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New Volumetric QC of Wavefield Separation for Dual-Sensor Streamer 4D Monitoring

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Summary

The abstract presents a new volumetric QC developed to assess wavefield separation stability in dual sensor towed streamer seismic acquisition, with a particular focus on 4D time lapse monitoring. The approach targets risks associated with low frequency reconstruction and spatial dealiasing, which can introduce subtle amplitude instabilities and signal leakage that are not captured by conventional QC. By comparing production wavefield separated data with a reference generated at coarser temporal sampling, survey wide NRMS based QC attributes are derived. Example of signal leakage due to suboptimal (too aggressive) anti-aliasing is also included and demonstrates quality risk. The proposed QC improves confidence in acquisition deliverables and supports the repeatability requirements of high precision 4D monitoring.

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Introduction

Most recent marine towed-streamer seismic surveys are acquired using dual-sensor streamer technology, both for conventional 3D seismic imaging and for 4D time-lapse monitoring. In many cases, the wavefield-separation step associated with dual-sensor acquisition is included in the acquisition contract and performed onboard, delivering upgoing wavefields (P-UP) and total hydrophone pressure recordings redatumed to specified depth (H-REC).
High precision and repeatability are critical requirements for 4D monitoring projects. To address this, Equinor and TGS updated existing QC standards in 2024 to include new volumetric QC procedures, specifically targeting the wavefield separation step. The updated QC procedures were successfully implemented during the 2025 Norwegian acquisition season and are currently part of the mandatory QC workflow for all dual sensor streamer acquisitions.
In this abstract, we demonstrate how the new volumetric QC is applied and highlight its importance for time-lapse seismic monitoring, where subtle amplitude changes can directly impact 4D interpretability.

Method and Theory

Day et al. (2013) described wavefield separation methods for dual sensor towed streamer data and discussed the practical limitations encountered in real data, together with mitigation strategies. The article highlighted the impact of variable noise levels, spatial aliasing, and the need for low frequency reconstruction of particle motion measurements using pressure data. These factors are closely linked:

- Spatially variable signal-to-noise ratio, especially in the low frequency band of the particle motion sensors, can degrade the reliability of low frequency reconstruction locally.
- The reconstructed low frequency content is used to derive weighting operators that are subsequently applied across the full bandwidth, including potentially aliased higher frequencies.
- Dealiasing may be applied to both hydrophone and particle motion data as part of the wavefield separation workflow.

To mitigate the risk of signal leakage, QC of the wavefield separation step should be performed in a volumetric sense throughout the survey area, as test results based on a small selection of lines may produce different results in areas of poor signal-to-noise. At the minimum, the QC should consist of stack RMS extractions in overburden and target windows. If a new 4D survey is being acquired and another vintage is available, 4D QCs can be analysed for unexpected 4D signal.
During a recent 4D survey, dealiasing applied as part of the wavefield separation process, due to the spatial sampling not meeting the aliasing criteria for the maximum recorded slowness. During subsequent processing, QCs showed areas of unexpected 4D leakage which was traced to suboptimal dealiasing in areas of poor signal-to-noise. This leakage was small and without an earlier vintage to measure against, would not have been detected. Therefore, a new volumetric QC procedure has been developed to identify poor quality wavefield separation results. The approach compares the production P-UP and H-REC data, produced at 2 ms sample rate and then resampled to 8 ms, with reference P-UP and H-REC volumes generated at 8 ms sampling on input to the wavefield separation process. At this coarser sampling, spatial aliasing is avoided, and no dealiasing is required; therefore, differences between the two products are primarily attributable to aliased energy and, to a lesser extent, high dip components arising from different extrapolation windows and transforms. Based on our observations, NRMS (mean value) of the range 4-6% indicates that the dealiasing process is safe.
This comparison enables the generation of shot averaged, volumetric QC attributes from the standard 4D metrics such as NRMS and predictability. This provides a clear, survey-wide assessment of the wavefield separation quality and increases confidence in the robustness and repeatability of the acquisition products.

Examples

The NRMS QC map, Figure 1, illustrates a case of stable and safe wavefield separation production. A complementary example demonstrates that inconsistent dealiasing can introduce coherent signal leakage into the separated wavefields (reconstructed total pressure in this case), illustrating the potential impact on repeatability and signal leakage on 4D difference if such effects are not identified during wavefield separation.

