G013

Event-driven Seismic Interferometry with Ambient Seismic Noise

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SUMMARY

By cross-correlating recordings of ambient seismic noise, one can retrieve the subsurface reflection response. The quality of the retrieved reflections would depend on the qualities of the ambient noise. In a previous study, we cross-correlated ambient-noise data recorded in a desert area in North Africa and showed that we retrieved reflections. This was done assuming that body-wave noise continuously illuminates the recording array. But this is not necessarily true - noise which carries body-wave information can be present only at certain times. We now use only parts of the recorded noise during the correlation process. These parts contain identifiable body-wave events. We show that the results, retrieved only from the noise containing the events, exhibit clearer reflection arrivals.

Introduction

During the last decade Seismic Interferometry, or SI, has gained rapidly in popularity among academia and the industry (Wapenaar et al., 2008; Schuster, 2009). One application of SI is the retrieval of the reflection response from the cross-correlation of ambient seismic noise. In general, we have no information on the noise sources, so we assume they are spatially uncorrelated, stationary noise sources that illuminate the recording array from all directions. To ensure this, we want to use recording times as long as possible. Correlating these long noise recordings would result in obtaining the best possible estimate of the complete Green's function including reflections, but also surface waves.

The assumption of the spatially uncorrelated, stationary noise sources is not necessarily fulfilled, especially with measurements in the field taken during a limited time span. In this case, the majority of the noise sources would, most likely, be concentrated close to the surface and, thus, would cause relatively strong surface waves. After cross-correlation, such noise would result in the retrieval of nearly only surface waves. For this reason one can choose to follow an alternative approach – to look in the ambient-noise data for parts of the noise that can be identified as body-wave arrivals. Such events are then selected and only these parts of the noise are cross-correlated. By manipulating the energy that is cross-correlated, that is, using in the correlation process only the body-wave parts of the noise, we can boost the contributions to the retrieval of reflections and, at the same time, minimize the contribution of those parts of the noise records that would retrieve surface waves. Draganov (2007) used this approach and showed that the retrieved reflections are enhanced when compared to retrieved results using all the recorded noise. In the following, we apply the event-driven approach to data from a passive experiment in which Shell recorded approximately 11 hours of ambient noise in the northeastern part of the Sirte Basin, east of Ajdabeya, Libya. We compare the retrieved results to the results that we had already obtained using all 11 hours of ambient seismic noise.

Method

We apply the event-driven SI to ambient-noise data recorded in 2007 by Shell in the northeastern part of the Sirte Basin, east of Ajdabeya, Libya (Draganov et al., 2009). About 11 hours of ambient noise was recorded and stored in about 900 time windows of 47 seconds (noise panels). The noise was recorded along eight parallel lines, lying 500 m apart, but below we will show example results along only one of the lines. In the northern end, around 14 km, the lines were bisected by a traffic road, which was a relatively continuous source of strong surface waves. Each line consisted of about 400 receiver stations with 50 m spacing, where each station represented a group of 48, 10 Hz, vertical-component geophones.

Fig. 1 shows time slices of two of the recorded ambient-noise panels. Fig. 1(a) exhibits only strong surface waves and is representative for the majority of the noise panels. Fig. 1(b) shows a specific noise panel that exhibits also nearly horizontal body-wave arrivals (events). The conclusion, that such arrivals are body waves and not surface waves propagating with a wave front parallel to the example line, was drawn after applying array analysis of the events using all eight lines. In total, there are about 100 noise panels containing identifiable events. We observe that these events have propagated as plane waves, which indicates that their sources have been relatively far away from the recording lines.

