Deblending 4-component simultaneous-source data – A 2D OBC case study in Malaysia

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Summary

In ocean-bottom cable (OBC) acquisitions, a significant part of the survey time is dedicated to source shooting. Simultaneous-source shooting, which allows time overlaps between shots, paves the way for an increase in acquisition productivity or better wavefield sampling (Hampson et al., 2008). However, blended datasets require specific treatment before being processed using conventional techniques (Davies et al., 2013). In this paper, we present the deblending work carried out on a blended 2D 4-component (4C) OBC shallow water dataset acquired in Malaysia with time dithering between sources. The deblending flow, based on a combination of iterative signal extraction and impulsive and interference noise attenuation, is described together with the QC procedures performed prior to migration. This flow is designed to tackle the deblending of both compressional and converted waves.

Introduction

Recent work has demonstrated the strong potential of simultaneous source shooting in OBC surveys to either decrease survey duration or increase the shot density (Abma et al., 2013). Time-dithering of the nearly synchronous sources is usually introduced to allow shot separation (Moore et al., 2008). It ensures randomization of the simultaneous-source cross-talk noise affecting the data in spatial sort domains (such as common receiver or CMP). The time delay between sources can also be due to natural variations in the source vessel speed in the case of fully independent simultaneous sources shooting on position.

Two main groups of methods are currently used to separate interfering simultaneous sources. The first group is based on the use of impulsive noise attenuation techniques to remove high amplitude cross-talk noise affecting the blended datasets (Wang et al., 2014). Methods belonging to the second group rely on a data modelling and subtraction scheme to perform the separation (Mahdad et al., 2011) which can be embedded in an inversion scheme (Peng et al., 2013). The modelling is usually performed in a domain where the data has a sparse representation such as the Fourier, curvelet, or Radon domain (Ibrahim et al., 2014) or by using decompositions over signal dictionaries built by machine learning (Zhou et al., 2013).

In the case of inversion-based deblending, the promotion of sparse models in specific domains is a way to minimise the effect of the simultaneous-source crosstalk on the model.

Deblending workflow

To separate blended shot records of a 4C OBC dataset, a workflow combining data modelling and subtraction, impulsive de-noising and interference noise attenuation was designed. All of these methods suffer from drawbacks when used alone because of the impact of the noise in the data — from random noise up to the low frequency and usually aliased mud roll noise. The modelling and subtraction method, which exploits signal coherency (and cross-talk noise incoherency) to justify sparse models, is less reliable in the presence of high-amplitude noise. Impulsive and interference noise attenuation techniques are efficient in removing the high amplitude part of the cross-talk noise affecting blended datasets, but are less able to remove blending noise with an amplitude level comparable to the amplitude of the signal.

To keep the advantages of the modelling and subtraction technique while increasing robustness in the presence of noise, the iterative coherency enhancement process described by Mahdad et al., (2011) is adapted as described in Figure 1.

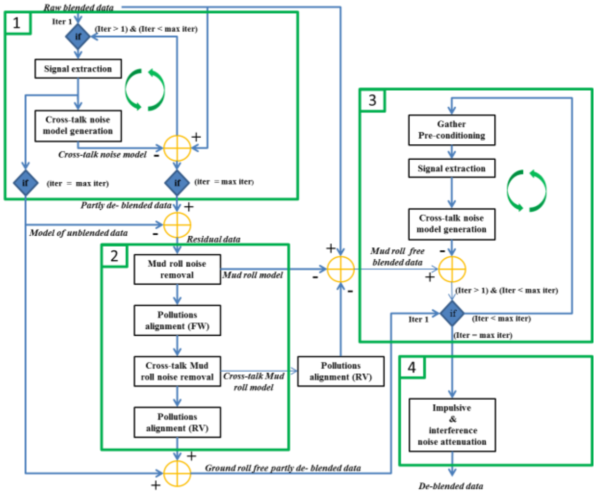

Figure 1 : Deblending sequence

A robust signal-modelling step is performed by linear event extraction in the tau-p domain in overlapping windows that are small enough to model coherent seismic signal as local planar events (Hugonnet and Boelle, 2007). This modelling

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process is constrained by amplitude and signal-to-noise ratio (SNR) criteria to avoid modelling noise and aliasing artefacts. The signal extraction algorithm is based on the minimization of the data residual after linear event extraction. The deblending process is performed in four main steps (see Figure 1):

1- Signal modelling and subtraction,
2- Mud roll noise model and associated cross-talk noise model estimation and subtraction,
3- Signal modelling and subtraction using pre-conditioned receiver gathers with subtracted mud roll noise model and associated cross-talk noise model,
4- Impulsive and interference noise attenuation.

