Seismic Interferometry by cross-correlation and by multi-dimensional deconvolution using ambient seismic noise

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When applying seismic interferometry (SI) by cross-correlation (CC), one assumes a known or regular source distribution. For applications in the field this condition will not be easily fulfilled. For this reason, one can make use of SI by multi-dimensional deconvolution (MDD) (Wapenaar et al., 2008). This method makes use of matrices, where a row of a matrix contains responses for a fixed receiver position and variable source positions The Green's function is retrieved using a matrix inversion. An advantage of the MDD method is that it can compensate for irregular distribution and strength of the sources. An additional requirement of this method is that the data to be inverted need to be recorded along a wide-aperture well-sampled receiver array. Contrary to this, SI by CC can be performed with recordings even at only two receivers.
Wapenaar et al. (2008) show the advantage of SI by MDD over SI by CC using numerical-modelling for acoustic fields when separate recordings are available at the receivers from each of the (passive) seismic sources.

When one wants to apply SI with ambient seismic noise, i.e., when no separate recordings at the receivers are possible from each of the passive seismic sources, then the matrices in the relation of SI by MDD will collapse to column vectors as each row will contain only one recording. We investigate SI by MDD with ambient noise with the help of numerical-modelling examples. We model surface waves propagating in a layered elastic medium. We first compute a dispersion curve for the upper 300 km of the PREM model (Dziewonski and Anderson, 1981) using an approach as described in Wathelet et al. (2004). Next, we forward-model fundamental Rayleigh waves based on the computed dispersion curve. The configuration that we use is shown in Figure 1. We use 150 simultaneously acting white-noise sources, represented by the blue stars, with an irregular distribution. In particular, we use two clusters of noise sources – the first one is concentrated around x_2=30 km and consists of 20 sources, while the second is concentrated around x_2=-100 km and consists of 30 sources. We record the emitted noise fields at two mutually perpendicular receiver arrays, which in the figure are represented by the green triangles. Array 1 is parallel to the source-distribution geometry and contains 129 receivers spaced at 2.5 km. Array 2 contains 16 receivers spaced at 20 km. The frequency spectrum of the noise sources peaks at 0.2 Hz, which is the double-frequency microseismic peak. The two arrays record the total noise for nearly 42 hours.

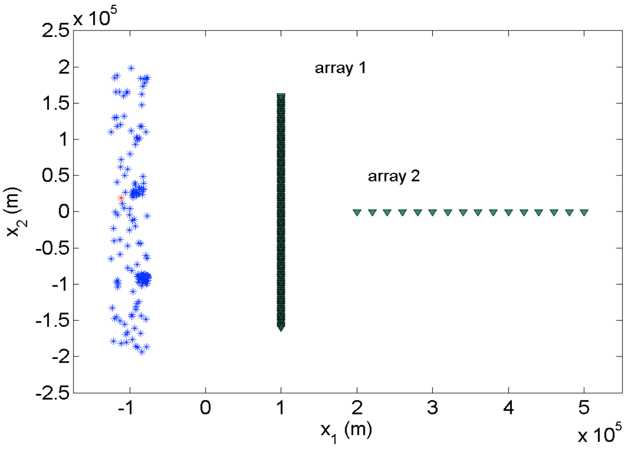

Figure 1. *Acquisition configuration used for numerical modelling. There are 150 sources (the blue stars) and 2 mutually perpendicular arrays of receivers (the green triangles).*

We choose to retrieve surface wave information as it would be recorded along array 2 in the presence of a virtual source at the position of the receiver with x_2=0 km in array 1. We first do this using SI by CC. We extract the noise trace at the chosen virtual-source position from array 1 and correlate it with all the noise traces from array 2. We then use SI by MDD to retrieve the same information. For this, though, we need all noise traces from array 1. MDD is a much slower process then CC. The computational time, though, can be made more acceptable if the noise traces are split into shorter noise windows. These noise windows are then arranged in matrices, which are then used instead of the two noise vectors recorded along the two receiver arrays. The MDD method is applied by least-squares inversion. In Figure 2 we show the amplitude spectrum of the virtual-source gathers along array 2 obtained using CC (top) and MDD (middle). At the bottom of Figure 2 we show for comparison the amplitude spectrum for a reference active-source gather. We see that the SI by CC has done a good job in retrieving the general character of the dispersive surface waves. Nevertheless, we see the amplitude spectrum has a gap at lower frequencies and that that it appears that the peak is slightly shifted to a higher frequency, namely to 0.3 Hz. These problems are consequences from the irregular source distribution. Comparing the result obtained using SI by MDD with the reference response, we see that the MDD process has corrected for thee discrepancies – the spectrum is less distorted and more continuous.

