Retrieval of reflections from seismic background-noise field data recorded in a desert area

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Summary

Seismic Interferometry (SI) can construct reflection data from seismic background noise. We attempt to construct reflection events from ten hours of background-noise data, recorded in a desert area. The results show several coherent events, aligning well with reflections from an active survey at the same location. These events can thus be interpreted as reflections and we can conclude that SI has has proven successful in this survey.

Introduction

In seismic interferometry (SI) we create new seismic records from the (time) cross-correlation of existing records. One application of SI is to retrieve the reflection response from the correlation of seismic background noise (*Draganov et al.*, 2006). It can provide new tools for exploration in areas where no conventional seismic sources, such as seismic vibrators and dynamite, can be used. It can also be beneficial for regional and global seismology as it can create additional seismic sources with a relatively dense distribution, whereas the spatial distribution of conventional sources in seismology is often limited to active faults.

Retrieval of reflections from seismic background noise

We follow *Wapenaar and Fokkema* (2006) to retrieve the Green's function from the recorded seismic background noise in the time domain:

$$\left\{G_{z,z}\left(\vec{x}_A,\vec{x}_B,t\right)+G_{z,z}\left(\vec{x}_A,\vec{x}_B,-t\right)\right\}*S\left(t\right)\approx\left\langle\left\{v_z\left(\vec{x}_A,-t\right)\right\}*\left\{v_z\left(\vec{x}_B,t\right)\right\}\right\rangle. \qquad (1)$$

The right hand side denotes the cross-correlation between the vertical components of the observed particle velocity background-noise traces at points *A* and *B*, respectively. The background noise is assumed to be caused by a distribution of temporally uncorrelated noise sources in the subsurface. The angle brackets denote an ensemble average, which in practice is approximated by averaging over different time windows. On the left-hand side we have the Green's function and its time-reversed version, representing the observed vertical particle velocity at a receiver at point *A* as if there were a vertical force source at point *B*. These Green's functions are convolved with the auto-correlation $S\left(t\right)$ of the noise sources in the subsurface.

In 2005, a small field experiment was carried out by SRAK with Shell's technical advice and support with the idea to test the applicability of the SI method for retrieval of reflections. Ten hours of background-noise-data were recorded along an array of 17 3-component geophones in a desert area. The specific place for the array was chosen to be along a line of an active exploration survey. As the geophones are placed at the surface, a possible retrieved Green's function, using equation 1, should consist of the reflection response and the direct arrival.

The noise was recorded in 523 panels of 70 seconds. In figure 1A we show ten seconds of the observed background noise of one such panel on the vertical (Z), the horizontal in-line (X) and the horizontal cross-line (Y) components. Even though the receivers were sensitive for frequencies between 1 and 80 Hz, we found that the useful information was concentrated between 2 and 10 Hz. The inclined events in Figure 1A represent propagating energy, mostly in the form of surface waves. This means that this energy originates from sources close to the surface, away from the array. After cross-correlation, such background-noise events will contribute to the retrieval of surface waves. Figure 1B shows the three components of 10 seconds of background noise from another panel. On the vertical component (Z) we observe nearly horizontal arrivals starting at about 12 seconds. The first, and hence fastest, arrival in Figure 1B is stronger in amplitude than the background noise in Figure 1A (the amplitudes have been rescaled in this display). Because this arrival is absent on the horizontal components (X and Y), we interpret it as propagating energy due to body P-waves from deeper sources, vertically below the passive array. After cross-correlation, these background-noise events will contribute to the retrieval of reflections from subsurface layers.

