Qualifying the Reliability of Opportunistic 4D for Seismic Monitoring

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Summary

Recent advances in 4D seismic workflows have renewed interest in leveraging non-dedicated acquisition for reservoir monitoring. In this study, we examine the performance of an opportunistic 4D monitor derived from Multi-Client data and compare it with a dedicated time-lapse survey acquired eight years later. The dataset includes a 2005 baseline, a high-quality dedicated monitor from 2017, an opportunistic monitor in 2022, and an ongoing dedicated monitor in 2025. The opportunistic 2017–2022 pair successfully detected production-related changes, though its broader acquisition differences and higher noise levels required more careful analysis to separate true subsurface responses from acquisition-related effects. In contrast, the dedicated 2017–2025 pair shows significantly improved repeatability, allowing more confident identification of pressure depletion, gas-cap evolution, and impedance changes associated with water flooding. Processing enhancements such as more effective debubbling and more precise time-shift corrections further improved the consistency and reliability of the dedicated 4D signal.
Preliminary results indicate that while dedicated acquisition remains the benchmark for high-fidelity reservoir surveillance, opportunistic 4D can provide meaningful early insights at significantly lower cost. This makes it a practical screening solution for assessing the feasibility and expected impact of seismic monitoring before committing to a full dedicated program.

Introduction

Conventional 4D seismic monitoring relies on careful survey design, controlled navigation and high repeatability between vintages. Recent work, including Milne et al. (2024), has shown that Multi-Client acquisitions can also be used opportunistically to extract time-lapse information, offering a lower-cost alternative for early monitoring insights. In 2025, a new dedicated monitor was acquired with a design optimized to maintain the strong repeatability achieved in earlier dedicated surveys. This study evaluates how an opportunistic 4D dataset compares with dedicated time-lapse acquisition for characterizing production-driven changes in the reservoir.
The Ærfugl field extends roughly 60 km in length and 2–3 km in width, narrowing into a stratigraphic pinch-out toward the east (Figure 1). A test producer drilled in 2013 confirmed the presence of gas, and full production began in 2020 with six wells brought online between 2019 and 2021. Before the 2025 monitor, two dedicated 4D surveys had been acquired in 2005 and 2017. Only minor water-flood–related changes were interpreted on the 2017 monitor, which is consistent with most production beginning after that time.
Based on the field's production history, several 4D effects are expected. In the southern area, water replacing gas should generate localized hardening, while softening is expected along the evolving gas–water contact. In the north, where wells are producing water, impedance increases are anticipated. Gas-cap expansion is expected to be a major contributor to the 4D response across the field, and exsolved gas within the aquifer may also produce measurable time-lapse changes.

Acquisition Geometry

The baseline survey over the field was acquired in 2005 using conventional shallow-towed hydrophone streamers. A first dedicated 4D monitor followed in 2017, acquired with deep-towed multi-sensor streamers and designed to closely replicate the baseline geometry, including matched shot and receiver positions and identical dual-source parameters. In 2022, TGS conducted a multi-client survey over the area which, although not optimized for repeatability, was later used as an opportunistic 4D monitor (Milne et al., 2024). This multi-sensor acquisition employed a wider streamer spread and a triple-source configuration, resulting in reduced

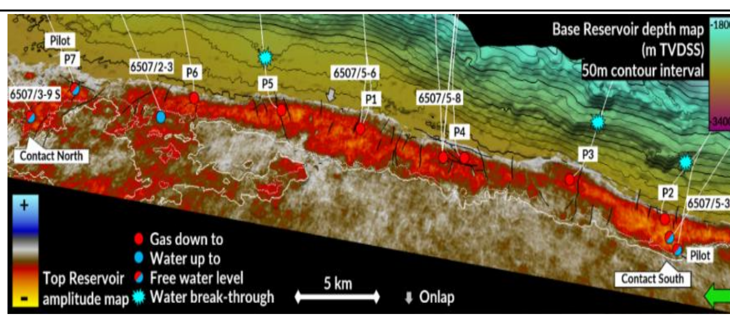

Figure 1: Top Lysing depth map onlapping the base reservoir depth surface. The attribute map is minimum amplitude extracted from an AVO fluid volume where warm colours indicate gas presence. Wells are shown in white, annotated with fluid contact information. (Hjellbakk et al. 2023).

geometric consistency relative to the earlier monitors. Most recently, in summer 2025, TGS acquired a new multi-sensor monitor survey specifically designed to reproduce the 2017 geometry, reinstating the same spread width and dual-source setup to enhance repeatability for 4D analysis.