Figure 3 shows the comparison between the virtual-source gather retrieved using SI by CC, shown in red, and the reference active-source gather, shown in black. We can see that the CC retrieves the moveout and dispersion chanracter of the surface wave. On the other hand, we see that the waveform is incorrectly retrieved - there are strong artefacts before the onset. These artefacts result from the cluster in the noise-source distribution that is concentrated around x_2=30 km. This cluster is situated in the stationary-phase region for the virtual source at x_2=0 km in array 1 and the receivers in array 2 and causes overillumination of that part of the region.

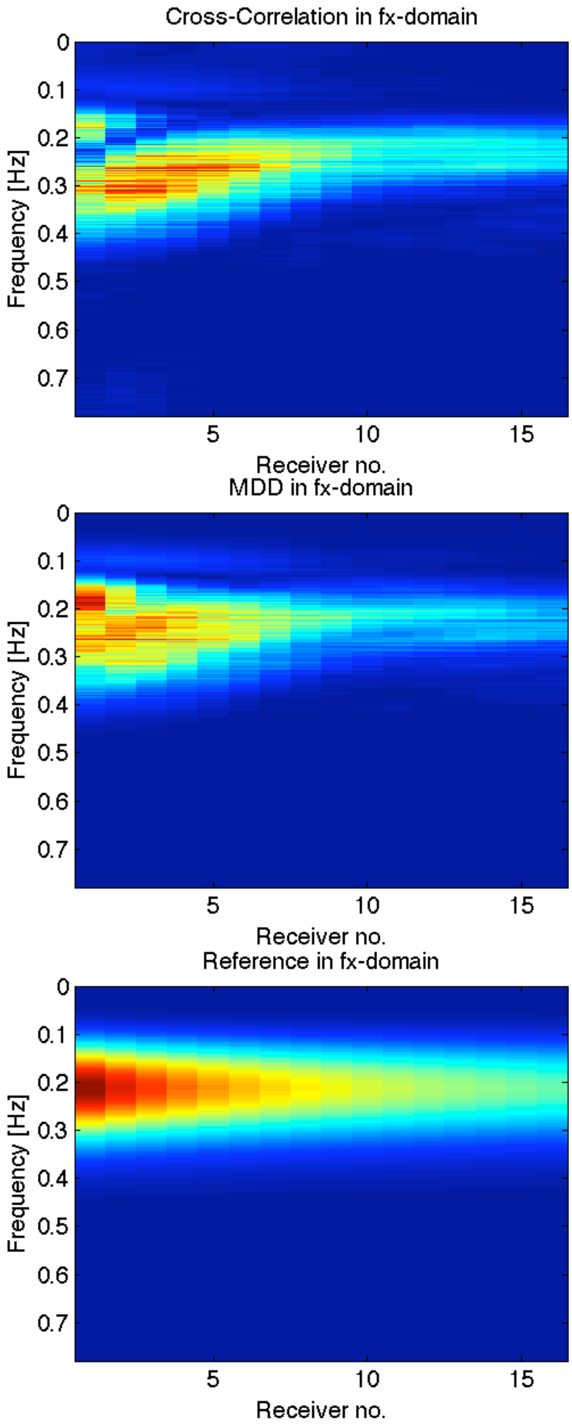

Figure 2. *Frequency spectrum of the virtual-source gathers obtained using SI by CC (top) and SI by MDD (middle). A reference active-source gather is shown at the bottom.*

In Figure 4 we show the comparison between the virtual-source gather retrieved using SI by MDD, shown in red, and the reference active-source gather, shown in black. We can see that the MDD process has retrieved not only the kinematics, but also has corrected for the overillumination due to the source cluster around x_2=30 km – the artefacts before the onset are largely compensated for and consequently suppressed.