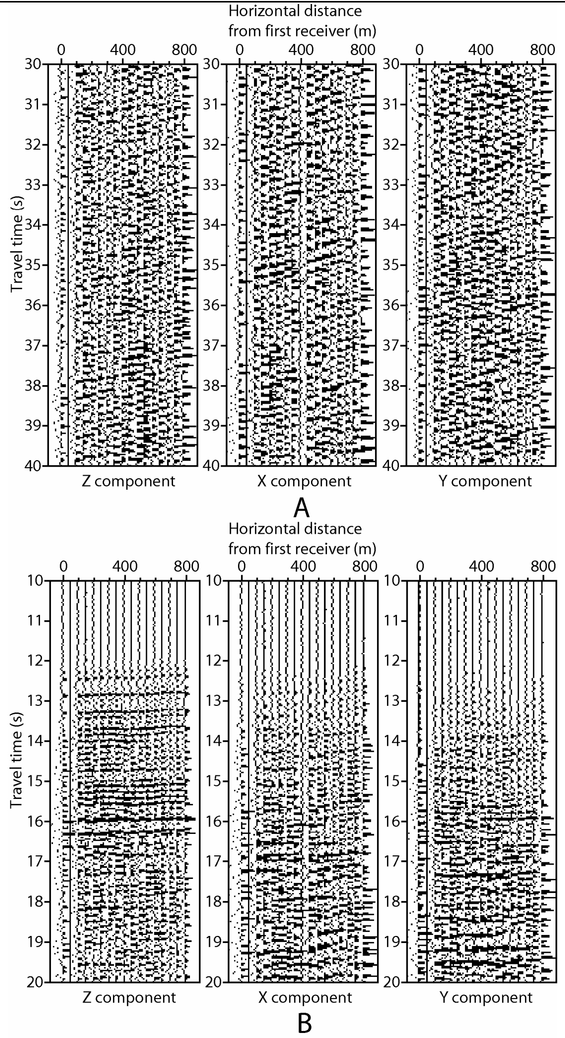

Figure 1. (A) Ten seconds of seismic background noise as recorded by the vertical (Z), the horizontal in-line (X) and the horizontal cross-line (Y) components of the geophones.
(B) Another ten seconds of seismic background noise.
The data are displayed after band-pass filtering between 2 and 10 Hz.

We energy-normalized the panels and cross-correlated each trace with the other traces in the same panel. These cross-correlated panels were summed, resulting in retrieved common-source gathers for each receiver location. The result was band-pass filtered between 2 and 10 Hz. We collected the retrieved source–receiver pairs with the same offset and summed them, resulting in a common-offset stack panel, which we normalized (Figure 2A). The same procedure was applied to the active data, using 17 common-source gathers with source positions around the corresponding locations of the geophones from the passive array. We applied (f,k)-filtering to eliminate the surface waves and then low-cut filtered at 20 Hz (Figure 2B). Still the retrieved surface waves in Figure 2A hampers the good comparison between the two datasets. Due to the very narrow frequency band of the retrieved data, we did not use an (f,k)-filter to eliminate the retrieved surface waves, but chose to suppress the inclined coherent events in a different way. By simply summing the retrieved common-source gathers (a so-called brute stack) we created the response of a line source along the passive array (Figure 2C). The retrieved coherent events show good arrival-time agreement with the reflection hyperbolae in the active data, as indicated with the red lines between Figure 2B and Figure 2C. This makes us conclude that the retrieved coherent events in figure 2C are retrieved reflection arrivals.

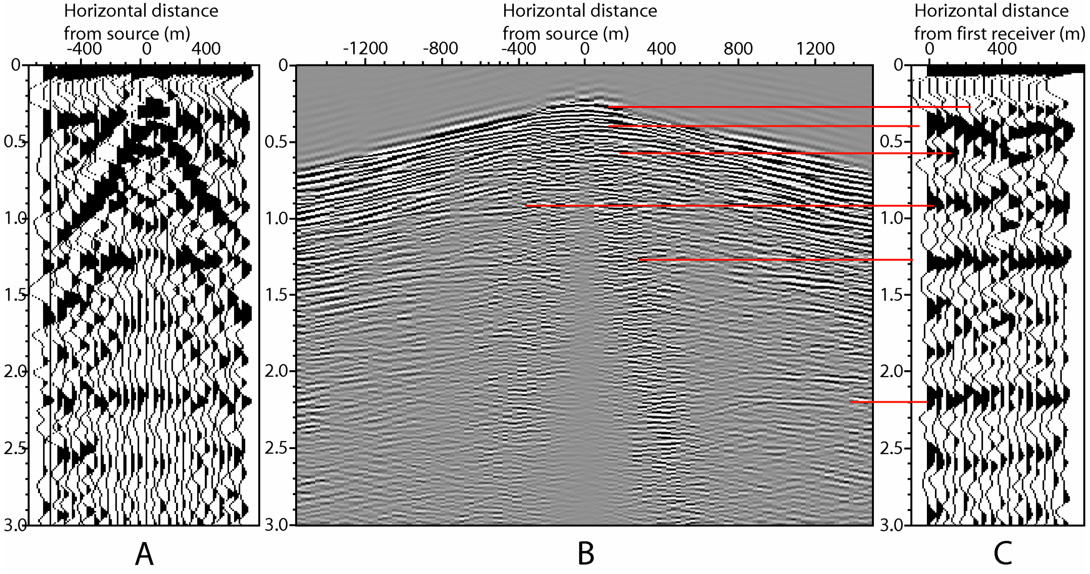

Figure 2. (A) Common-offset stack panel obtained from the common-source gathers retrieved from the passive data. **(B)** Common-offset stack panel after surface wave elimination in the active survey. **(C)** Line-source response obtained by summing the common-source panels retrieved from the passive data (brute stack).

Conclusion

Theory predicted that by cross-correlation of uncorrelated seismic background-noise the reflection response can be retrieved. We correlated ten hours of surface-recorded noise, which resulted in several coherent events that aligned well with events in active exploration data; this being a strong validation that Seismic Interferometry can indeed be used to obtain the reflection response from a passive data set. Applications in regional seismology, frontier exploration and long-term monitoring of processes in the earth's subsurface seem promising.

Acknowledgements

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