On Top of Seismic Sampling - Benefits of High Resolution Source-Over-Streamer Acquisition

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Summary

Recent years have seen growing interest in improved shallow resolution images of the subsurface. This has led to ever more innovative acquisition approaches, each tailored to individual geological settings. We focus on a towed streamer acquisition in the Barents Sea which deployed five sources above the streamers for high definition imaging, along with a single source towed behind the streamer vessel to acquire long offset data for full waveform inversion. Firstly we demonstrate how accurate deblending is a key processing step to uncover the potential of these data. We then perform decimation tests so we may compare with conventional and short-offset conventional acquisition configurations. We assess the benefits of the small bin size, short offsets, and high trace density provided by the source-over-streamer acquisition. Our analysis highlights the extent to which these factors improve free surface multiple attenuation and spatial resolution of the final image. Finally we illustrate that the temporal resolution of the source-over-streamer data is similar to an equivalent nearfield hydrophone section. This comparison is made above 20 Hz, below which the nearfield hydrophone result is heavily contaminated by noise.

Introduction

Over recent years marine acquisition campaigns have become increasingly tailored to meet subsurface sampling requirements for each individual geological setting. Partnered with innovations in imaging technology, this has led to significantly improved images of the subsurface. In the Gulf of Mexico, the use of wide- and multi-azimuth surveys are well established approaches to greatly improve illumination of the subsurface (Michell et al., 2006). These multi-vessel acquisitions utilize many sources which, when fired sequentially, result in a decrease in image fold compared to conventional dual-source acquisitions. As arrivals from deep targets are relatively low in frequency, this decrease in sampling can often be tolerated in the Gulf of Mexico without significant spatial aliasing problems. For shallower areas, however, higher frequencies and dense spatial sampling are necessary. The use of triple sources was proposed by Langhammer and Bennion (2015) as a way to increase crossline trace density over conventional two-source designs, a strategy that has been extended to the eight-source design of Vinje et al. (2019). For a given boat speed, trace density may be increased by shooting more frequently, but this comes with the drawback of introducing cross-talk noise at the end of the shot records. While boat speed may be reduced, this comes with significant practical and cost implications.

In this paper we examine the benefits of a source-over-streamer acquisition conducted in the Barents Sea in 2019. We will demonstrate how accurate deblending was vital for the success of this acquisition, examine the benefits the short offset data brought to multiple prediction, and illustrate the benefits that dense sampling offered for shallow imaging.

Acquisition

Located in the Barents Sea, the survey area featured a highly iceberg-scoured water bottom at ~400 m depth with a significant Tertiary uplift and associated high velocities. The availability of short offset data is a widely recognized prerequisite to illuminate the shallow section with small refection angles. With conventional multi-streamer 3D acquisitions (Figure 1a), the near offset is typically of the order of 150 m on the innermost streamers, but several times larger than this on the outer streamers. Although multiple reflections have been shown to provide illumination with longer offset data (Whitmore et al., 2010), in practice the results may be contaminated by cross-talk which must be carefully handled. One approach to acquire short offset data is provided by source-over-streamer acquisition (Vinje et al., 2017). Recognizing the value long offset data brings to full waveform inversion, this method was refined by towing a source behind the streamer vessel (Vinje et al., 2019, Poole et al., 2019a). The deployment of five sources above the streamers (referred to as *Top-Sources*) with a span of 300 m provided a large near offset footprint as shown in the acquisition configuration of Figure 1c.

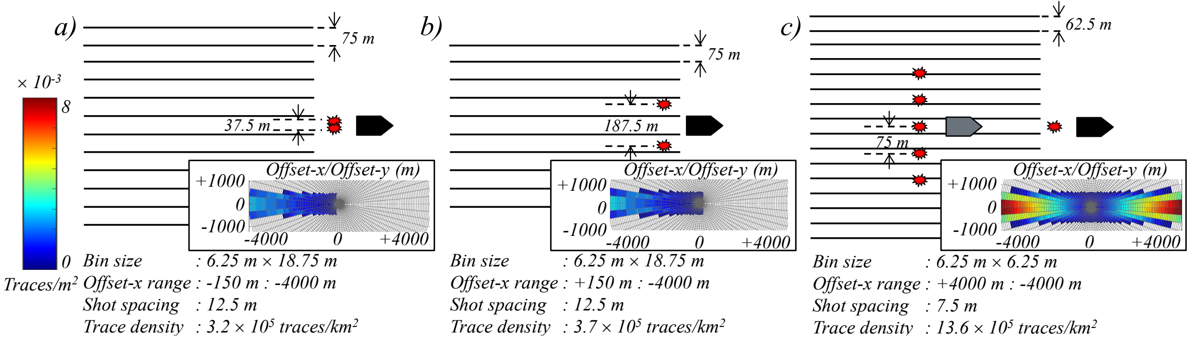

Figure 1 *Acquisition configuration comparison for a) Conventional acquisition, b) Short-offset conventional acquisition, and c) Source-over-streamer acquisition. The rose diagram bins relate to a 75 m offset increment and 5 degree azimuth increment.*

