Deblending of OBN ultralong-offset simultaneous source acquisition

Yi Xuan, Raheel Malik, Zhigang Zhang, Manhong Guo and Yi Huang (TGS)*

Summary

Ocean Bottom Node (OBN) data can be acquired using blended acquisition or simultaneous shooting that allows temporal overlap among different sources. A higher blending ratio can help reduce the acquisition cost more, but also poses more challenges in separating the signal from the blending noise. We demonstrate a case study of deblending in an ultralong-offset OBN survey with six simultaneous sources utilizing a hybrid approach. The approach includes a rank minimization based denoise and local window FK based inversion. The effectiveness of this deblending approach is confirmed by RTM migration QC.

Introduction

Blended acquisition, or simultaneous shooting (Beasley et al., 1998; Berkhout, 2008), is a technique used to reduce survey time and therefore the acquisition cost, or increase source sampling and reduce aliasing issues. The strategy is to allow temporal overlap among different sources and use data processing, called deblending, to separate the signals from different sources. How heavily the acquisition is blended, or the blending ratio is an important factor for consideration. While a higher blending ratio has the economic advantage (e.g., Abma et al., 2012) in the acquisition cost, it also introduces more challenges in deblending due to its ill-posed nature that the number of outputs is more than the number of independent inputs.

In 2019, a very large scale multi-client deepwater OBN survey was acquired in the Gulf of Mexico. The survey was designed with two objectives in mind, both imaging and FWI velocity model update. The node area covered over 2700 km^2 with 3002 nodes deployed at 1000 m by 1000 m separation. The source area was over 7800 km^2 with a source grid of 50 m inline interval and 100 m source line spacing. Because deep FWI velocity model update requires long offsets, this survey was designed to achieve 40 km crossline offset for each node location. To reduce the operational cost, and acquire all 1.6 million shots within the battery life of the node, the survey was acquired in a blended style with six unique sources firing independently. Three source vessels were used and each towed two sources with separation of 100 m. The two sources on each vessel were fired nearly simultaneously, with plus-minus one second time dither from the preplot source location.

To characterize the blending ratio of this acquisition, we introduce an estimation with the following steps: 1. Replace all acquired traces by 1/t and mute above direct arrive to represent the unblended signal, 2. Blend the signal from step 1 from all traces using acquisition time and position to represent the blending amplitude containing signal and noise, 3. The ratio of blended amplitude, i.e. step 2 output, over the unblended signal, i.e. step 1 output, represents the blending ratio. This estimation allows us to get a messure of how heavily the acquisition is blended on different traces and at different sample points before separating the signals from different sources.

We applied the blending ratio analysis on field data examples that are two source lines extracted from a node gather shown in Figure 1. The left panel is a typical case for a relatively higher average blending ratio, and the right panel is a typical case for a relatively lower average blending ratio. The blending ratios are plotted in Figure 1a and Figure 1b, and their histograms in the region between the direct arrival and second-shot direct arrival are shown in Figure 1c and Figure 1d, respectively. The histograms show the blending ratio for the left panel is 7 to 8 and for the right panel is 4 to 5. The blending ratio variation could come from the distance variation among source vessels, e.g. closer vessel distance introduces a higher blending ratio. This analysis confirms that the 6 sources are actively involved, i.e. not spatially or temporally separated, during the simultaneous shooting.

The unique challenges of deblending for this survey come from the combination of the following factors: six simultaneous sources, more than 50 km ultralong offset, 40 s trace length, 100 m source line spacing which doubles the spacing from regular OBN survey.

Methods

We utilized a hybrid deblending approach including a rank minimization based denoise for signal extraction and a local window FK domain inversion based deblending for residual deblending (extended from Masoomzadeh, et al., 2019). Strong amplitude signal from the shallow portion is extracted first and the residual is passed to FK domain deblending.

We design our rank minimization based denoise to extract the signal as clean as possible. The extracted signal is then reblended and subtracted from the input data. Minimizing the extra noise introduced by this step is critical for the success of the whole deblending step.

The FK domain deblending technique conducts deblending by iteratively modeling the most energetic and coherent events, enhancing and updating the total model, reblending the latest model and subtracting the result from the input data to obtain the deblending residuals. The whole process continues until the residual energy is insignificant. It is performed in the 3-dimension f-kx-ky domain which is transferred from sliding t-x-y cubes. To mitigate the aliasing from the strong events, a hyperboloidal moveout per trace

