Strategies for High Resolution Towed Streamer Acquisition and Imaging of Shallow Targets

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Summary

The challenging combination of shallow water and shallow exploration targets in larger parts of the Barents Sea cannot be sufficiently addressed by the application of conventional marine seismic acquisition and imaging techniques. High resolution data, proper spatial sampling, as well as near offset/near angle information are key elements for imaging and quantitative interpretation. We first discuss several existing acquisition and imaging technologies that have been applied in the area, including standard towed streamer surveys, p-cable, and imaging with separated wavefields. We then introduce novel acquisition concepts. The innovative combination of high density seismic and wider towing of sources can be a cost-effective approach to acquire high quality seismic data with significantly improved near offset coverage and denser spatial sampling for shallow imaging. These configurations can be tuned such that both shallow and deeper targets are optimally imaged.

Introduction

The challenging combination of shallow water and shallow exploration targets in larger parts of the Barents Sea cannot be sufficiently solved by the application of conventional marine seismic acquisition and imaging techniques. The need for temporal and spatial high resolution imaging requires modern dual-sensor/multi-component streamer acquisition systems as well as high density spatial sampling. The lack of near offsets caused by relatively large minimum distances between seismic source arrays and outer streamers in typical marine acquisition can result in significant acquisition footprints at shallow target levels. In addition, AVO/AVA analysis may become difficult. While perfectly sampled data can certainly be recorded by increasing the acquisition effort, the cost and operational complexity will rapidly increase and become the limiting factor. Here, we discuss several acquisition and imaging strategies that address real world challenges in the Barents Sea. The main focus will be on innovative single 3D streamer vessel configurations.

Recent Experiences from the Barents Sea

3D seismic group shoots and multi-client campaigns in the Barents Sea South East during 2014 and 2015 were acquired with spreads of 10 and 12 dual-sensor streamers, with a 75m separation and using dual sources (Table 1). These configurations were chosen as optimal trade-offs between geophysical illumination and sampling requirements for the exploration targets and acquisition efficiency (cost). The processing of the data resulted in high quality shallow target images and contained an impressive spectral bandwidth of 2-200Hz. The lack of near offsets which caused footprints in imaging (Figure 1) and which lead to incomplete angle gathers for AVO/AVA analysis, was overcome by utilizing separated wavefield imaging technology (Naumann et al., 2016). Sea-surface reflections, which are captured in the downgoing wavefield of dual-sensor streamer acquisitions, are used as virtual sources providing the near surface information missing from primary reflections (Whitmore et al., 2010).

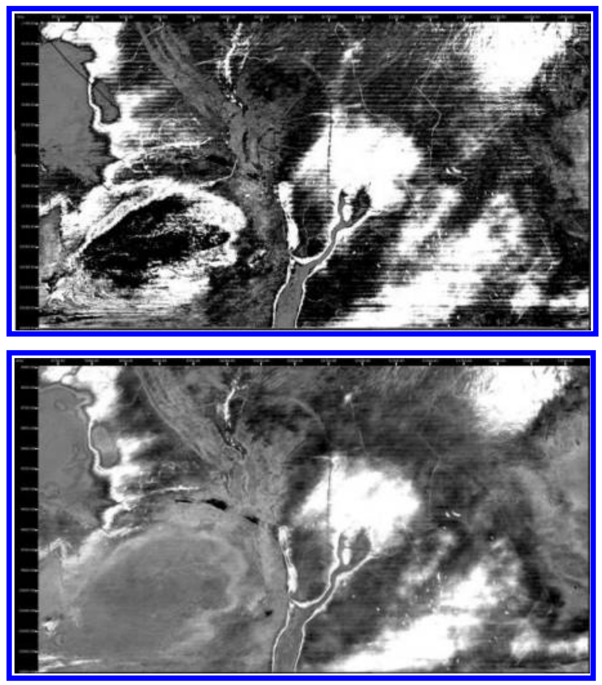

Figure 1: The near surface time slice (ca 350ms TWT) generated by conventional imaging with primaries is clearly suffering from the lack of near offsets (top). Separated wavefield imaging is used to mitigate the footprint challenge (bottom). The example is from the Barents Sea South East.

