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Behold the multiples! From scourge of imaging to friend of acquisition

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Summary

Multiple reflections, which have long been considered as noise in marine seismic, can now be used to image the subsurface. The enhanced illumination they provide, especially for the near-surface, leads us to rethink the way we acquire marine surveys. More geophysical objectives can be achieved without increasing the cost of the survey and efficiencies can be gained without compromising the quality of the final image. Both streamer and ocean-bottom seismic surveys can benefit from these new survey designs.

Introduction

The art of designing a seismic survey boils down to finding the most efficient acquisition template that meets the required geophysical objectives. This is not always straightforward as oftentimes the best solutions exceed the allocated budget. It then becomes a matter of compromise, prioritizing the most important geophysical objectives at the expense of secondary ones. For example shallow targets require high spatial and temporal resolution while deep targets require large low-frequency sources and wide aperture. A survey designed to properly image both deep and shallow targets could become extremely expensive as it requires fine sampling over a large area. Likewise, an exploration survey should ideally serve as the baseline for future time-lapse surveys. However, the acquisition requirements of a 4D survey may far exceed the budget allocated for field exploration. Congested offshore areas often require undershooting or ocean-bottom nodes to properly image below surface facilities, which may prove unaffordable.

Until recently, subsurface imaging was performed using exclusively primary energy. Multiples, which always affect marine seismic data, were considered undesirable noise and even influenced survey design to ensure they could be properly eliminated at the processing stage. New developments in seismic processing instead make use of surface-related multiples to improve subsurface imaging. This has led us to rethink our marine survey design strategy, taking advantage of the abundance of multiple reflections – which are recorded at no additional cost – to enhance target illumination and possibly achieve more of our geophysical objectives without exceeding the allocated budget.

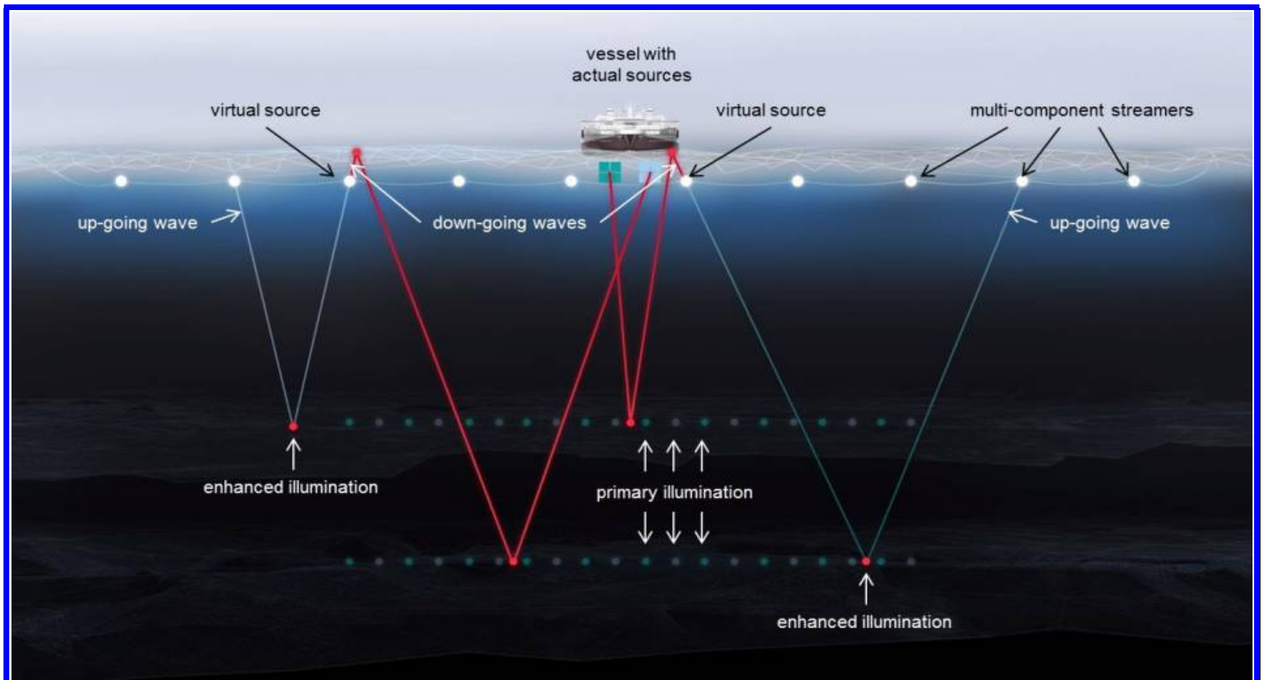

Figure 1: Schematic description of separated wavefield imaging. The down-going wave is deconvolved from the up-going multiple to provide enhanced illumination from a receiver/virtual source.

