Improved multiple attenuation through 5D near-offset extrapolation for convolutional 3D SRME and optimized adaptive subtraction

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Summary

Effective multiple attenuation is a key challenge in the Norwegian Sea that needs to be addressed to produce high-quality data to reveal and de-risk future drilling opportunities. With data from a new multi-azimuth data campaign, we present a workflow that uses a 5D interpolation scheme to reconstruct near-offsets beyond what is originally recorded in the legacy azimuth to improve multiple modelling. Combined with an optimized adaptive subtraction flow that separates multiples into fast and slow components, the final data show significant improvements in multiple attenuation compared to legacy data sets in the area.

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Introduction

The Norwegian Sea is known for good-quality hydrocarbon reservoirs and complex geology, and recent discoveries prove the considerable remaining potential in the region. The water bottom is hard and rugose, and the overburden is characterized by high impedance contrasts and rough surfaces, which generates strong noise and multiples, affecting both shallow and deep targets. Multiple attenuation is therefore considered a key, but challenging processing step to produce high-quality data to reveal and de-risk future drilling opportunities. Two challenges in particular need to be properly addressed to successfully attenuate the multiples. Firstly, the multiple modelling techniques should accurately model the observed multiples in the data. Secondly, successfully adaptively subtracting multiple models from data require good separation between primaries and multiples in the domains of the adaptive subtraction.

The legacy single-azimuth dataset, acquired in 2011 and reprocessed in 2021, served as a foundation for previous work in the area. However, in 2022, PGS acquired a new azimuth of multisensor streamer data as part of their multi-azimuth data campaign. The configuration of the new azimuth with wide-tow triple source setup, illustrated in Figure 1 together with the legacy azimuth, provides data with denser crossline sampling and improved near-offset distribution (Widmaier et al., 2019). The new data have been processed together with the legacy azimuth over the Slagugle discovery using a state-of-the-art depth imaging flow to provide a data set with higher signal-to-noise, improved resolution and better continuity of events than existing data. As part of the work, a workflow has been designed to leverage the improved near-offset distribution from the new azimuth to improve multiple modelling for the legacy azimuth, allowing for more effective multiple modelling. Combined with an optimized adaptive subtraction, the new data shows significant improvement in multiple attenuation compared with the legacy data. As a final product from the dual-azimuth processing, the two azimuths are stacked together, which further attenuates residual multiples in the data as multiples are less repeated than primaries between azimuths.

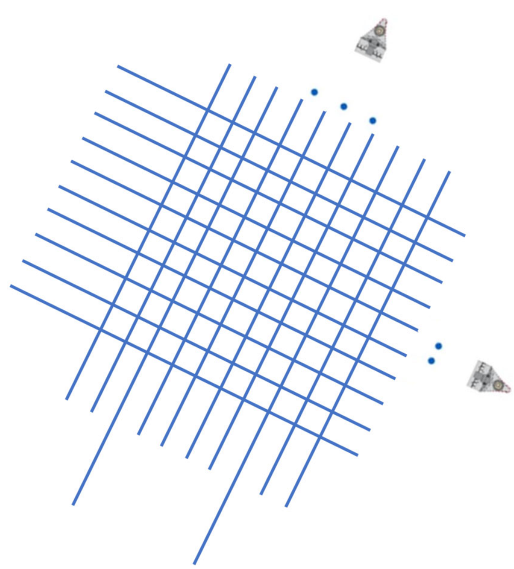

Figure 1 *Illustration showing the legacy dual-source acquisition and recently acquired new azimuth with wide-tow triple-source configuration. The new azimuth has longer tails to provide deeper Full Waveform Inversion (FWI) updates. Note that the display is not at scale.*

Multiple modelling

The first step of multiple attenuation consists of computing multiple models, commonly using 3D techniques such as 3D Surface Related Multiple Elimination (Berkhout et al., 1997) and 3D Wavefield Modelling (Pica et al., 2005).

