

Validating Opportunistic 4D as a Proof of Concept for Seismic Monitoring

Introduction

Standard 4D time-lapse acquisitions require extensive planning, specialized navigation equipment and strict repeatability for both source and receivers. Milne et al. (2024) demonstrated that multi-client datasets can be used in an opportunistic way to improve understanding of reservoir production. In 2025, a new monitor was acquired with a design focused on maintaining the repeatability achieved in previous dedicated surveys. This case study compares the results obtained from an opportunistic 4D approach with those from a dedicated 4D acquisition.

The Ærfugl field is approximately 60 km long and 2-3 km wide, with a stratigraphic pinch-out to the East (Figure 1). A test producer P1 drilled in 2013 proved the presence of gas before start-up of the first regular producer in 2020. In total, 6 wells were set on production in the period 2019 to 2021. Prior to the 2025 new monitor, two conventional 4D surveys were acquired, in 2005 and 2017 respectively. Only minor water flooding effects were interpreted on the 2017 data. However as most of the production started after 2017, it is expected to see some hardening in the south where water is replacing gas and some softening along the gas-water contact. In the north area, some hardening is expected as wells are producing water. Gas cap expansion is expected to be a major contributor to the 4D signal. Additionally, gas out of solution in aquifer could be a potential 4D signal.

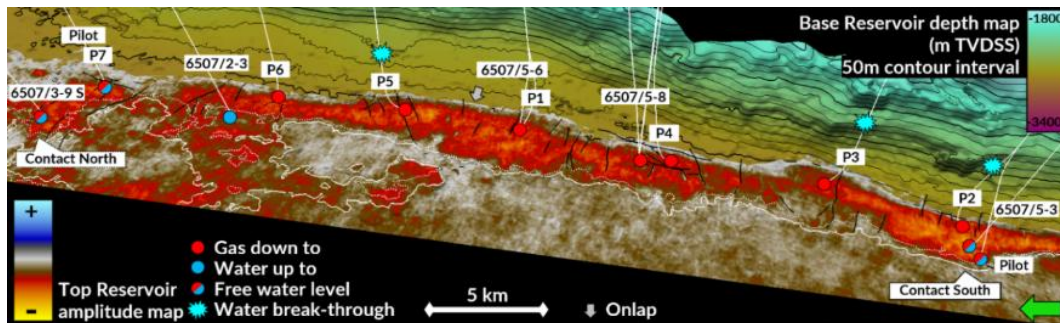


Figure 1 Top Lysing depth map onlapping the base reservoir depth surface. The attribute map is minimum amplitude extracted from an AVO fluid volume where warm colours indicate gas presence. Wells are shown in white, annotated with fluid contact information. (Hjellbakk et al. 2023).

Acquisition geometry

The baseline survey was acquired in 2005 using conventional shallow-towed hydrophone streamers. A first monitor followed in 2017, acquired with deep-towed multi-sensor streamers and designed as a dedicated 4D survey, with the goal of closely matching the baseline shot and receiver positions while maintaining identical dual-source specifications. In 2022, TGS carried out a multi-client program over the field, later used as an opportunistic 4D monitor (Milne et al., 2024). This multi-sensor acquisition was not intended for strict repeatability, including a wider triple-source configuration and a broader streamer spread. Finally, in summer 2025, TGS acquired a new monitor using multi-sensor technology, specifically designed to reproduce the geometry of the 2017 monitor, including the same spread width and dual-source setup.

4D processing

The objective of this case study is to build on the 4D approach presented by Milne et al. (2024) and compare results from an opportunistic 4D project with a new interpretation based on a 4D dedicated project. During the opportunistic processing in 2023, the following pairs were processed: 2005 (base), 2017 (monitor 1, repeated) and 2022 (monitor 2, non-repeated). In the new 4D processing project in 2025, the pairs processed were: 2005 (base), 2017 (monitor 1, repeated) and 2025 (monitor 2, repeated). Because the field experienced limited production between 2005 and 2017, the 4D signal for that interval is weak. Furthermore, the 2005 baseline does not fully cover the Ærfugl field. Consequently, this

comparison focuses primarily on the 2017-2022 pair from the opportunistic project and the 2017-2025 pair from the dedicated 4D acquisition.

