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Quantifying 4D Repeatability Improvements with Evolutionary Acquisition on the Gullfaks Field, North Sea

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Summary

This article presents quantitative measures of geometrical repeatability versus time-lapse data quality, showing the advantages of the deep-tow multisensor streamer acquisition for 4D projects. Authors demonstrate that the multisensor streamer enabled the optimization of the acquisition turnaround together with the improvement of the 4D data quality. They propose to look at both the NRMS and the fNRMS attributes (NRMS value calculated per single frequency) to evaluate 4D repeatability and therefore data quality improvements with evolving acquisition technology over the last 34 years of the reservoir monitoring program over the Gullfaks field, North Sea.

Introduction

The Gullfaks area is located in block 34/10 on the west flank of the Viking Graben in the Norwegian North Sea. The geological setting over the main field is presented in Figure 1. The main reservoirs are located below base cretaceous unconformity (BCU) in the Brent Group and the Cook and Statfjord Formations. Production from those levels started in 1986. The younger secondary reservoirs, in the Shetland Group and the Lista Formation, came into production in 2012. Diagonally across the field, an overburden glacial wedge structure exists near the seabed. Velocity variation within the wedge causes attenuation/transmission losses and distortion of the amplitude and continuity of the events down to the reservoir level.

There have been 11 4D marine seismic streamer surveys acquired over the Gullfaks Main field in the last 34 years. The first one was acquired in 1985 and last one in 2019. A variety of different acquisition setups and technologies used along those years have given us a good opportunity to quantify the uplifts in repeatability and 4D data quality in connection with the evolving acquisition technology.

The processing of the vintages used for the below analysis is still ongoing. The data is currently at the regularization stage and has denoise, pure 3D demultiple and the 4D sail line related corrections applied. Six seismic vintages (Table 1) with equalized spectral bandwidth are used for this particular comparison. The 2016 and 2019 vintages are the multisensor acquisitions, utilizing the total pressure wavefield for the purpose of this study. It is important to retain the integrity of the data between all the vintages and at all depths.

This paper aims at quantifying the improvements in the geometrical repeatability and time-lapse data quality for each of the step changes in the acquisition technology.

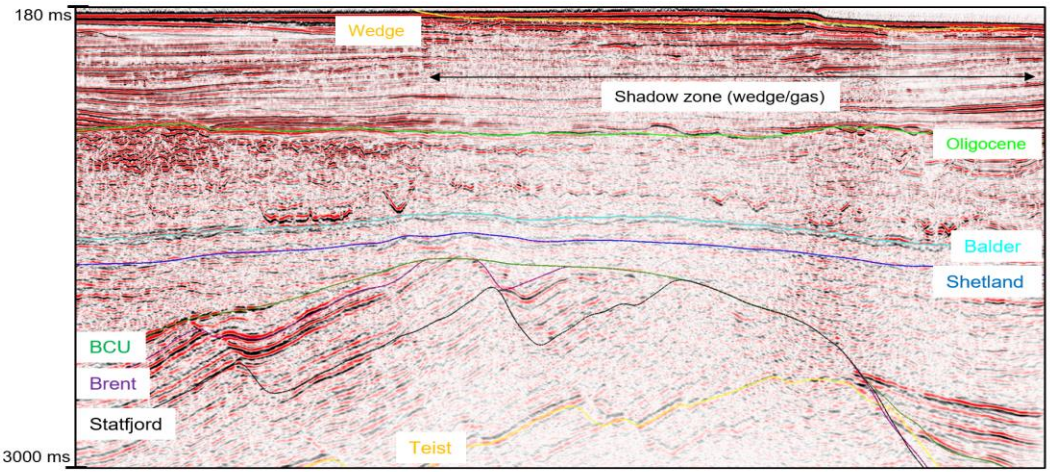

Figure 1 *Depth migrated stack section (TWT) of 2019 vintage showing the geological setting over the Gullfaks Main field (intermediate processing stage – after demultiple and sailline related corrections).*

How well are the acquisitions repeated?

