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Triple Source in Seismic Exploration – Experiences Offshore Norway

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Summary

In this paper we present best practices, learnings and benefits of using triple source configurations in connection with large marine exploration campaigns. The utilization of more sources behind a streamer vessel will increase efficiency and improve sampling in between the streamers leading to cost savings and improved quality of data. In addition, using a source setup of two sub-arrays instead of three sub-arrays, will reduce the sound pressure level from each source, hence reducing the environmental impact from each shot. However, despite the reduction in sound pressure levels, sufficient acoustic energy is still available for maintaining a good signal-to-noise ratio, and hence, producing excellent data volumes. The process of deblending of overlapping recorded shot data was found to be data dependent and different schemes had to be applied to the data from the two different geological regions. However, when comparing the 3D fast-track migrated data volume with the vintage 2D data confirmed that the deblending workflows preserved deeper structures in the zones of overlapping records. The use of tripe source has become a new standard in marine seismic exploration campaigns.

Introduction

The use of triple source in marine seismic towed streamer data acquisition has been tested and reported as a success when it comes to increasing the spatial resolution in between the streamers for exploration purposes (Langhammer and Bennion, 2015). The increase in resolution does not come at the expense of reduced efficiency and thereby increase in cost, in fact, by utilizing a triple source configuration, both resolution and efficiency can be increased. In addition, by going from two to three sources, a streamer vessel can support a larger total spread, or reduce the number of streamers towed in the water, and still maintain the same crossline subsurface bin size. This win-win situation has gained more and more recognition in the industry during the last couple of years. The development of the concept of using more sources than two, has also plowed the ground of even applying five sources in so-called penta source mode towed behind one single streamer vessel (Hager et al., 2015). The main operational effort has been to make use of already existing inventory of guns and subarrays onboard today's high-end 3D vessels. If aiming for maintaining the fold of the subsurface sampling lines between the streamers, more sources will inevitably end up in a shorter "clean" record length of overlapping shots, when fired in sequential mode. However, with the recent advances in handling simultaneously acquired data, and overlapping shot records, the fold can be maintained and even increased. The data acquired in such a high-sampling mode calls for an additional step in the processing flow. Deblending of the overlapping shot records is necessary for separating the shot records without reducing the data quality. The increased sampling and efficiency achieved by the use of the triple source concept suggest that this way of operating available onboard source inventory has become the best practice and has finally made a breakthrough since it was first tested in the 1980's.
As a result of the increased efficiency and finer sampling, the exploration surveys offshore Norway in 2017 were designed to utilize triple source configurations as a standard approach. In this presentation, we first go through the experiences on the operational side and the additional processing step, then we present some data samples from the different regions offshore Norway.

The acquisition campaigns

As shown by polygons in Figure 1, the survey areas are the western part of the Norwegian Sea situated between 62-66 degrees north, and the southwest part of the Barents Sea located between 71 and 72 degrees north.