The retrieval process using SI starts with a choice of a master trace that will be correlated with the rest of the traces; the SI would turn this master trace into a virtual source. Before cross-correlation, each event panel is band-pass filtered between 6 Hz and 24 Hz, frequency-wavenumber filtered and trace energy normalized. After cross-correlation, each correlated event panel is deconvolved for its noise time function. To maximize the chance of retrieving a more complete set of reflection arrivals, normally, when all the recorded noise is used, the causal and the acausal parts of a correlated noise panel are summed. As the body-wave noise has propagated as (near-)plane waves with a small inclination to the horizontal, such direct summation would give rise to artefacts. To minimize the artefacts, we make use of the fact that the subsurface below the survey lines is close to horizontally layered (Draganov et al., 2009) and that the body-wave noise has propagated mainly from right to left along the lines with small angles of incidence with the vertical. For each correlated panel, we take the causal part of the traces that lie to the left of a virtual source and concatenate to them the acausal part of the traces that lie to the right of the virtual source; for more explanations on this approach, see Ruigrok et al. (2009). After this, as a last step, all processed correlated event panels are summed together to obtain a final retrieved common-shot gather.

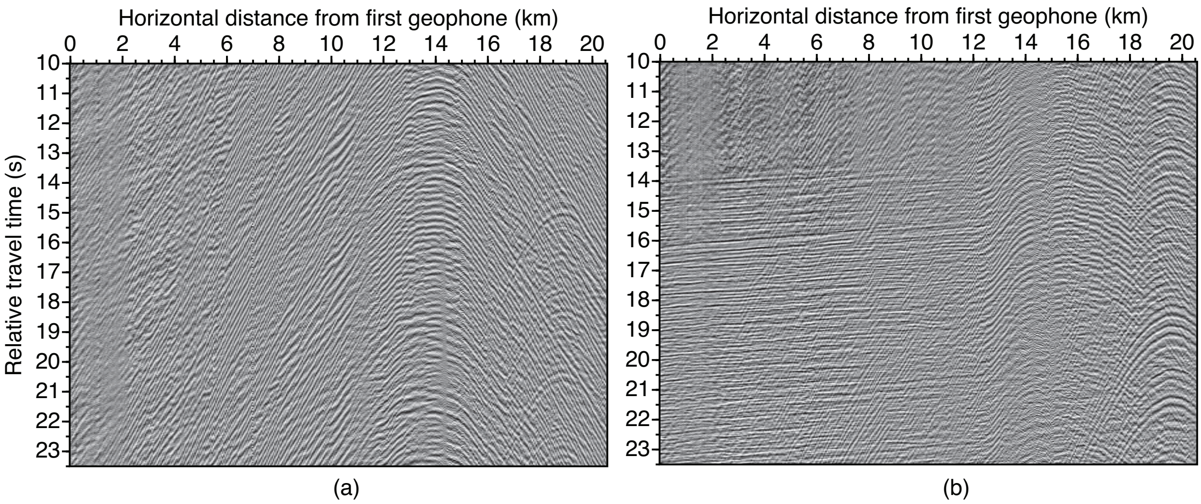

Figure 1 ***(a)*** *Time slice of a noise panel where only steeply inclined events – surface waves – are visible. This type of noise is characteristic for the majority of the noise panels.* ***(b)*** *Time slice of another noise panel exhibiting nearly horizontal arrivals – body waves.*

