# Source separation of simultaneous source OBC data

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**Summary**

To attain the benefits of simultaneous shooting in marine data acquisition, either the simultaneous sources have to be placed far apart to minimize the interferences from one another or sufficient attenuation of the interferences is necessary. Attenuating the interferences in a domain where they are randomly distributed has a potential of attenuating the signals particularly when they have conflicting dips. Our experiments indicate that it is easier to preserve the signals if the interference is removed by modeling them in a domain where they are coherent and adaptively subtracting them from the data. In addition, with effective attenuation of the interference, the distance between the simultaneous sources can be substantially reduced.

**Introduction**

Potential benefits of seismic data acquisition with simultaneous sources in marine environments are either more data or reduced acquisition time. In streamer acquisition, we can collect more data (denser shot spacing, more azimuths, or longer offsets) in a given amount of acquisition time (Beasley et. al. 1998 and Stefani et. al., 2008). More data could provide improved illumination, better multiple attenuation, or reduced shot aliasing. On the other hand, in land, OBC/OBS or walkaway VSP acquisition, we can significantly reduce the acquisition time by using simultaneous sources. In either case, we have to deal with the interferences from the simultaneous sources.

Recently, with the increased level of interest in simultaneous sources, different approaches have been reported to attenuate the interferences from the other simultaneous source. Fromyr et. al. (2008) reported that 3-D migration alone was sufficient to attenuate the interferences from the other source to obtain an image that was comparable to an image of conventional single source data. The distance between the two simultaneous sources in their experiment was over 8 km which greatly reduced the overlapped time of the responses from the two sources. This could be the reason why 3-D migration alone was sufficiently effective in attenuating the interferences in their data.

The use of Radon transform in a domain where the interferences from the other source appear random has also been reported (Moore et. al., 2008 and Akerberg et. al., 2008) with the result suggesting that further refinements are needed. Due to leakage, the approaches based on Radon transform could damage the weak signals while subtracting the interferences. Prediction error filtering is mostly influenced by high-amplitude events, resulting in a loss of low-amplitude events with conflicting dips. Spitz et. al. (2008) introduced an interesting approach to separate the simultaneous sources. Since the location and timing of the simultaneous sources are known, the response to each source can be modeled using the wave equation. The modeled responses are in turn used to adaptively subtract the actual responses from the data, respectively. However, modeling the responses using the wave equation requires a reasonably accurate earth model. It is also computationally intensive to compute them for every source location. In addition, field data often contain events that can not be accounted for by the acoustic wave equation.

We report a simple approach to model the interference from the other source that can be used for adaptively subtracting the actual interferences in the data while preserving the weak signals.

**Emulated OBC Data with simultaneous sources**

Figure 1 shows the acquisition geometry of an OBC survey. There were two receiver cables (dashed lines) of 12 km length and 6 shot lines (only two lines are shown) of 30 km length. To emulate OBC data with simultaneous sources, we added the shot gathers with random delays less than 1 s along the bottom shot line to the shot gathers along the top shot line assuming two source vessels were sailing in the opposite direction.

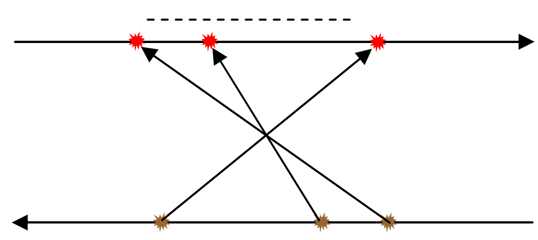

Figure 1. OBC data acquisition geometry. The dashed lines indicate the cables, and the solid lines the shot lines.

Figure 2 shows an emulated shot gather. The red star indicates the location of a shot on the top line, and the brown star the location of the shot on the bottom line that was added to the shot on the top line. Figure 3 shows the spectra of the signal and the interference. Note that the interference is about 30 dB higher than the signal. The high amplitude interferences are the first arrivals from the shot on the bottom shot line.