All the three vintages were processed together from raw data to ensure the best repeatability in processing sequences and algorithms across both projects. Although only two years separate the two 4D case studies, some differences in the processing flow were introduced. The first change occurred at the debubbling stage: signature filters were derived from wavelets extracted from the data and applied using a consistent target wavelet for all vintages. This updated approach significantly reduced bubble imprint in the 4D differences and improved the signal-to-noise ratio, particularly at low frequencies (Figure 2).

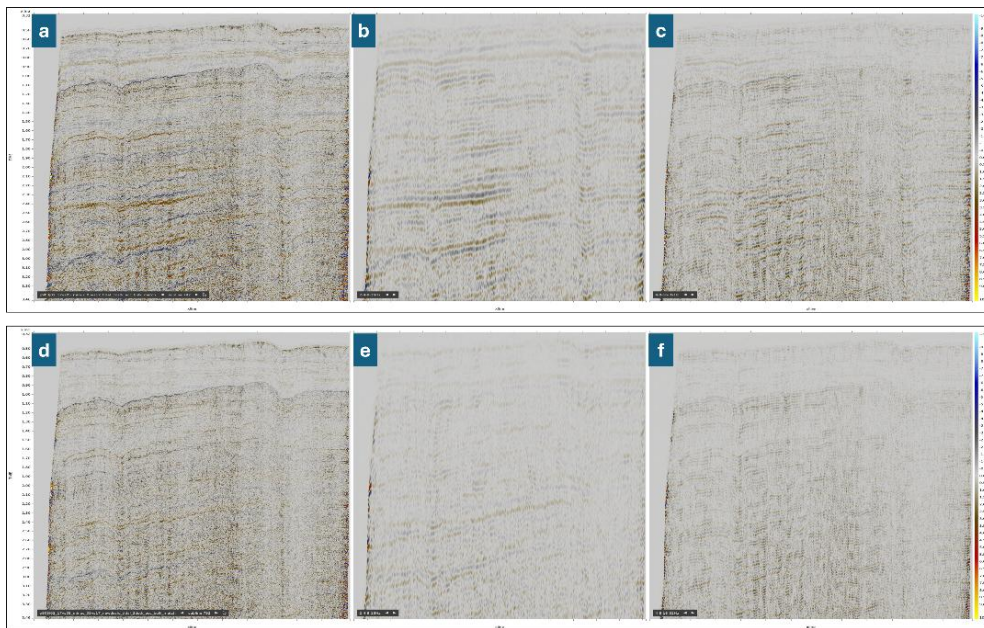


Figure 2. Comparison of 4D differences (2017–2005) between opportunistic 4D (a–c) and dedicated 4D (d–f). Panels a and d show full bandwidth; b and e cover 4–8 Hz; c and f cover 8–16 Hz. Improved signal-to-noise ratio and better bubble attenuation.

One of the main challenges in this area is the presence of multiples. The reservoir interval between the Lysing and top Lange horizons is almost invisible before demultiple and denoise, and the 4D signal only becomes apparent after migration. Although these surveys are not in shallow water, multiples remain a significant issue. The water bottom has a two-way travel time of about 500 ms and is relatively hard, generating strong multiple reflections. In addition, its highly rugose nature in some areas produces complex diffracted multiples. For each vintage, multiple models were generated, and adaptive subtraction parameters were validated directly through 4D difference optimization. The same strategy applied in the previous study is used here,

The second difference occurs prior to regularization, specifically in the calculation of time destriping. In 2025, a cascaded approach was introduced: first, a dynamic time shift was computed using three offset panels (near, mid, and far). After applying this dynamic correction, a static time shift was derived from the full stack (10–50°).

4D Signal comparison

During the 2023 opportunistic 4D project, amplitude Q compensation was deliberately omitted to avoid amplifying noise. However, phase Q was applied on the opportunistic 4D using the same reference frequency prior to migration. For the comparison presented in this study, amplitude Q compensation has now been applied to ensure consistency between datasets. Another difference lies in the migration velocity models used for each project. The dedicated 4D processing has not yet reached the RMO or trim statics stage, so these corrections are currently absent. As a result, some reflection events may exhibit vertical misalignments between the datasets.