An alternative approach for near surface imaging in the Barents Sea is based on the P-cable system. The P-cable system consists of many very short and densely separated streamers towed from a cable perpendicular to a vessel's steaming direction and a single source. A 16 x 12.5m configuration as deployed in 2014 (Ratnett et al., 2015) provides superior near offset coverage and a crossline bin size of 6.25m (Table 1). However, the lack of longer offsets and fold, restricts, e.g., the use of the data to shallow targets and does not enable full integrity imaging and AVO/AVA analysis. In addition, the sail line separation of 100m (which is a consequence of the very narrow 16 x 12.5m spread) makes data acquisition for larger areas quite ineffective compared to a 12 x 75m towed streamer spread with a nominal sail line separation of 450m.

Considerations and Acquisition Concepts for Future Seismic Surveys

With recent success stories and lessons learned in mind, the natural question to ask is whether there are possibilities to further optimize and adapt the acquisition set up for the shallow plays in areas like the Barents Sea and whether this can be done in a cost-effective manner. In the following paragraphs several of the key aspects are addressed in a conceptual manner:

Temporal resolution:
Recent Barents Sea case studies have shown that seismic images of shallow plays can have a spectral content in the 2-200 Hz range and higher. It is well known, that towing streamers deep can ensure the recording of high quality low frequency signal (e.g., Widmaier et al., 2015). Deeper tow of hydrophone-only streamers will however sacrifice the integrity of the higher frequencies. E.g., a streamer towed at 50m will have the first receiver ghost notch at 15Hz and up to 13 (!) notches in the 2-200Hz bandwidth aimed for (considering normal incidence for the sake of simplicity). Deep-tow dual-sensor/multi-component systems with complementary ghost responses do not compromise the integrity of the entire frequency range and elegantly reduce de-ghosting complexity and uncertainty.

Spatial sampling:
Preservation of the recorded spectral bandwidth throughout a 3D imaging workflow requires denser crossline sampling compared to what is usually acquired. The nominal crossline bin size for the 12 x 75m configuration (dual source) referred to above is 18.75m which needed to be interpolated to 9.375m in the examples shown in Figure 1. Langhammer and Bennion (2015) proposed the re-introduction of the triple source concept for acquiring high density seismic. The 12 x 75m configuration combined with a triple source would provide a crossline bin size of 12.5m.

Modern high capacity seismic vessels can tow many streamers with a dense separation without sacrificing efficiency. E.g., an 18 x 50m streamer configuration matches the efficiency and the footprint of a 12 x 75m spread. An 18 x 50m spread reduces the nominal crossline bin size to 12.5m (dual source) and 8.33m (triple source) and also improves receiver side sampling (Table 1). By combining triple source with a streamer separation of 37.5m a nominal crossline bin size of 6.25m can be achieved, i.e., the same spatial sampling as delivered by the P-Cable example in Table 1.

The introduction of additional sources can potentially further reduce the crossline bin size. However, additional sources may result in increased shot point intervals (and reduced fold) or must be assisted by overlap shooting, source blending and de-blending techniques. These techniques may have an impact on image quality and quantitative interpretation, especially, when geological targets at several depth levels are being considered or pre-stack data has to be analyzed.

Acquisition Parameters	Dual Source	High Density Dual Source	Triple Source	High Density Triple Source	P-Cable Single Source	High Density Triple Source
Streamer Spread	12x75m	18x50m	12x75m	18x50m	16x12.5m	16x37.5m
Crossline Bin Size	18.75m	12.5m	12.5m	8.33m	6.25m	6.25
Sail Line Separation	450m	450m	450m	450m	100m	300m

Table 2: Parameter comparison for towed streamer acquisition solutions including p-cable. For conventional acquisition, the sail line separation controls both cost and near offset coverage.