Step 1 aims at removing most of the cross-talk noise, particularly from direct arrivals and refractions, which can be troublesome for mud roll noise attenuation. The second step is performed in two passes that are both based on an adaptive ground roll attenuation process working in the f-x domain (Le Meur, 2010) to remove the mud roll noise present in the data. The first pass removes the mud roll in the receiver domain, while the second pass removes the mud roll cross-talk noise after alignment using source time-delay compensation. The mud roll noise removal is performed on the residual data obtained after step 1 to avoid primary leakage. The mud roll attenuation step is especially effective for the deblending of the geophone components.

The third step aims at generating very close estimates of the unblended data, which also means increasingly better estimation of the cross-talk noise model. It requires gather preconditioning to avoid high amplitude cross-talk noise residue in the data model which could result in data leakage at a further stage in the workflow, namely after the cross-talk noise model subtraction.

In the fourth step residual cross-talk noise is targeted using both mild impulsive noise attenuation based on f-x projection filtering (Soubaras, 1995) and interference noise attenuation techniques (Gulunay, 2008).

Case study

Our blended dataset is a 2D-4C OBC simultaneous-source pilot survey acquired offshore Malaysia. The cable, with 25 m receiver spacing, has one hydrophone component and three orthogonal MEMS accelerometer components in a flat pack housing. The acquisition configuration consisted of two source vessels separated by approximately 3,000 m, shooting along the same line above the cable on the sea floor, and advancing in the same direction. The master vessel shot at pre-plot positions as for a conventional acquisition while the slave vessel was allowed to shoot at any time during small time periods of a 400 ms duration centered on the master vessel shooting times. This shooting rule randomized the time delay between the two nearly synchronous sources (Figure 2) while preserving the distance between sources.

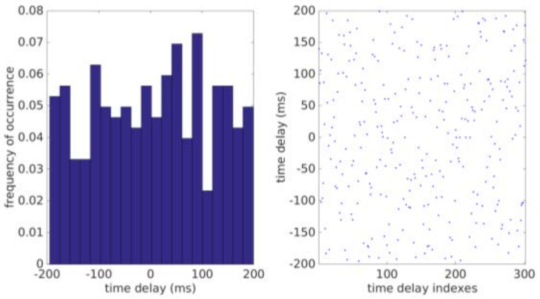

Figure 2: Properties of the time delay between nearly synchronous sources; a) Time delay distribution; b) Time delay versus simultaneous source sequence number.

Pseudo-deblending was first performed for each component which resulted in two copies of the blended shot records corrected for the time delay of each source. The four-step deblending approach was then performed separately on each of the four components (Figure 3). Convergence was assessed quantitatively at each step using the deblended dataset and the estimated cross-talk noise after repositioning and source time delay compensation. These two datasets are estimates of the same unblended data. In fact, in the case of an ideal deblending process, these two estimates would be identical. The difference in energy between the datasets is a good indicator of the level of convergence achieved by the deblending (Figure 4 shows RMS amplitude comparisons at the different deblending stages for the four components).

After completion of the deblending process, a robust fast-track processing sequence was applied. For the hydrophone and vertical geophone this sequence included hydrophone-vertical geophone summation, impulsive de-noising, surface-consistent amplitude corrections and 2D pre-stack time migration (PSTM). Sensor reorientation, de-noising, statics corrections, surface-consistent amplitude corrections, and 2D PS-PSTM were performed for the horizontal components. The raw blended and repositioned cross-talk noise datasets were processed in the same way except for the de-noising steps.

