Solid Earth Discuss.,
https://doi.org/10.5194/se-2020-157-RC2, 2020

Solid Earth
Discussions

Interactive comment on "Evaluating Seismic Beamforming Capabilities of Distributed Acoustic Sensing Arrays" *by* Martijn P. A. van den Ende and Jean-Paul Ampuero

Anonymous Referee #2

Received and published: 31 October 2020

General overview:

This work aims to explore the performance of DAS array for the purpose of beamforming, in comparison with a co-located nodal seismometer array. The authors used ground motions generated by a ML 4.3 earthquake that occurred on 21 March 2016 and located 150 km of the geothermal field of Brady Hot Springs. The Poroelasctic Tomography (PoroTomo) project conducted an experiment on this geothermal site in March 2016, involving an array of 238 3C seismometers deployed over an area spanning 1500 by 500 m, as well as several fibre-optic cables for DAS sensing. After a presentation of the PoroTomo experiment and an introduction of the MUSIC beamforming method

used in this work, spectral characteristics of the signal recorded by nodal sensors and DAS are presented showing that DAS has a flat frequency response even at very low frequencies and is characterized by the lack of directional sensitivity.

Beamforming analysis applied to nodal arrays with P- and S-waves shows a well-resolved source with a back-azimuth close to the true back-azimuth. This result is consistent with a very strong coherence of waveforms across the entire nodal array. In strong contrast with the nodal array, P- and S-waves recorded by the DAS show a low degree of coherence, which means that DAS array is unable to produce a robust source back-azimuth and apparent velocity. By simulating DAS recordings from nodal array, the authors show that the lack of coherence and beam resolution seen in the DAS data cannot be attributed to DAS-specific technicalities like coupling of the DAS cable with the ground. This kind of analysis is very useful and informative for the DAS community. However, clarifications should be provided. To compare the strain rate obtained with the nodes to that measured with the DAS, shouldn't we use a distance between the nodes equivalent to the gauge length? This is not clear to me and it is important to clarify this point in the article.

The authors then selected individual small, linear segments of the DAS array, which exhibit high waveform coherence. Combining the beamforming results of these segments, they obtained results in better agreement with the true arrival of the seismic source. Nevertheless, this work and theses analysis show that beamforming methods that are traditionally applied to particle velocities don't give so good results when applied to strain rates. DAS array reveals source locations that likely correspond with shallow scattering sites. In conclusion, authors state that the waveform low coherence is inherent to DAS measurement principle, which leads to lower sensitivity of DAS recordings to waves arriving at the array with a steep inclination, and amplifies scattered waves arriving at shallow inclinations.

This article is very well written and presented, the data analysis is clearly outlined, even if some clarifications have to be provided. This is probably one of the first analysis comparing results of beamforming analysis obtained with strain rate recorded with a DAS and particle velocities recorded with a co-located nodal array. The contribution of this work is significant because it constitutes an advance in the better understanding of DAS recordings. It also constitutes an important contribution from the point of view of beamforming analysis of strain rate data. This work shows the limits of the application of beamforming methodology to strain rate data as it is usually applied to particle velocities recorded with inertial seismometers and this constitutes a very useful information for the seismological community. From my point of view, this work deserves to be published. I have some minor remarks in the following.

Minor comments:

3.2 Beamforming results of the nodal and DAS arrays

- Line 117: Indicate is beamforming was performed by using all the sensors. An array response function could be useful to see the influence of the geometry of the array. As the number of seismometers is huge, I am wondering if you tried to analyze data recorded by sub-arrays.

- Lines 125-126: "(consistent with the ratio of vertical to horizontal amplitudes of the nodal P-waveforms)". This sentence is not clear to me. Amplitudes of vertical and horizontal components are not commented in the text.

- Line 134: I don't understand what "polarity flips" mean in this context. Can you clarify ?

- Line 138: It is not clear if all the fibre-optic cable was used for the beamforming analysis. The gauge length should be indicated, as well as the distance between each strain rate measurement and the total number of individual SR measurements used in the beamforming analysis.

3.3 Simulating DAS recordings from the nodal array

-Line 152: one component of strain

- Line 166: The angle teta is considered relatively to North ?

- Line 155-171: The simulated strain rate is calculated with node pairs separated by a distance less than 80m. Is this distance equal or bigger than the gauge length used during the experiment (the GL used during the experiment is not indicated in the manuscript)? Why not showing in a figure simulated strain rate signal and measured strain rate on the same segment?

3.4 Selective beamforming of the DAS array

The beamforming analysis on the P-waveforms recorded by the DAS array should be clarified. Are you using the same analysis parameters as for the beamforming of the nodal array? In term of frequency range, time window length? It would be useful to indicate how long are the segments of fibre used for beamforming analysis and how many strain rate measurement points they include.

- Line 233-234: Indicate in parentheses the segments corresponding to a direction-of-arrival between the east and the south and a direction-of-arrival from the north. The text will be easier to read if you indicate the number of the segments.

- Line 233-234 and figure 12: What is discriminating more between the 2 groups of segments, the back-azimuth or the apparent velocity ?

- Line 240: "implicitly"

- Line 245: As mentioned before, indicate the number of the segments.

- Line 245: When excluding segments 4 and 6, the geometry of the DAS array used for beamforming is relatively linear. This geometry probably explain the elongating shape of the PDF in figure 12d. As I mentioned before for Line 117, it would be useful to show the array response function.

Have you tried to estimate the slowness vector with sub-arrays? For example, segments 1, 2 and 3 constitute an array with a less linear geometry.

Figures:

Figure 8: The indication of the direction of propagation of the wavefield would help to better understand the selection of the segments in red.

Figures of beamforming results: Apparent velocity values are difficult to read, either because they are represented in red, or because character size is too small.

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