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Deblending of Large 3D Surveys Acquired with Triple Sources in NW Europe

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Summary

By increasing the number of sources, the crossline spacing is decreased for a given cable spacing, making it possible to efficiently acquire high resolution seismic data. To maintain CMP fold the shot spacing is reduced, leading to overlapping of the seismic sources within the desired record length. Separation of overlapping sources is therefore required prior to further processing. During 2017 TGS acquired ~50,000 km2 of blended seismic data offshore NW Europe. Careful testing was carried out to design the deblending methodology, with the location of the data being a significant factor in the selection of the final workflow for each survey. The final results show good separation of sources and a close correlation to underlying nonblended surveys.

Introduction

Acquisition of blended data is now a standard part of seismic survey acquisition. Acceptance of the fact that seismic data may be blended and later deblended without damage to the signal has made it possible to reduce crossline sampling by increasing the number of sources, allowing high resolution seismic data to be efficiently acquired. As blended survey sizes grow, the challenge is to design efficient workflows for production scale processing and QC of blended data.

A lot of excellent work has been published on deblending methodologies that cannot all be summarized here. A range of techniques are available for deblending including inversion (Moore, 2013) and model based approaches (Peng et al, 2013).

In 2017, TGS acquired three large 3D surveys using triple sources: Atlantic Margin in the Norwegian Sea, Crean in the Celtic Sea and Carlsen in the Barents Sea. When complete, the total size of the three surveys will be over 60,000 km^2. The shot spacing is 12.5 m per source. This shot spacing together with a boat speed of around 4 knots, gives approximately 5.3 s of “clean” data before the onset of data from the next source. For processing the records were cut at 11 s (Langhammer et al., 2018). We describe the testing methodology, final production workflow and QC steps for the model-based deblending workflows that were applied to these surveys.

Testing Methodology

The acquisition set up described in the previous section gives a blended data set with three overlapping shots. These are identified as S1, S2 and S3 respectively (Figure 1). For a given source, S1 & S3 represent the overlapping of the previous and next shots, while S2 represents the data that is referenced to the firing time of the selected source. For the Atlantic Margin and Carlsen surveys, testing started prior to the start of acquisition using a simulated blended data set created from nonblended 2D lines from an earlier acquisition phase, which underlay the new 3Ds. From this an initial flow was established, which was further refined once the production blended data was received in the processing centre.

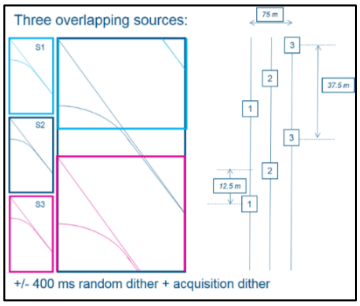

Figure 1 *Diagram showing the relationship of the three sources S1, S2, S3.*

Due to the shallow area of interest one of the first tests to be run assessed the impact of S1 on the shallow S2 data. This testing showed that the S1 data did not have a significant effect on the S2 data. While appropriate for these surveys, this finding cannot be extended to other data sets without further analysis, since factors including water bottom depth, reflection coefficient, boat speed and processing record length will affect the ratio of energy between S1 and S2 at shallow times. Based on this test, the decision was made to focus the deblending effort solely on the separation of S2 and S3 energy.

In earlier trials (Langhammer and Bennion, 2015) S3 energy arrives simultaneously with the S2 data, separated only by a random dither and a delay due to the source separation. The ratio of S2/S3 energy was therefore close to one. Liu et al. (2014) demonstrate that this data can be successfully deblended using a combination of median filtering and random noise attenuation. In the new acquisition, the switch from simultaneous to overlapping sources increases the time between consecutive shots, which, in turn, increases the energy ratio between S2/S3 to -40 dB to -50 dB, creating a more challenging deblending problem (Figure 2). The task becomes one of isolating and removing strong (S3) energy while preserving weak (S2) data. The later arrival time of the S3 data also has some positive effects. For example, due to the late arrival times S3 energy is concentrated mainly within angles of incidence between 0-5 degrees.

The use of a simulated data set was found to be beneficial during the initial testing phase. The results of different deblending methodologies could be referenced to the target nonblended data, allowing the magnitude of S2 attenuation or S3 residual to be assessed. However, when the production data arrived in house, it became clear that the simulated dataset presented a deblending challenge that was in general more difficult than that presented by the field data. This was due to several factors, including the additive effect of noise in the blending simulation and the presence of some preexisting energy from the previous shot above the water bottom in the nonblended data.