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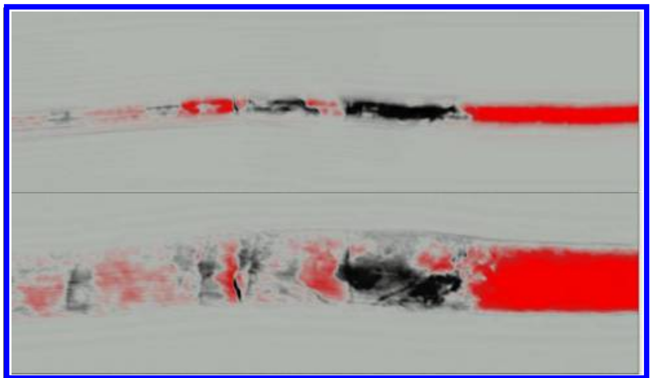

Figure 2: Single vessel pass imaging using SWIM (bottom) and primaries only (top). The spread was made of 10 multi-component streamers 100m apart and the depth slices are at 290m.

Separated wavefield imaging (SWIM)

Whitmore et al. (2010) show that when up- and down-going waves are used in a migration algorithm with a deconvolution imaging condition, surface-related multiples naturally contribute to subsurface imaging with minimal interference (cross-feed) noise. Since primaries and multiples sample the earth in different and complementary ways, the resulting images are automatically enhanced. In essence, as indicated in Figure 1, every receiver becomes a secondary source and the entire receiver spread acts as a virtual source spread. Up- and down-going wavefield separation, a required step in this process, is achieved precisely using collocated geophones and hydrophones in a multi-component streamer.

The main benefit of SWIM is to enhance shallow imaging. While primaries start refracting as offset (and thereby incidence angle) increase, multiples keep bouncing in the water column and maintain a narrow incidence angle even at large offsets. In fact, as illustrated by Figure 1, illumination with multiples almost reaches the outer edges of the streamer spread when primary illumination is limited to half the spread, or even less when refractions start kicking in. Hence, a single vessel pass provides much wider illumination using up- and down-going waves than using primaries alone (Figure 2). This feature is invaluable when shooting large spread exploration surveys over shallow water areas (Figure 3) or in the presence of obstructions where the extended illumination can minimize the need for undershoots.

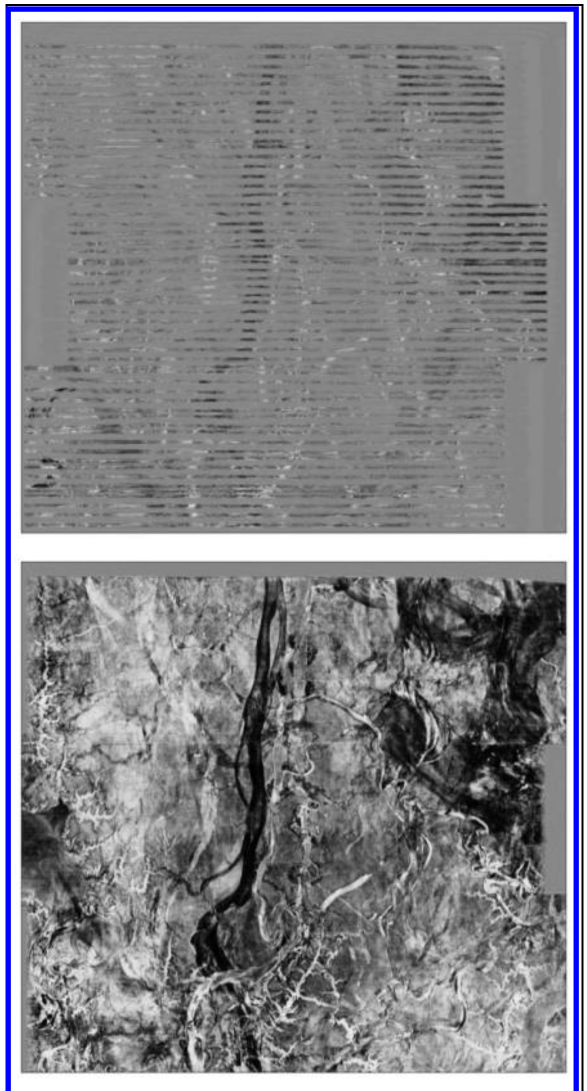

Figure 3: Shallow water survey (ca. 70m) offshore Malaysia (courtesy Lundin). The SWIM image at 105m depth (bottom) has accurately filled in the holes caused by refraction when only primaries are used (top). The spread was made of 12 multi-component streamers 75m apart.