Deblending

Assuming a boat speed of 2.5 m/s, the *Top-Source* shot spacing of 7.5 m related to a nominal 3 s shooting rate, chosen to avoid contamination of primary targets in the first 2.6 s from the following shot. An optimised shot-to-shot timing variation with maximum ± 200 ms was used to increase cross-talk incoherency in the common channel domain, where the deblending would be performed. The source towed by the streamer vessel (referred to as the *Front-Source*) was activated at every 6th *Top-Source* shot, with ± 400 ms optimised firing timing, thus limiting additional *Front-Source* cross-talk to every 6th *Top-Source* shot record. Figure 2a shows a raw shot record containing arrivals from three shots; *Front-Source* (red arrow), main *Top-Source* shot (green arrow), and the following *Top-Source* shot (white arrow). Changes in boat speed resulted in additional timing variations. Figure 2d shows the *Top-Source* input stack with the three arrivals labelled in the same way.

Deblending was performed using a modified implementation of the inversion-driven approach of Peng and Meng (2016), as described by Poole et al. (2019b). The approach was parameterised so as to deblend all six sources in one application by respecting the continuous recorded nature of the data. Deblended shot records for *Top-Source* and *Front-Source* arrivals are given in Figures 2b and 2c respectively. *Top-Source* stacks after deblending and a stack of the removed crosstalk are shown in Figures 2e and 2f respectively. The data after deblending exhibited very little residual cross talk noise, and no observable signal damage was seen in the differences, indicating an accurate deblending.

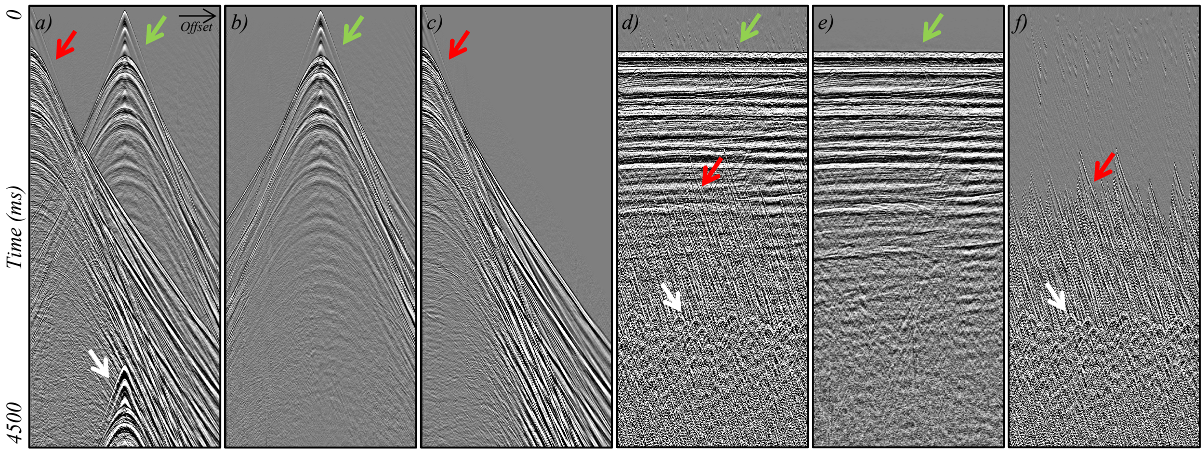

Figure 2 *a) Shot record before deblending, b) Top-Source arrivals after deblending, c) Front-Source arrivals after deblending, d) Top-Source stack before deblending, e) Top-Source stack after deblending, and f) Difference d) minus e).*

Decimation tests

In order to assess the benefits of this source-over-streamer acquisition, two decimation tests were performed. The first test involved dropping source-streamer combinations to simulate a conventional, single-vessel, dual-source configuration with 12 streamers at 75 m spacing with a minimum offset of 150 m, as shown in Figure 1a. The second scenario simulated positioning the sources partway along the streamer, as shown in Figure 1b, to reduce the minimum near offset. These decimation tests had a bin size of 6.25 m × 18.75 m, three times larger than the source-over-streamer bin-size of 6.25 m × 6.25 m. It should be noted that the trace density (relating to offsets < 2 km) of the source-over-streamer data was approximately 3.5 times higher than the single vessel configurations, due to the higher shot density and split-spread offsets. A summary of the main geometry differences is given in Figure 1. The following discussions compare the scenarios outlined in Figure 1 in the context of free surface demultiple and high fidelity imaging.