Results

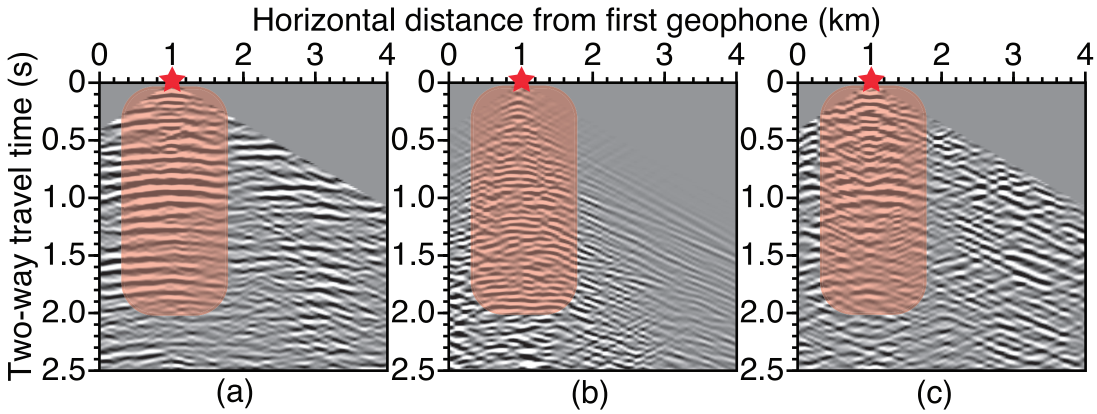

Figure 2 *Common-shot gathers:* ***(a)*** *retrieved from the ambient noise using only noise panels with identifiable events in them;* ***(b)*** *from active reflection data;* ***(c)*** *retrieved from the ambient noise using all noise panels. In all three cases, the (virtual) source, indicated by the red star, is situated at 1 km from the beginning of the line. The transparent-red areas highlight reflection arrivals.*

Fig. 2(a) shows a virtual common-shot gather obtained using event-driven SI with ambient noise for a virtual shot at 1 km from the beginning of the line. We can see in it several coherent arrivals. In the area highlighted in transparent red (for small to moderate offsets), these arrivals coincide very well in travel-time with some of the reflectors in an active common-shot gather, Fig. 2(b), recorded with a vibroseis source situated 12.5 m away from the virtual-shot position. Note that the differences in the frequency content of (a) and (b) are due to the lower-frequency character of the recorded body-wave noise compared to the vibroseis source. Outside the highlighted area, the retrieved events do not exhibit the expected hyperbolic moveout, but continue as more or less straight lines. This can be explained by the fact that we correlate (near-)plane waves, which illuminate the geophones stations from angles that are very close to each other. To obtain the hyperbolicity, we would need illumination from all possible angles. If we use in the correlation process all recorded ambient-noise panels, see Fig. 2(c), we can see that retrieved reflection events exhibit hyperbolicity. That means that using only the chosen noise panels with events, we have rejected parts of the noise that have illuminated the geophone stations from more diverse angles. On the other hand, comparing the highlighted parts of (a) and (c), we can conclude that using only selected parts of the noise has improved the continuity and the signal-to-noise ratio of the retrieved events at small to moderate offsets (up to about 1 km). This is achieved by the simple process of eliminating noise panels strongly dominated by surface-wave energy, that was not suppressed by the geophone groups and the extra filtering steps before the correlation.

We repeat the retrieval process for all the traces on the geophone lines to obtain virtual sources at each station position. Having done that, we proceed to obtain poststack time-migrated sections of the surface following a standard processing sequence (Yilmaz, 1999). Part of the sequence is a performance of velocity analysis on common-midpoint gathers. As the reflection events, retrieved using event-driven SI, exhibit insufficient curvature, they can not be used for velocity analysis. Instead, in the normal-moveout process we can use velocities picked from the data retrieved using SI with all noise panels. During the picking of the velocities from the latter, we are helped by information from the former - the apexes of the reflection events are better retrieved when using events only and, thus, can point out to us where exactly to pick velocities in the velocity-semblance panels constructed from the retrieved reflection arrivals when using all the recorded noise.

The top panel of Fig. 3 shows the poststack time-migrated section under the example line obtained using the events. Comparing this result to the poststack time-migrated section obtained using the active data (Fig. 3, middle) we can appreciate the travel-time coincidence of four reflectors at earlier times. At later times, the lateral coherence of the events in the top section is broken and does not allow comparison with the active data. We also see that the closer the events to the traffic road at 14 km, which was the main source of the strong surface waves, the lower the signal-to-noise ratio and the less the continuity of the reflectors. Comparing the top stacked section with the poststack time-migrated section retrieved using all the recorded noise (Fig. 3, bottom) we see again the improvement when using only events are used – the retrieved reflectors are more clearly visible. Furthermore, the event at about 1.3 s could be interpreted as a reflector in the top section of Fig. 3, while in the bottom section at this time we see only artefacts.

