Towards better deblending – Application of wave equation based demigration

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Summary

Many deblending approaches utilize coherency criteria to separate blended signals and often involve a trade-off between cross-talk attenuation and primary signal preservation. For this reason conservative deblending is often performed, and as a consequence residual cross-talk noise can remain in the data after deblending, which can affect subsequent processing steps, such as de-ghosting and de-multiple. We present a wave equation based demigration flow to help protect primary signals for deblending. It can be combined with existing deblending approaches to achieve cleaner deblending results with reduced primary damage. The workflow has been tested with a numerically blended data set using acquired wide azimuth data. The method is shown to overcome deblending challenges that exist when shots are coarsely sampled and the dithering time is small.

Introduction

Thanks to more mature deblending technology and an increased urgency to reduce acquisition costs, towed-streamer simultaneous source acquisitions have begun to appear in production (van Borselen et al., 2013; Long et al., 2014; Langhammer and Bennion, 2015). However, due to the physical limitation of some marine towed-streamer configurations, two main challenges remain for utilizing simultaneous shooting: coarse shot sampling and small ranges of dithering time. Coarse shot sampling is especially severe with wide azimuth (WAZ) and full azimuth (FAZ) acquisition geometries, while in some cases the small dithering time range is a consequence of relying on the natural boat speed to bring randomness.

Even with anti-aliasing approaches, the separation of blended signals with coarse shot sampling can never be perfect, especially for areas with a low signal-to-noise ratio (S/N), such as subsalt regions in the Gulf of Mexico (GOM). Furthermore, with small ranges of dithering time, low frequency signal separation is difficult (Abma et al., 2012). Choices must be made either to aggressively deblend with some primary damage or to use a conservative deblending technique that leaves some residual cross-talk noise. Conservative deblending is more often chosen to protect the primary signals and because the residual cross-talk noise is further attenuated with the migration operator and stacking power. But when the shot sampling is too coarse and the dithering time is small, the deblending must be very conservative and can leave a considerable amount of cross-talk noise. In some cases, this large amount of noise can affect later processing steps such as de-ghosting and de-multiple.

To protect primary signals during deblending, we have developed a wave equation based demigration approach that can be combined with any existing deblending workflow. The original deblending approach used in this paper was an inversion-based method with 2D high angular resolution complex wavelet transform (HARCWT) (Peng, personal communication, 2015). The method has been tested on a numerically blended data set using real GOM data. The workflow can be used in particular to reduce some of the deblending challenges when shots are coarsely sampled and the dithering time is small.

Method

The workflow can be described with the following six steps:

1) Apply aggressive deblending to achieve clean data in the time domain, albeit with anticipated primary energy removed with the blended noise.
2) Migrate the deblended data.
3) Apply demigration (e.g., wave equation) to produce synthetically generated time data.
4) Match the synthetically generated time data (3) with the deblended data (1) in the curvelet domain.
5) Adaptively subtract the matched synthetic time data (4) from the removed blended noise (Input – (1)) to estimate the primary damage.
6) Add the subtraction result, i.e., the primary damage, back to the deblended result (1).

Due to the migration/demigration flow, depth information is incorporated into the deblending process. This provides more information about our expected deblended result in time.

A drawback of this method is that high frequency wave-equation migration and demigration are known to be computationally costly. To mitigate this issue, we run a low frequency demigration and match the spectra of the generated time data with the real data in the curvelet domain. We then adaptively subtract the matched synthetic time data from the estimated cross-talk noise. This process helps to give some tolerance to velocity errors in the migration/demigration stage. The subtracted result is considered to be primary damage and is added back to the original deblended data to produce the final result.

Results

The field data set was acquired in 3D WAZ configuration, as illustrated in Figure 1, with a 25 m shot sampling. Data from source 2 (Figure 1b) were shifted by a random dithering time (maximum ±1000 ms) and summed with source 1 data (Figure 1a) to simulate a simultaneous source acquisition (Figures 1c and 1d).

Figure 2 shows the following: a) a blended channel, b) the unblended channel for source 1 (i.e., the raw data before numerical blending), c) the deblended channel after the original inversion-based flow using 2D HARCWT, and d) the deblended channel after the demigration flow. Figures 2e and 2f show the differences between the deblended channel and unblended channel with and without the demigration flow. In Figure 2e we can see that the deblending method has separated the signals of the two sources reasonably well and that no obvious coherent residual is visible on the difference. After the demigration flow, some weak primary energy has been added back to the deblended result (Figure 2f), but seeing it in the time difference is difficult. This also suggests that the original HARCWT deblending may have been the best we could have reasonably achieved in the time and common channel domain.