In conclusion, we showed the application of SI by CC and by MDD to ambient seismic noise. Due to irregular distribution of the noise sources, some artefacts might arise in the CC result. SI by MDD could compensate for the irregular source distribution and suppress such artefacts.

References

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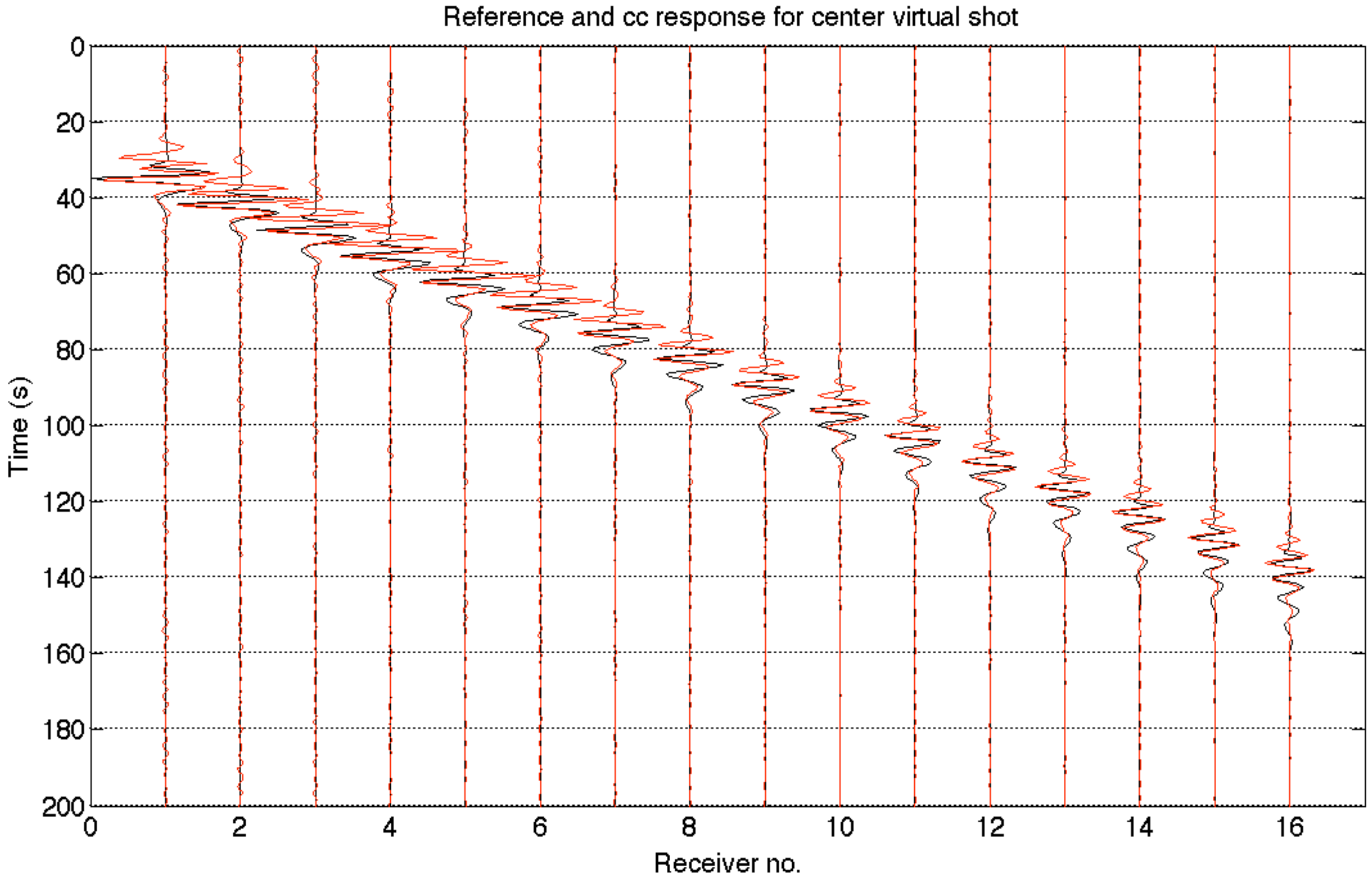

__Figure 3.__ Comparison between results retrieved using seismic interferometry by cross-correlation (in red) and the directly modelled surface wave (in black) for a source at the position of the receiver at x_2=0 km in the first array.