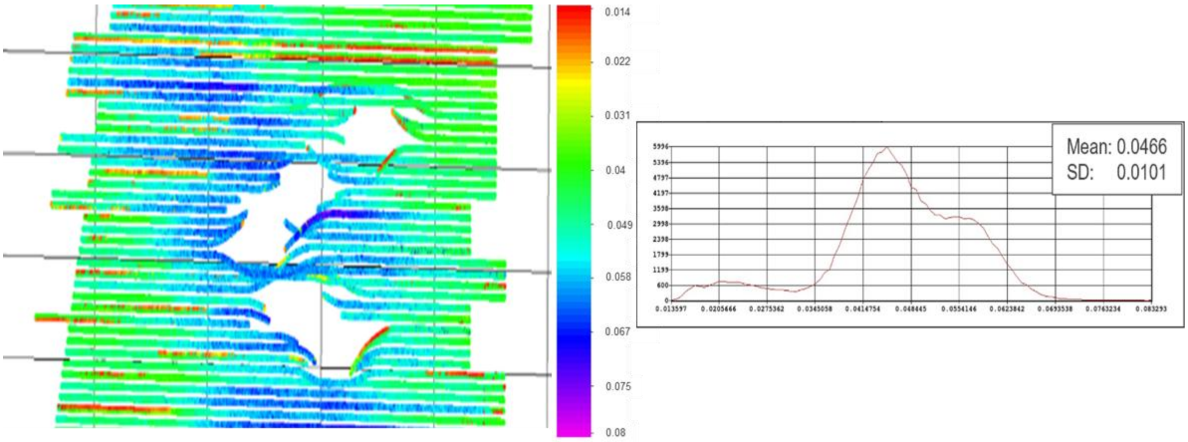

Figure 1 *NRMS map computed between H-REC generated at 8ms and production H-REC. Mean NRMS value of 4.7% suggesting two datasets are highly consistent.*

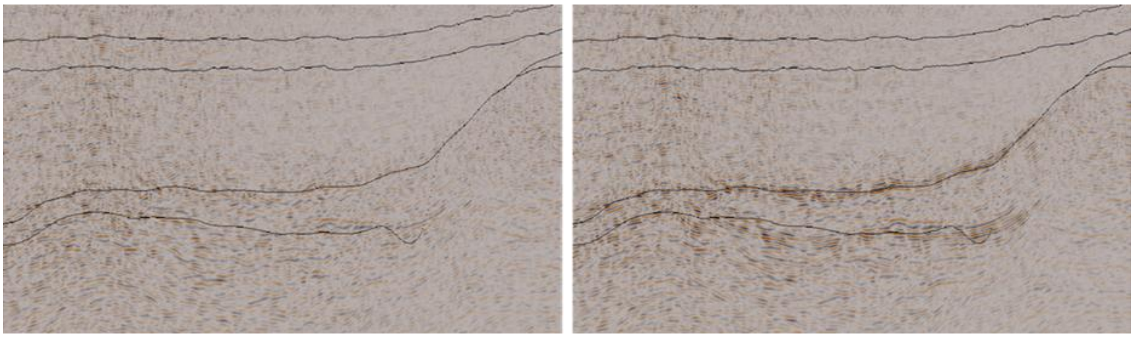

Figure 2 *Effect of inconsistent dealiasing on 4D difference of total pressure (H-REC) processing. Left: production data with adjusted parametrization and accurate imaging of genuine 4D signal. Right: non-optimal parametrization of dealiasing step in wavefield separation, leading to extensive signal leakage.*

Conclusions

The proposed volumetric QC provides a robust and intuitive means of identifying and mitigating risks of amplitude instability during the wavefield separation process linked to variable noise level and spatial aliasing. It therefore helps acquisition and processing teams to ensure wavefield separation stability at the survey scale and supports more reliable delivery of dual-sensor streamer products suitable for high-precision time-lapse monitoring.

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References

Day, A., et al. (2013). Wavefield-separation methods for dual-sensor towed-streamer data. Geophysics, 78(2), WA55–WA70