Data driven techniques like 3D SRME rely heavily upon their underlying assumptions and a priori information, such as that any two events forming a surface multiple must also be present in the data. This can be a challenge (especially in shallow to medium water depths) in the case of poor near-offset sampling because the near offsets cannot be reconstructed beyond what is recorded. With modern wide-tow source acquisition configurations, this challenge is partly overcome as the distance from the source arrays to the outer cables is significantly reduced, improving the sampling at near offsets (Figure 2).

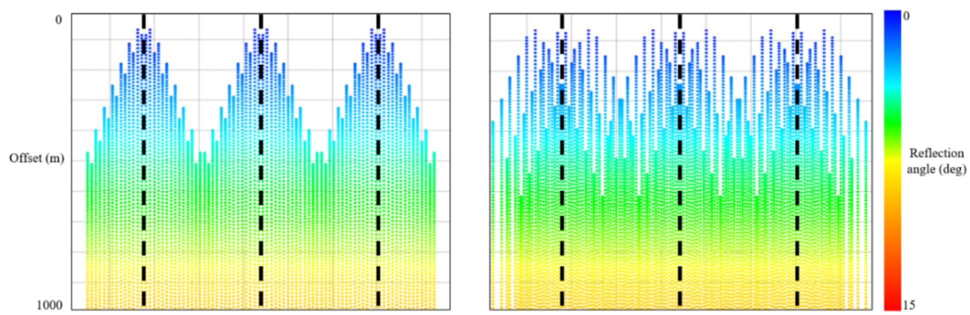

Figure 2 *Offset distribution for three saillines for conventional dual-source acquisition (left) and wide-tow triple-source configuration (right), where the colours show modelled reflection angle of incidence at a depth of 3 km. The separation between saillines is 525 m. The near-offset sampling is greatly improved with the wide-tow triple-source configuration, which is key for 3D SRME multiple modelling.*

Because azimuthal effects can be assumed to be negligible at close to vertical incidence, the complimentary data from the new acquired azimuth can also be used to reconstruct near-offsets for the legacy azimuth where these offsets are originally missing, as shown from the receiver map in Figure 3. The reconstruction is done using a 5D regularization scheme, allowing for interpolation across inlines, crosslines, offsets, azimuths and time (where azimuth is included to ensure a seamless transition between very near offsets and the rest of the data).

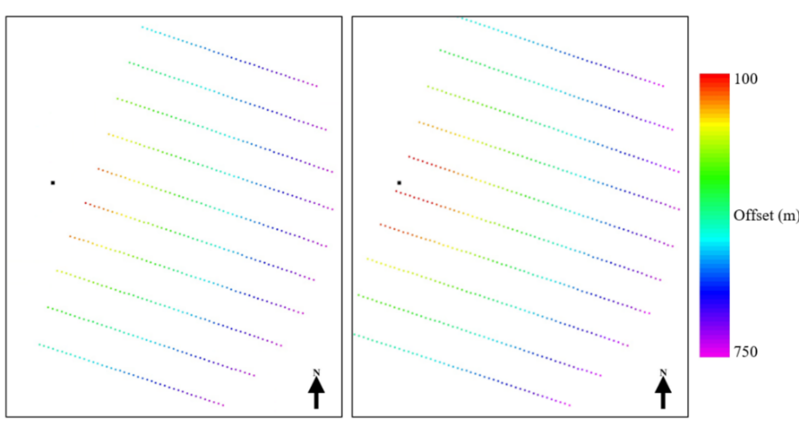

Figure 3 *Receiver map up to 750 m offset from a single shot before (left) and after (right) near-offset reconstruction. Shot position is shown as a black square.*

The improvements in 3D SRME modelling are clear from Figure 4, which shows a common near-trace display from an inner cable from input, 3D SRME model with no near-offset reconstruction and

3D SRME model with near-offset reconstruction. The arrows highlight areas where the multiples are better predicted when near offsets are reconstructed before multiple modelling. Further, it can also be observed that the differences between the two models is increasing with two-way travel time. This is expected, as the higher order multiples rely more on reconstruction of near offsets because they propagate closer to vertical incidence than the first-order multiples.