4D processing

The goal of this study is to build on the work presented by Milne et al. (2024) by comparing results from an opportunistic 4D processing effort with a new interpretation derived from a dedicated 4D acquisition. The opportunistic project completed in 2023 included the 2005 baseline, the repeated 2017 monitor, and the non-repeated 2022 survey. In the dedicated 2025 4D processing project, we used the 2005 baseline, the repeated 2017 monitor, and a new repeated 2025 monitor acquired with geometry specifically matched to the 2017 survey. Because the field experienced limited production between 2005 and 2017, the 4D signal for that interval remains weak, and the 2005 baseline provides only partial coverage of the Ærfugl field. Therefore, our comparison focuses primarily on the 2017–2022 pair from the opportunistic project and the 2017–2025 pair from the dedicated 4D program.
All three vintages were reprocessed jointly from raw data to maximize repeatability in both workflows and algorithms across the two 4D studies. Despite the short two-year interval between the projects, several updates were introduced in the processing sequence. The most significant change was applied during debubbling: designature filters were generated from data-derived wavelets and applied using a unified target wavelet across all vintages. This revised strategy substantially reduced bubble imprint in the 4D differences and improved the signal-to-noise ratio, particularly at low frequencies (Figure 2).

A key challenge in this area is the strong presence of multiples. The reservoir interval between the Lysing and Top Lange horizons is barely visible prior to demultiple and denoise, and the 4D signal becomes interpretable only after migration. Although the surveys are not acquired in shallow water, multiples remain significant: the relatively hard water bottom at ~500 ms two-way time generates strong reverberations, and its locally rugose character introduces complex diffracted multiples. For each vintage, multiple models were generated and adaptive subtraction parameters were validated directly through optimization of the 4D differences, following the strategy used in the earlier study.
The second difference between the two projects occurs prior to regularization, in the time-destriping workflow. For the 2025 processing, a cascaded approach was implemented: a dynamic time shift was first estimated using near-, mid-, and far-offset panels, followed by a static correction derived from the full stack (10–50°).
The third difference is the introduction of interbed multiple elimination in the 2025 project, applied to remove remnant multiples in the Cretaceous package above the reservoir and further clean the seismic response.

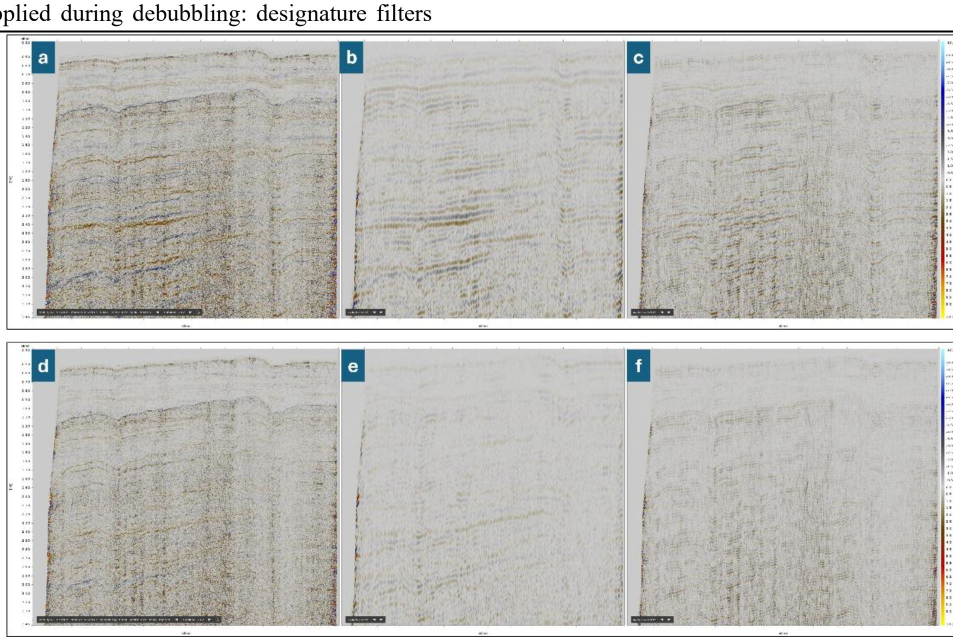

Figure 2: Comparison of 4D differences for the 2017–2005 pair from the opportunistic (a–c) and dedicated (d–f) processing projects. Panels (a) and (d) show full-bandwidth differences; panels (b) and (e) highlight the 4–8 Hz band; and panels (c) and (f) show the 8–16 Hz band. The dedicated workflow delivers improved signal-to-noise ratio and more effective bubble attenuation.