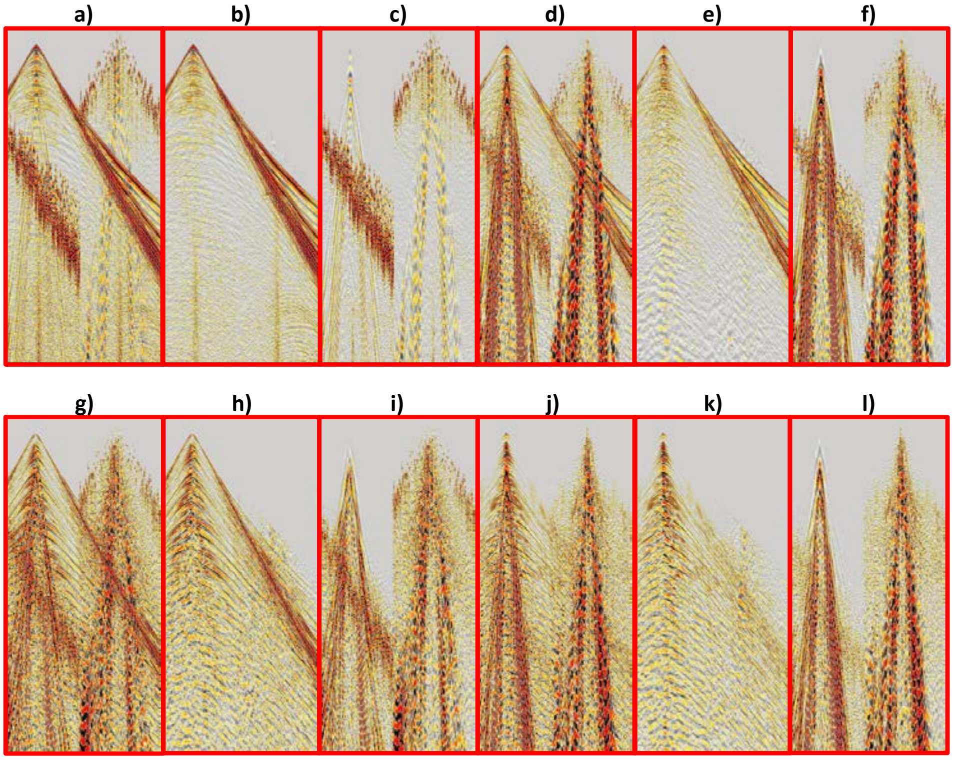

Figure 3 *:* Common receiver gather: hydrophone for a) raw blended data, b) deblended data, c) extracted cross-talk and mud roll noise; Z-geophone for d) raw blended data, e) deblended data, f) extracted cross-talk and mud roll noise; X-geophone for g) raw blended data, h) deblended data, i) extracted cross-talk and mud roll noise; Y-geophone for j) raw blended data, k) deblended data and l) extracted cross-talk and mud roll noise.

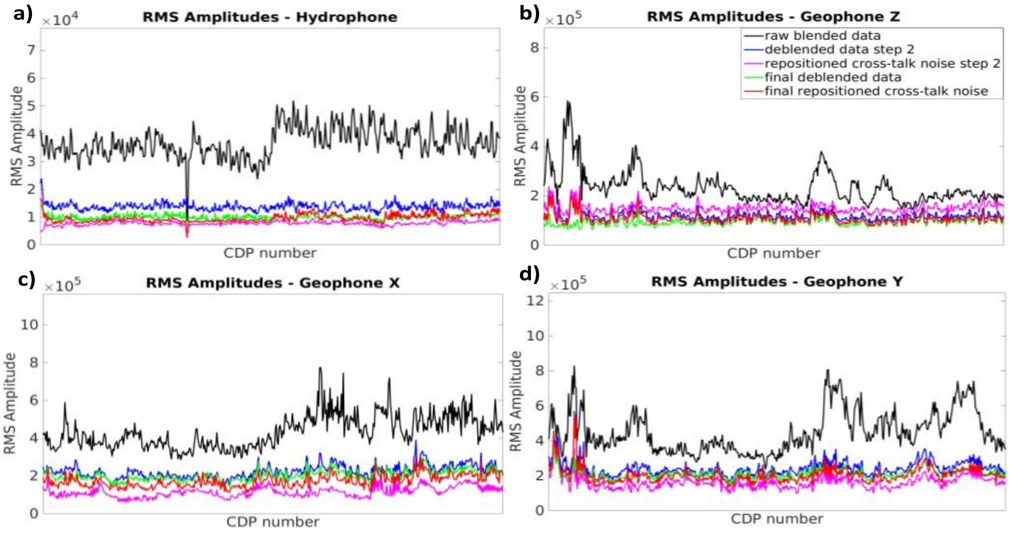

Figure 4 : Average RMS amplitude per bin gather for raw blended datasets (black), deblended dataset at step 2 (blue), repositioned cross-talk noise at step 2 (purple), final deblended data (green), final repositioned cross-talk noise (red) for a) Hydrophone, b) Z-vertical geophone, c) X-horizontal geophone, and d) Y-horizontal geophone.