Near offset/near angle coverage:
The high density seismic approach discussed above does provide improved spatial sampling but the near offset/angle challenge has still to be solved. An obvious way to improve the near offset coverage is to reduce the streamer count and thus the spread width for the configurations discussed above. This would however result in more sail lines and consequently increased turnaround and cost. Several authors (e.g., Long, 2013) revived the idea of placing the seismic source array in the center of a streamer spread. While such a solution provides close to zero offset for the receivers closest to the source, the crossline distance to the outermost streamers remains the same and so does the near offset problem (unless sail lines are interleaved). Also, this solution is associated with extra cost and risk as it requires an additional source vessel operating on top of a streamer spread.

Another idea is to operate with many distributed smaller sources. Such concepts have been discussed in several visionary papers (e.g., Berkhout, 2009) but are not yet feasible with today's marine seismic technology and inventory. A step in the right direction can be wider towing of the existing source arrays. Wider towing means that the source separation, which is typically 25m for dual source acquisition with 50m streamer separation, would be increased to, e.g., 175m. Such source configurations can be deployed from existing streamer vessels. Wide towed sources have recently been proposed to increase acquisition efficiency as this technique spreads out the CMP coverage in crossline direction and therefore the sail line separation may be increased (e.g., Brice et al., 2015). The penalty however is that, e.g., every other outer CMP subline has zero fold and data interpolation would be required. If the efficiency gain is not a goal and the nominal sail line separation for the given streamer spread is kept, then the zero fold sublines are filled in a complementary manner by the adjacent sail lines. This approach requires strict pre-plot shooting supported by streamer and source steering in order to ensure homogenous coverage across swath boundaries. In order to predict and understand the implications of this non-standard marine seismic acquisition method on fold coverage and infill requirements, we have initiated a modelling study.

In the context of the shallow imaging challenge in areas like the Barents Sea, wider source towing may be utilized to improve the near offset distribution for streamer acquisition. In the case of a dual source set-up, widening the source separation moves the two seismic sources out of their centered locations behind the seismic vessel towards the outermost cables on their respective side of the spread. Moving the sources thus reduces the crossline distance to the streamers in parts of the spread but increases the crossline distance to the remainder. The resulting near offset distribution is then characterized by alternating smaller-larger-smaller source-receiver distance patterns. With this pattern, larger areas can be populated with near offset traces compared to standard dual source acquisition. In combination with the crossline sampling provided by high density acquisition, this also provides a much improved starting point for near trace interpolation and regularization (Figure 2, middle).

Wider source towing is not restricted to dual source configurations. The same concept can be applied to triple source or higher source count configurations. A near offset distribution resulting from an 18 x 50m streamer spread with a wide tow triple source set up is shown in Figure 2 (bottom). Please note that the latter configuration also provides superior spatial sampling with a crossline bin size of 8.33m compared to two other acquisition configurations discussed in Figure 2.

The near offsets can in principal be further optimized by staggering the streamer front ends in the inline direction. Compared to the standard front end set-up, a source-receiver distance reduction can be achieved. Examples for wide dual source and wide triple source are shown in Figure 3 and Figure 4 respectively.