Demultiple

Many multiple prediction methods are based on the principle of convolving data with primary arrivals (for example SRME, Berkhout and Verschuur, 1997). In shallow water areas, strong multiple generators, such as the water bottom, are not sufficiently well recorded, making demultiple particularly problematic. Several approaches have been proposed to help overcome this issue, either by deriving multiple prediction operators statistically by deconvolution (Biersteker, 2001) or by making assumptions about the kinematics of the multiple generator (Wang et al., 2011). These methods, however, solve only part of the problem, as the multiple prediction operator must still be convolved with short-offset data. For this reason, missing near offsets are often reconstructed using differential normal moveout of available near offset data. In the case of source-over-streamer acquisition, near offsets have been properly recorded, reducing the reliance on signal processing extrapolation methods. Even when near offsets are available, multiple prediction also relies on adequate spatial sampling of the data.

SRME multiple modelling was performed for the different acquisition scenarios of Figure 1, as discussed previously. Figure 3a shows an input shot gather (after deblending, source designature, and source and receiver deghosting). Figure 3b shows a zoomed input gather, with Figures 3c, 3d, and 3e displaying SRME multiple predictions for the conventional acquisition offset range, obtained from conventional, short-offset conventional, and source-over-streamer data respectively. These displays highlight an increase in temporal and spatial resolution in the prediction of multiples as we move from conventional, to short-offset conventional, and finally to source-over-streamer configurations. A stack section for input data is given in Figure 3f with a zoom in Figure 3g. Global adaptive subtraction stack results improve as we move from conventional, to short-offset conventional, and finally to source-over-streamer results in Figures 3h, 3i, and 3j respectively.

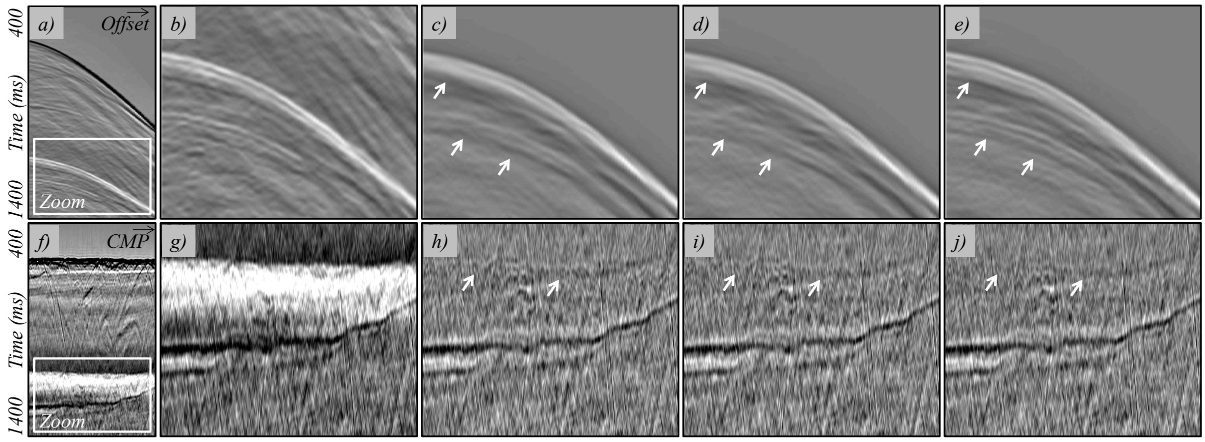

Figure 3 *Shots (upper row) and Stacks (lower row) for: a) & f) Input; b) & g) Zoomed input; Multiple predictions for: c) Conventional, d) Short-offset conventional, and e) Source-over-streamer. Adaptive subtraction: h) Conventional, i) Short-offset conventional, and j) Source-over-streamer.*

Resolution

The spatial resolution of seismic images depends heavily on diversity of sampling in both offset and azimuth. As introduced earlier, the source-over-streamer data was decimated to simulate imaging results for the acquisition scenarios given in Figure 1. The decimation was performed before data regularisation, which mapped all scenarios to a common bin size of 6.25 m × 6.25 m, after which time migration was applied using identical migration parameters. Time slices are shown in Figures 4a to 4c for conventional, short-offset conventional and source-over-streamer acquisition scenarios respectively. An improvement in spatial resolution can be observed as we move from the conventional to source-over-streamer approaches.