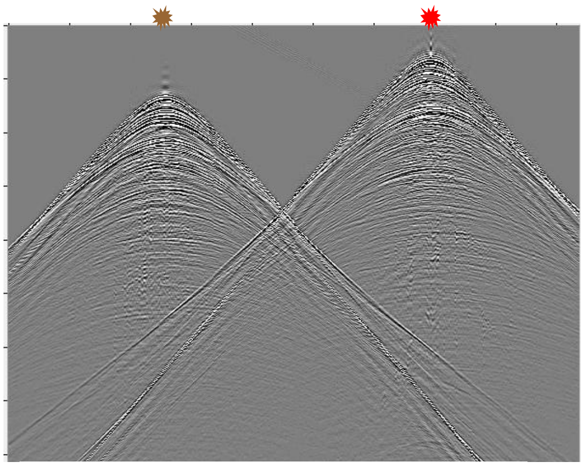

Figure 2. An emulated shot gather

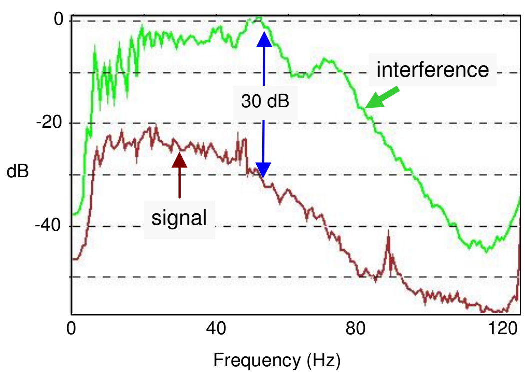


Figure 3. Spectra of the signal and the interference.

Because of random delays (or advances) to the shots on the bottom shot line, the interferences will be randomly distributed in common offset or common midpoint (CMP) domain. The S/N enhancement factor by 3-D migration is the ratio of the number of traces in the Fresnel zone to the square root of the number of traces in a migration aperture (Krey, 1987). To attenuate the interference 20 dB below the signal by migration alone, the enhancement ratio should exceed 300. Assuming a Fresnel zone of 1 km$^2$, a migration aperture of 10 x 10 km and a trace density of 1 million traces/km$^2$, the S/N enhancement factor by migration is about 100, indicating that it would be difficult to sufficiently attenuate the interferences by migration alone when the amplitude of the interferences is very high (Stefani et. al., 2007).

**Source separation**

We will call primary for the shots that were fired at the predetermined firing times and secondary for the shots that were fired with a random delay or advance with respect to the primary shots. By shifting the shot records, we can make the primary shot responses coherent and the secondary shot responses random and vice versa. Several approaches have been reported to separate the primary shot responses by making the secondary shot responses random. However, removing random events using Radon transform or prediction error filter has a danger of attenuating weak signals, particularly when their dip is quite different from that of other high-amplitude events.

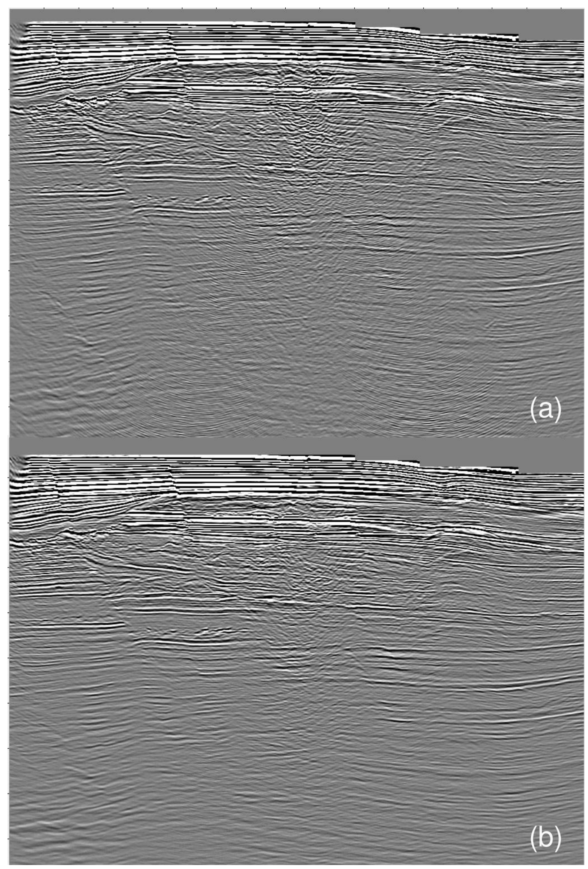


Figure 4. Kirchhoff migrated images of (a) the simultaneous source OBC data and (b) the data after attenuating the secondary shots as random events.

Figure 4a shows a Kirchhoff-migrated image of the simultaneous source OBC data, and figure 4b that of the data after attenuating random events. Although the migration artifacts due to the interferences are substantially reduced, steeply dipping events are also removed in the migrated image of the data after separation. A combination of a median filter and a prediction error filter in the frequency domain was used to remove random events.