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4D Signal Comparison

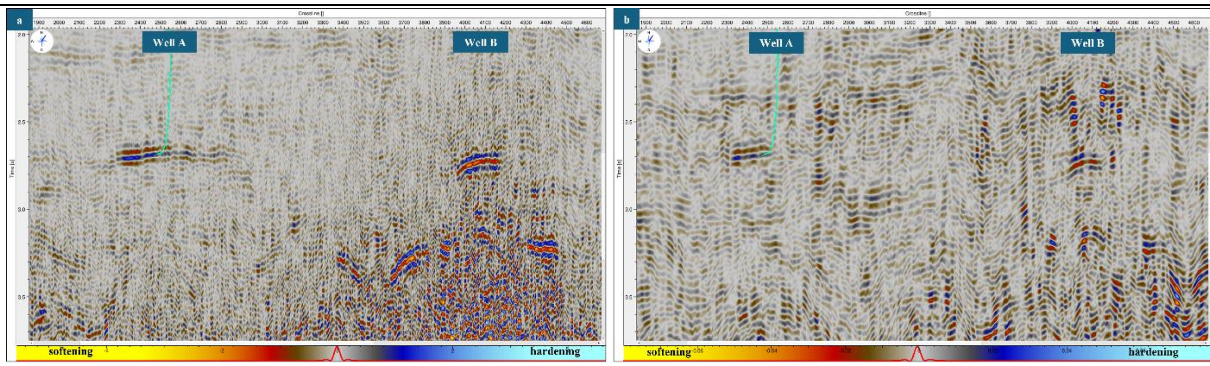

Figure 3: Comparison of 4D differences with quadrature applied in the 8–16 Hz band for the dedicated 4D (a) and the opportunistic 4D (b). Two well locations are indicated. The dedicated dataset exhibits a strong and coherent 4D response at both wells, while the opportunistic dataset captures the same features with reduced definition, reflecting the acquisition and processing differences.

During the 2023 opportunistic 4D project, amplitude Q-compensation was intentionally omitted to avoid amplifying noise, whereas phase Q-correction was applied using a consistent reference frequency prior to migration. For the comparison presented in this study, amplitude Q-compensation has now been applied to the opportunistic dataset to ensure consistency across all vintages.

Another difference arises from the migration velocity models used in each project. The dedicated 2025 4D processing has not yet progressed to the RMO or trim-statics stages, meaning these corrections are currently absent. As a result, some reflection events may display minor vertical misalignments between datasets.

The opportunistic 4D data show indications of response at both well locations (Figure 3b). At Well A, a potential hardening is suggested at the Lysing level, while at Well B a weak softening appears at a slightly deeper interval. In contrast, the dedicated 4D dataset (Figure 3a) provides a clearer and more coherent picture: the hardening at Lysing is distinctly observed at Well A, and at Well B the softening at the Gråsel level is well defined. Additionally, the dedicated data reveal a deeper 4D response associated with Skarv, which was not apparent in the opportunistic 4D. Overall, the opportunistic 4D requires prior knowledge of field behavior to confidently interpret subtle signals,

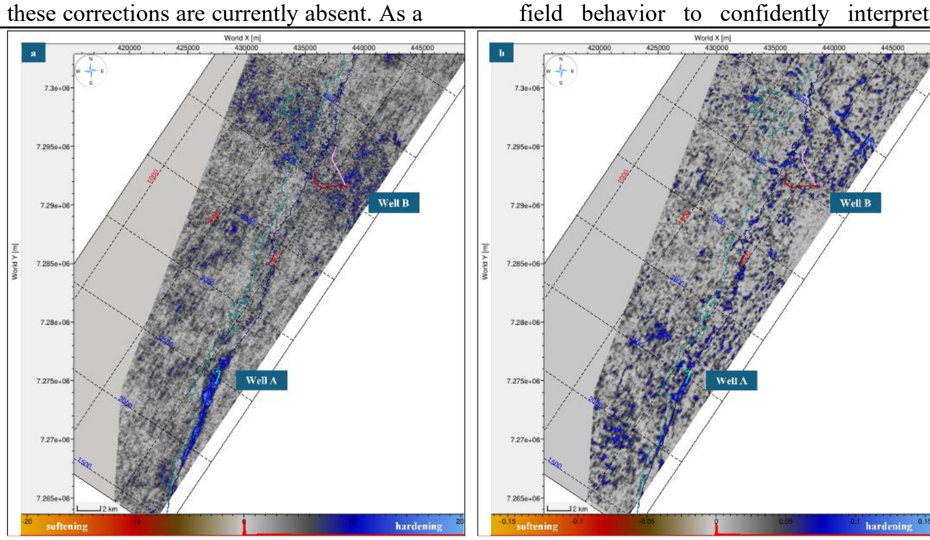

Figure 4: Sum-positive amplitude maps at the Lysing level for the dedicated 4D (a) and opportunistic 4D (b). A strong hardening effect is observed at Well A in the dedicated dataset and is consistently identified in the opportunistic data. The additional hardening feature between Wells A and B seen in the opportunistic 4D, however, is not reproduced in the dedicated dataset.