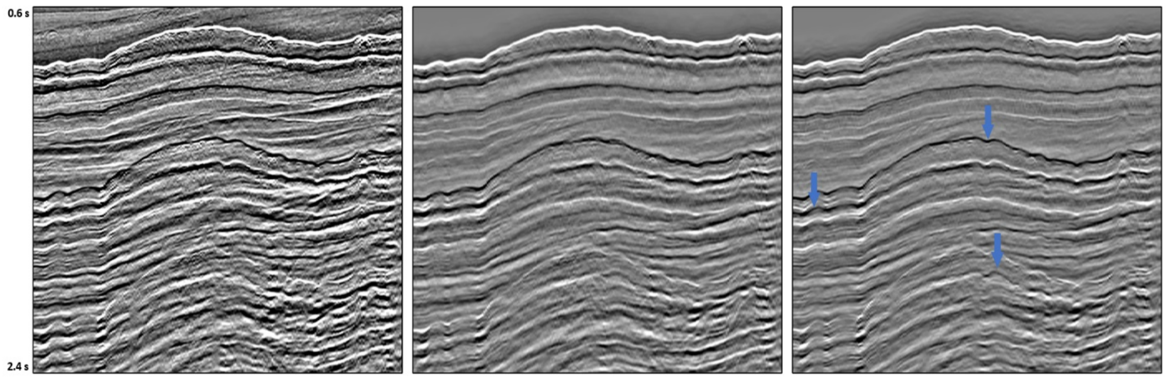

Figure 4 *Common near-trace display of input (left), 3D SRME model with no near-offset reconstruction (center) and 3D SRME model with near-offset reconstruction (right). The arrows highlight examples where the near-offset reconstruction helps to improve the multiple modelling. An increase in acoustic impedance is shown as a black event (peak).*

Adaptive subtraction

The second step of the multiple attenuation consists of subtracting the multiple models from the data in order to get a multiple free data set. Effective adaptive subtraction requires good separation between primaries and multiples in the domain of the subtraction. Intelligent Subtraction (Perrier et al., 2017) is a multi-dimensional, multi-scale and multi-model subtraction, which uses a combination of least-squares fitting (LSF) subtraction and curvelet transforms to subtract multiples from data. Being a multi-model subtraction, the algorithm assigns weights to each multiple model before subtraction.

Additionally, surface-related multiples can be split into two types based on move-out. Multiples that have predominantly propagated in the water column will have more move-out due to the low velocity, while longer-period multiples that have been more exposed to higher velocities in the subsurface will have less move-out. Splitting the original multiple models into slow and fast components can yield improved multiple attenuation as the subtraction can assign weights not only to the multiple models themselves, but also to the fast and slow components. This is evident in Figure 5, where cross-cutting multiples are clearly better attenuated when multiple models are split into fast and slow components for the adaptive subtraction.