Figure 5 shows a flow diagram of a new approach for attenuating the interferences in the data. Instead of making the interferences randomly distributed, we first randomize the events that we want to preserve and remove them. After undoing the random time delays for the secondary shots, we sort the data into a secondary shot common offset domain. In this domain, the events from primary shots are randomly distributed. We then use a combination of the filters in the frequency domain to remove the randomly distributed primary events. We use the filters somewhat harshly to ensure the removal of all the primary events. Of course, the remaining secondary events may be distorted, but we regard them as a model to the secondary events in the data and adaptively subtract them from the data.

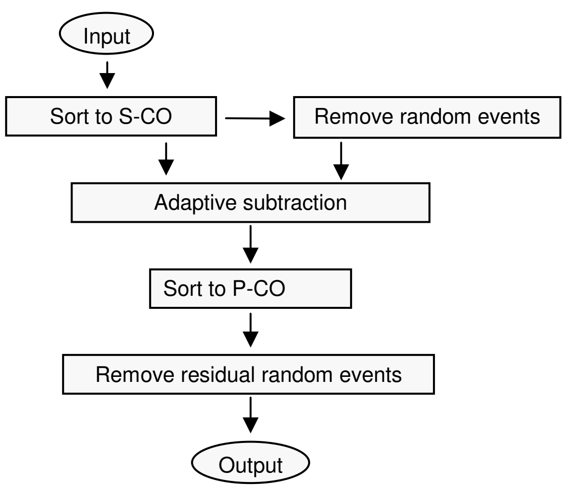


Figure 5. A flow diagram for separating the primary shots.

Figure 6 shows (a) the data in the secondary shot common offset domain, (b) after the removal of the random primary events, and (c) the result of adaptive subtraction of (b) from (a) using (b) as a model. In figure 6c, there remain some coherent events which will be randomly distributed if the result is sorted to the primary shot common offset domain. We used a very mild attenuation of the remaining secondary shot events in the primary shot common offset domain. Additionally, the data can be sorted into the primary shot CMP domain where the residual secondary shot events will be randomly distributed and can be further removed. Care must be taken, however, not to remove the weak signals. In fact, the additional subtraction did not help much because migration was able to remove the remaining secondary events.

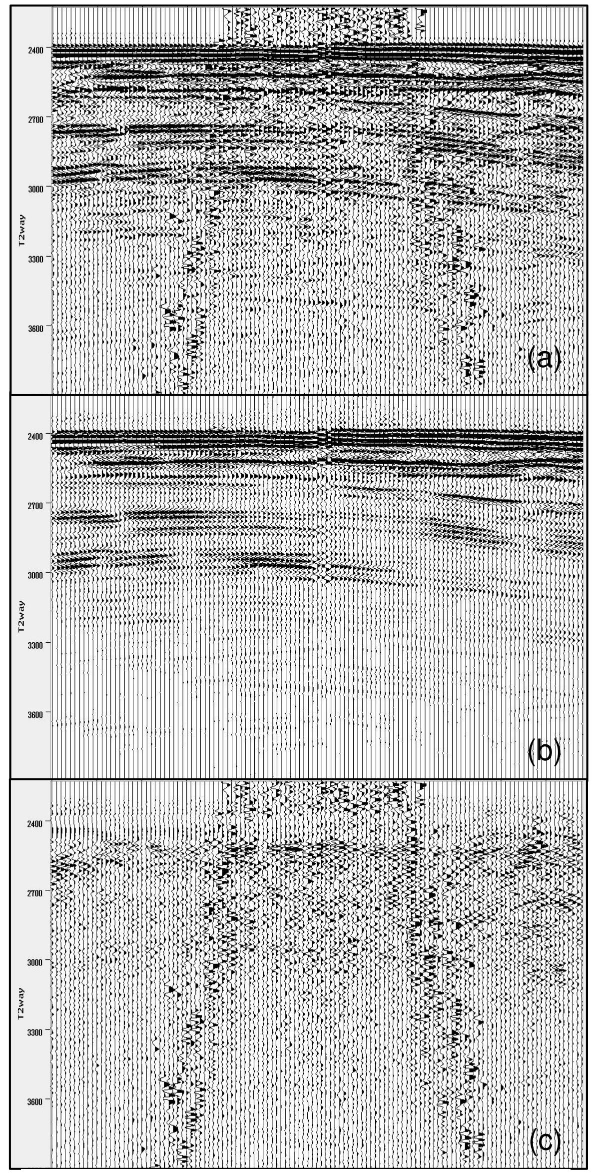


Figure 6. (a) Data in the secondary shot common offset domain, (b) data after removal of the random events, and (c) after adaptive subtraction of (b) from (a).