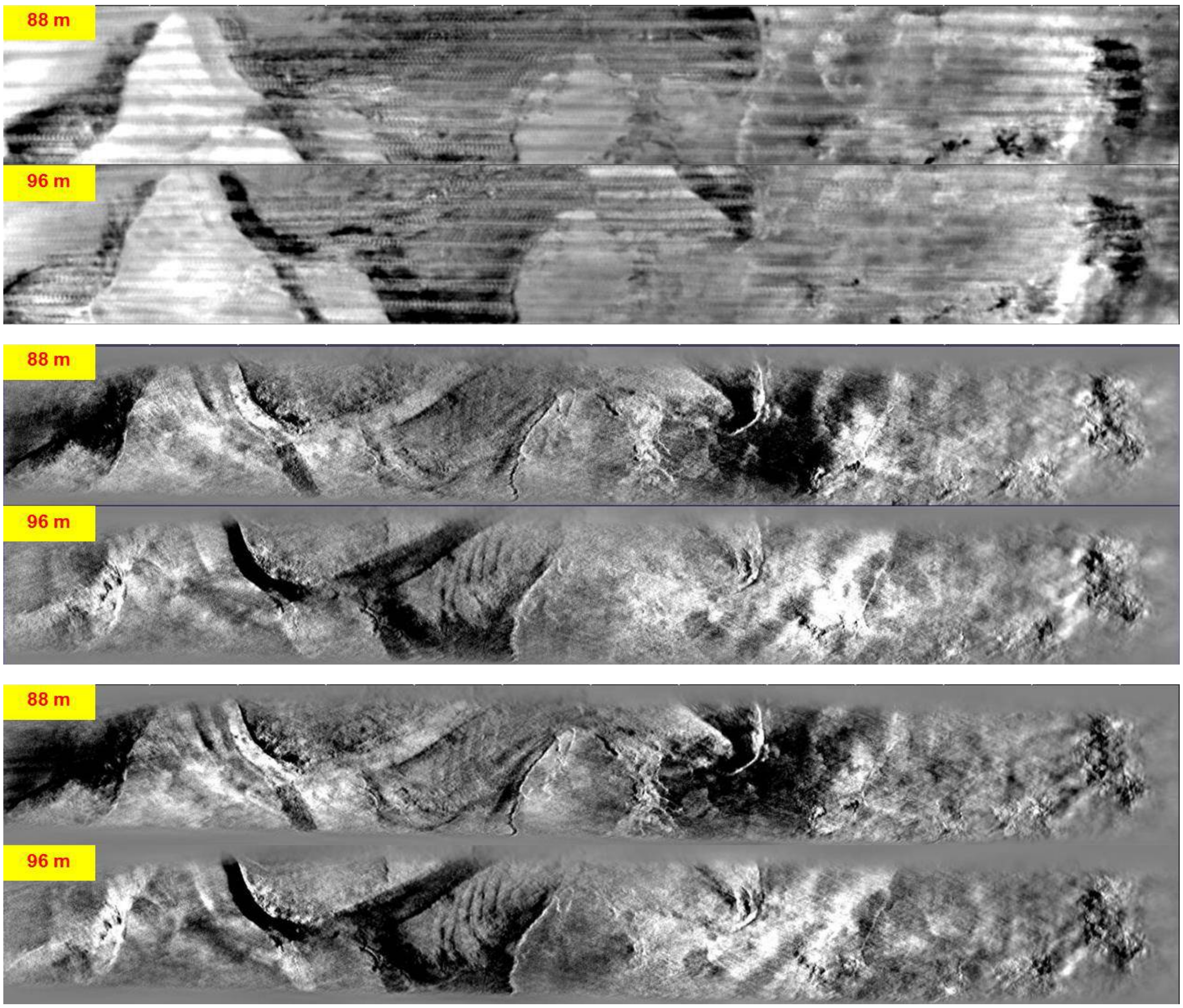

Figure 4: Depth slices on primaries interpolated to a 6.25m streamer separation (top panel). SWIM on the interpolated streamers (middle panel). SWIM on the original streamer spread: 8 multi-component streamers 75m apart (bottom panel). The SWIM examples are only applied to 5 sail lines.

Examples

Offshore Brunei has areas with very shallow waters and extremely complex near-surface geology (steeply dipping events and large offsetting faults). Accurate understanding of the near-surface is key to properly image the deep reservoirs. This is a case of competing geophysical objectives which can lead to expensive acquisition designs. The client decided to use multi-component streamers to enhance resolution and reconstruct streamers as if they were acquired with 6.25m separation (a 12 to 1 interpolation). However, even though the sail line separation was reduced to 250m, holes in the shallow images were inevitable due to refraction of primaries (top Figure 4). In contrast, separated wavefield imaging can reconstruct the near-surface to a very high resolution thanks to the rich multiple content (middle Figure 4). There is in fact no need for streamer interpolation as the original streamer separation leads to virtually the same result (bottom Figure 4). The slightly better images using the original streamer separation probably owe to the fact that primaries and multiples cannot be interpolated with the same degree of accuracy for aliasing-prone shallow data.

