Solid Earth Discuss.,
https://doi.org/10.5194/se-2019-29-AC2, 2019

Solid Earth
Discussions

Interactive comment on "Improving quality of empirical Greens functions, obtained by cross-correlation of high-frequency ambient seismic noise" *by* Nikita Afonin et al.

Nikita Afonin et al.

nikita.afonin@oulu.fi

Received and published: 1 May 2019

Michał Chamarczuk mchamarczuk@igf.edu.pl

Received and published: 2 April 2019

Referee: Please see below the comment to the manuscript about method for retrieval of Green's function (GF) with high S/N ratio in selected time window. This post is encouraged by one of the comments of the Anonymous Refree #1 suggesting to focus on the originality of proposed ambient-noise processing technique. In this paper authors propose a method to retrieve improved version of Green's function between receiver pairs and apply it on two different datasets. The paper is enjoyable to read and seems like a great case study. The method is based on rejecting cross-correlation functions which after stacking do not increase the S/N ratio in the time window related to arrivals of the desired phases. The S/N ratio in this method is calculated according to equation 1 (Page 3), and generally is obtained by dividing the maximum amplitude in time interval of expected arrival by the summed amplitudes in the remaining part of CCF. If adding the CCF does not increase the S/N ratio, then it is rejected. Generally all methods basing on S/N criteria are robust and effective, and they are commonly used as part of ambient-noise processing workflows. The main issue of 'S/N ratio stacking' proposed here is that the method seems to be not novel. To give some examples please see the papers by Olivier et al. (2015) and Nakata et al. (2015). Both papers describe the process of extracting body-waves form ambient noise and both apply S/N ratio based method as one of the steps in processing workflow. Olivier et al. (2015) designs the selective stacking algorithm for enhancing the S-wave arrivals recorded with array of receivers in the underground mine. In their method the root-mean-square value (RMS) of the signal in the lag-time window of the correlation function around the expected arrival times of the S-waves is divided by the RMS of the signal in the time window of coda waves. It is practically the same method, just instead of maximum amplitude authors use rms. Nakata et al. (2015) as part of his ambient-noise processing designs two different S/N ratio based techniques. First one is more elaborate, so please see the mentioned publication. The second one is (direct citation from paper): "To confirm that we can successfully isolate the traces with strong body wave energy with the second correlation, we compute SNR, which is defined as the average RMS amplitudes between 1.3 and 1.9 s divided by the average RMS amplitudes between 0.0 and 4.5 s." – again please note the striking similarity of the method. It is important to note that the two above techniques were just one step of the more elaborated processing workflows, and both of the mentioned papers included also extensive synthetic tests and applications of tomography.

Authors: 1) The novelty of our technique compared to the other techniques mentioned by the reviewer is that we applied global optimization algorithm to objective function (SNR of EGF in our case) for evaluation of the best solution (EGF of the highest quality). In our proposed algorithm, we calculate SNR as a function of several parameters (time lags with an expected signal, initial time windows number etc., see the algorithm description). A parametrisation of the global optimization problem is based on the a-priori information and generally, is problem-dependent. After this, the algorithm finds the best solution corresponding to the global maximum of SNR function.

2) The other important feature of our algorithm is that the signal-to-noise ratio is estimated in the time-domain and hence the objective function in global optimization problem is sensitive to variations of not only the RMS, but also to other parameters. For example, changing the azimuth to noise source will shift the position of the signal maximum in the time window considered. In this case, the RMS for this window may be the same, but the position of the maximum will be shifted. Therefore, our algorithm will reject this function, while algorithms based on RMS would not. It is true that our method is using the ideas proposed by other authors, and we cited all these studies in our paper. However, we developed the original method of signal-to-noise ratio optimisation, which is more sensitive, because we use the maximum of CCF instead of RMS. We compared results obtained by several methods (RMS-based stacking and weight stacking (figure 6)) and found out, that our proposed technique allows obtaining EGFs of better quality. Moreover, we advanced the algorithm of stacking by using of global optimization of SNR, which makes results more robust and independent on initial cross-correlation function. Suggested papers have been cited in the text.

