Time-reversal, cross-correlation and resolution of the focal spot: A novel seismological imaging approach based on properties of refocusing surface wavefields

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Modern dense seismological deployments allow the reconstruction of the seismic wavefield in the near-field from noise cross-correlations. The correlation approach makes it thus feasible to resolve the focus or focal spot, which is a characteristic feature of the cross-correlation wavefield at zero lag time t. The emergence of the focal spot is tied to the physics of a time-reversal process. Based on the equivalence of time-reversal and cross-correlation, the spatial correlation amplitude patterns at different lag times correspond to a converging (surface) wavefront at $t < 0$, the collapse or focal spot at $t = 0$ and the diverging wavefront at $t > 0$. We introduce a seismological imaging method based on high resolution reconstructions of the focal spot (Fig. 1a). This approach has been used in acoustics, nondestructive testing and medical imaging; we apply it here for the first time in a seismological context. The approach is based on the dependence of the spot shape on local properties of the propagation medium. We construct noise correlation functions from data collected by a highly-dense Nodal array centered on the San Jacinto fault zone south of Anza (southern California). The focal spot is obtained from the cross-correlation amplitude distributions at zero lag time (Fig. 1a). Strong body and fault zone waves that are associated with the complex fault zone structure prohibit the straightforward analysis of the spatially variable zero lag time distributions. We remove the body and fault zone wave components with a filter in the wavenumber domain. This yields improved reconstructions of the surface wave focal spot. The associated data of amplitude vs. distance are fitted with a damped Bessel function. The first zero-crossing of the function is directly proportional to a well-defined fraction of the seismic wavelength at the location of the correlation reference station. We repeat this analysis using each geophone location as the collapsing point to which the estimates of the wavelength or -speed (Fig. 1b) and of the damping-factor are related. Estimates of medium anisotropy can also be directly inferred from the non-circular spot shape (Fig. 1b). The overall consistency of the local wavespeed estimates from the focal spot properties and images obtained with a traditional travel time inversion using the same dataset validates the near-field approach. Both methods reveal a complex velocity structure that exhibits pronounced low-velocity zones whose location, extension and continuity depend strongly on frequency and hence depth.

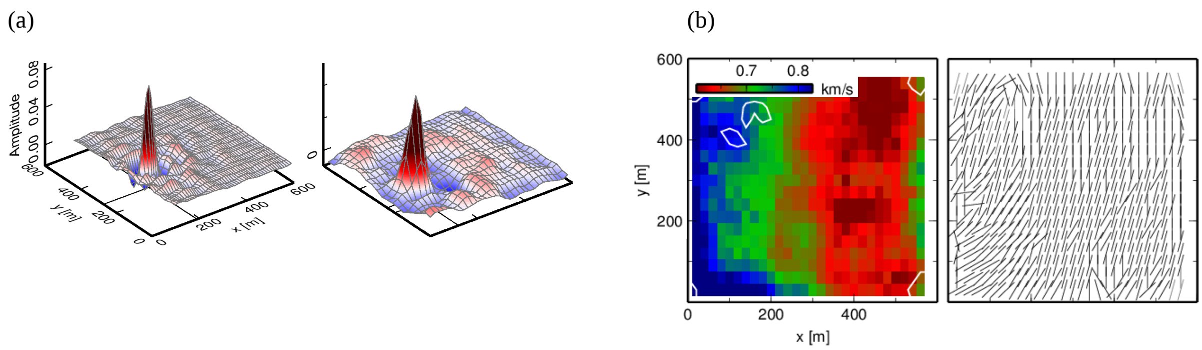

Figure 1. (a) Reconstruction of the refocusing surface wavefield in two frequency bands associated with a virtual source at the indicated locations. The focal spots are zero lapse time noise-correlation amplitude distributions obtained from correlation functions between the reference or source station and all other stations on the regular grid. (b) Measurements of the size and shape of the obtained focal spots yield, among other properties, spatial distributions of wavespeed estimates (left) and the directions of fast propagation (right). The spatial domain is defined by the array deployment.