reflection imaging shown in this study, Day 6 is actually 'worse'. As we show in Figure R1 in this response, Day 2 and Day 6 differ significantly in the dominant directions of recorded ambient noise (indicated with the black arrows). Apart from the beamforming plots, Figure R1 contains the exemplary, representative types of waveforms recorded during both considered days, with insets showing zoomed parts of the data in the black rectangles. Essentially, as revealed by Figure R1, Day 2 is typified by body-wave events, while Day 6 is typified by a combination of random noise, and local (affecting up to several-tens of stations) surface-waves. However, as visible in the beamforming plots, despite the total differences in the recorded waveforms, the apparent slowness for both days is high (>4.8 km/s). The reason for this, is that surface waves travelling at angle can be recorded with apparent velocity that is typical for body waves. Therefore, as explained in the manuscript, we need some further verification which events are body waves, which we achieved with TWEED.

As explained in the manuscript, we were looking for days that altogether form the omnidirectional contour, such that each day (here represented by single beamforming plot in Figure 3 in the manuscript) taken for this subset provides a more or less unique illumination direction that is not covered by other days. In the ideal situation, it would be for instance 360 days (or even much less), each contributing with unique dominant azimuth(s). However, since we deal with field data, the subset of days to choose from is inherently limited, and the ambient-noise contributing to given day has quite random distribution from several dominant directions (as shown with black arrows for Day 6 in Figure R1 in this response). To fully visualize this feature of the field data, we decided to show in the manuscript the analysis for the full 30 days, which in our opinion is interesting by itself, and is rarely shown. Day 2 exhibited a desired, unique illumination direction, while Day 6 exhibited three different dominant directions, that were not needed, because we already chose other days, that covered each of these directions, as a single, dominant contribution.

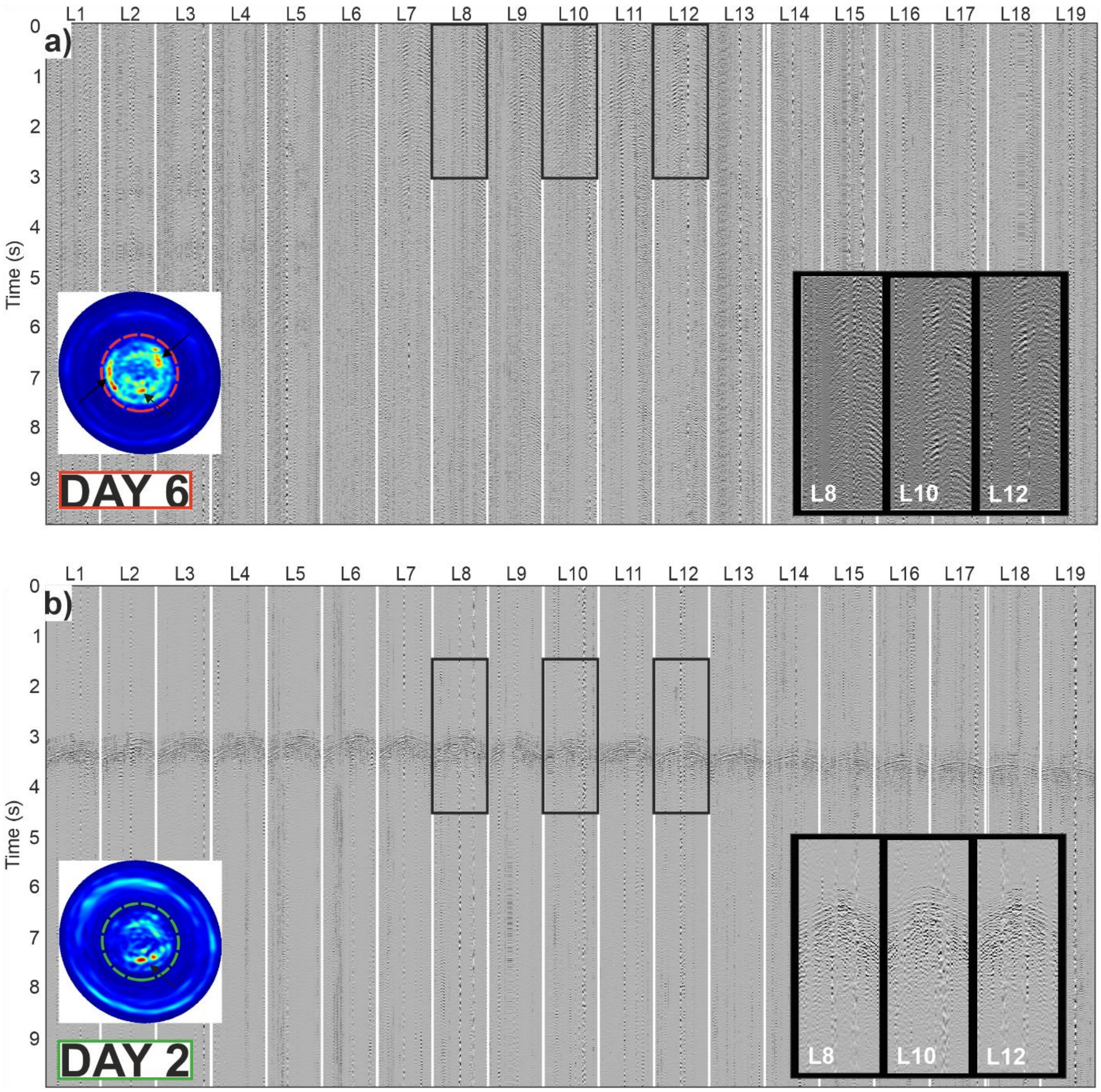

Figure R1. Representative seismic events recorded by all 19 receiver lines of the Kylylahti array during Day 6 (a), and Day 2 (b) of the acquisition period. Colored insets show beamforming results for the respective day, and the grey scale insets show zoomed part of data denoted with black rectangles.

Improving the resolution of figures would be greatly appreciated.

Thank you. This time we uploaded all figures as individual files, that were rendered in high resolution.

Lastly for future consideration, perhaps implementing a slowness filtering for all the dataset (30 days) would get the best of both approaches, selectively isolating body waves and at the same time using the entire continuous dataset. Something to consider.

Thank you for this suggestion. This idea sounds very interesting and appears as a processing strategy that could improve our results. Do we understand correctly: it is about applying some velocity filtering on the time-windowed data (noise panels) before the crosscorrelation?

It seems that the key aspect here would be the optimization of such solution to minimize the computation time necessary to process all recorded panels. On the other hand, the TWEED method is also a kind of slowness evaluation, which scans for dominant velocities in the preselected range, therefore essentially provides the required a-priori information which is needed for slowness filtering. Alternatively, the conventional solutions like Tau-P or f-k filtering could be utilized, as a robust tool for filtering of the continuous recordings.

Thank you for all of your comments and time devoted to read our answers!

On behalf of the authors,

Michal Chamarczuk

References:

Väkevä, S.: Using Three-Component Data for Seismic Interferometry Studies at the Kylylahti Mine (Unpublished master's thesis). University of Helsinki, Finland, 2019.