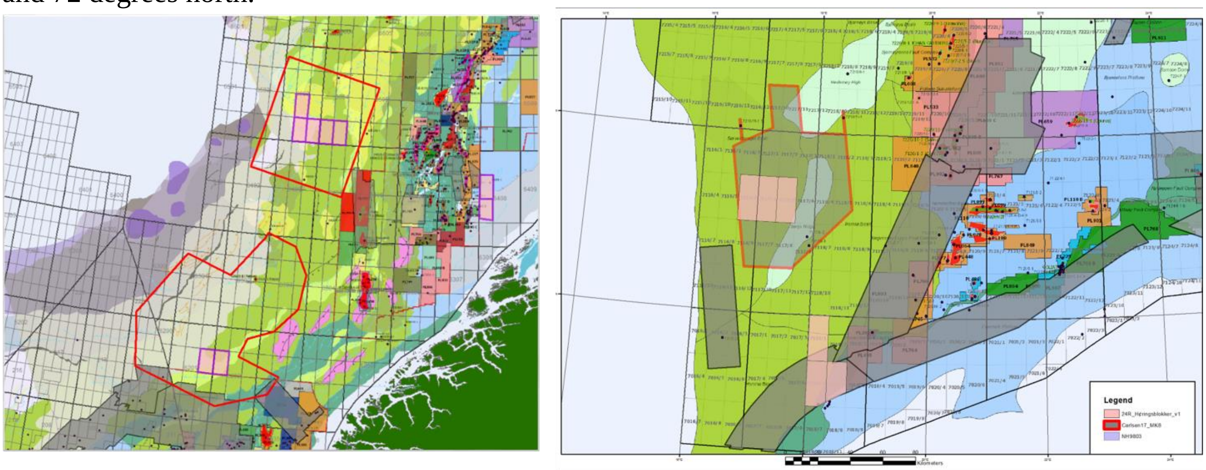

Figure 1: The Atlantic Margin survey area polygons (left) and the Barents Sea West survey area polygon (right). The survey areas are 40,000 sq.km. and 5,800 sq.km., respectively.

Atlantic Margin survey area: The Møre Basin is an elongated SW-NE trending rift basin associated with the opening of the North Atlantic during Createaceous time. It is a huge area, comprising a variety of play models from rotated Jurassic and Cretaceous faults blocks, to stratigraphic and structural traps in Paleocene and Cretaceous turbidite/fan deposits. The water depth in the northern area is varying from 500 m to 2500 m, and in the southern area is in the range of 250 m to 1500 m. The central and Western part of the area are influenced by volcanic activity, i.e. presence of sills and basalts.

Barents Sea West survey area: The survey includes the Senja Ridge which is a SE-NW trending uplifted ridge created during the opening of the North Atlantic in late Cretaceous/early Paleocene. West of the ridge, the Sørvestnaget Basin contains rotated Paleocene and Cretaceous fault blocks, and also what has been interpreted as sand injectites. The water depth within the polygon is in the range between 200 m to 300 m.

Acquisition parameters

Based on the geological structures, targets and geophysical objectives in the two regional areas, Atlantic Margin and Barents Sea West, the acquisition parameters obtained, based on survey evaluation and design, are given in Table 1:

Atlantic Margin		*Barents Sea West*	
Streamer length:	8100 m	Streamer length:	8100 m
Streamer separation:	112.5 m	Streamer separation:	75 m
Streamer depth:	12 m	Streamer depth:	12 m
Triple source of sizes:	2965/3090 cu.in.	Triple source of size:	2965 cu.in.
Source depth:	7 m	Source depth:	7 m
Shot point interval:	12.5 m	Shot point interval:	12.5 m
Bin size:	6.25 m x 18.75 m	Bin size:	6.25 m x 12.5 m

Table 1: Acquisition parameters defined for both Atlantic Margin and Barents Sea West areas.

With a pre-plot shot point interval of 12.5 m, and vessel speed of around 4.5 knots, the nonoverlapping shot record will be about 5.3 seconds. The continuous recording facilities available onboard the vessels allowed for generating longer records, which will require a deblending process to separate the overlapping shots. To ensure sufficient random behavior in the process of separating the overlapping shot records, a randomization of +/-400 ms of firing the sources around each pre-plotted shot point location was added. Given the size of the Atlantic Margin survey area, two vessels could work together within the polygons without coming into conflict with respect to seismic interference (SI). It has been shown previously that it is possible to manage vessels operating close to each other in a manner that could reduce the impact of SI to a minimum level, so that it can be addressed properly in processing (Laurain et al., 2014). Use of such procedures represents a significant step towards minimizing time sharing between vessels, and hence, increasing efficiency and saving cost.
Another important cost saving element is the use of triple source. A spread of streamers with 100 m separation, when using dual source, will give us a natural bin size of 25 m in between streamers. A triple-source configuration with a streamer separation of 112.5 m results in a natural bin size of 18.75 m in between streamers. The triple-source configuration is then 12.5 % more efficient, which provides an increase in both efficiency and quality of data. Table 2 summarizes the main differences in parameters using either dual or triple source when having a streamer length of 8100 m.

Spread	Source mode	Bin size [m]	Fold	Efficiency
12 x 100 m	Dual	6.25 x 25	81	100%
12 x 112.5 m	Triple	6.25 x 18.75	108	112.5%

Table 2: Bin size and efficiency comparison of similar towed streamer spreads when going from dual-to triple source configuration. A triple source solution gives a more cost effective operation, while the spatial resolution in between the streamers is increased.