Table 1 shows a comparison of the relevant acquisition parameters, which have gradually changed. The 1996 vintage was the first survey where a straight line pre-plot for source positions was introduced. In the 2005 acquisition, a streamer spread overlap was introduced to mitigate holes in coverage between saillines. The increase in the towing capacity in 2008 brought a high-density acquisition configuration with 17 streamers and 50 m streamer spacing. The uplifts set a new baseline for the future surveys over the Gullfaks field. In addition to that, the 2008 acquisition made use of the available source and streamer positioning system. However, from 2011 and onwards a more advanced source and streamer steering was implemented. In 2016, the upgrade from conventional hydrophone-only streamers to multisensor streamer technology set a new milestone in the monitoring program. The wavefield separation process, utilizing the pressure sensors together with particle velocity sensors (Söllner et al. 2008), has given a flexibility to create the up-going only wavefield (P-UP) for broadband processing while still being 4D backward compatible by making use of H-REC which is the total pressure wavefield (Day et al. 2010). The use of multisensor streamer technology allowed for deeper towing depths, thus reducing noise level, enhancing signal-to-noise ratio and increasing acquisition efficiency without compromising the bandwidth (Fahimuddin et al. 2015). Since the 2019 survey is a repeat of the 2016 one, there is a clear opportunity to quantify the uplifts on the 4D results.

Survey	1996	2005	2008	2011	2016	2019
Number of sources	2	2	2	2	2	2
Number of streamers	6	8	17	17	17	17
Streamer overlap	x	2	4	4	4	4
Streamer spacing	100	100	50	50	50	50
Streamer depth	8	8	8	8	20	20
Streamer type	hydrophone	hydrophone	hydrophone	hydrophone	multisensor	multisensor
Streamer/source steering	x	x	✓	✓	✓	✓

***Table 1** Summary of the towed-streamer acquisition parameters over the Gullfaks field.*

Typical measures of the geometrical repeatability for the time-lapse monitoring surveys are dS (difference in source position), dR (difference in receiver position) and dSdR (difference in source+receiver position) between two vintages for a given trace pair. There is a straightforward correlation between the dS, dR and dSdR maps and the respective acquisition technology uplifts as presented in Figure 2. The 1996 vs. 2005 maps show quite poor source and receiver repeatability as the 2005 acquisition was shot on a pre-plot built on heavily smoothed 1996 source locations. The first significant repeatability improvement is associated with the introduction of the high-density acquisition and the implementation of the source and streamer steering systems in 2008. Further improvements can still be seen up to and including the 2016 multisensor deep-tow acquisition. In 2019, steering strategy was relaxed to enable faster acquisition. Strict shooting on shot position was replaced with shooting on a mean source position, with a consequent reduction in inline repeatability in the order of 1m. The 2019 vintage was also acquired in difficult weather conditions. The deeper tow seemed to be largely unaffected by the adverse weather. Faster acquisition turnaround and good source and streamer repeatability was achieved with the positioning being far more stable than in 2011. 1 m average difference in the source positions and 8 m average difference in receiver positions in this particular marine environment have set a benchmark for the future.

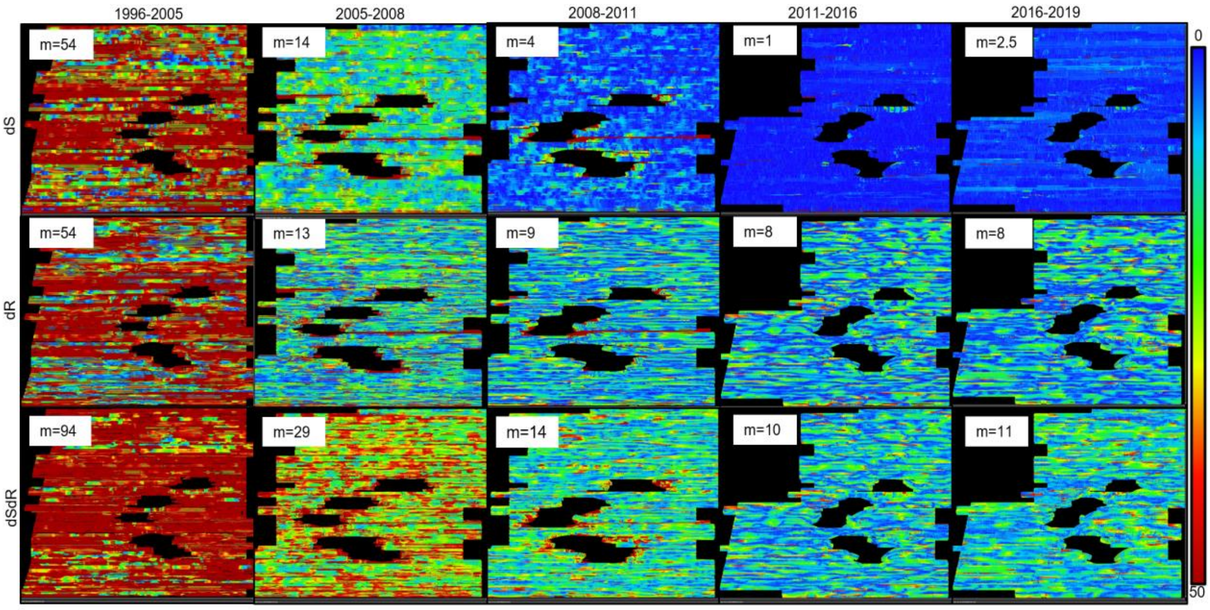

***Figure 2** dS, dR and dSdR maps for 1996-2005, 2005-2008, 2008-2011, 2011-2016 and 2016-2019 vintages. 'm' is the median value in meters.*

