OPTIMISING 4D SEISMIC WITH EVOLVING TECHNOLOGY OVER 20 YEARS OF RESERVOIR MONITORING OF THE GULLFAKS FIELD, NORTH SEA

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Introduction

The Gullfaks field lies in the northern part of the Norwegian North Sea. Production from Jurassic sandstone reservoir units consisting of the Brent, Cook and Statfjord formations started in 1986 and since 2012 the shallower reservoir units of the Shetland and Lista formations have been producing. The Gullfaks asset has been running a successful seismic monitoring program since 1995 when a 4D survey was performed on a research basis, the conclusions of which resulted in the acquisition of the first monitor survey in 1996. Since then 4D surveys have been acquired at regular intervals to monitor production in the reservoir.

During the 21 years of seismic monitoring on the Gullfaks field there have been a number of changes in acquisition systems and processing algorithms. This paper summarizes the various acquisition changes and demonstrates the benefits of the latest processing technologies used in the current processing.

Improvements in Seismic Acquisition

Including the original 3D seismic survey shot in 1985, there have been nine towed streamer surveys acquired on the Gullfaks field. Step changes in acquisition systems and survey design standards have resulted in geometries which fall into four separate phases of 4D monitoring. The first phase comprises the first 3D survey in 1985, which serves as the baseline pre-production survey. The second phase includes the initial 4D monitor surveys of 1995 to 1996, where geometries were significantly different to the 1985 acquisition.. The three monitor surveys acquired between 1999 and 2005 are in phase three, and were planned to maximize repeatability, using overlapping streamers and planned preplots to reduce the impact of feathering. The latest phase (2008-2016) took advantage of a general increase in towing capacity available in the seismic industry to perform High Density 3D acquisition with a towed spread of 17 streamers at 50 m spacing. In addition, the 2016 acquisition has steerable sources and streamers to further improve the 4D repeatability.

A common measure of repeatability in 4D monitoring surveys is dS+dR which is the sum of the difference in source and receiver positions between two vintages for a given trace pair. Figure 1 shows dS+dR maps between 2011 and 1985 (left), 2011 and 1996 (middle) and 2011 and 2008 (right) for the 500 m offset class. These maps show an improvement in dS+dR as the acquisition geometry gets progressively more repeated.
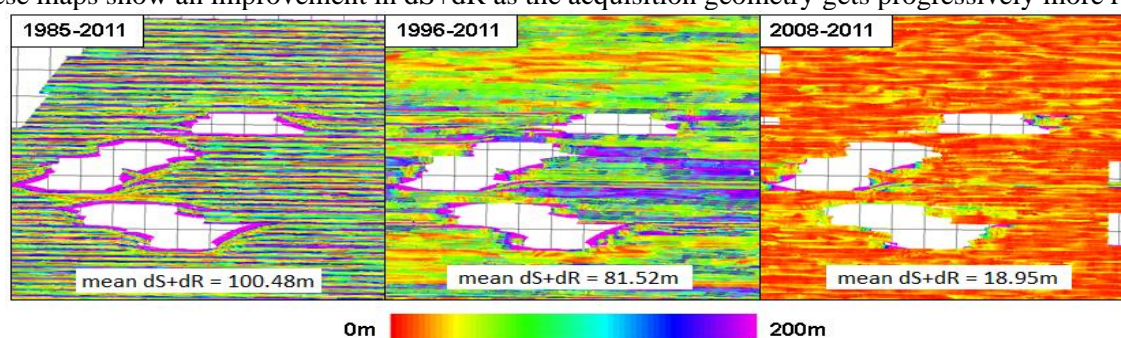

Figure 1 Maps showing the difference in source and receiver positions between the 2011 vintage and 1985 (left), 1996 (middle) and 2008 (right). The maps clearly show the improvement in acquisition repeatability over the years.

While the acquisition geometry and preplot for the latest (2016) monitor survey is the same as in 2008, there was one change which has the potential to improve the imaging further, that being an upgrade from conventional hydrophone-only streamers to multisensor streamer technology. The use of pressure sensors together with particle velocity sensors in wavefield separation allows for deeper towing depths than hydrophone only acquisition, thereby reducing noise levels and increasing acquisition efficiency without

compromising the bandwidth. In addition, the wavefield separation as presented by Söllner et al. (2008) offers the flexibility to output the upgoing wavefield (P-UP) for broadband processing and a reconstructed hydrophone dataset (H-REC) for 4D backward compatibility. Therefore the 2016 survey sets a new milestone in the monitoring program and opens up for the future broadband 4D seismic.

Improvements in Seismic Processing

The move to broadband acquisition has seen a need for an improvement in the handling of the low frequencies, especially during the designature processing step when trying to minimise the bubble effects. Any inaccuracies in designature manifests itself on 4D differences as low frequency ringing. The 2016 processing used ghost-free hybrid signatures instead of purely modeled far-field signatures. Generating the signatures involves the measured near field signatures to improve the low frequencies, combined with modeled near-fields at high frequencies. These hybrid signatures are then matched to a zero phased desired output based on the instrument response of the acquisition system.

In addition to adding 4D noise, residual bubble can have a cumulative effect in the processing sequence. In shallow-water marine towed streamer processing, Tau-P deconvolution is commonly used to remove multiples. In this method any residual bubble present can affect the quality of the demultiple when the water bottom is of a similar depth to the bubble period. This can result in different behaviour in demultiple even though the same parameters have been used for each 4D survey, resulting in residual multiples left on the 4D difference. These in turn can affect any time shift calculations and so on. The current processing did not rely on Tau-P deconvolution and instead used fully 3D demultiple processes - seabed convolutional 3DSRME and 3D wavefield extrapolation SRME which were simultaneously adaptive subtracted, followed by muted 3DSRME to remove longer period multiples.

Figure 2 shows 4D difference sections of 2011 to 2008 data processed in 2011 (left) and 2016 (right). The main differences are due to improved designature and debubble. The green arrow points to an event indicating production effects. Here the latest processing shows improved 4D signal. The black arrows show areas with residual bubble present, along with "unexplainable" 4D effects which are now removed due to the improved demultiple. The 4D differences show that the improved processing sequence reduces 4D noise and improves confidence in the 4D results, even for surveys with well repeated acquisition (2008 and 2011).

Conclusions

The Gullfaks seismic monitoring program has made successful use of available acquisition and processing to make improvements to the repeatability and the 4D image. Employing up-to-date acquisition and processing technologies, including broadband solutions, sets a path towards future high resolution 4D projects.

Figure 2 *4D difference sections between the 2011 and 2008 vintages showing the reduction in 4D noise for data processed in 2016 (right) compared to 2011 (left).*

References

Söllner, W., Day, A. and Tabti, H., 2008. Space-frequency domain processing of irregular dual-sensor towed streamer data. 78th Annual International Meeting, SEG, Expanded Abstracts, 1078–1082.