Preliminary study of precursor and scattered waves imaging of ambient noise cross-correlations from the Seal Beach dense array

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Abstract

Virtual Green's function constructed using seismic noise can provide useful information about the subsurface. Dispersion phenomena of the direct arrival can be used to retrieve the subsurface velocity structure on dense seismic arrays (Castellanos and Clayton, 2021). In addition, when velocity anomalies are present, these virtual source gathers present scattered and precursory energy. These apparently events can be used to image scatterers by performing a coherent stacking process (Ma et al., 2013). We present a method that form images of these velocity anomalies using cross-correlation scattered and precursory waves. We describe a synthetic example of imaging a fault line and report preliminary observations of precursory energy in noise cross-correlations obtained on seismic data recorded by a dense station array in the Seal Beach area (Jia et al., 2021). These observations are parallel to the recently identified Garden Grove fault line present in the Los Angeles basin (Gish and Boljen, 2021).

Noise cross-correlation scattering and precursors

To simulate cross-correlation precursors and scattered waves caused by velocity anomalies present in an area, we employ a simple constant velocity model in which we add a velocity anomaly resembling a fault line (Figure 1b). We generate data using 701 sources with a band-limited wavelet between 0.1 and 1.0 Hz recorded by two receivers (Figure 1a) and compute the cross-correlations for each source using a non-uniform source energy distribution (Figure 1c). When a line of stations (blue triangles in Figure 1a) crossing the fault line is employed to construct the noise cross-correlation for a given virtual source (red triangle) (Figure 1d), we can observe scattered waves departing from the direct arrival at the position of the station on top of the anomaly. In addition, because of the non-uniform source distribution, in the non-physical gather portion, a precursor arrival can be generated.

