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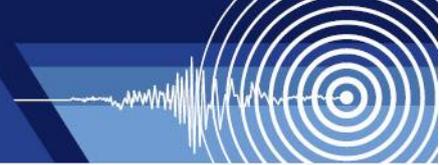
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Subsurface characterisation with three-component ambient noise beamforming: theory, codes, and applications

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We developed a beamforming toolbox for three-component ambient seismic noise data (B3AM) that enables characterisation and monitoring of the (near) subsurface, and provide a comprehensive overview of its workings and applications. Beamforming is an array technique that analyses phase shifts of the recorded wavefield across the different stations of a seismic array, thereby providing estimates of dominant wave velocities and propagation directions. Measuring phase shifts across the three components of each station further enables us to perform polarisation analysis and identify different wave types and their respective characteristics, for example, Rayleigh wave ellipticity. We explain how these phase shifts are related to a set of intuitive geometric parameters, such as azimuth and dip angle, uniquely describing a specific wave and its propagation properties. As a result, we obtain a quantitative wavefield composition plot as a function of frequency as well as wave type specific dispersion curves and direction of arrival plots.

We show examples of B3AM analysis in geothermal fields providing shear-wave velocity profiles and surface wave anisotropy estimates related to the presence and orientation of faults. Examples from ambient noise data in the Groningen area (NL) and the Weisweiler geothermal development (DE) show the potential of the method to improve thickness estimates of sedimentary layers, an important parameter in seismic hazard assessment and reservoir characterisation. Using synthetic data, we demonstrate that B3AM can also be used on transient data and allows us to identify arrival time windows of different waves (in particular Rayleigh waves) in a complex wavefield. The code package is available in both MATLAB and Python (B3AMpy).

