SI attenuation as part of simultaneous source acquisition: GOM field data exercise

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Summary

Seismic interference (SI) still is a considerable problem in marine seismic acquisitions. Looking at the number of marine seismic surveys that are acquired in close vicinity of each other nowadays, seismic interference forces to either acquire surveys in time-sharing mode or apply substantial processing schemes to attenuate the SI-energy afterwards.
Looking at the characteristics and challenges of SI-energy, we see that it is very much related to the deblending challenges faced in simultaneous source acquisitions. Just like the interfering simultaneous sources, which are fired with dithered firing-times, the SI energy show irregular behaviour from shot to shot. Considering the resemblance between the two, it seems natural to treat blending- and SI-energy in one and the same algorithm. In this paper it is discussed how an inversion-based source separation method is extended to include SI-energy as well. The extended method is applied to simultaneous long offset (SLO) field data which is contaminated by SI. Good results are obtained for both source separation and SI attenuation.

Introduction

Simultaneous source acquisition, where seismic data is recorded with a temporal overlap between the shots, offers a very efficient way to apply the large, multi-vessel, acquisitions that are required nowadays to obtain data that is densely sampled both in terms of source/receiver-location, azimuths & offsets. Although development is still going strong, deblending algorithm are very well capable to actively separate simultaneous source data and simultaneous source acquisitions are getting more and more industry accepted.

Common practice in simultaneous source acquisition is to apply randomized time-delays to the sources during the acquisition of the data. As a result of using randomized firing schemes, coherency measures in the proper domains (for instance common receiver, common offset and or CDP) can be utilized to actively separate the recorded data over the individual sources. All energy that can be uniquely identified as coherent, after alignment for any one of the sources, is distributed to that source. All energy that the algorithm could not distribute to any of the sources is collected in the residual or noise-bucket.

SI energy behaves very similar way to the energy from the simultaneous sources. From shot to shot it arrives with randomized arrival times, the same way we enforce the energy from the simultaneous sources to behave by applying the dithered firing times. In this abstract an inversion-driven source separation method is utilized and illustrated how SI-energy can be included in the algorithm. The method is explained further in the next section, after which we illustrate the method on a SLO field data example.

Method

Source separation or deblending can be treated as an inverse problem. In this paper, an inversion based source separation method (Baardman and van Borselen 2012, van Borselen et al. 2012) is used and extended to include SI attenuation. The method constrains the inversion based on coherency measures (Abma *et al.* 2010). In an iterative way, the method aims to construct the separated sources through the minimization of a cost function that describes the “data misfit” (see, for example, Akerberg *et al*. 2008 and Moore *et al.* 2008). The “data misfit”, or so called noise-bucket, **r** is given by:

$$r = \quad y - A\begin{bmatrix} x_1 \\ x_n \end{bmatrix}, \qquad (1)$$

where **y** is the recorded blended data, **A** the blending operator (Berkhout, 2008) and $\mathbf{x_1}$,$\mathbf{x_n}$ the separated data for the individual sources where the inversion is solved for. Initially the noise-bucket equals the full blended input data: in each iteration, after aligning the data for the different sources, coherent energy is extracted from the noise-bucket and distributed to the separated data gathers of the individual sources. Energy that appeared to be incoherent, independent for what source it was aligned, will remain in the noise-bucket after the separation. Note that energy in the noise-bucket is not lost since it can always be added to the separated data afterwards.
After the separation, the noise-bucket could contain different types of data:

- Incoherent primary energy.
- Incoherent noise
- SI- ,cross-talk or any noise that is coherent in shot domain but incoherent in the domains where the source separation is applied

If we would know the firing times and locations of the sources that initiate the SI we could simply include the SI

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source(s) in the deblending problem and extract/separate the SI-energy using current deblending algorithms. You would add additional unknown x_i's to equation 1 that represent the SI source(s). Like for the simultaneous sources, the blended data could be aligned for the SI-source(s) after which its energy becomes coherent allowing the deblending algorithm to separate the SI energy from the data.

As long as this information is unavailable, the firing times and locations of the SI sources can't be used to align and extract the SI-energy in the same way it is done for the simultaneous sources. Nevertheless, the incoherent behaviour of the SI-energy still allows us to include it in the deblending algorithm. In the proper domain(s), the SI-energy should be left unattributed during the separation process. This means that the SI would not end up in the separated gathers of the individual sources but can be isolated in the noise-bucket after the separation is done. With the SI isolated in the noise-bucket, it becomes easier to attenuate it compared to attenuation to the blended data. In the next section a field data example is used to illustrate how the source separation is applied and, at the same time, it was possible to attenuate the SI-energy from the noise-bucket in an efficient way.