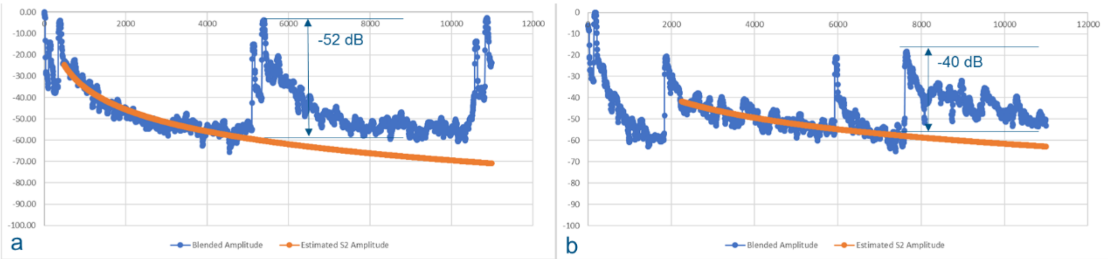

Figure 2 *Estimates of the ratio between S2 and S3 amplitudes. The blue curve shows the amplitude decay for a near channel, the orange curve is a least square best fit extended beneath the S3 arrival. The amplitude ratio is annotated in dB: a) Carlsen, b) Atlantic Margin.*

Deblending Workflow

For the Atlantic Margin and Crean surveys, a multistep deblending workflow was developed (Masoomzadeh et al. 2018). In this flow, key to addressing the “strong on weak” deblending challenge was to use the High Resolution Moveout Transform (Masoomzadeh and Hardwick, 2012) to build a model of the S3 energy in the 2D CMP domain. This step is preceded by a weighted local stack in the common channel domain and followed by a pass of multidomain noise attenuation in the CMP and common channel domains.

Several factors differentiate the Carlsen survey from the Atlantic Margin and Crean surveys: the water depth is consistently shallow, the interval velocities immediately below the water bottom are fast and the signal to noise ratio is low. The shallow water and fast velocities generate high energy reflections with a significant degree of curvature, which cross deeper reflectors at further offsets. In addition, the shallow geology contains significant levels of diffracted energy that do not conform to the hyperbolic

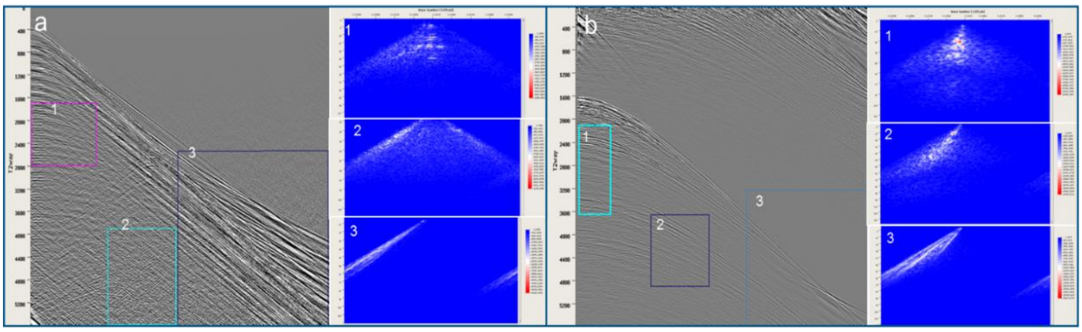

Figure 3 *Example shots from a) Carlsen and b) Atlantic Margin. The additional complexity in the Carlsen data can be seen by comparing FK spectra (panel 2) between the two surveys.*

assumptions of the HM transform (Figure 3). As a result of these differences an alternative workflow was developed for Carlsen. The workflows are summarized in Figure 4.

A key step in the Carlsen workflow was to sort the data to a common receiver gather, shift to S3-time and to take advantage of shot to shot variations in arrival time to randomize the S2 energy. Source separation was performed using a tau-*p* transform. Noise attenuation in the receiver and CMP domains in S2-time was used to address the remaining residual S3 energy.

Aside from standard production QCs, several additional QCs were found useful for evaluating the deblending results. Near stacks limited in angle to the area overlain by S3 prevent high angle S2 reflections that have not seen any S3 energy from colouring the stack response when evaluating deblending performance. Postdeblending gathers from domains where S3 energy is random (e.g. CMP or common channel) shifted to S3-time are another useful QC. Residual S3 energy will appear as coherent, while zeros or small values indicate possible S2 energy removal. Trains of reverberating short period multiples in the S2 data provided an unexpected QC tool. Their predictable nature with time across the onset of the S3 data proved a useful indicator of the performance of the deblending process.

***Figure 4**. Schematic representations on deblending workflows for the three* surveys.

Results

Figure 5a shows a 3D inline stack from the Atlantic Margin survey; Figure 5b shows the same inline from a fast track PSTM volume after deblending, deghosting and preliminary demultiple. After deblending, the deep reflections show good structural continuity amplitude variation. Figure 6a shows 3D CMP gather data from the same stages. In Figure 6b, the deep reflectors show no indication of contamination by blended energy, especially for the near angle data where S3 energy was concentrated.

