Deblending continuous records by sparse inversion of energetic and coherent surfaces

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Summary

We have developed an efficient deblending technique for 3D surveys acquired by continuous recording. The method involves detection and separation of the most coherent events in a cube of data formed of adjacent shot gathers. Direct arrivals and coherent horizons are separated by using local means in the channel domain. The remaining coherent events are then detected by using iterations of amplitude thresholding in the 3D F-K domain, while performing various hyperbolic static shifts in every iteration. Residual blending noise is further reduced by using a multidomain time-frequency median filtering algorithm. We share examples from a large 3D survey from the Norwegian Sea acquired with triple sources.

Introduction

In conventional marine seismic data acquisition, the temporal gap between adjacent shots is made long enough to ensure that every gunshot literally breaks the silence once the uproar caused by the previous shot has diminished. In recent years however, acquiring seismic data in a ‘blended’ style has become more common. Blended data has been acquired in different ways, for example by using additional source vessels situated in different sides of the streamers, or by using two or three sources towed by the same vessel, firing into the same shot record but at slightly different times. A third approach involves continuous recording with a randomized delay time of about 5 seconds between adjacent shots. These approaches not only reduce the cost of operations by acquiring larger surveys in shorter times than usual, but also facilitate an increase in the trace density in both inline and crossline directions.

Many technical and logistical problems have been solved in the acquisition side before continuous recording became possible. In the context of a conventional processing workflow, the overlapping shot records need to be untangled first. Hence, deblending has become a serious challenge for the processing community. In the recent years a number of methods have been introduced for various blending scenarios. Abma et. al. (2010) proposed a method of separating simultaneous sources by using sparse inversion. Liu et. al. (2014) proposed an Enhanced Adaptive Subtraction (EAS) method, which involves iterations of random noise removal and adaptive subtraction, gradually optimizing the estimated noise model while switching between the source times. This method performs best when dither times are small, so that the amplitudes of coherent signal and incoherent noise are of similar strength. Baldock et. al. (2018) demonstrated an efficient method of deblending using a coherency filter based on a semblance-weighted high-resolution moveout transformation method introduced by Masoomzadeh and Hardwick (2012).

We propose an efficient deblending method applicable to continuous records divided into overlapping segments, each of which resemble a standard shot gather. In other words, every individual shot (S2) is contaminated with some weak noise from a preceding shot (S1), and some strong noise from the next shot (S3) (Figure 1). Once the shot records are oriented based on S2 times, blended data appears coherent in the common-shot domain but incoherent in other domains including common-midpoint, common-receiver and common-channel domains. Thus, the deblending challenge is down to separating strong coherent data (S2) from weak incoherent background (S1) at the top, or equivalently, removing strong incoherent noise (S3) from weak coherent signal (S2) at the bottom of each trace.

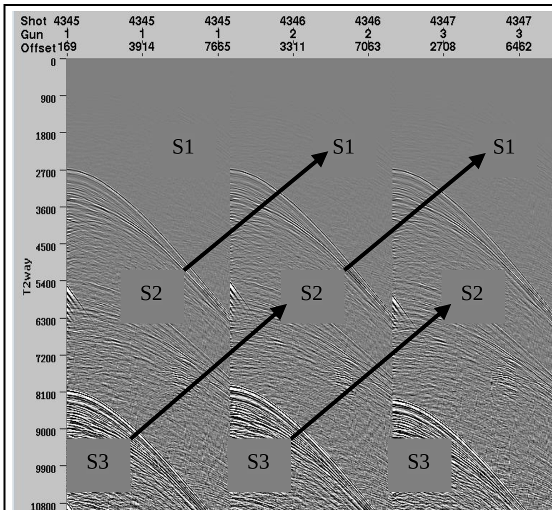

Figure 1 Three successive shot gathers extracted from a continuous record acquired in Atlantic Margin, displayed after a time-squared spherical divergence correction. Every main shot (S2) is contaminated with a preceding shot (S1) and a succeeding shot (S3). Arrows show that the main body of each shot is in fact a tail contamination for the previous shot as well as a head contamination for the next shot. Being acquired with (~5 ± .4 s) dither times, this data presents about 30 dB amplitude difference between coinciding data from overlapping shot records, which means that the deblending process can be more challenging than shorter dither times.

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Deblending with sparse inversion

Our inversion-based deblending method involves iterations of modeling the most energetic and coherent surfaces, reblending the total model and subtracting the result from the input data to work out the residuals, until the residual energy is insignificant. We perform this process in a moving cube of data containing tens or hundreds of successive shot records.