Figure 7a shows a Kirchhoff-migrated image after separating the simultaneous shots using the procedure outlined in figure 5. Note that while migration artifacts are well reduced (Compare with figure 4a), the steeply-dipping reflections are better preserved compared with the image shown in figure 4b. Figure 7b is the migrated image of the original data without any interference, which should be regarded as an ideal image. Although the image with source separation is still nosier than the ideal image, where the distance between the two simultaneous sources are very close, the image with separation is nearly identical to the ideal image where the distance is larger.

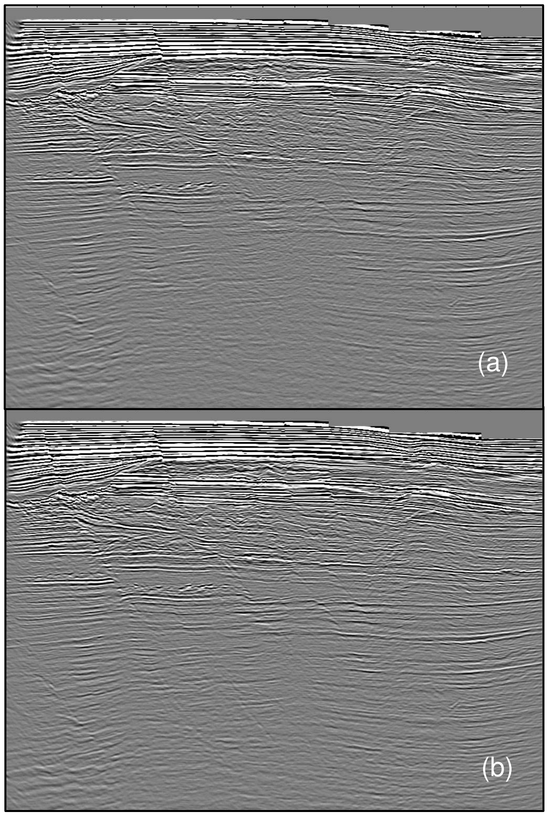


Figure 7. (a) A Kirchhoff-migrated image after separation of the primary and secondary shots and (b) that of the data without the secondary shots.

Figure 8 shows the cross correlation between the ideal image and (a) the image without separation and (b) with separation, respectively. Although cross correlation may not be an ideal measure of the image quality, figure 8 clearly suggests that, when the simultaneous shots generate very high-amplitude interferences, migration alone is inadequate to remove the interferences. Premigration source separation is a must to attenuate the high-amplitude interferences from the simultaneous shots to the extent that the remaining interferences can be further attenuated by migration.

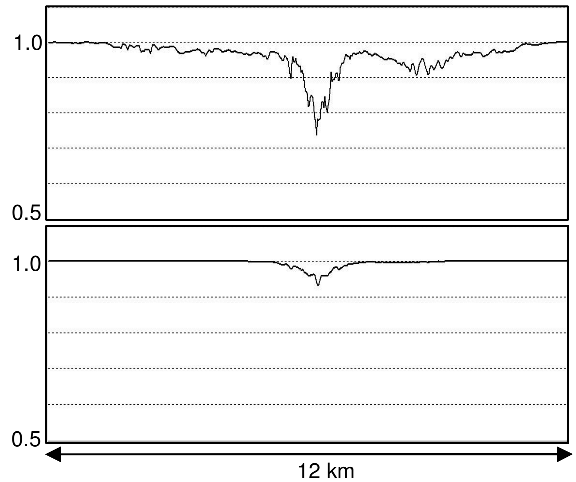


Figure 8. Cross correlation between the ideal image and (a) the image of the data without source separation and (b) with separation.

## Conclusions

In an environment where the simultaneous shots generate very high-amplitude interferences, unless overlapping of the responses from the two simultaneous shots is minimal by placing the two simultaneous shots far apart, migration alone cannot sufficiently attenuate the interferences. Attenuation of the interferences during source separation is necessary to obtain image quality comparable to that of single source data.

Removing the interferences in the domain where they are random can pose a danger of attenuating weak signals unless the employed method can perfectly separate the interferences from the signals. We found that it is easier to preserve the weak signals by modeling the interferences in the domain where they are coherent and adaptively subtracting them from the data.

Although our technique was quite effective in separating simultaneous shots, it was inadequate to remove the interferences when the distance between the simultaneous shots is small. The correlation study suggests that, unless a more effective separation technique is developed, the distance between the two simultaneous shots should be kept over 2 km.

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## EDITED REFERENCES

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