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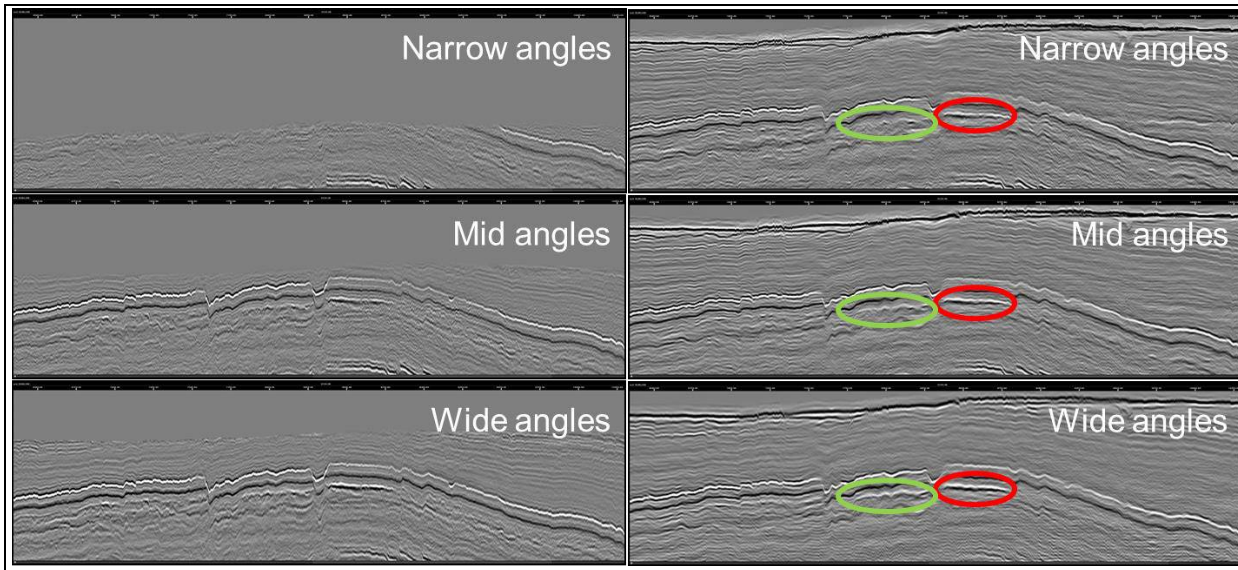

Figure 5: Primary imaging (left) cannot recover shallow narrow angles as the acquisition was designed primarily for efficiency (10 multi-component streamers 75m apart). SWIM (right) recovers the full angle range thanks to the narrower incidence angles of multiples. A Class 2 AVO anomaly (green) can easily be distinguished from a Class 3 (red), which would be challenging with primaries only.

The Barents Sea features a combination of deep and shallow targets with the latter (at ca. 700m) being the primary objective. However, exacting weather conditions only allow for a short acquisition window and compromises have to be found between shallow resolution and survey efficiency. For the BSSE Area A survey, shot in the summer of 2014, this meant the shallow targets would not have enough near-angle coverage to perform a meaningful AVO analysis. Figure 5 shows how this problem was circumvented using separated wavefield imaging and benefitting from the rich near-angle content of multiples (Rønholt et al., 2015).

SWIM can also be applied to multi-component ocean-bottom surveys (nodes or cables). Wavefield separation is achieved via dual-sensor summation and reciprocity is invoked so that every source becomes a secondary receiver. This dramatically extends imaging aperture to match the source blanket area, and improves shallow imaging. It also allows a dramatic reduction in the number of nodes required as the coverage is primarily provided by the sources. This can have a significant impact on survey cost. In addition, separated wavefield imaging has proven to be 4D compatible (Lecerf et al., 2015) which can also lower the cost of repeat node surveys or the initial investments for permanent monitoring.

Conclusions

The advent of separated wavefield imaging, which benefits from the complementary contributions of primaries and multiples, has changed the way we design marine seismic surveys. The requirements for shallow imaging, which may be necessary for shallow targets, hazard detection or a complex near-surface, can be dramatically relaxed as multiples offer enhanced illumination. This means efficient wide-spread acquisitions are possible even in a shallow water environment. Similarly, nodes and other ocean-bottom surveys can benefit from the technology and decrease their cost. This truly represents a paradigm shift as more geophysical objectives can be achieved without exceeding the allocated budget. After all, the recording of multiple energy comes at no additional cost!

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