Data example: SLO

In this example, the proposed method is deployed using field data from a multi-vessel full-azimuth simultaneous source survey acquired over 10.000 km^2 in the Gulf of Mexico. In order to obtain very long offsets, needed for imaging below the very complex salt structures in this area, the data is shot in SLO mode. In Figure 1 the acquisition setup is shown. The whole survey is shot using simultaneous sources and is acquired in 3 azimuths. Sources 1 and 5, in front of the streamers, contribute the very long offsets up to 16km. Together with the near-offset sources close to the streamers a full-azimuth illumination is achieved (Long et al, 2014).

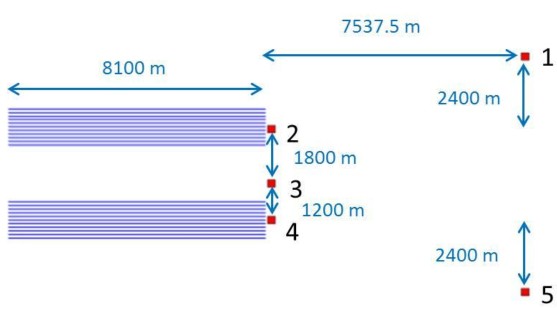

Figure 1: multi-vessel simultaneous source acquisition.

In SLO mode a source closest to the streamers is fired simultaneously with one of the far-offset sources. Pseudo-randomized time-delay (Baardman and van Borselen, 2013) are used to optimize the separation process.

Here we will focus on one of the SLO source-pairs and show the source separation and SI attenuation for cable 5. Figure 2 show 2 shot gathers from the blended input data: indicated by the green arrow is the energy from the far-offset source, the red arrows for a near-offset source and the yellow arrows indicate the SI-energy.

The separation & SI-attenuation is performed in 3 steps:

1. A conservative separation is applied to the data. Goal is to separate the strongest coherent energy parts of sources 1 & 2 without affecting the SI-energy. Conservative settings are used to avoid that any SI-energy is distributed to any of the simultaneous sources but will remain isolated in the noise-bucket
2. Once the SI-energy is isolated in the noise-bucket, standard SI attenuation is applied to the noise-bucket
3. After the SI-energy is removed from the noise-bucket a second, less conservative, step of source separation is applied.

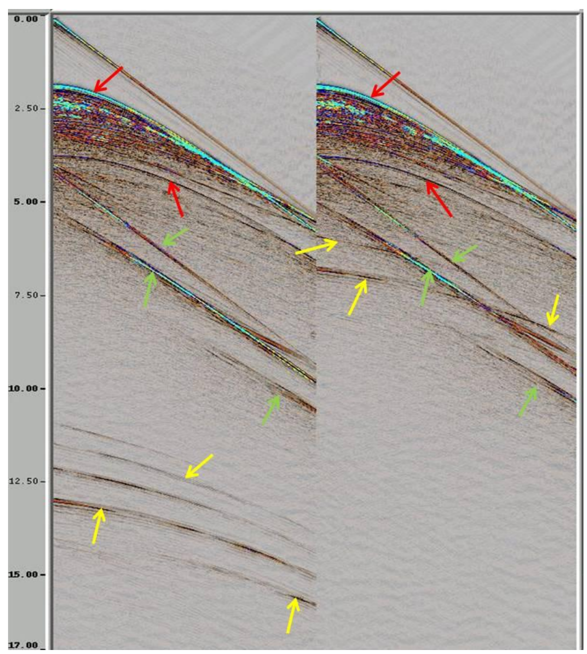

Figure 2 blended input shot gathers. Indicated with the green arrows is the energy from the near-offset source, indicated with the blue arrow the energy from far-offset source and with the yellow arrows the SI-energy.

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Figure 3 shows the resulting noise-bucket after the first, conservative, source separation step. A considerable amount of energy has been extracted from the data (separated to the different sources) while all SI-energy is still in the noise-bucket. In figure 4 the same noise-bucket is shown after the SI-attenuation is applied. SI-energy has been attenuated quite effectively without losing any of the primary signal. The separated SI-energy is plotted in figure 5. The noise-bucket of figure 4 is input to the second step of source separation. In Figure 7 the final separated data for the near-offset source is plotted. Notice that only a minimal amount of energy from the interfering far-offset source has leaked into this gather. Separated data for the far-offset source is plotted in Figure 8. Again very good separation result with minimal energy leaking from the interfering near-offset source into the gather. QC analysis, like migrated difference plots, also indicated minimal leakage in the separation result of both sources. The updated noise-bucket after the second step of source separation is shown in figure 6. The separation method was not able to identify this energy as coherent for any of the sources. Some remnant energy is incoherent primary energy for either one of the two simultaneous sources while the rest is incoherent noise which a coherency-based separation process is expected to leave in the noise-bucket.