We first transform every trace into the frequency domain, then in every frequency slice we replace all samples with their mean in the common-channel direction. This operation is equivalent to a notch filter passing the zero-k component of the inline ω-k domain. This is particularly helpful for modelling the direct arrivals, which appear as coherent events in the channel domain, while rapidly decaying in the offset direction. To acknowledge the fact that every gun has a different wavelet signature, we perform this common-channel operation for each gun separately. A few iterations of this ‘sparse filtering’ process moves horizontal surfaces into the model domain. Further iterations of this process can be performed after an energetic event, such as the water bottom reflection or its multiples, has been flattened. These initial 2D iterations provide a relatively clean model above the earliest S3 time. Therefore, we mute the deeper parts of this initial model to form a clean starting model for the next step, where the remaining heterogeneous features will be addressed.

In the second step, every frequency slice is transformed into the k_x-k_y domain, where amplitudes are calculated and normalized. Since the remaining energy at this stage is mainly from reflections and multiples, in every iteration we apply a hyperbolic temporal shift before performing the spatial transformation, and reverse it after the inverse transformation. These shifts are consistent with some strong events in the data, such as the water bottom reflection and its multiples. This feature not only helps modelling more coherent energy in a smaller number of iterations, but also enhances the antileakage feature of the method. Moreover, these nonstretch hyperboloidal corrections make this method more appropriate for ocean bottom node (OBN) data (Figures 2 and 3).

While in the transformed domain, we apply a coherency criterion, meaning that only those elements with a higher amplitude than a given threshold will be inverted back (after Abma et. al., 2010). We begin the inversion process with a high threshold value (e.g. 99%), however, whenever the residual energy is not decreasing fast enough, the inversion engine updates this parameter automatically. This thresholding criterion results in sparse components corresponding to coherent extensions of hyperbolic cylinders in the time-space domain.

Finally, we use a multidomain denoising operation (Masoomzadeh et. al., 2017) to further attenuate any remaining incoherent noise. This process can also be performed in a multidomain style. Every trace is divided into overlapping segments, then the frequency content of each segment is balanced after a comparison against the median amplitude of a large number of neighbors.

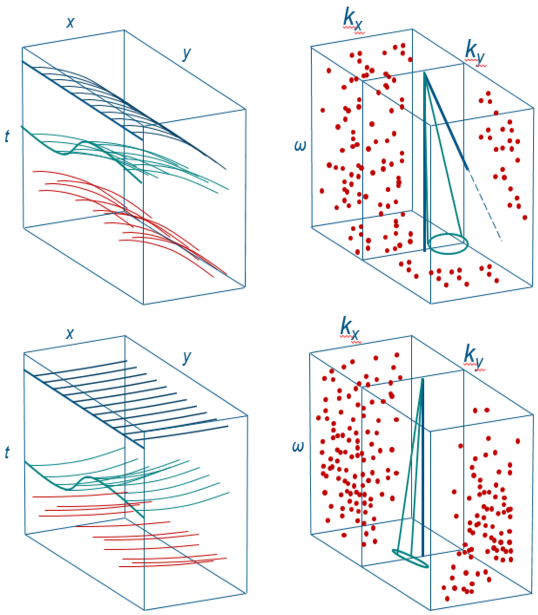

Figure 2 A schematic view of ω-k_x-k_y transformation, without applying a constant hyperbolic shift (top), and with applying the shift (bottom). Application of various hyperbolic shifts in every iteration helps with the concentration of coherent hyperbolic cylindrical surfaces in the transformed domain, while reducing the chance of aliasing at the same time. This means that the inversion process can converge in a smaller number of iterations. Moreover, this feature makes the method more appropriate for the OBN data, where the desired events are in a hyperboloidal shape.

Field data example

Aiming to improve on crossline sampling in an efficient manner, in the summer of 2017 several large 3D surveys were acquired in the North Atlantic Margin, using a triple-source configuration, with 37.5 m lateral spacing between the sources, and 5000 +/- 400 ms variable delay time between successive shots. Figure 4 illustrates three successive shot records as well as a near-offset common-channel gather, both before and after deblending using the method explained above.