Referee: Second part of comment is related to the line 15 (Page 2) in the discussion manuscript where authors provide their definition of 'coherent' term. According to this definition the two EGFs are coherent if their maxima fall in the same time window (appear at the same time-lag). While, this definition of coherence is comfortable in terms of improving Green's function it might not necessarily be correct for the field applications.

Authors: We used the term “coherence” in order to simplify the description of the method and we explained in what sense it is used. We think that our definition is close to the standard definition of this term in physics, but in our case, a wave is a cross-correlation function. In our case, increasing of SNR after stacking of two cross-correlation functions is the same as a result of interference of two waves which are coherent to each other. There are also some differences from the standard physical definition of coherence. For example, we use time lags with maximums instead of phase differences.

Referee: In lines 25-30 (Page 2) Authors argue that stacking only EGFs with which increase S/N ratio given in equation 1, does automatically increase the coherency. This is true, but only for the specific definition of coherency given in this manuscript, which however does not relate to the retrieval of correctly estimated Green’s function, which needs source in the stationary phase areas.

Authors: We agree with this comment, but we explained in our paper in what sense we use the term “coherence”. Our proposed technique allows increasing signal-to-noise ratio, but it does not guarantee to estimate of the true EGF, because the source may be located outside the stationary phase area. Nevertheless, using our technique together with the array analysis techniques, which allow estimating azimuth to the noise source, makes it possible to evaluate EGF of high quality. The discussion has been added to the Conclusion part of the manuscript.

Referee: In line 10 (page 2) authors indeed comment that its important to use systems which allows to estimate the azimuth distribution of noise sources (to increase a chance of capturing the sources in stationary phase areas), yet this comment does not suffice to make a method feasible for improved processing, as usually the exact distribution of sources is not known. In such cases, specific methods can be used for estimation these azimuths (like beamforming etc.), yet when this directional analysis is already done, then it is enough just to stack these sources. After this, any measure of the increase of amplitude in expected time window becomes trivial task.

Authors: In our paper, we consider two cases that are of practical importance for geophysical explorations: the first one is brownfield exploration, in which position of the dominating noise source is relatively well known (e.g. mine) and the second one is greenfield exploration, in which we have no any a-priory information about spatial and temporal distribution of noise sources. In the first case, after directional analysis of noise sources, the EGF evaluation is an easy task if one of the following conditions is satisfied: 1) the azimuthal distribution is homogeneous; 2) there are sources located in some limited area and producing noise of high energy. However, if the noise sources are stochastically distributed both in time and in space and are weak, then using simple stacking for extraction of EGF is not a guarantee of a good result, even if one can estimate the azimuthal distribution of noise sources, and evaluation of EGF become not a trivial task. We demonstrated this by our Kuusamo experiment (see fig. 10).

Referee: Generally, it is reasonable to measure the EGF using coherency because it will, in ideal situation, selectively correct virtual traces, which contribute to the stack. However, using S/N ratio in selected time windows might not be necessarily correct, as the source we are stacking might be located in non-stationary phase areas. In other words, the maximum amplitude we eventually get, may not mean we stack sources related to the stationary phases (which depends on the source-receiver configuration).

Authors: This issue is partially solved by using global optimization of SNR in our proposed algorithm (see also our reply to the comment above).

Referee: Second issue related to possibly biased coherency improvement is related to the division in equation 1. The coherency improvement is theoretically assured if S/N ratio calculated from equation 1 is increasing. This might not be necessarily true, e.g., if coda wave part gets smaller (the denominator in equation 1) the S/N also increases, and again it means that source contributing to desired time-windows might be not related to the stationary region.

Authors: This is one of the possible problems of the method. The correspondent dis-

Printer-friendly version

Discussion paper

cussion has been added to the text. But in our paper, we considered two real data cases that are of practical importance for geophysical exploration, and we demonstrated that method is working.

Thanks for reading and looking forward to your reply. Kind regards, Michal Chamarczuk

---

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2019-29, 2019.