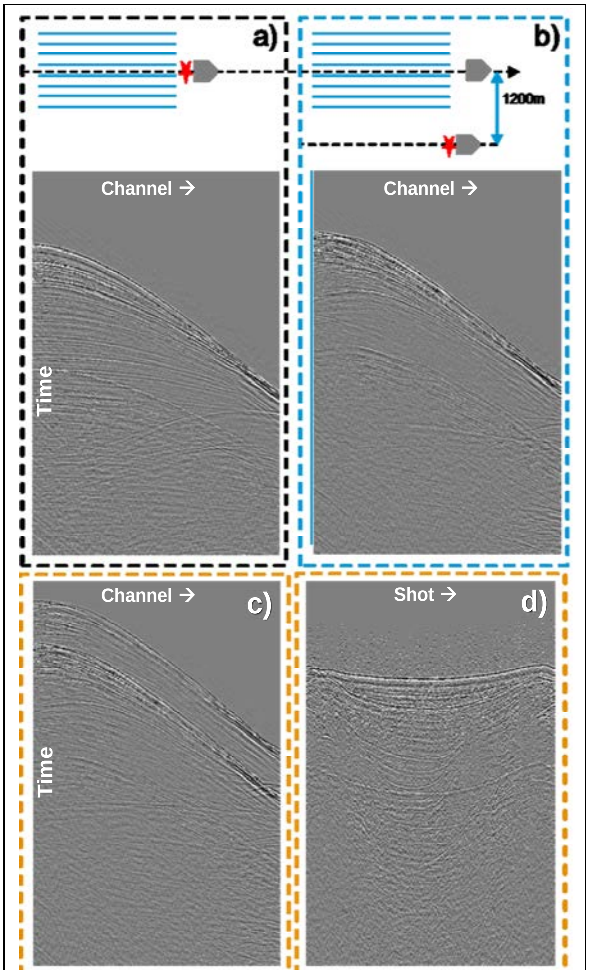

Figure 1: a) Shot gather from narrow azimuth configuration; b) shot gather from WAZ configuration; c) numerically blended shot gather from configurations a) and b); d) one channel of numerically blended data.

Figures 3a-3c show the 25 Hz reverse time migration (RTM) for the deblended data after the original flow, the

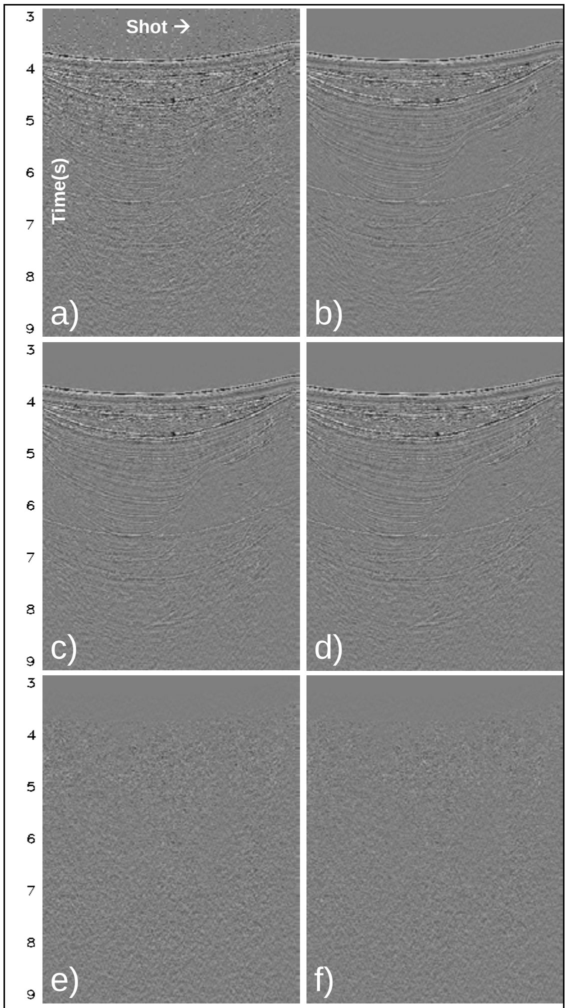

Figure 2: A common channel for a) blended data; b) unblended reference; c) deblended data after original flow; d) deblended data after demigration flow; e) difference between deblended and unblended data after original flow (+6 db gain); f) difference between deblended and unblended data after demigration flow (+6 db gain).

deblended data after the demigration flow, and the difference between the deblended and unblended migration after the original flow with 9 db gain, respectively. Unlike the time domain image (Figure 2e), weak coherent leakage can be seen in the difference (Figure 3c), especially below the salt where the S/N is low. Figure 3d shows the migration difference relating to the demigration flow; no obvious primary damage can be observed, even after a 9 db gain. This indicates that the demigration flow has been successful in repairing the primary damage.