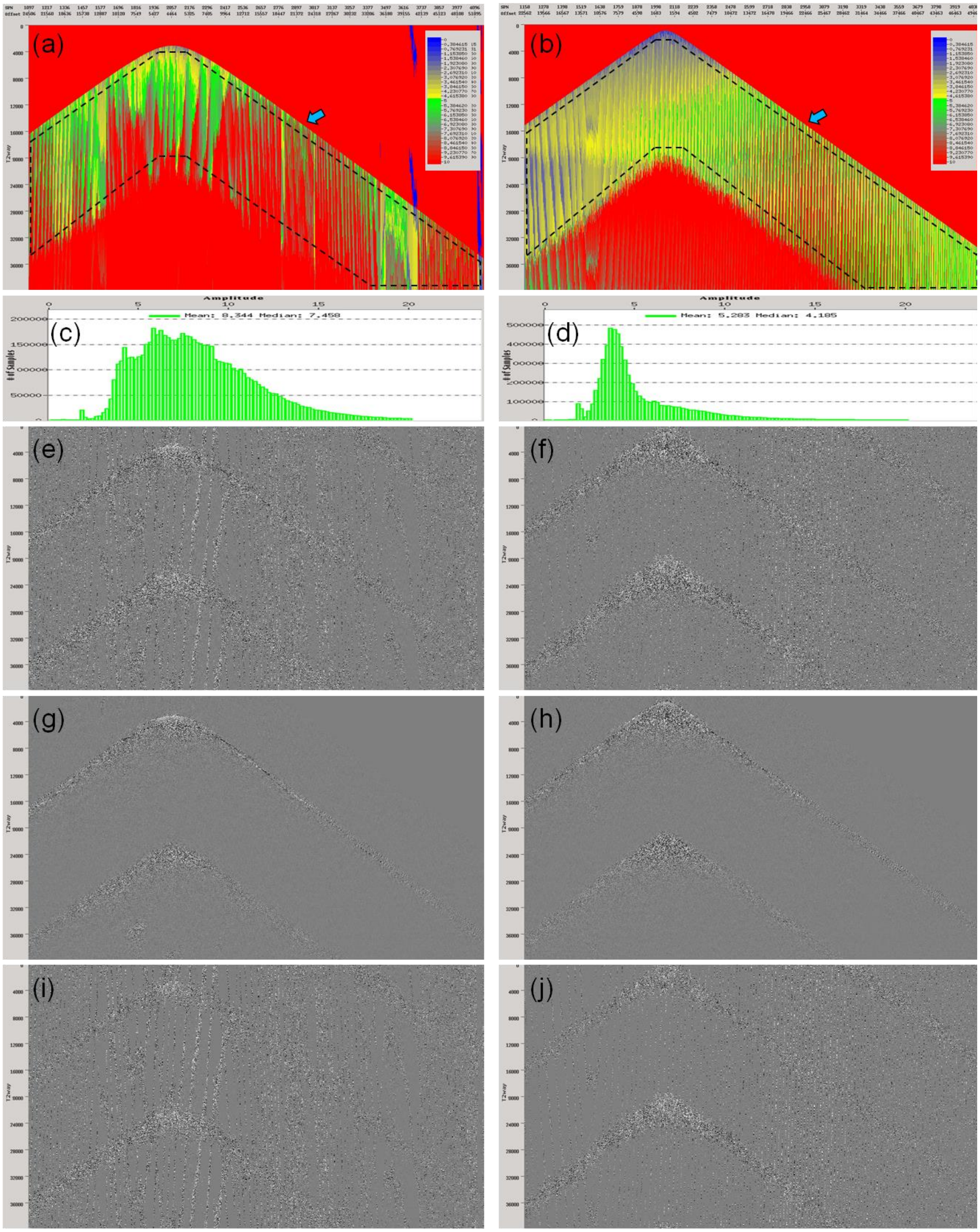

Figure 1. Two source lines from a node gather: (a) and (b), estimated blending ratio, the arrow indication the direct arrival time; (c) and (d), histogram corresponding to dashed line area in (a) and (b) respectively; deblending inputs, outputs and difference are in (e) and (f), (g) and (h), and (i) and (j), respectively, corresponding to (a) and (b), respectively.

segment in the t-x-y cube is introduced for spatial transformation, as well as the temporal shifts corresponding to the seabed event and its first to third multiples, respectively, during the iterations.The poor sparsity in the FK domain of the whole data gather may cause difficulties for any sparsity promoting algorithms, including the greedy algorithm or various L1 optimization algorithms. The sliding t-x-y window and local flattening of strong events help focus the energy in FK domain and make the inversion easier and more stable.

Results

Two raw gathers as deblending inputs are shown in Figure 1e and Figure 1f. The corresponding deblending outputs are shown in Figure 1g and Figure 1h, respectively, and the removed blending noise is shown in Figure 1i and Figure 1i, respectively. We can observe that the deblending outputs have increased coherence and the removed blending noises are mainly incoherent energy. Note that we didn't focus on the removal of the self-blending noise in this study, which comes from the next shot which appears about 16 seconds later than the direct arrival.