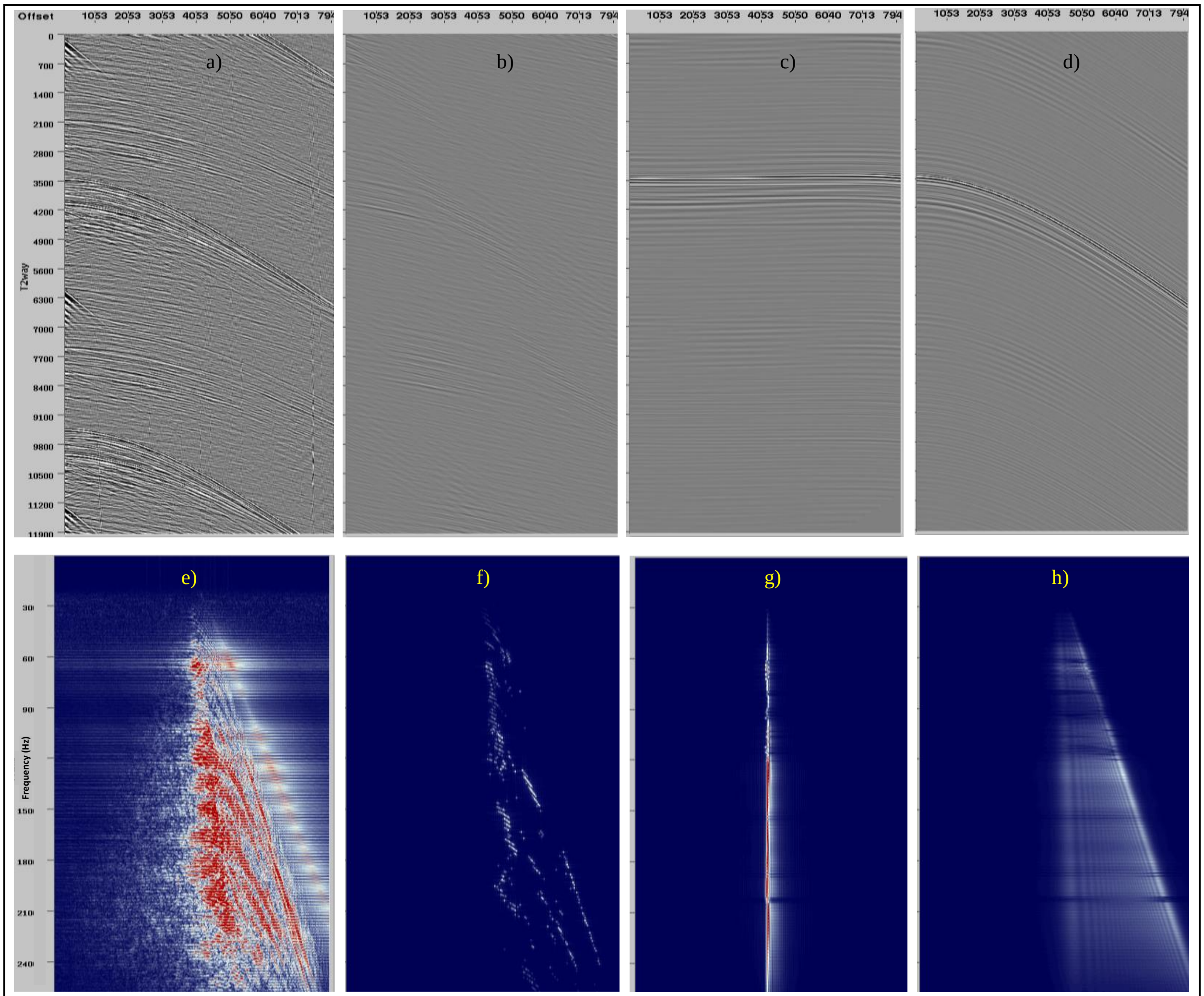

Figure 3 a) A blended shot gather; b) after one iteration of retrieving strongest planar elements in the 3D FK domain; c) after one iteration in which a hyperbolic time shift was applied; d) same as c) after reverting the shift; e) to h) 2D FK representations of the above data. It can be seen that the application of a hyperbolic time shift improves energy concentration in the transformed domain, which means more energy can be claimed in smaller number of iterations. Meanwhile, this approach helps reducing the chance of spatial aliasing in higher frequencies.