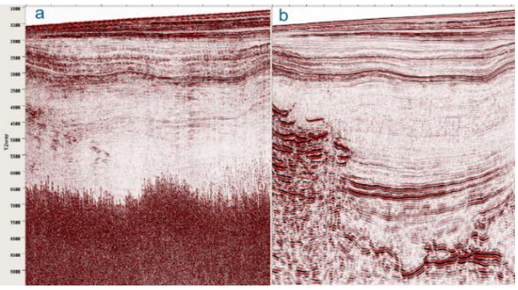

***Figure 5** Atlantic Margin: a) 3D Stack prior to deblending, b) 3D PSTM Fast Track Stack after deblending.*

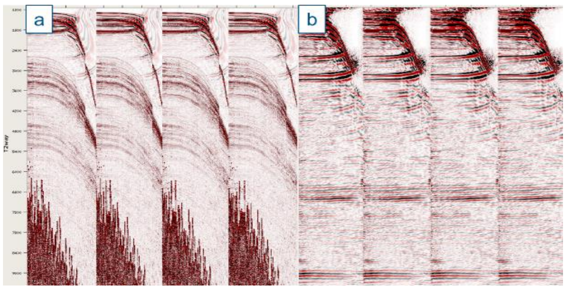

***Figure 6** Atlantic Margin: a) 3D CMP gathers prior to deblending, b) 3D PSTM Fast Track CMP gathers. after deblending.*

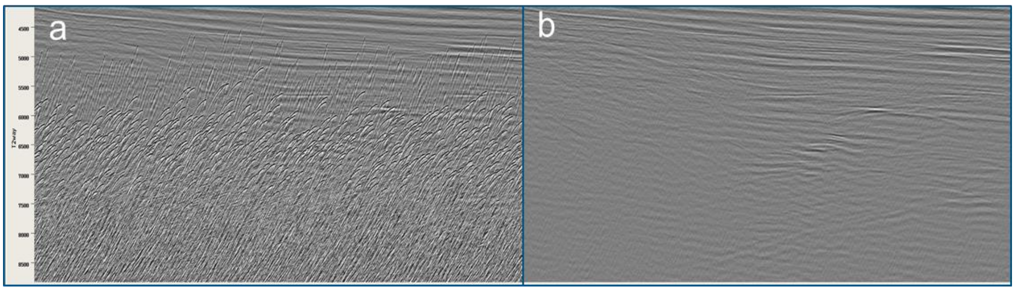

***Figure 7** Sail line **s**tacks from the Crean survey before and after deblending. Figure 6a, stack of the blended data. Direct arrivals for S3 appear at about 5.3 s; Figure 6b, stack of data after the 3-step deblending flow.*

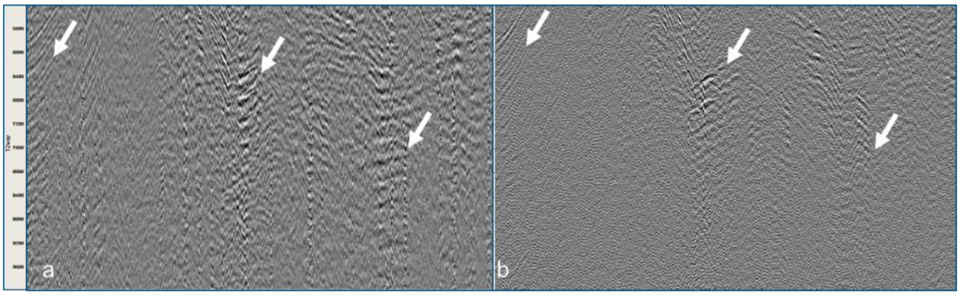

***Figure 8**: a) Oblique line from the deblended stack of the Carlsen survey; b) underlying nonblended 2D line. The arrows indicate places of good correlation between the deblended and nonblended result.*

Figure 7a and 7b show a sail-line stack from the Crean survey before and after deblending Residual S3 energy is minimized and deep reflectors are revealed. Figure 8a shows an oblique line extracted from a 3D stack volume of the Carlsen data. Figure 8b, shows a 2D line from the same location from a nonblended 2D survey. The deblended data show good structural correlation with the nonblended data demonstrated that the deblending workflow has successfully separated S3 from S2 energy.

Conclusions

Several large 3D seismic surveys acquired with triple sources have been successfully deblended using multistage workflows. The key deblending element in each workflow was found to depend on several factors including water depth, velocity and signal-to-noise ratio. Simulated 2D data sets were created to test the deblending process. While this proved invaluable, it was found to present a more complex deblending problem compared to that of the field data. Data examples demonstrate the effectiveness of the deblending process on stacks and gathers.

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