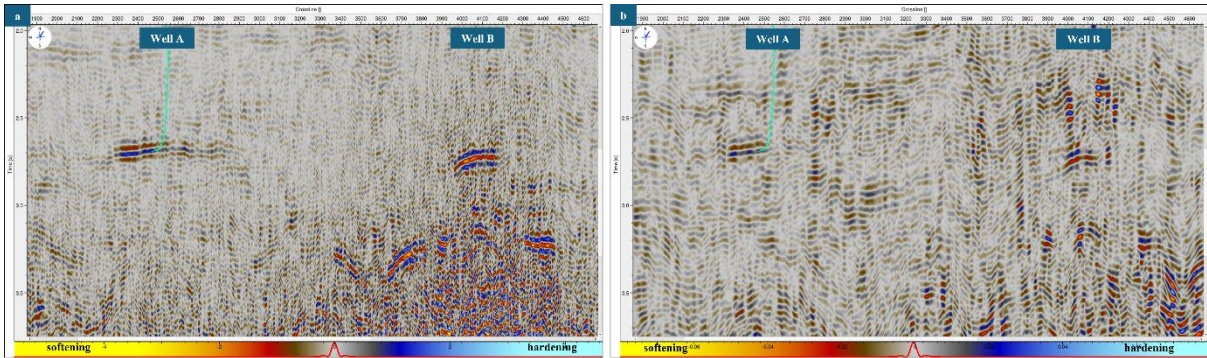


Figure 3 Comparison of 4D differences with quadrature in the 8–16 Hz frequency band: (a) dedicated 4D and (b) opportunistic 4D. Two well locations are indicated. In (a), the 4D signal is strong at both well positions, whereas in (b) the signal is present but less well defined.

The opportunistic 4D shows some signal at both well locations (Figure 3b): at Well A, there appears to be hardening at the Lysing level, while at Well B, a slight softening is visible at a deeper level compared to Well A. In contrast, the new dedicated 4D (Figure 3a) confirms the hardening at Lysing for Well A. For Well B, the softening at the Gråsel level is clearly observed, along with an additional deeper 4D response corresponding to Skarv—something that was not evident in the opportunistic 4D. In short, with the opportunistic 4D, identifying 4D signals requires prior knowledge of the field history, whereas the dedicated 4D makes these signals clearly recognizable even without such context.

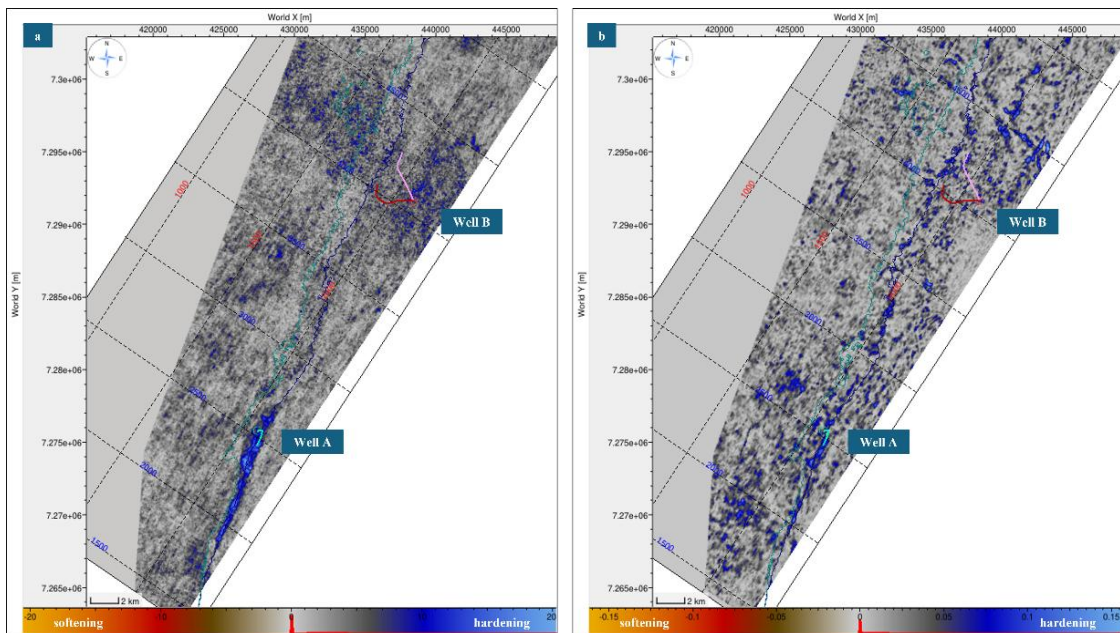


Figure 4 Sum of positive amplitudes at Lysing from Figure 3: (a) dedicated 4D and (b) opportunistic 4D. A strong hardening effect is evident at Well A in the dedicated 4D and can be correlated with the opportunistic 4D. However, additional hardening observed between wells A and B in the opportunistic 4D are not present in the dedicated 4D.