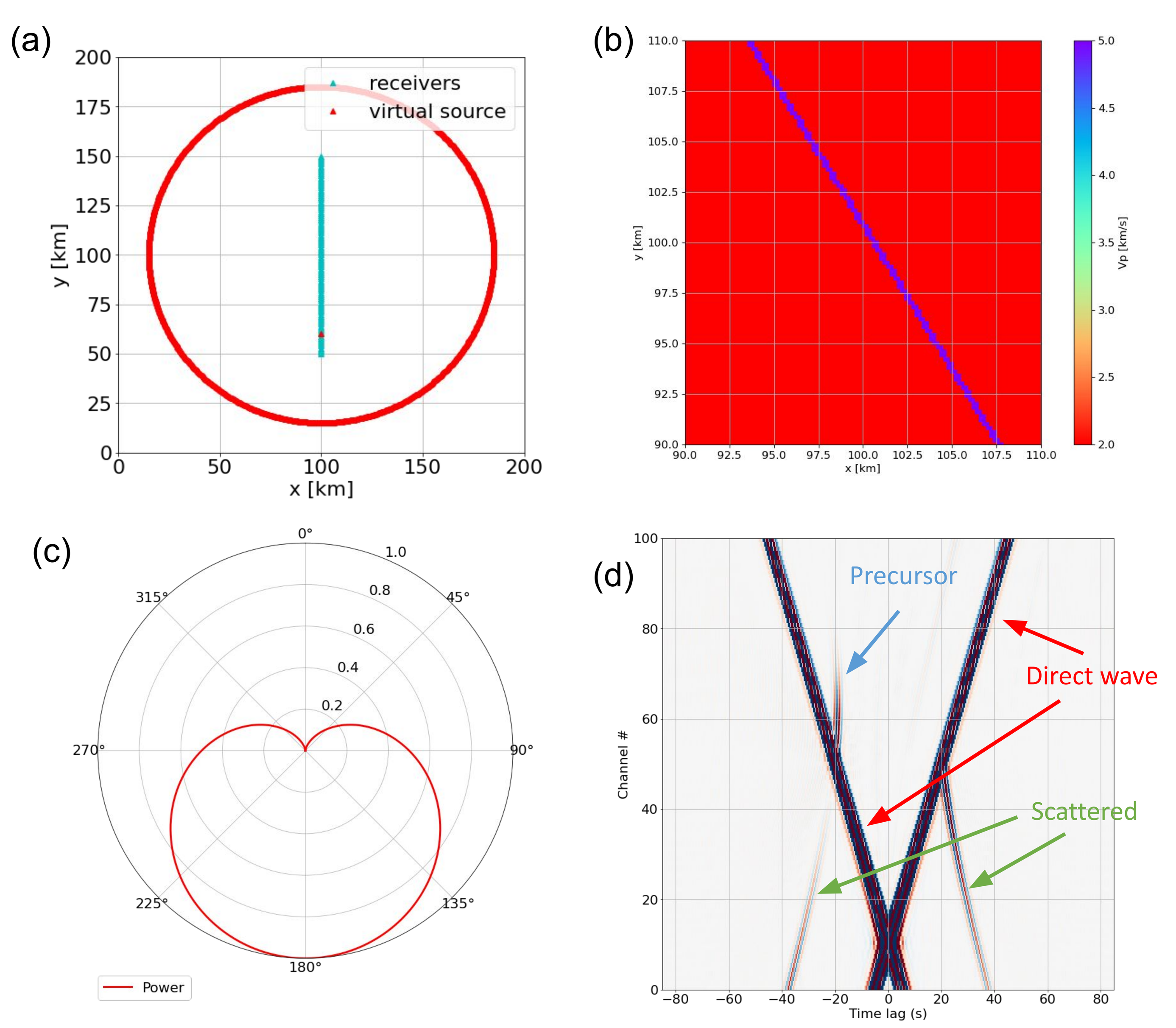

Figure 1: (a) Source distribution (red circles) and station line (blue triangles) chosen to show an example of cross-correlation data for a given virtual station (red triangle). (b) 2D velocity model used for the synthetic test. (c) Source energy azimuthal distribution chosen. (d) Interpreted cross-correlation panel for the virtual source chosen in panel (a).

Cross-correlation imaging

We design a delay and sum process where the energy belonging to imaging precursors is coherently stacked to form an image of potential scatterers present in an area. The image I is formed by computing the following summation:

$$I(\mathbf{x}) = \sum\sum CC[\mathbf{x}_s, \mathbf{x}_r, \tau_c(\mathbf{x}, \mathbf{x}_s, \mathbf{x}_r)],$$

where $\mathbf{x}$ denotes the image point, τ is the cross-correlation lag, $\mathbf{x}_s$ is the virtual source position, $\mathbf{x}_r$ is the receiver coordinate, and τ_c is the precursor or direct scattering traveltime. This process effectively produces an image cube as a function of 2D spatial coordinates. If the precursory or scattered energy is coherently summed, then this energy would focus on image positions corresponding to potential scatterers.

Synthetic test results

To highlight the ability of this stacking process to image fault lines, we construct virtual source gather using the same synthetic test as in the previous section but we employ the station geometry depicted in Figure 2a. Figure 2b shows some stacking curves for different image points (blue curves) corresponding to the traveltime curves $\tau_c(\mathbf{x}, \mathbf{x}_s, \mathbf{x}_r)$. To avoid stacking energy associated with the direct arrival, we neglect any point falling within the portion delimited by the red curves within Figure 1b. By stacking the energy for all virtual source-receiver pairs, we can form a clear image of the fault line (Figure 2c). A similar image would be formed when the waves corresponding to the precursory energy are employed in the stacking procedure.