Energy left in the noise-bucket can always be added back to both sources to avoid the loss of remnant primary energy. A conservative approach is taken here by preferring to leave a bit more energy in the noise bucket instead of making the separation more aggressive and risking more leakage from one source to the other, which implies signal loss. In practice, the noise-bucket is added to the separated data of both sources. Given the huge amount of data, the little additional noise you add back as well won't affect any further processing and imaging results.

Conclusions

An extended inversion-based method to apply source separation and SI attenuation has been utilized and demonstrated on field data from a multi-vessel full-azimuth simultaneous source survey. It is demonstrated that SI energy can be isolated in a noise-bucket after a conservative separation process. It is also showed that the SI energy can then be efficiently removed from this noise-bucket. Once the SI is removed, a second step of source separation lead to very good source separation results.

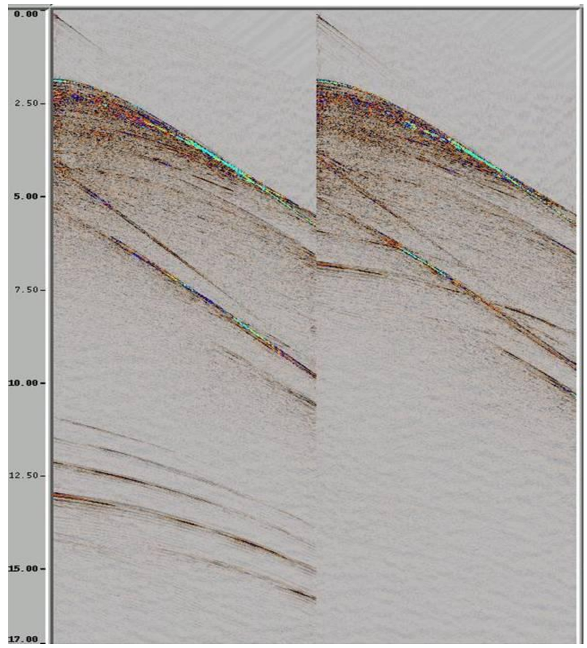

Figure 3 Noise-bucket after first, conservative, separation step. Notice how well the SI-energy is isolated in this noise-bucket.

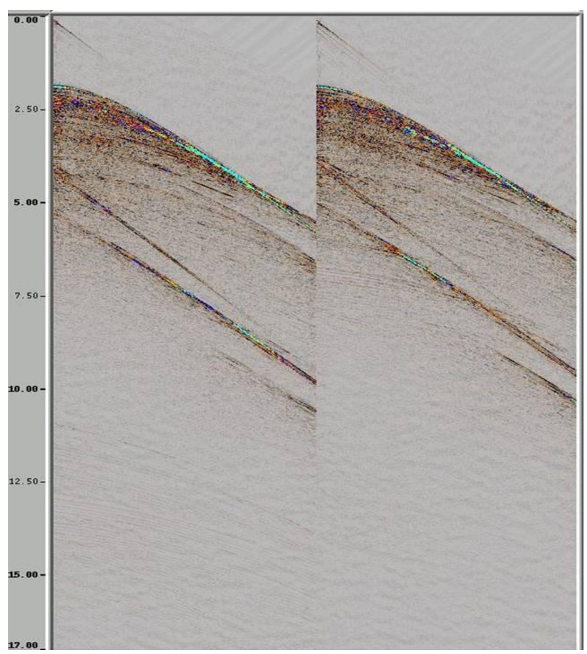

Figure 4: Noise-bucket after SI attenuation applied to the result of figure 3. This will be input to the second step of source separation.

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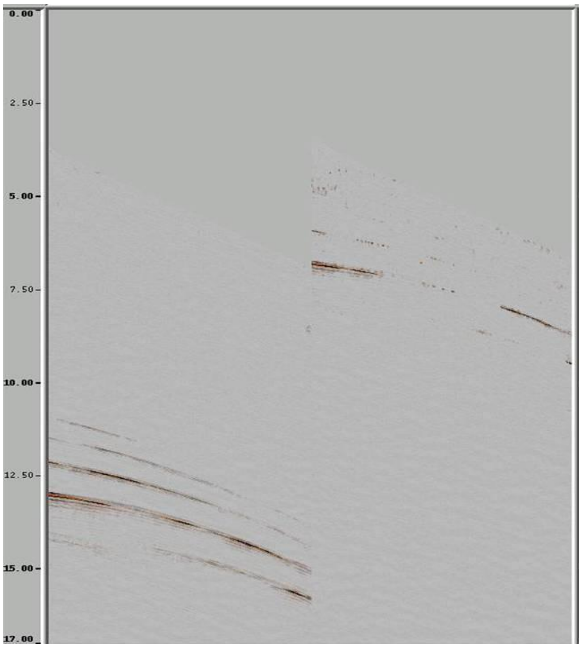

Figure 5: Removed seismic interference. Difference between Figures 3 & 4.