A local swath RTM migration QC was performed to check the imaging impact of our deblending approach. Figure 2 shows the image comparison. We can observe that the structural coherence is drastically improved in the images of deblending outputs. The difference showed that the removed energy from deblending is generally either in a random pattern or not conformal to the main events, indicating the signal is effectively preserved. Note the heavy blending noise can generate local coherence features in the image domain but these features don't conform to the true geology.

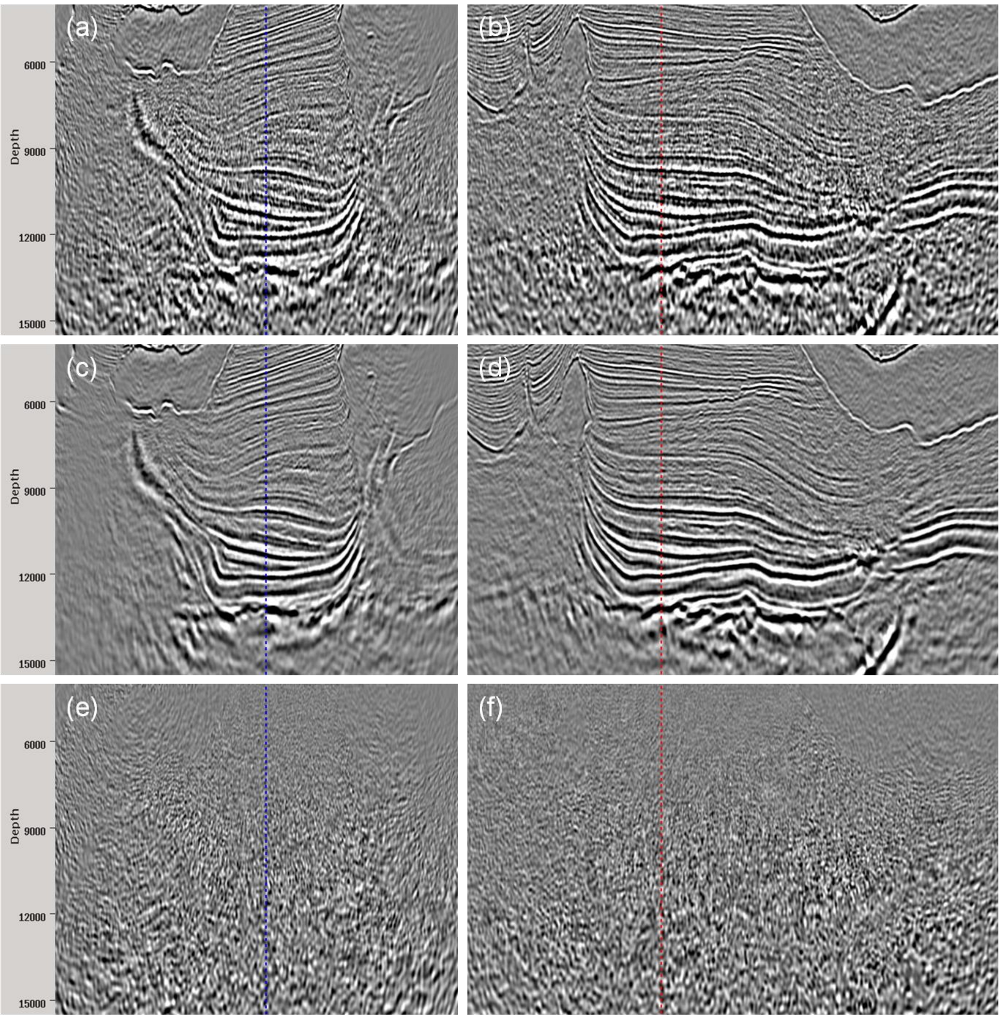

Figure 2. RTM migration QC: inline section in left panel and crossline section in right panel; (a) and (b) are from input; (c) and (d) are from deblending output; (e) and (f) are the difference.

Discussions

In this case study, the challenges mostly come from the high blending ratio where the data is heavily blended by a six-source simultaneous shooting. In practice, most inversion based deblending approaches tend to become unstable or intractable when the blending ratio gets very high. It is frequenly observed in deblending practice that leakages of the extremely high amplitude energy will smear and accumulate so that the inversion solution diverges when the deblending strategy is not carefully designed. To handle this difficulty, we particularly utilize a hybrid approach combining rank minimization based denoise for signal extraction and local window FK based inversion. The effectiveness of the approach is demonstrated in the imaging domain through the RTM migration QC.

We know acquisition could be more economical with a higher blending ratio, but where is the limit? Does this approach still have room to improve to allow even more blending? In the future, different sparse transform domain separation and different L1 norm solvers will be tested to improve the deblending quality.

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