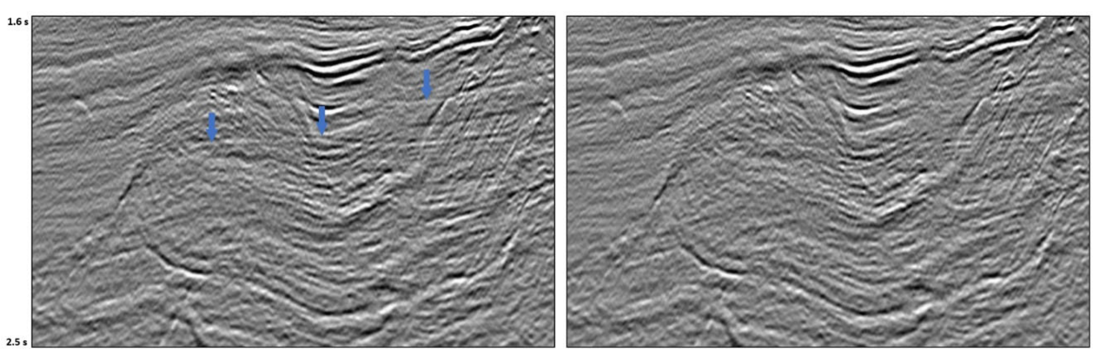

Figure 5 *KPSDM near stack after adaptive subtraction without (left) and with (right) velocity splitting. The arrows highlight cross-cutting multiples that are better attenuated with velocity splitting for adaptive subtraction. An increase in acoustic impedance is shown as a black event (peak).*

Comparison with legacy processing

The legacy azimuth was reprocessed in 2021 with a state-of-the-art depth imaging flow. Although the final data showed significant uplift compared to available data sets at the time, residual multiples were still apparent at target levels, as highlighted in Figure 6. The legacy azimuth from the new reprocessing shows significant uplift from the improved multiple modelling and adaptive subtraction. As a final product from the 2023 processing, the legacy and new azimuth are stacked together to create a dual-azimuth stack. This shows further improvement in multiple attenuation, as multiples are less repeated than primaries between azimuths and therefore stacks out from the dual-azimuth stacking.

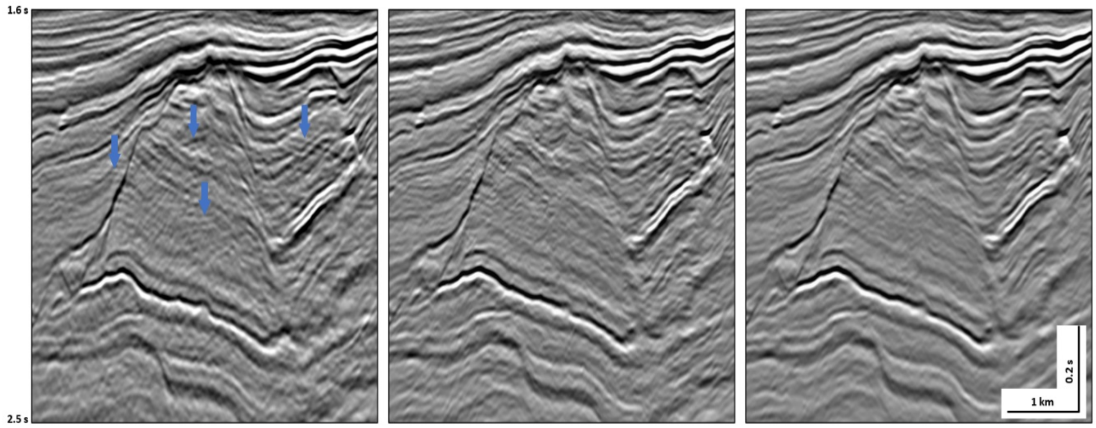

Figure 6 *3D KPSDM full stack from 2021 reprocessing of legacy azimuth (left), from 2023 reprocessing (center) and after dual-azimuth stack (right). The improvements in multiple attenuation between the 2021 and 2023 reprocessing of the legacy azimuth is clear. The final dual-azimuth stack shows further reduction in multiple content as multiples are less repeated than primaries between azimuths. An increase in acoustic impedance is shown as a black event (peak).*

Conclusions

Improved multiple attenuation is a key objective to deliver high-quality data in the Norwegian Sea. Firstly, we have shown how combining complementary data from two azimuths to improve near-offset sampling can improve multiple modelling which is of importance for successful demultiple. Secondly, separation of multiples into fast and slow components has shown to further improve the results. Finally, as multiples are less repeated than primaries between azimuths, the final dual-azimuth stack shows reduced multiple content and improved resolution and continuity of events, leading to better interpretability.

Acknowledgements

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