The above results were based on a 25 m shot spacing and a 1 s dithering time, but may not be realistic for some blended towed-streamer acquisitions in practice. In WAZ and FAZ acquisitions, for example, the sources are normally coarsely sampled, above 100 m. Additionally, if dithering times rely on natural boat speed variations, the randomness is usually in the order of 200 ms. Both of these practical issues are likely to degrade the deblending results (Peng et al., 2013). Figures 4a and 4b show a scenario for a common channel with 100 m shot interval after the original deblending flow and after the demigration flow. Figures 4c and 4d show the migration differences of this scenario for the original flow and the demigration flow respectively. As the shot spacing increases, the degradation of deblending quality can be clearly observed (Figures 3c vs. 4c). However, when using the wave equation based demigration, the primary leakage was greatly reduced (Figure 4d), even in this coarsely sampled case.

Figure 5a shows a blended channel with 4000 ms ± 200 ms dithering time range. In this case, the strong blending noise overlaps weak subsalt primary signals, making deblending very challenging. If minimal primary damage is the goal, a conservative deblending approach can be applied, which gives the result in Figure 5b. We can see noticeable residual blend noise remaining in the data (red arrow in Figure 5b). On the other hand, if an aggressive deblending approach is used we can achieve a cleaner result (Figure 5c) but at the expense of obvious primary damage after migration (Figure 5e). If the demigration flow is applied after the aggressive deblending, we can achieve a clean result in the time domain (Figure 5d), while still preserving most primary signals after migration (Figure 5f).

Conclusions

In the case of coarsely sampled shots and small dithering time ranges, the separation of simultaneous source data in the time domain is seldom ideal. We propose a wave equation based demigration workflow to reduce some of these issues. Using depth domain information in the approach is shown to significantly reduce primary damage, even for coarsely sampled shots with small ranges of dithering time.

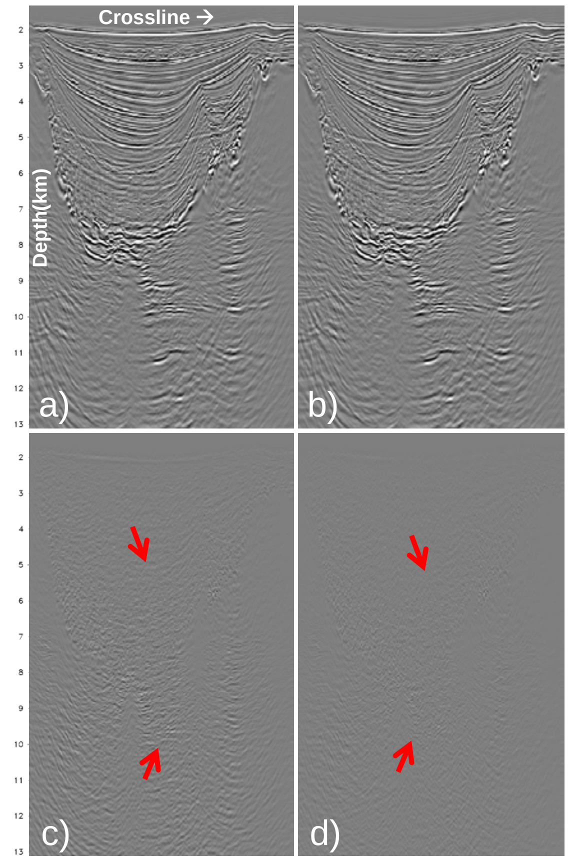

Figure 3: Migration stack for a) deblended data after original flow; b) deblended data after demigration flow; c) difference between deblended and unblended data after original flow (+9 db gain); d) difference between deblended and unblended data after demigration flow (+9 db gain).

This workflow is not without limitation. The accuracy of the velocity model affects the migration/demigration results, and, practically, only low frequency wave-equation demigration can be used. In this example, curvelet domain matching and adaptive subtraction helped mitigate these issues but could not solve them completely, as residuals can still be seen in Figures 4f and 5f.

The workflow is not a substitute for current deblending algorithms, but can be combined with any existing method in order to obtain deblending results with reduced primary damage.