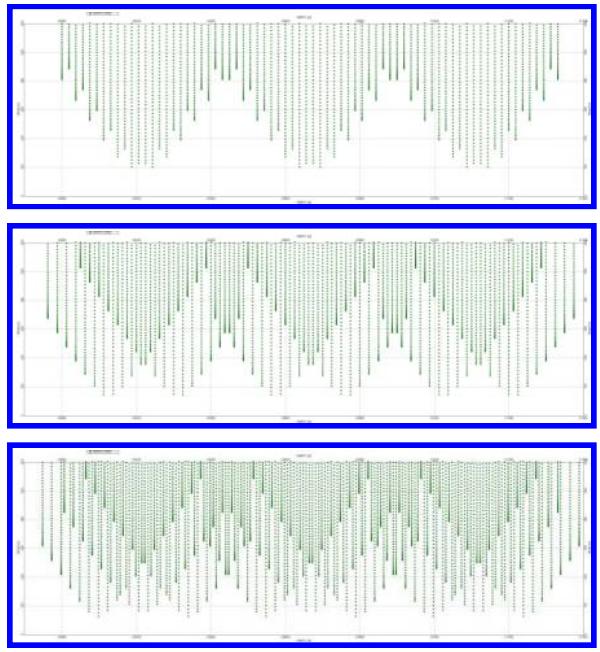

Figure 2: Near offset distribution for a 12 x 75m spread with standard dual sources (top) compared to an 18 x 50m spread with a wide dual source separation of 175m (middle), and an 18 x 50m spread with a wide triple source separation of 233m (bottom). The arrows indicate the sail lines. Three adjacent sail lines are shown. CMP-X positions are along the x-axis, source-receiver offsets are along the y-axis. Deploying more sources or reducing the spread width can further improve the near offset distribution but cost and quality implications have to be taken into account. The nominal crossline bin sizes for these three examples are 18.75m (top), 12.5m (middle), and 8.33m (bottom). Please see also Table 1.

Further Optimization of the Acquisition Configuration

Seismic exploration surveys are usually not targeting only one specific geological formation but are supposed to provide a good image of larger geological setting covering both shallow and deep structures. The need for high density acquisition for shallow plays as discussed above can be relaxed for imaging of deeper geological targets. At the same time, imaging and quantitative interpretation of deeper targets requires longer offsets. As seismic vessels do not have unlimited towing capacity and streamer inventory, streamer spreads with varying cable length and separation may be a pragmatic and cost-effective way to provide optimal sampling and data quality from shallow to deep (Figure 5).

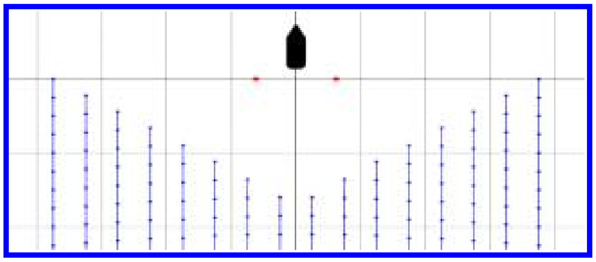

Figure 3: Inline staggering of streamer fronts to reduce source-receiver offsets. The generic example with a wide dual source separation and a 16 x 50m streamer spread is not drawn to scale.

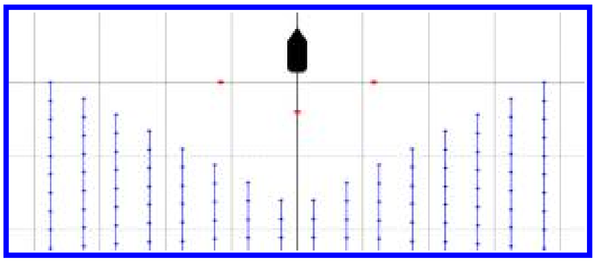

Figure 4: Inline staggering of streamer fronts and source array positions. The generic example shows a triple source with wide separation and a 16 x 50m spread. The example is not drawn to scale.

Figure 5: High density streamer spread with varying cable length and separation. The generic example is not drawn to scale.

Conclusions

Imaging of shallow targets in shallow water environments like the Barents Sea benefits from innovative acquisition and processing solutions. High resolution data, proper spatial sampling, as well as near offset/near angle information are key elements for success. We discussed several concepts to provide optimal seismic data, including the innovative combination of high density acquisition and wider towing of seismic sources. The examples are provided on a general basis. Specific configurations have to be tailored using survey design with well-defined geological and geophysical objectives in mind and are also subject to operational feasibility as well as a cost analysis.

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EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2017 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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