The Barents Sea West survey utilized a streamer separation of 75 m. A triple source configuration will give a bin size of 12.5 m as opposed to 18.75 m when using dual source for the same streamer separation. The finer spatial sampling provided by a triple source setup gives in this case a better resolution at the same cost as for a dual-source configuration. A further optimization of efficiency is due to infill reduction. A so-called fan-mode of streamers, with a gradual increase of distance between streamers ending up in 25% expansion at tail, was used for all vessels throughout the surveys.

Triple source configuration

Most modern 3D vessels today are equipped with six subarrays. A dual source usually consists of three subarrays, while a triple source will have to consist of two subarrays. However, for a narrow-azimuth survey this will not represent any harm to the data because both source power and directivity pattern from previous testing have shown to be more than good enough for the purpose. Going from three to two sub-arrays could result in differences in the pressure signature, but not so large that it could not be handled in the designature process. In addition, reducing the volume of released air in each shot, and using just two subarrays instead of three, hence reducing the emitted sound pressure level (SPL level), also has a positive environmental effect. In the recent years the industry has been focused on using sources with less energy output per shot, without compromising quality and geophysical integrity of the data.

Deblending and separation of overlapping shot records

When sources are fired as often as every 12.5 m, the overlapping records will require deblending for producing the final record length longer than just a bit more than 5 seconds. After cutting continuous data to 11 second shot records, the resulting blended dataset contains three overlapping shots. These are shown in Figure 2, labelled S1, S2 and S3. For a given source, S1 & S3 represent the overlapping of the previous and next shots respectively, while S2 represents the data that is referenced to the firing time of the source. Because of significant differences in water depth and shallow geology at the Atlantic Margin and in the Barents Sea, different approaches of deblending the overlapping records were necessary to use (Baldock et al., 2018), and main differences are given in Figure 2. The Atlantic Margin data called for a three-step deblending workflow, which utilizes a modified High Resolution Moveout Transform (HMT) (Masoomzadeh and Hardwick, 2012) to generate a model of the S3 energy in the CMP domain. The Barents Sea deblending workflow included a shift to S3-time, giving a randomization of the S2 energy and separation of shot records was performed in the tau-p domain. Further attenuation of the remaining residual S3 energy was performed in S2-time in the receiver and CMP domains. An important learning from the deblending exercises is that different areas may call for different deblending schemes.

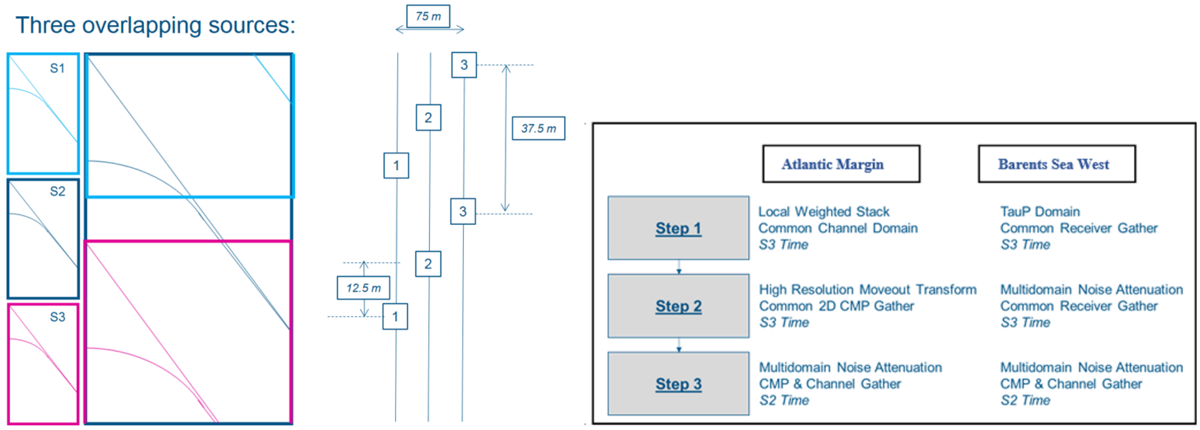

Figure 2: Schematic representation of the blended data when acquiring overlapping data records from multiple sources (left) and workflows for the three-stage deblending methodology developed for separating the overlapping blended data from the two geographic areas (right).

