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4D Processing between Variable-depth and Conventional Streamer Data

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SUMMARY

Processing data with variable-depth streamer acquisition has recently become possible through a new advanced algorithm called joint deconvolution (Soubaras, 2010). In this particular acquisition, the receiver depth increases smoothly with offset and this allows for a wide diversity of receiver ghosts to be recorded. This acquisition and associated processing increases dramatically the possible frequency bandwidth. While most acquisitions in the future will certainly be realized with broadband techniques, the question of 4D matching between conventional and BroadSeis data must now be addressed during an intermediate period when the baseline data is a conventional acquisition. The case between BroadSeis and conventional data has one problem to solve: the difference in cable profiles. This paper considers this problem, addresses the following topics: wavelet processing, time de-striping, 4D binning, regularization, imaging, final matching and demonstrates that a relevant 4D response can be obtained.

Introduction

Processing data with variable-depth streamer acquisition has recently become possible through a new advanced algorithm called joint deconvolution (Soubaras, 2010). In this particular acquisition, the receiver depth increases non-linearly with offset and this allows for a wide diversity of receiver ghosts to be recorded. This acquisition and associated processing dramatically increases the possible frequency bandwidth, on both low & high frequencies sides, from 2.5Hz to the source notch. This particular broadband technique will be referred to as BroadSeis in this paper. While most acquisitions in the future will certainly be realized with broadband techniques, the question of 4D matching between conventional and BroadSeis data must now be addressed during an intermediate period when the baseline data is a conventional acquisition. This paper considers this challenge and demonstrates that a good 4D response can be obtained

Compared to conventional flat streamer data, processing variable depth streamer data implies a major change: the receiver ghosts are rigorously taken into account, whereas they cannot be removed from the wavelet in conventional flat streamer processing. The variable receiver depths of BroadSeis give asymmetrical ray paths which are taken into account by the imaging process and by the proper summation of the up-going and down-going wave fields in the joint deconvolution.

Typical cross-equalization in a 4D process aims at solving issues related to differences in the vintages acquisition (acquisition related time- and amplitude differences) and positioning (4D binning). The case between BroadSeis and conventional data has one more problem to solve: the difference in cable profiles. This problem can be handled by joint de-ghosting and re-ghosting processes. In the following sections, we will discuss all these topics: wavelet processing, time de-striping, 4D binning, regularization, imaging and final matching. The dataset used for this comparison is a dual recording acquired by Shell in a highly structured deep offshore play.

Data Overview

While shooting a conventional 3D survey offshore Gabon, Shell acquired an additional 430 sq km swath of BroadSeis data to evaluate the uplift brought by the broadband image. The first comparison on PSTM data was generated in the end of 2011 and is shown in Figure 1. It shows the overall improvement typically achieved by BroadSeis in terms of enhanced spectral bandwidth.

The acquisition geometry consists of 10 cables, 8000m long. The conventional streamers were towed at 11m depth with a source depth of 9m, while the BroadSeis configuration was towed between 11m and 50m with a source depth of 7m. No specific repeatability of source positions was requested when the vessel acquired these swaths, as shown by the azimuth maps of the two acquisitions (Figure 2). With these limitations in mind, both volumes were processed in a 4D sense in order to assess any impact of the variable streamer depth on the 4D signature, which should ideally be zero in the

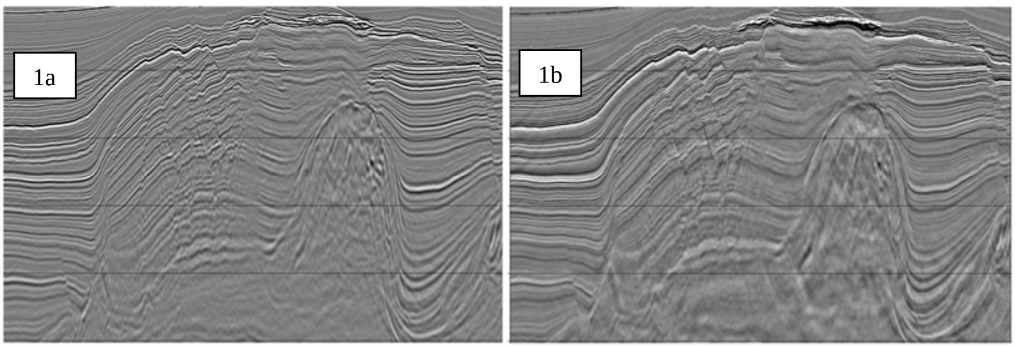


Figure 1 *Crossline PSTM comparison between a) conventional and b) BroadSeis.*

common bandwidth.