whereas the dedicated 4D makes these responses evident without relying on external context.

When examining the attribute maps, a stronger agreement between the opportunistic and dedicated datasets becomes evident. The hardening associated with water replacing gas is clearly observed on the sum-positive amplitude maps in the southern part of the survey (Figure 4). The localized hardening between Wells A and B that appears in the opportunistic 4D is less straightforward to confirm in the dedicated 4D.

The previous study identified a softening response at Well B, interpreted as gas injection into an oil-filled sand during reservoir pressure decline. The new dataset confirms this behavior, showing a clearer and stronger softening at Well B (Figure 5). In addition to acquisition improvements, two additional years of production separate the dedicated and opportunistic surveys, likely contributing to the enhanced 4D response in the 2025 data. While the opportunistic results successfully indicate similar trends, they are noticeably noisier and can suggest 4D effects that are not supported by the dedicated dataset. Across Figures 3, 4, and 5, features that appear as potential signals in the opportunistic 4D are reliably confirmed at the well locations in the dedicated 4D, whereas the apparent anomaly between the two wells does not persist in the dedicated dataset.

Conclusions

This case study compares an opportunistic 4D dataset with a dedicated 4D survey to evaluate their respective abilities to resolve production-related changes. Despite differences in acquisition design and processing maturity, the opportunistic dataset captured several genuine and geologically meaningful 4D responses that are independently confirmed by the dedicated survey. These early indications demonstrate that opportunistic 4D can provide valuable, timely insights into reservoir behaviour.

Not all anomalies observed in the opportunistic data persist in the dedicated results, which exhibits a clearer signal-to-noise ratio and enables more robust interpretation. This work highlights the strong value of well-repeated 4D for reliably characterizing production-driven changes, and confirms that opportunistic 4D, while informative, is not suitable for drilling or field development decisions in this setting.

Nevertheless, opportunistic 4D proves to be an effective screening tool, helping assess the feasibility of 4D seismic monitoring, pointing to areas with potential production-related changes, and guiding expectations ahead of a dedicated acquisition. Its ability to highlight consistent 4D effects emphasizes its role as a complementary and cost-effective component of the seismic monitoring workflow.

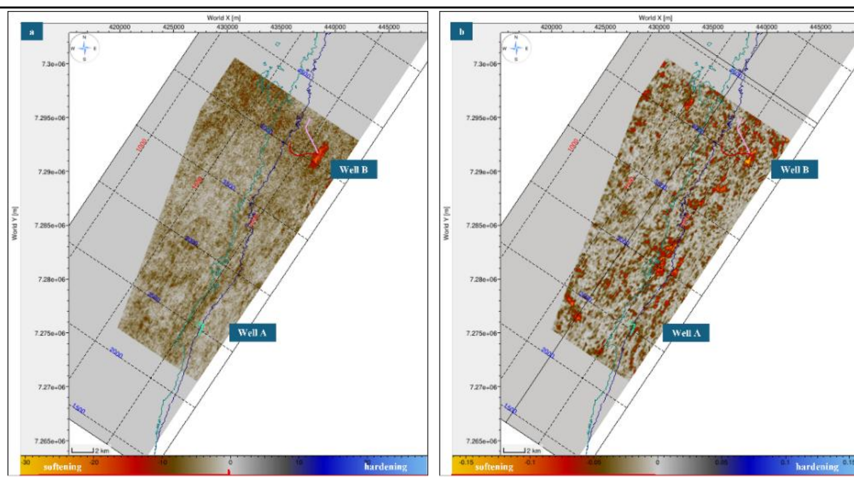

Figure 5: Sum-negative amplitude maps at the Gråsel level for the dedicated 4D (a) and opportunistic 4D (b). A strong softening response is observed at Well B in the dedicated dataset and is consistently identified in the opportunistic data. The additional softening feature between Wells A and B that appears in the opportunistic 4D is not reproduced in the dedicated dataset.

Acknowledgments

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