When examining attribute maps, more similarities between the opportunistic and dedicated datasets become apparent. Hardening caused by water replacing gas is clearly visible on the sum of positive amplitude maps in the southern part of the survey (Figure 4). However, localized hardening between Wells A and B observed in the opportunistic 4D is difficult to correlate in the dedicated 4D.

The previous study identified a softening effect at Well B. This softening can be interpreted as gas injection into an oil filled sand as reservoir pressure declines. The new dataset confirms the softening at Well B, where the effect is much stronger and better defined (Figure 5).

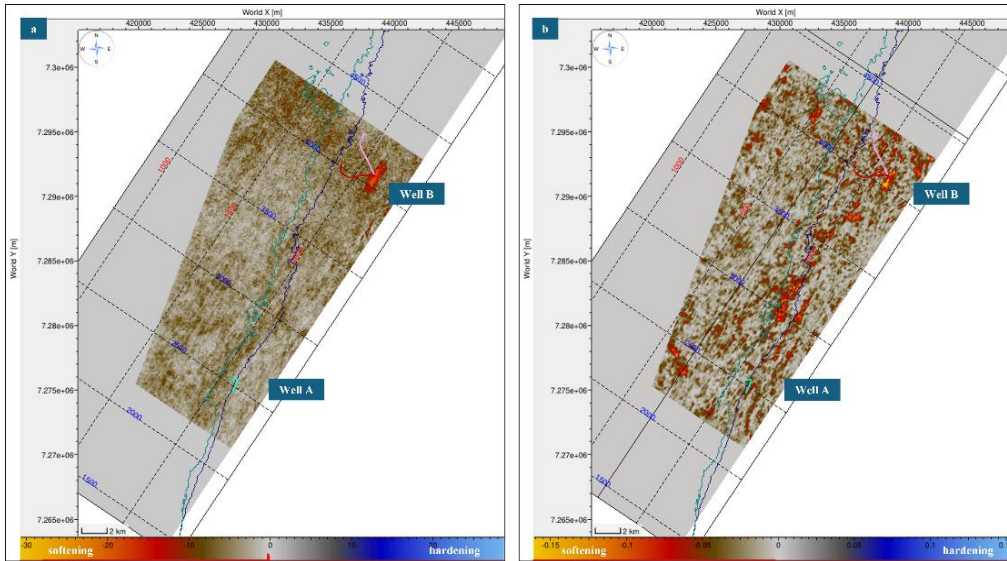


Figure 5 Sum of negative amplitudes at Gråsel from Figure 3: (a) dedicated 4D and (b) opportunistic 4D. A strong softening effect is evident at Well B in the dedicated 4D and can be correlated with the opportunistic 4D. However, additional softening observed between wells A and B in the opportunistic 4D are not present in the dedicated 4D.

In addition to acquisition differences, two years of oil production separate the dedicated and opportunistic surveys, which likely contribute to the stronger 4D response in the 2025 data. However, opportunistic results are clearly noisier and might suggest a presence of non-existing 4D effects. Figures 3, 4, and 5 illustrate that what appears as a signal in the opportunistic 4D can be confirmed at the well location in the dedicated 4D, whereas the potential signal between the two wells is not clearly visible or validated in the dedicated 4D dataset.

Conclusions

This case study highlights the comparison between an opportunistic 4D dataset and a dedicated 4D survey. Despite differences in acquisition timing and processing workflows, the opportunistic dataset captured genuine 4D signals, as confirmed by several consistent features across both surveys. However, not all anomalies observed in the opportunistic data were validated by the dedicated survey. The dedicated dataset delivers a markedly superior signal-to-noise ratio, enabling clearer interpretation of 4D effects. Although processing of the dedicated survey is still ongoing, the findings demonstrate that opportunistic 4D can serve as a valuable screening tool—helping assess the feasibility of seismic monitoring and detect early 4D responses before committing to a dedicated 4D acquisition.

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References

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