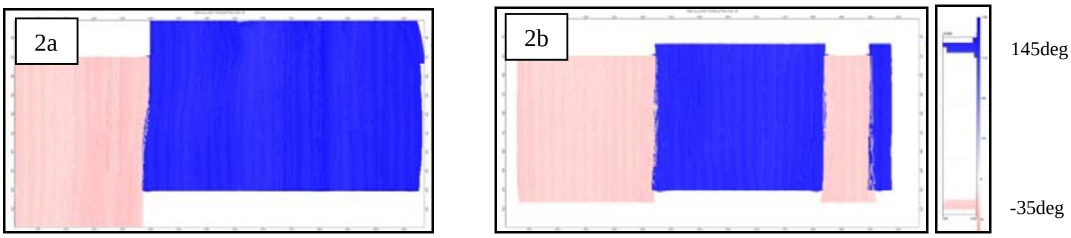


Figure 2 *Azimuth maps of the a) conventional and- b) BroadSeis surveys.*

Detailed steps for addressing the 4D challenge

We will now examine the main steps of the processing flow where the receivers' variable depth of the broadband acquisition has to be considered and which differ from standard 4D processing on conventional flat streamer data.

Wavelet matching

The wavelet matching is performed in two steps. The first consists of a partial de-signature so that both wavelets are aligned and can be compared for further 4D matching. The BroadSeis data is initially only deconvolved for the source response, postponing the receiver de-ghosting until after the imaging (joint deconvolution of up and down wavefields). The conventional data is processed in the same way: we initially remove only that part of the ghost related to the source. The receiver de-ghosting is deterministically applied after cross-equalization processes to complete the zero phasing before final matching to final BroadSeis data. In Figure 3, the cross-equalization is done at step 3c for conventional and 3e for broadseis data.

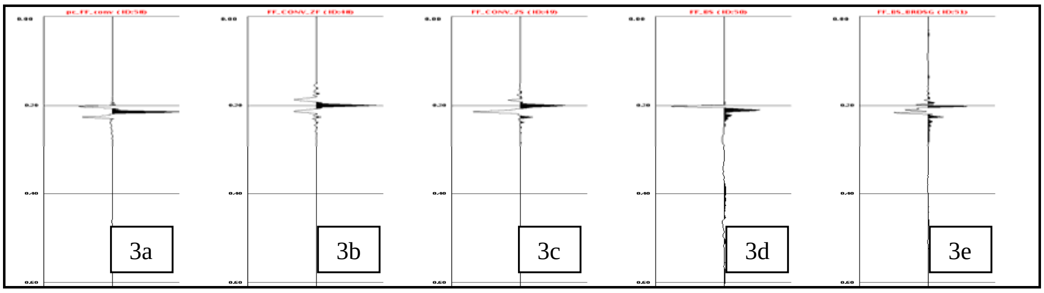


Figure 3 *wavelet matching: a: Conventional Far Field (FF) signature with receiver ghost, b) after full zero-phase de-signature, c) after removal of the receiver ghost, d) BroadSeis FF signature, e) BroadSeis after source de-signature only.*

In a second step, at the end of the processing, the two datasets should be compared in their common bandwidth. As we cannot boost the conventional data without generating noise on the low and the high end of the spectrum, we therefore downgrade the BroadSeis data to the conventional by applying the ghost corresponding to the receiver depth of the conventional data and by designing a global matching filter to complete the work.

4D time de-striping

The imaging algorithm takes into account the source and receiver depths to bring the output data to the sea surface, using a unique velocity model referenced at the same datum. This method had originally been developed for Ocean Bottom Node data processing together with the option of generating the mirror response. We have now extended it to be applicable in the Normal Move Out (NMO) process and this allows for a first provisional correction and cross-equalization of the conventional and BroadSeis data before imaging. After the wavelets have been properly matched, the time de-striping can be performed using the near traces which, on both data-sets, have almost the same depth. As the NMO corrected data is correctly positioned in time, the de-striping can then be performed as usual by using auto picking or cross-correlation of the near traces.

3D SRME

Independent convolutional 3D SRME was performed to remove free surface multiples. It has been demonstrated by Sablon et al. (2011) that, providing some receiver ghost normalization prior to the modelling, the multiples models can directly drive the adaptive subtraction. Specific care is also applied to the ghost protection at this latest step. We verify here that the results are comparable

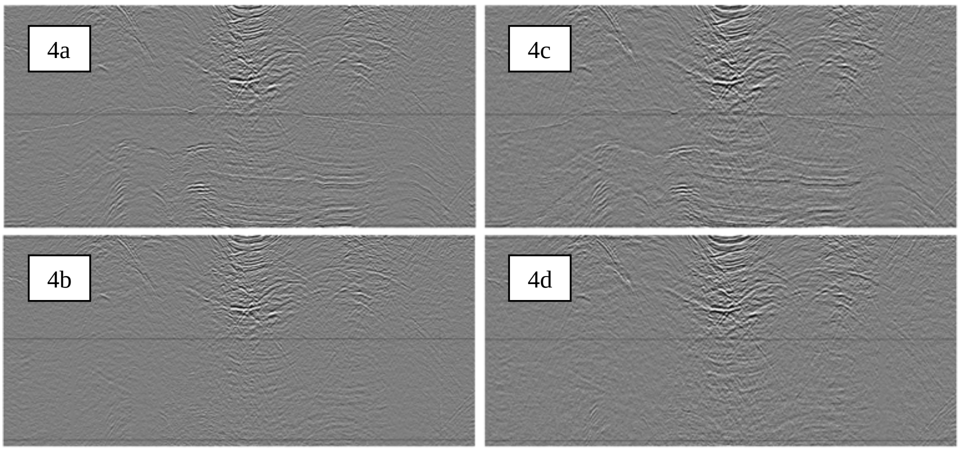


Figure 4 *BroadSeis a) before and b) after SRME. Conventional c) before SRME and d) after SRME.*