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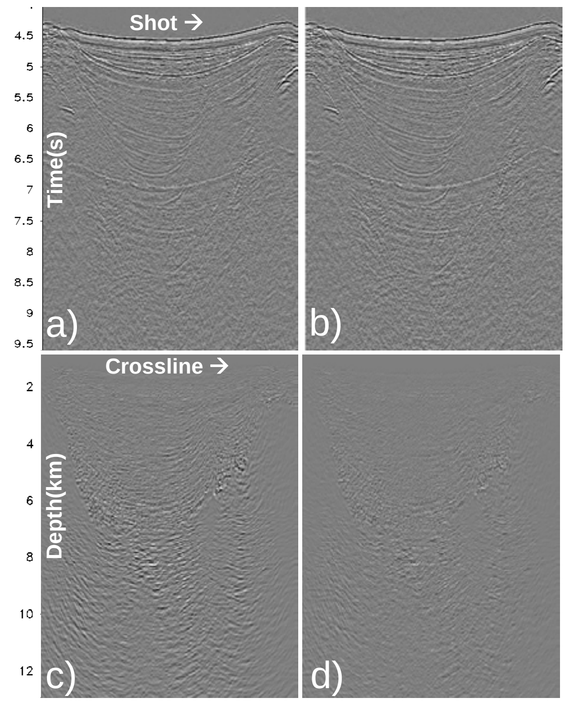

Figure 4: Common channel with 100 m shot interval for a) deblended data after original flow; b) deblended data after demigration flow.
Migration image of 100 m shot interval data for c) difference between deblended and unblended data after original flow (+9 db gain); d) difference between deblended and unblended data after demigration flow (+9 db gain).

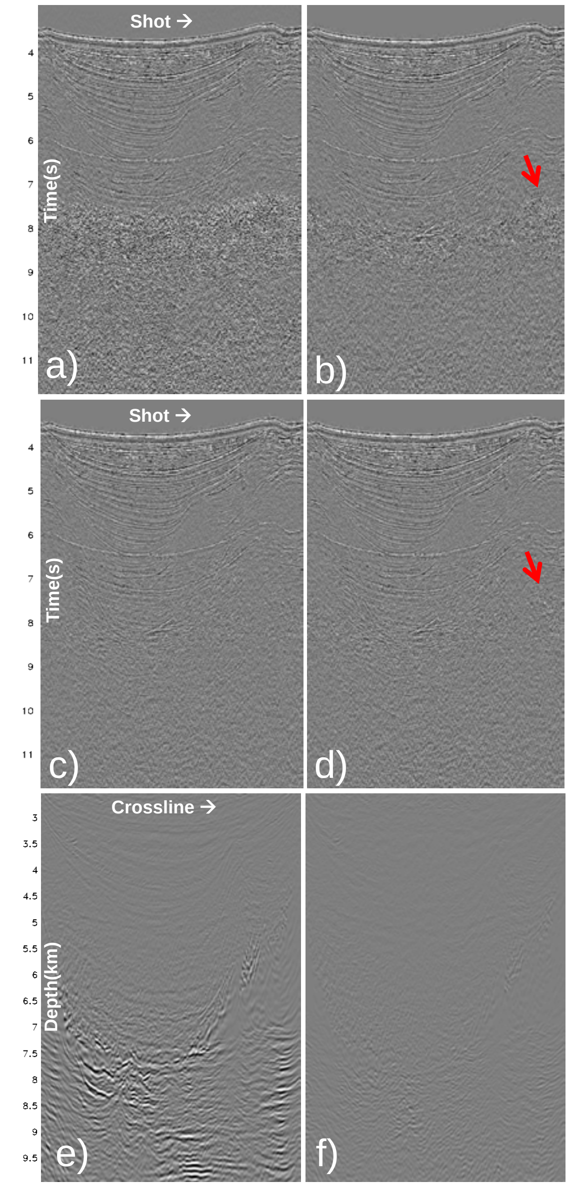

Figure 5: Common channel relating to 4000 ms ± 200 ms dithering time scenario for a) blended data; b) deblended data after conservative deblending; c) deblended data after aggressive deblending; and d) deblended data after aggressive deblending followed by the demigration flow.
Migration differences relating to 4000 ms ± 200 ms dithering time scenario for e) difference between deblended and unblended data after the aggressive deblending flow (+9 db gain); f) difference between deblended and unblended data after aggressive deblending and demigration flow (+9 db gain).

EDITED REFERENCES

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