What are the added benefits of a repeated multisensor acquisition to the quality of 4D datasets?

NRMS (normalized RMS difference) is typically used as a 4D repeatability and 4D data quality attribute. Anderson et al. (2017) presented a clear correlation between the geometrical repeatability, the NRMS values and the data quality at the Gullfaks field.

We propose to look at both the NRMS and the fNRMS attributes. The fNMRS is the NRMS value calculated per single frequency (Charron et al. 2019). In Figure 3, the maps and the median values illustrate the achieved improvement in the 4D repeatability for the 2016-2019 multisensor comparison. Around 0.1 points reduction of fNRMS value for frequency 30Hz and 0.04 points reduction of full bandwidth NRMS is a significant upgrade. Even within the wedge area and around the rig holes, the uplift is noticeable. Correspondingly, Figure 4, showing a graph of NRMS value along key processing stages, clearly demonstrates the improvement in NRMS level between the modern and the older acquisitions. The difference in the NRMS value between 1996-2011 and 2011-2016 comparison is around 0.2 points at the final product stage. Further NRMS reduction is expected for 2016-2019 multisensor comparison. That level of improvement of the fine details is important to reduce 4D noise and to increase confidence in the 4D results (Anderson et al. 2017). Minimizing the uncertainty of the reservoir models can help to improve the production plan.

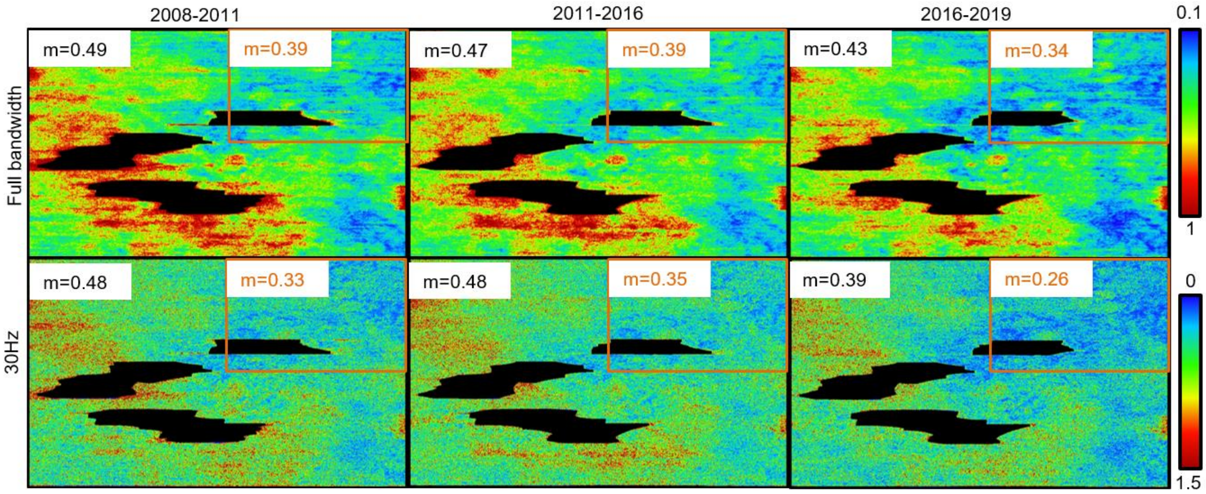

Figure 3 *NRMS maps between 2008-2011, 2011-2016, 2016-2019 and 2011-2019 vintages (upper raw). fNRMS maps for 30Hz frequency component (lower row). Calculation window is -200/+200 ms around the Balder horizon (not including 4D effects). 'm' is the median value calculated for the entire area (black) and outside of the wedge (orange) respectively. The NW-SE structure with lower NRMS/fNRMS is corresponding to the extent of the wedge. The black zones are the rig holes.*

The overall median NRMS values from Figure 3 are expected to further drop after each production stage (Anderson et al. 2017). The uplift is estimated to be around 0.3 points reduction from the current regularization to the final production step as shown in the vintage processing example in Figure 4.

