Th PRM 05

The Impact of Environmental and Acquisition Variations for PRM 4D Processing - Snorre Case Study

K. McCluskey* (CGG), S. Buizard (CGG), M. McCluskey (CGG), R. Zietal (CGG) & N. Moyle (Statoil ASA)

SUMMARY

Since going live in 2014, five permanent reservoir monitoring (PRM) surveys have been acquired over the Snorre field at regular intervals. The PRM installation itself is currently the largest in the world consisting of 57 cables containing ~10,000 multi-component (4C) buried receivers and covering an area of around 200km2.

The processing effort of the early PRM surveys was dedicated to establishing and optimising a robust, repeatable sequence with the objective of providing fast turnaround, high quality 4D seismic data. For key processing steps such as geophone reorientation and PZ summation the high degree of receiver repeatability allows us to apply operators derived on the base to subsequent monitor datasets. However, variations in environmental and acquisition conditions between surveys are observed and can impact the 4D response (generating so-called 4D noise). The purpose of this abstract is to highlight some of these issues and how they are dealt with in the context of fast delivery Snorre PRM data. The topics summarised are those which have been especially important to the Snorre dataset: source layback, water velocity and shot coverage harmonization.

Introduction

Since going live in 2014, five permanent reservoir monitoring (PRM) surveys have been acquired over the Snorre field at regular intervals. The PRM installation itself is currently the largest in the world consisting of 57 cables containing ~10,000 multi-component (4C) buried receivers and covering an area of around 200km^2. The resulting time-lapse data has significantly aided the reservoir monitoring of the field and has specifically captured the water-alternating-gas enhanced oil recovery program with sufficient sampling to successfully support well operations (Thompson et al., 2016).

The processing effort of the early PRM surveys was dedicated to establishing and optimising a robust, repeatable sequence with the objective of providing fast turnaround, high quality 4D seismic data. For key processing steps such as geophone reorientation and PZ summation the high degree of receiver repeatability allows us to apply operators derived on the base to subsequent monitor datasets. However, variations in environmental and acquisition conditions between surveys are observed and can impact the 4D response (generating so-called 4D noise). The purpose of this abstract is to highlight some of these issues and how they are dealt with in the context of fast delivery Snorre PRM data. The topics summarised are those which have been especially important to the Snorre dataset: source layback, water velocity and shot coverage harmonization.

Source Layback

Source layback describes the difference in location between the nominal position of the sources calculated from GPS measurements, and the geophysical position of the effective point sources as they are towed behind the vessel. Environmental and acquisition factors, such as currents, tides, source configuration (including length and tension of the tethering cables) and vessel crabbing contribute to layback, which vary between successive monitor surveys.

A single layback correction is calculated per survey using picked direct arrival times which are extracted from offset-limited hydrophone data (after compensation for source directivity). The picked travel times are inverted for each receiver to obtain the deviation in source x and y positioning. A single correction is applied according to sail line direction after averaging the positioning deviations across all receivers in the survey. It can be seen on Figure 1 how the horizontal striping in the water velocity estimate (b) and (c) correlates with shooting direction (a). Although the layback adjustment is small (typically < 1.5 m) it is necessary to apply this correction to accurately derive subsequent data-driven water velocity corrections.

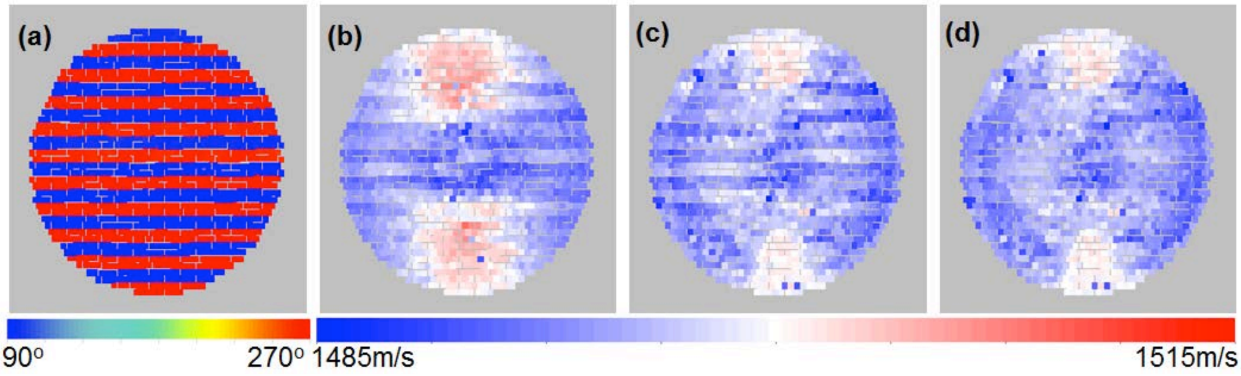

Figure 1 *Single receiver display showing (a) sail line direction (b) initial estimated water velocity (c) water velocity estimation after offline source directivity correction and (d) water velocity estimation after offline source directivity and layback correction. The points in each circle represent the offset limited shot locations at the receiver. Note the reduction of horizontal striping that correlates with shooting direction after the layback correction has been applied seen on (c) and (d). Some residual source directivity is observed in the crossline direction.*

