The virtual refraction: Useful spurious energy in seismic interferometry

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Seismic Interferometry is rapidly becoming an established technique to recover the Green's function between receivers, but practical limitations in the source energy distribution inevitably lead to spurious energy in the results. Instead of attempting to suppress all such energy, we use a spurious wave associated with the crosscorrelation of refracted energy at both receivers to infer estimates of subsurface parameters. We name this spurious event the virtual refraction. Illustrated by a numerical two-layer example, we find that the slope of the virtual refraction defines the velocity of the faster medium and the stationary phase point in the correlation gather provides the critical offset. With the associated critical time derived from the real shot record, this approach includes all the necessary information to estimate wave speeds and interface depth without the need of inferences from other wave types.

Consider the two-layer acoustic model shown in the left of Figure 1. We place an explosive seismic source (with a dominant wavelength of ~ 30 m) at the first receiver location ($r1$) and model the wavefield for 0.8 s after the explosion on 101 receivers evenly spaced on a 400 m line, 52 m above the interface. We use the SPECFEM2D seismic wave propagation code to model the wavefield. The middle left panel of Figure 1 shows three coherent events: 1) the direct wave, 2) the reflected wave from the interface, and 3) the refracted wave at offsets greater than 300 m. Now, using seismic interferometry we attempt to recover the wavefield between two receiver positions based on equation 19 from [1], which represents the exact acoustic Green's function:

$$\hat{G}(\mathbf{x}_A, \mathbf{x}_B, \omega) + \hat{G}^*(\mathbf{x}_A, \mathbf{x}_B, \omega) \;=\; \oint_S \frac{-1}{j\omega\rho(\mathbf{x})}(\hat{G}^*(\mathbf{x}_A, \mathbf{x}, \omega)\partial_i(\hat{G}(\mathbf{x}_B, \mathbf{x}, \omega)) - \partial_i(\hat{G}^*(\mathbf{x}_A, \mathbf{x}, \omega))\hat{G}(\mathbf{x}_B, \mathbf{x}, \omega))n_i dS,$$

After summing the crosscorrelations for all sources on the circle in the acoustic model we obtain the virtual shot record shown in the middle right panel of Figure 1. We simplify equation 1 by making a far-field approximation and obtain the wavefield in the right plot of Figure 1. Again we recover the correct direct, reflected, and refracted waves. However, we also observe a spurious linear event traveling at $v_1 = 1750$ m/s going through the origin. We call this spurious wave the virtual refraction.

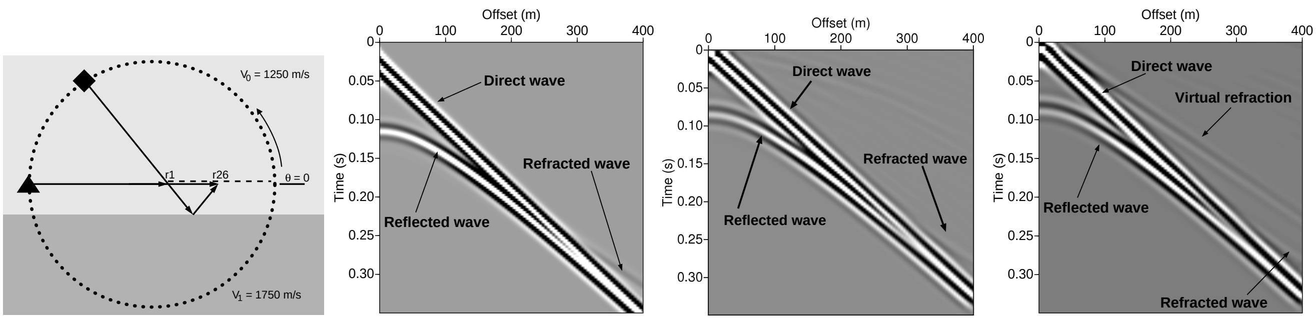

FIG. 1: Left: Layout of the acoustic numerical model with 2880 sources on a circle with radius 475 m. Receiver $r1$ is located 75 m to the right of the circle center. The diamond and square infer stationary phase points, important in the stationary-phase analysis. Middle left: shot record from an explosive source placed at receiver $r1$ showing the direct, reflected, and refracted waves. Middle right: virtual shot record based on a exact seismic interferometry equation. Right: virtual shot record using only monopole sources on the circle. In addition to the real events, we observe a linear spurious event: the virtual refraction.

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[1] Wapenaar, K. and J. Fokkema, 2006, Green's function representations for seismic interferometry: Geophysics, **71**, S133–S146.