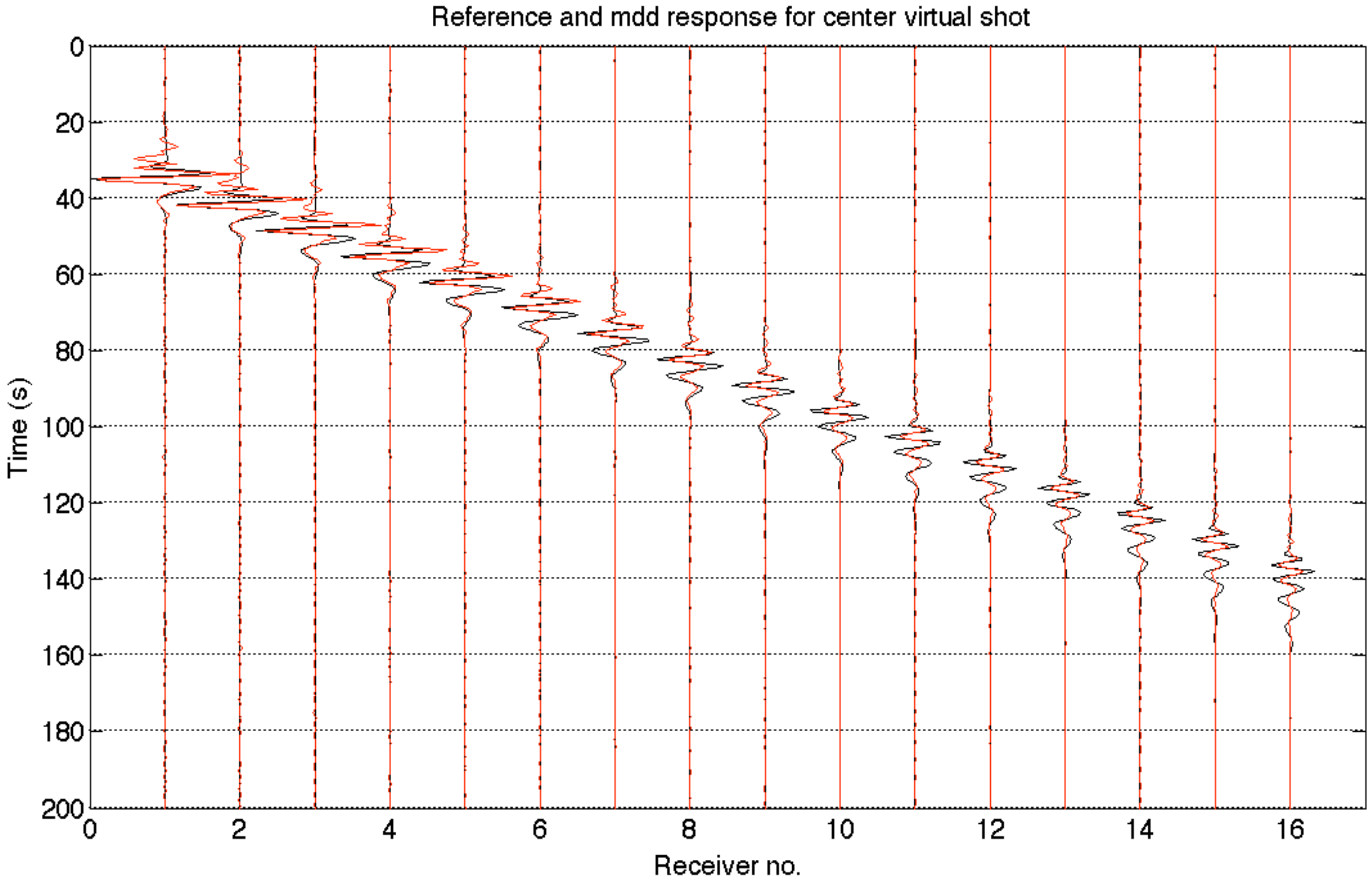

Figure 4. *Comparison between results retrieved using seismic interferometry by multi-dimensional deconvolution (in red) and the directly modelled surface wave (in black) for a source at the position of the receiver at* x_2*=0 km in the first array.*