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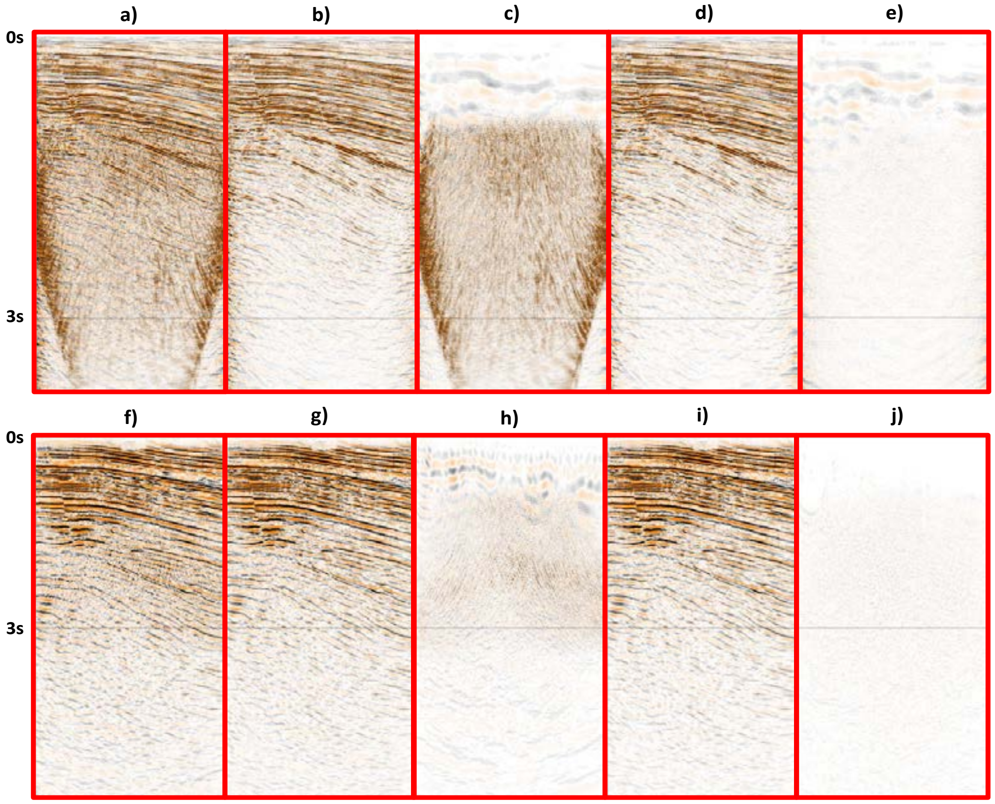

Figure 5: Deblending results after 2D PSTM: a) raw blended PP data processed up to PSTM; b) PP final deblended data; c) difference a) – b); d) PP repositioned cross-talk noise with mud-roll model and associated cross-talk noise subtracted; e) difference b) – d); f) PS raw blended data processed up to PSTM – Radial projection; g) PS final deblended data – Radial projection; h) difference f) – g); i) PS repositioned cross-talk noise with mud-roll model and associated cross-talk noise subtracted - radial projection; j) difference g) – i)

Figure 5 shows the final deblending QCs that compare deblended data, raw data, and repositioned cross-talk noise after 2D PSTM. These QCs reveal little primary leakage and very minor differences between the two unblended data estimates, thus illustrating the deblending convergence for both P-P and P-S data. The main differences are in the low frequency part of the data and are related to the ground roll residues removed at step 4 together with the remaining cross-talk noise. These low frequencies appear therefore in the repositioned extracted noise. Differences in the high frequencies can also be noticed, related to the difficulty in modelling the high frequencies which have poor signal to noise ratio.

Conclusion

Using a combination of data modelling in tau-p domain and linear, impulsive, and interference noise attenuation techniques, each component of a 2D-4C OBC dataset was successfully deblended and processed up to the PSTM stage.
To assess deblending efficiency, the complete cross-talk noise extracted by the deblending process was repositioned and further processed in the same way as the deblended data; results were compared and convergence was checked. The final results did not show primary damage but residual cross-talk noise was detected, due to the difficulty in modelling high frequency data with low signal-to-noise levels.

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EDITED REFERENCES

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