Conclusions

We applied seismic interferometry to ambient seismic noise recorded in the northeastern part of the Sirte Basin, east of Ajdabeya, Libya, with the aim to retrieve P-wave reflections. Using the fact that retrieval of reflections would result from correlation of body waves present in the recorded noise, we correlated only those noise panels that contained identifiable body-wave noise (events). The results from this approach exhibit higher signal-to-noise ratio and better continuity of the retrieved reflections on the time-migrated section when compared to the results obtained using all recorded noise panels. On the other hand, the former results can not be used for velocity analysis as the retrieved reflections do not exhibit sufficient curvature in the common-shot domain allowing velocity picking. Nevertheless, analysis of the reflection arrivals obtained from events can be used during the velocity picking from reflections retrieved using all the noise. Using the two approaches complementary helps retrieve better reflection sections.

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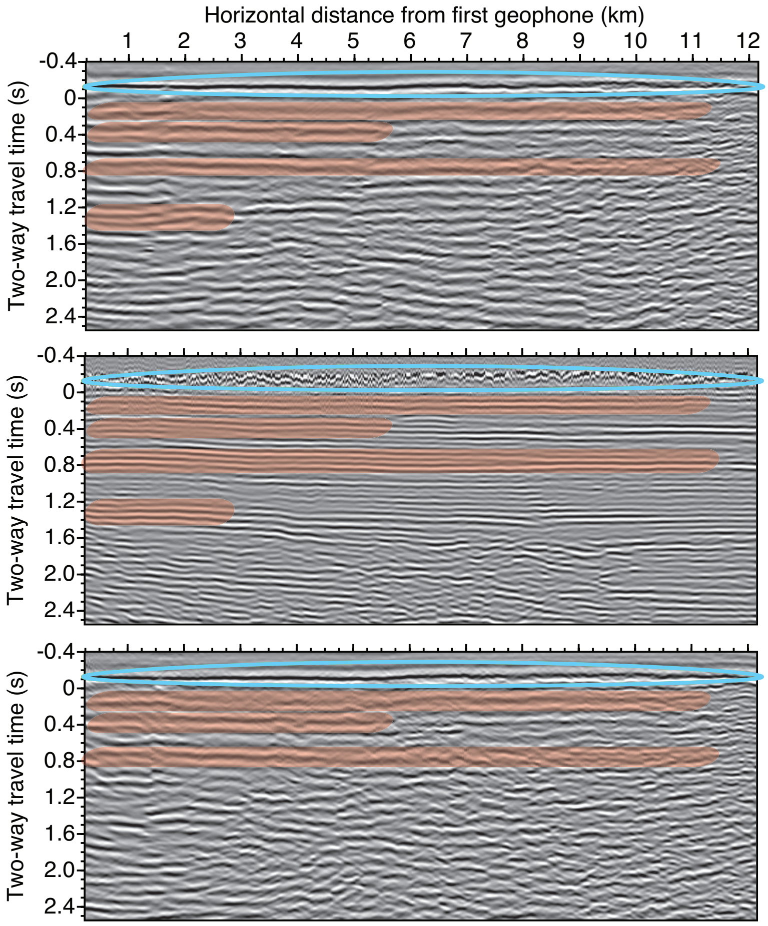

Figure 3 *: Poststack time-migrated sections of the subsurface below the example line obtained using: (top) event-driven seismic interferometry; (middle) the active data; (bottom) seismic interferometry with all noise panels. The transparent-red areas indicate reflectors that coincide in travel-time sense. The blue ellipse indicates the Earth's surface.*

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