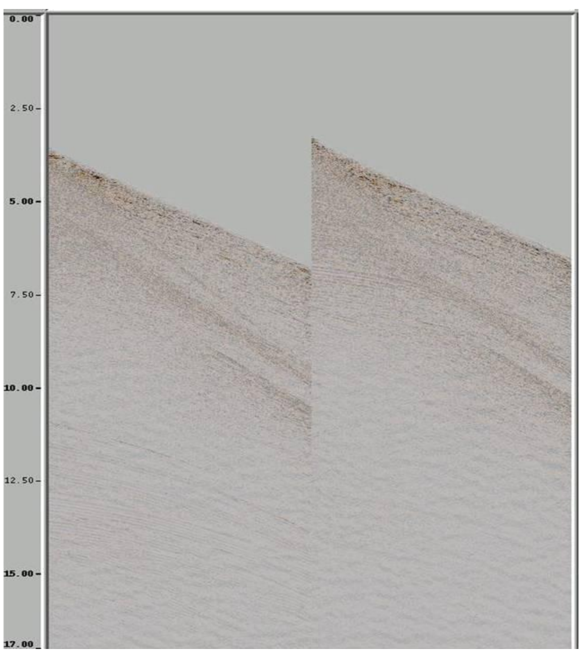

Figure 6: Final noise-bucket: Note that this remnant energy can be added back to separation results of both sources to prevent signal loss

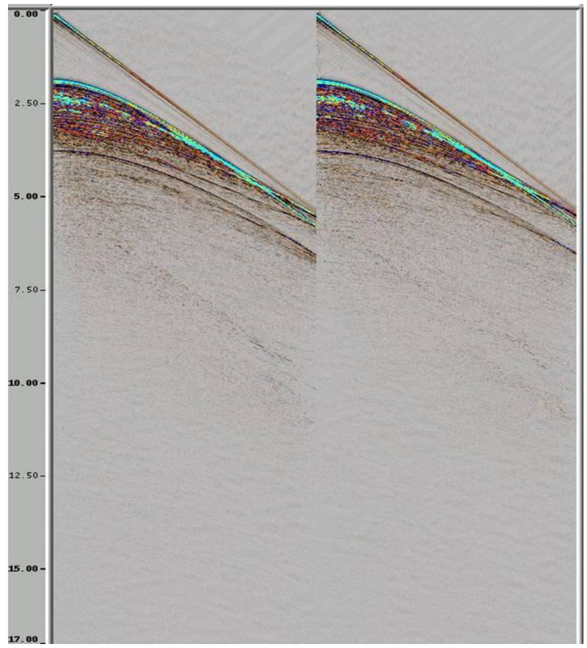

Figure 7: Final separation result for the near-offset source. Overall good separation result is obtained with minimal leakage.

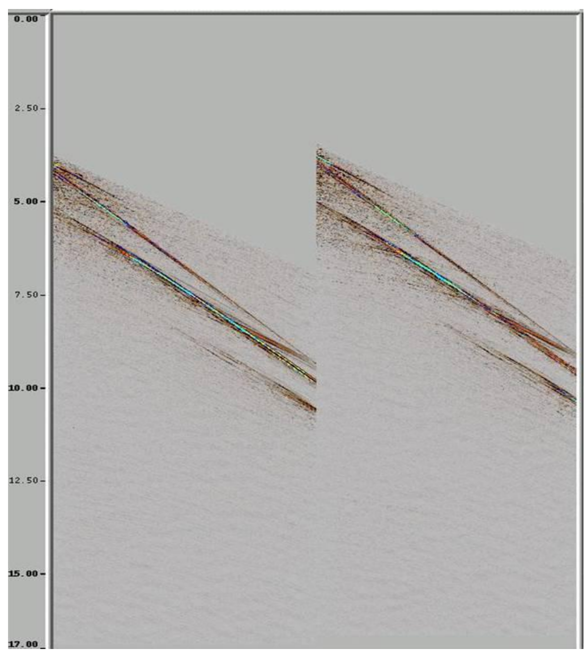

Figure 8: Final separation result for the far-offset source. Result show good separation with minimal leakage.

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EDITED REFERENCES

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