Conclusions

We present an efficient deblending method applied to continuously recorded high density data acquired by using a triple-source configuration with (~5 ± .4 s) dither times. The large temporal gap results in a large ratio of coinciding amplitudes from successive shots, which in turn makes the deblending process more challenging compared with smaller dither times. We began with modelling the most strong and coherent shallow events including direct arrivals by averaging in the channel domain, then we continued building up the model of coherent hyperbolic cylindrical surfaces via amplitude thresholding in the ω-k_x-k_y domain, while various constant moveout hyperbolic shifts were applied. Finally, we further attenuated the incoherent residuals by using a multidomain denoising tool.

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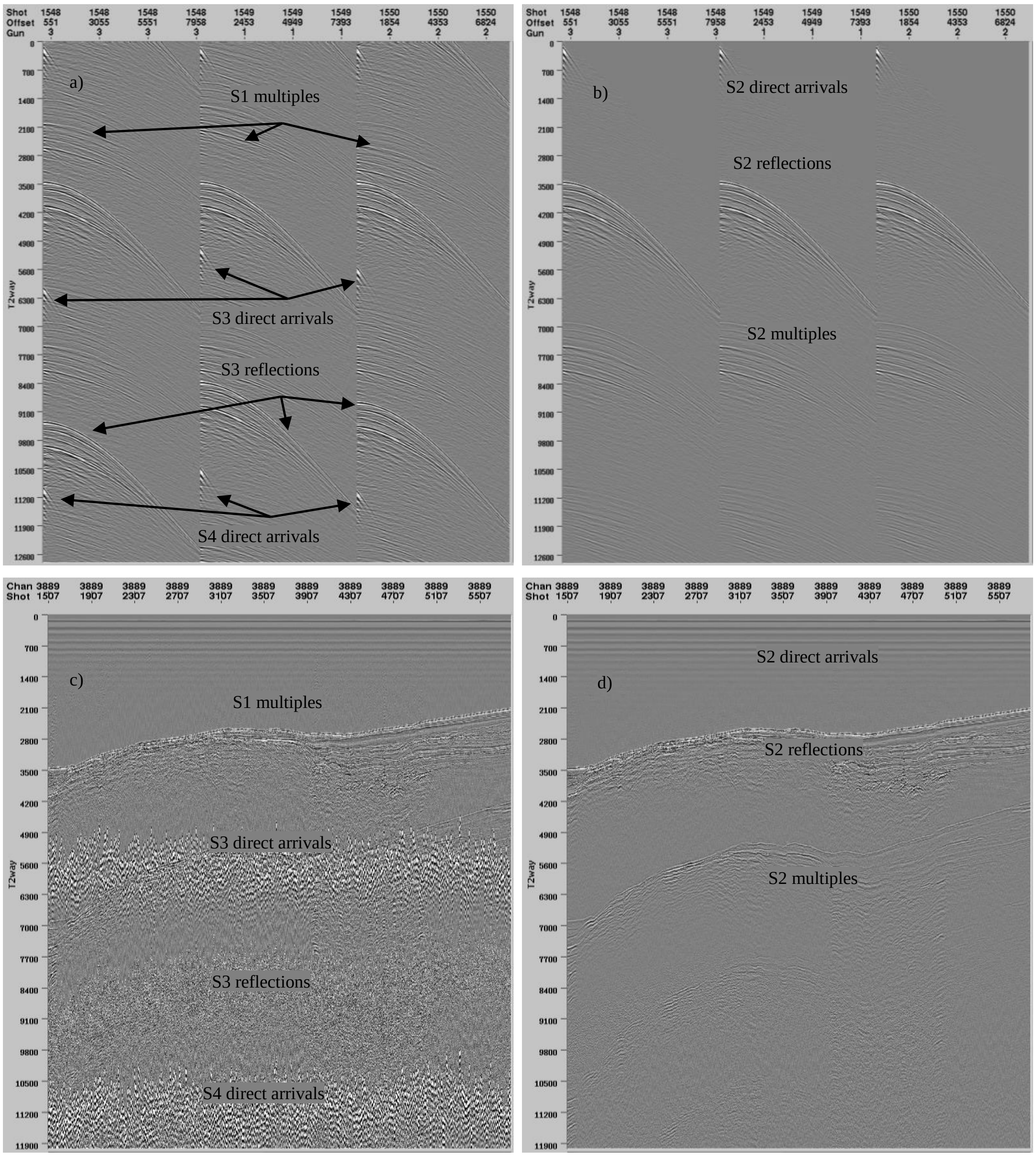

Figure 4 a) Three successive shots acquired in a continuous recording style, before deblending; b) same data after deblending using the method explained in the text; c) A near offset common-channel gather before deblending; d) same data after deblending.

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