Data examples

Fast track volumes of the data were produced. A first glance of the data shows the good promise of the increased quality. Figure 3 shows a comparison of a 2D line and the same area line extracted from the 3D fast track volume. When comparing 2D versus 3D migrated data the uplift in improvement of the complicated structures is striking. After tuning for full resolution in space and time, final volumes to come will present data with further uplift in sub-basalt events and of shallow structures as well.

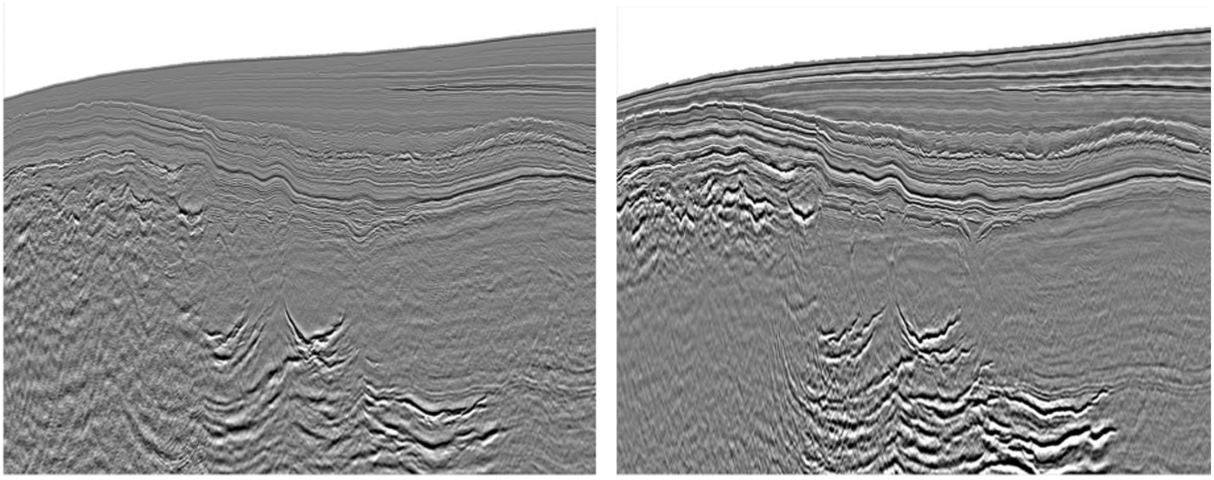

Figure 3: Example of a 2D line (left) and a random line from the fast track 3D in the core of the Atlantic Margin area.

Conclusions

The concept of triple source in 3D streamer acquisition has proven to be very efficient. Not only is this an advantage for shallow targets, but also in areas of deeper waters and targets when increased efficiency is required to cover large survey polygons and still maintain, or even increase, subsurface spatial sampling in the crossline direction. Firing sources more often also calls for deblending to separate overlapping records and this has been performed with great success. The method of deblending may also call for different schemes depending on water depth and geology. The physical change of sources of going from three to two subarrays does not degrade the output source signature and excellent quality source signatures are still generated. Meanwhile, smaller sources and lower sound pressure levels contribute to reduced environmental impacts. Finally, the triple source has now gained a breakthrough in the business contributing to increased data quality, increased efficiency and hence reduced cost.

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References

Baldock, S., Masoomzadeh, H., Ratnett, N., Liu, Z., O'Keefe, S., Travis T. and Drewell, S. [2018] Deblending of Large 3D Surveys Acquired with Triple Sources in NW Europe. Abstract submitted to 80th *EAGE Conference and Exhibition.*

Hager, E., Rocke, M. and Fontana, P. [2015] Efficient multi-source and multi-streamer configuration for dense cross-line sampling. *85th Annual International Meeting, SEG*, Expanded Abstracts, 100-104.

Langhammer, J. and Bennion, P. [2015] Triple-source simultaneous shooting (TS3), a future for higher density seismic? *77th EAGE Conference and Exhibition*, Extended Abstracts, We N101 06.

Laurain, R., Ruiz-Lopez, F. and Eidsvig, S. [2014] Improving acquisition efficiency by managing and modelling seismic interference. *First Break*, **32** (11), 79-85.

Masoomzadeh, H. and Hardwick, A. [2012] High-Resolution Moveout Transform – A Robust Multiple Attenuation Technique. *74th EAGE Conference and Exhibition*, Extended Abstracts, I033.