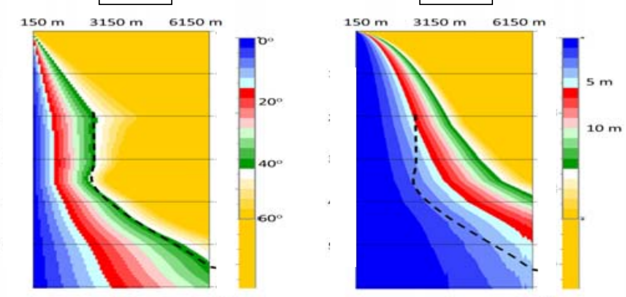
between conventional and broadband SRME (see Figure 4.)

4D Binning, regularization and imaging

Common practice for 4D binning is to retain traces which have the closest ray paths, by minimizing the difference of distances between receiver and shot positions. In our case the surface position is not sufficient to provide this criterion and we must take into account the variable receiver depth. In Figure 5b we show the mis-positioning of the cmp due to the asymmetry of the BroadSeis ray path. For an angle of 40 degrees the maximum cmp shift would be 5 meters.

It is possible to provisionally compensate the receiver positions to minimize the error at the target (reservoir). This technique is generally used for matching OBC to streamer data. However, given the small size of the misfit, shown in Figure 5b, we concluded that the non-repeatability of the acquisition would generate higher 4D noise than this approximate correction, so we did not apply it. Note that the regularization and the migration are performed in offset-inline domain instead of offset domain, in order to avoid manipulating volumes with varying receiver depths.

5a 5b



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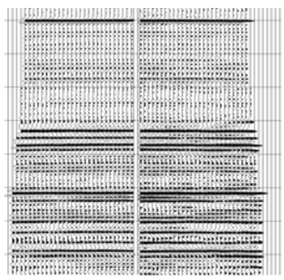

Figure 5 *a) map of incidence angles and b) associated CMP shift due to the variable depth streamer shape.*

Figure 6 *Back to back a) conventional and b) BroadSeis gathers after matching.*

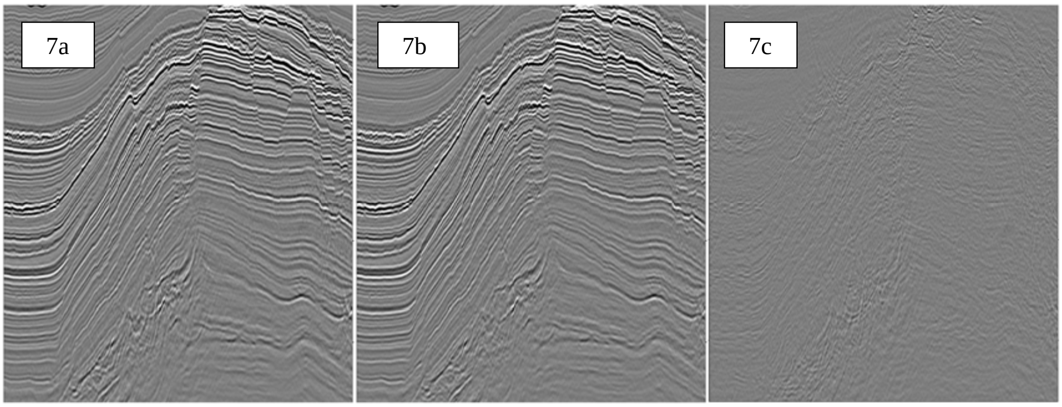

Figure 7 *PSTM stacks for a) conventional and b) BroadSeis after de-ghosting and matching. The difference section c) contains mainly noise.*

Final results and discussion

The datasets (BroadSeis and conventional) have gone through the 4D co-processing discussed above. Figure 6 shows a pair of final 3D PSTM gathers, and Figure 7 shows section views. The final 4D processed data are very close, and the difference section is weak. Most of the energy in the difference section is un-cancelled migration artifacts (swings), which are mostly related to suboptimal acquisitions and noise. The peak NRMS is about 22%, which can be considered as a good 4D response (Helgerud et al 2009) particularly for different acquisition styles. We can further improve upon these results by doing the following: first to have optimal 4D acquisitions, the key is to repeat the shot/receiver locations as closely as possible; secondly to apply amplitude 4D de-striping, which has not been applied to the results in Figure 7; thirdly to take into account the ray-path difference during 4D binning. Therefore, for a well-planned 4D survey between BroadSeis and conventional data, we conclude that an NRMS of less than 20% is achievable.

One sacrifice we have to make here is to downgrade the bandwidth of the BroadSeis data due to the constraints from the conventional data. If the 4D processing was done between two BroadSeis surveys, we would expect to produce a broadband 4D response. This could become a step-changing technology in reservoir monitoring.

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