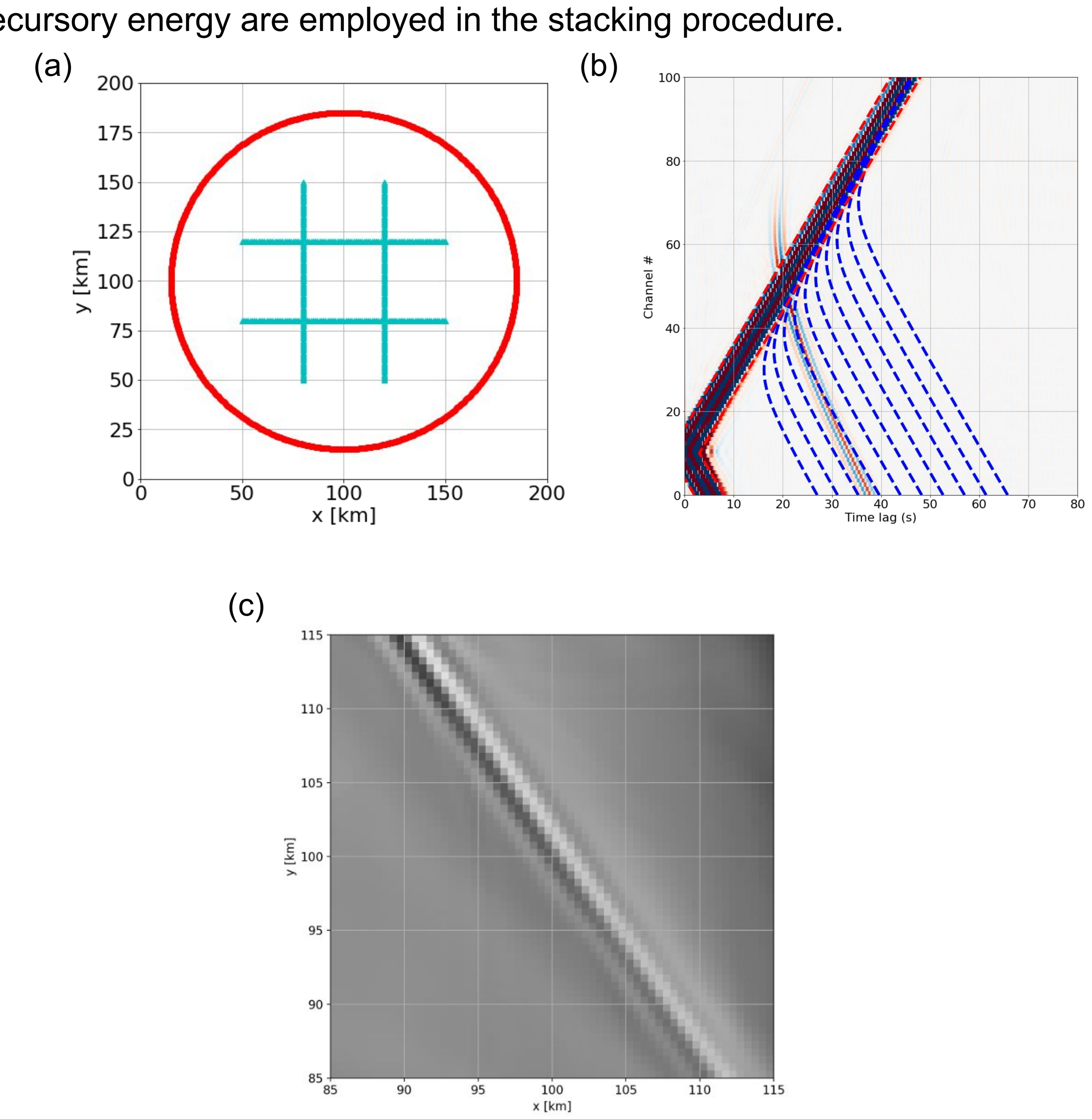

Figure 2: (a) Selected stations employed to form an image of the fault line of Figure 1b (b) Folded virtual source-gather showing the portion of data containing the direct arrival (limited by the red lines) and various stacking curves (blue lines) for various image points. Only some will stack coherently the scattered arrival. (c) Obtained image of the fault line using the described procedure. A similar image is produced when the precursory energy is used instead of the direct scattered waves.

Seal Beach observations

We process data from the dense Seal Beach array to study the presence of potential fault lines within the Los Angeles basin (Figure 3a). To this end, we employ two lines of stations and use the high-resolution model by Castellanos and Clayton, 2021. Figure 3b shows the shallow seismicity of the area in which events are distributed along a line between the Newport-Inglewood and Los Alamitos faults. This seismicity is aligned with the presence of two precursors observed in the binned cross-correlations of two different station lines (Figure 3c-d). The positions of the precursors match the locations of the shallow seismicity in Figure 3b.