In recent years, images from nearfield hydrophone (NFH) recordings have been shown to approach the resolution of site-survey data (Nevill et al., 2019). In Figure 5 we compare a near channel from the source-over-streamer data with a stack of NFH recordings from an inactive source at 75 m offset-y. The displays are presented after source and receiver deghosting and low-cut filter at 20 Hz to attenuate noise in the nearfield hydrophone section. While the nearfield hydrophone section is noisier overall, the temporal and spatial resolution of both images is similar. It should also be remembered that source-over-streamer data provides a 3D volume, while NFH data provides only a series of 2D lines.

Conclusions

We have described a source-over-streamer acquisition conducted in the shallow waters of the Barents Sea. The approach provided a dense sampling of near offsets, a small bin size of 6.25 m × 6.25 m, and high split-spread fold. An additional source was towed by the streamer vessel to provide long offset arrivals for full waveform inversion. Decimation tests have demonstrated the superiority of the source-over-streamer configuration to two single vessel alternatives, in the areas of multiple prediction and shallow imaging. Images from source-over-streamer and NFH data have been shown to be similar in resolution, with the source-over streamer image providing a 3D cube and lower noise content.

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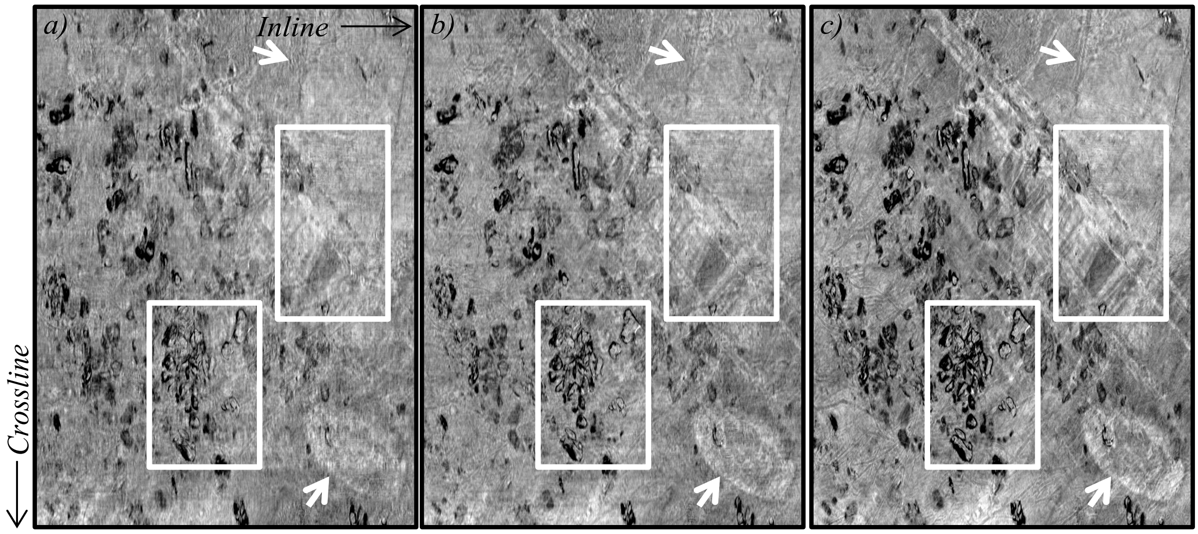

Figure 4 *Timeslices at 600 ms for: a) Conventional decimation, b) Short-offset conventional decimation, and c) Source-over-streamer acquisition.*

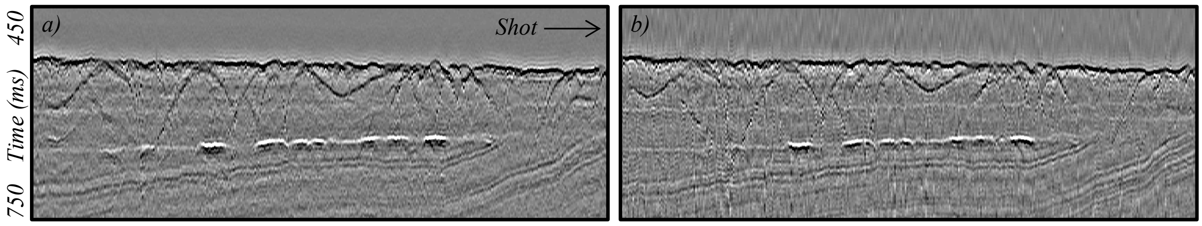

Figure 5 *Common offset comparisons: a) Source-over-streamer, and b) Inactive source NFH data.*

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