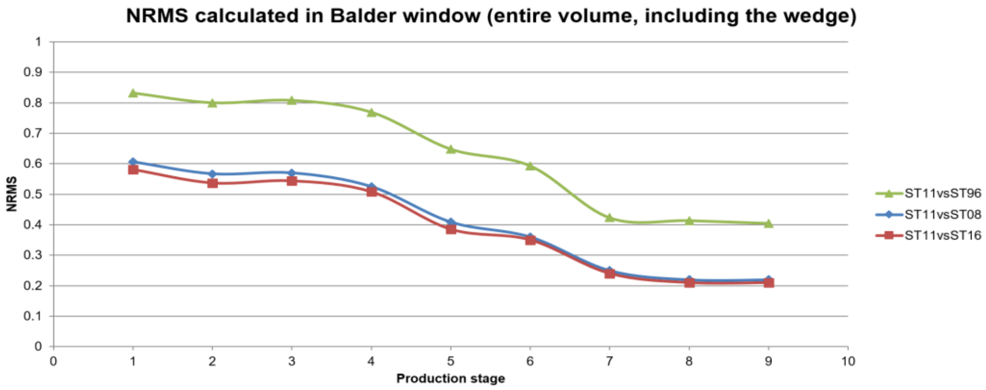

Figure 4 *Graph of data processing stage vs. NRMS between 1996-2011, 2008-2011 and 2011-2016 vintages from the Gullfaks 4D project run in 2016. Stage 4 is the regularization stage and stage 9 is the final product.*

Figure 5 shows the preliminary 4D results. There are different strengths of 4D signal expected in this reservoir. In the upper row inline example, the 4D signal is relatively weak and can be obscured by the level of noise, while in the lower row, the 4D signal appears significantly stronger compared to the background noise, albeit not in the 2011-2016 comparison. Lowering the 4D noise is therefore critical in mapping all the 4D effects. In 2016-2019 comparison, a general reduction in the 4D difference noise level can be seen, supporting the conclusions from the NRMS/fNRMS plots in Figure 4.

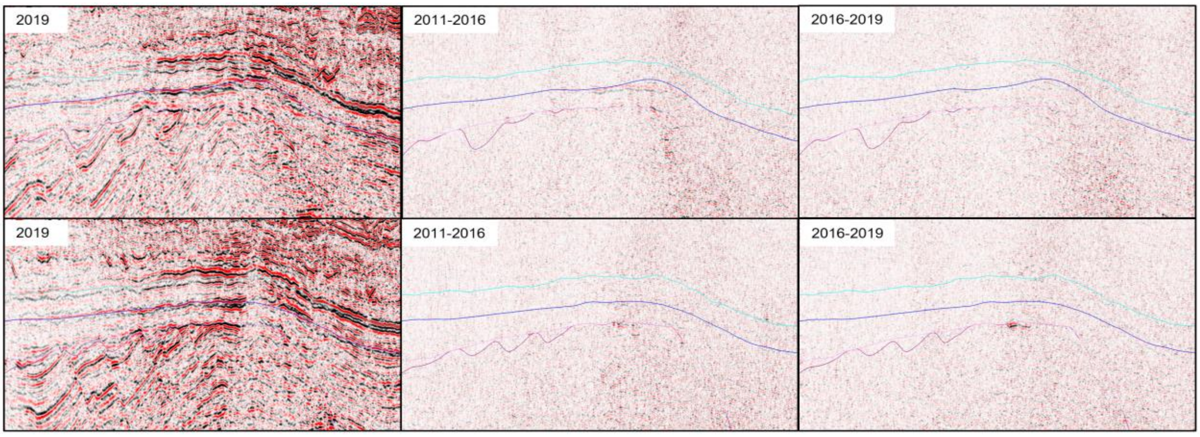

Figure 5 *Depth migrated stacks (in time) for two different inlines and 4D difference sections with real 4D response (intermediate result – after demultiple + sailline 4D corrections + regularization).*

Conclusions

This work shows how the multisensor streamer acquisition enables the optimization of the acquisition turnaround together with the improvement of the data quality for 4D projects. The multisensor acquisition ability to tow deep is resulting in a higher signal to noise ratio and therefore lower NRMS value. Around 0.2 points NRMS value reduction is associated with the acquisition geometry improvements from 2008 onwards. Further improvement is expected at the final stage for the multisensor on multisensor 2016-2019 comparison as these two latest vintages demonstrate superior NRMS and fNRMS values at the current regularization stage.

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