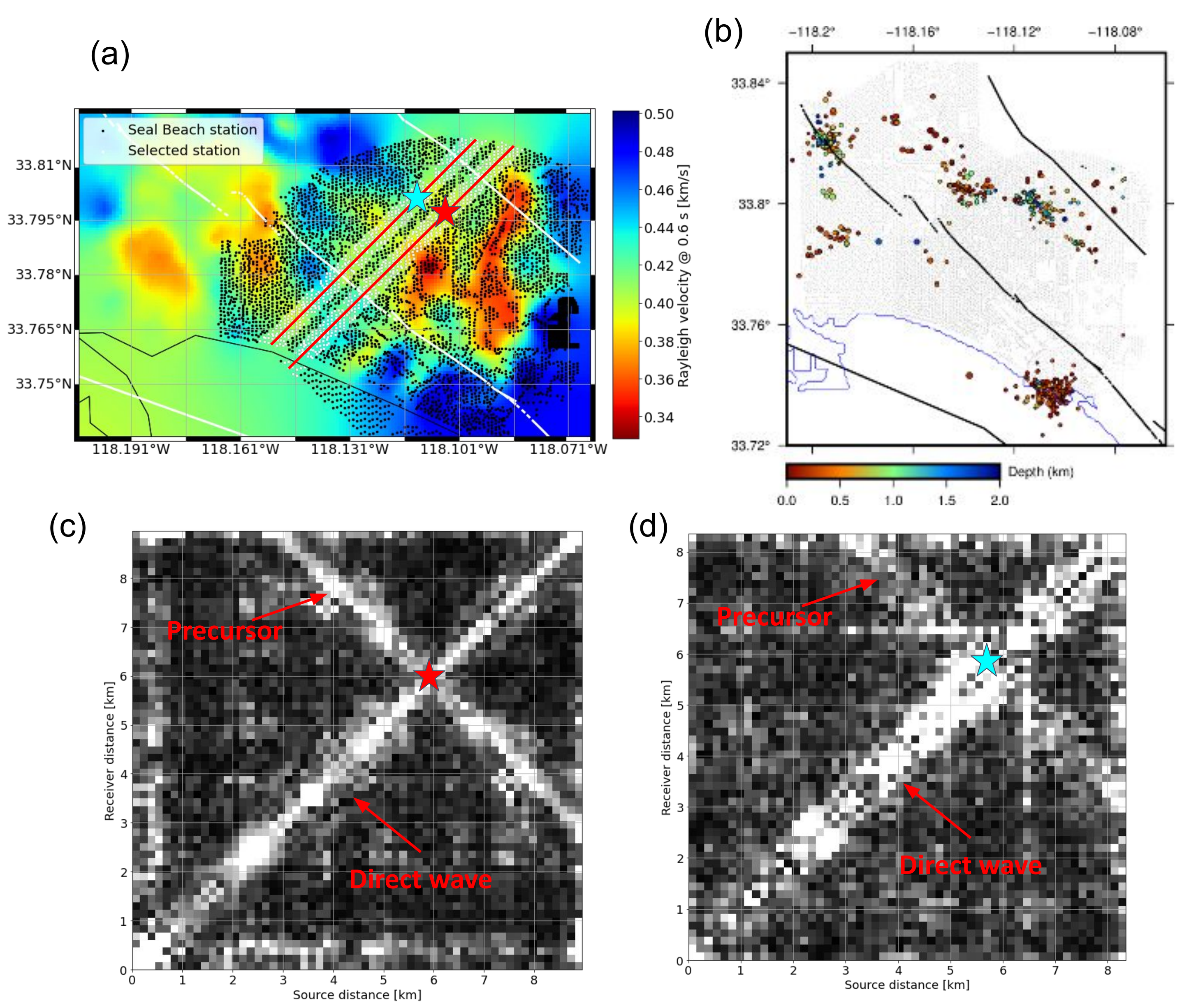

Figure 3: (a) Rayleigh velocity map of the Long Beach and Seal Beach area (Castellanos and Clayton, 2021) overlaid with the dense array stations (black dots) and the selected ones (white dots). The white lines represents the USGS mapped fault lines (b) Shallow seismicity of the area (Yang and Clayton, 2022). (c-d) Binned lines of cross-correlation function at zero-lag in which clear evidence of a precursor can be observed. The colored stars corresponds to the scatter locations in panel (a).

Conclusions

We present a stacking process that can be employed to image fault lines present in an area. This process employs noise cross-correlations constructed using dense seismic arrays. We report preliminary observations on the presence of a new Garden Grove fault line within the Los Angeles basin.

References

Castellanos, J.C. and Clayton, R.W., 2021, The Fine-Scale Structure of Long Beach, California, and Its Impact on Ground Motion Acceleration. Journal of Geophysical Research: Solid Earth, 126(12), p.e2021JB022462.

Gish, D. and Boljen, S., 2021, Newly identified fault in Seal Beach, CA, quietly rattles beneath the city, Temblor, http://doi.org/10.32858/temblor.219

Jia, Z. and Clayton, R.W., 2021, Determination of Near Surface Shear-Wave Velocities in the Central Los Angeles Basin With Dense Arrays. Journal of Geophysical Research: Solid Earth, 126(5), p.e2020JB021369.

Ma, Y., Clayton, R.W., Tsai, V.C. and Zhan, Z., 2013, Locating a scatterer in the active volcanic area of Southern Peru from ambient noise cross-correlation. Geophysical Journal International, 192(3), pp.1332-1341.

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