Water Velocity Correction

Water velocity variations during or between surveys are a well-documented cause of noise in time lapse data (Amini et al., 2016). The water depth at the Snorre field varies between 280-350m, which is deep enough that changes in water velocity can accumulate significant 4D effects in the PRM data.

During PRM surveys water velocity measurements are obtained from Temperature Salinity [TS] Dip profiles and Pressure-Inverted Echo Sounders (PIES) recordings. The TS Dip profiles are recorded on an ad-hoc basis and are therefore too sparse to derive meaningful daily water velocity changes. The PIES devices work by transmitting an acoustic signal upwards through the water column and capturing the echo returned from the sea surface at frequent intervals. This raw data is then processed to determine the two-way travel time of the acoustic signal (Wang et al., 2015). The PIES devices were deployed at one (or two) locations at the start of the acquisition and recovered at the end. However, when the corresponding water velocity variations were corrected in processing they were not successful at addressing all water column static issues.

In preference to the deterministic methods described above, a time and spatially variant data-driven scheme which minimizes sensitivity to water depth and uses data redundancy to increase robustness and precision was employed to measure water velocity (Zietal and Haacke, 2016). During the first phase of this process an inversion is performed to estimate water velocity from first break picks made on offset-limited data. Analysis is performed on a receiver by receiver basis with compensation for source directivity. Outliers are discarded using an alpha trim and the results obtained over different receivers are averaged and smoothed along the sail-line direction. At this stage only shots from the offset limited data have a water velocity associated to them. The last step is to interpolate / extrapolate this data to ensure every shot-point of the survey has an associated water velocity and the result is a time and spatially varying solution. To check if the observed variations were valid, a daily average was also extracted; the resulting velocity (the red line in Figure 2) is similar in trend to that recorded with the PIES data (shown as blue lines in Figure 2), however, a bulk shift is observed which may be attributed to how the raw PIES data is recorded or processed.

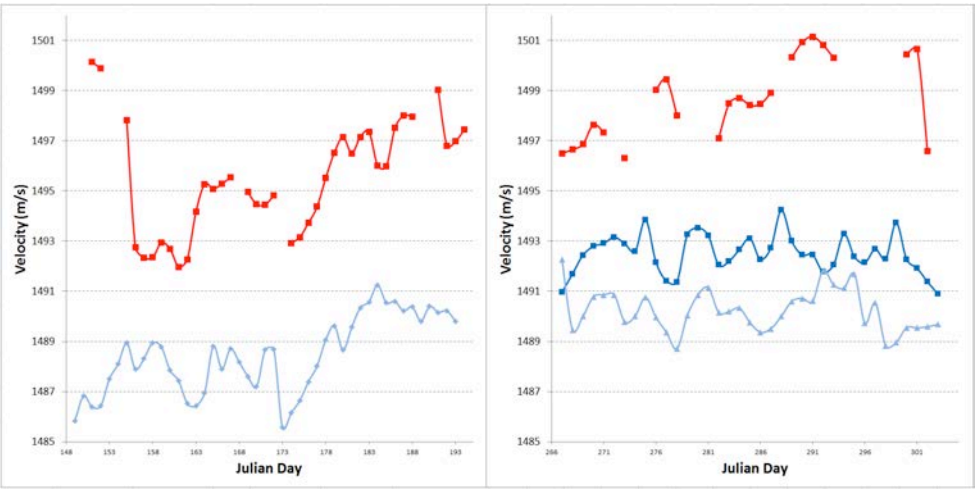

Figure 2 *Comparison of PIES (light and dark blue lines) and data-driven daily average (red line) water velocity trends for spring 2015, PRM3 (left) and autumn 2015, PRM4 (right). Two PIES units were deployed on PRM4.*

The results of the data-driven solution were applied dynamically using differential normal-moveout correction (Lacombe et al., 2006) for the daily water velocity average (Figure 3c) and time / spatially varying water velocity (Figure 3d). Examination of 4D difference stacks and 4D attributes (cross-correlation time shift, NRMS, RRMS etc. not shown in this abstract) indicated that the greatest improvement was obtained using the time and spatially varying adjustment.

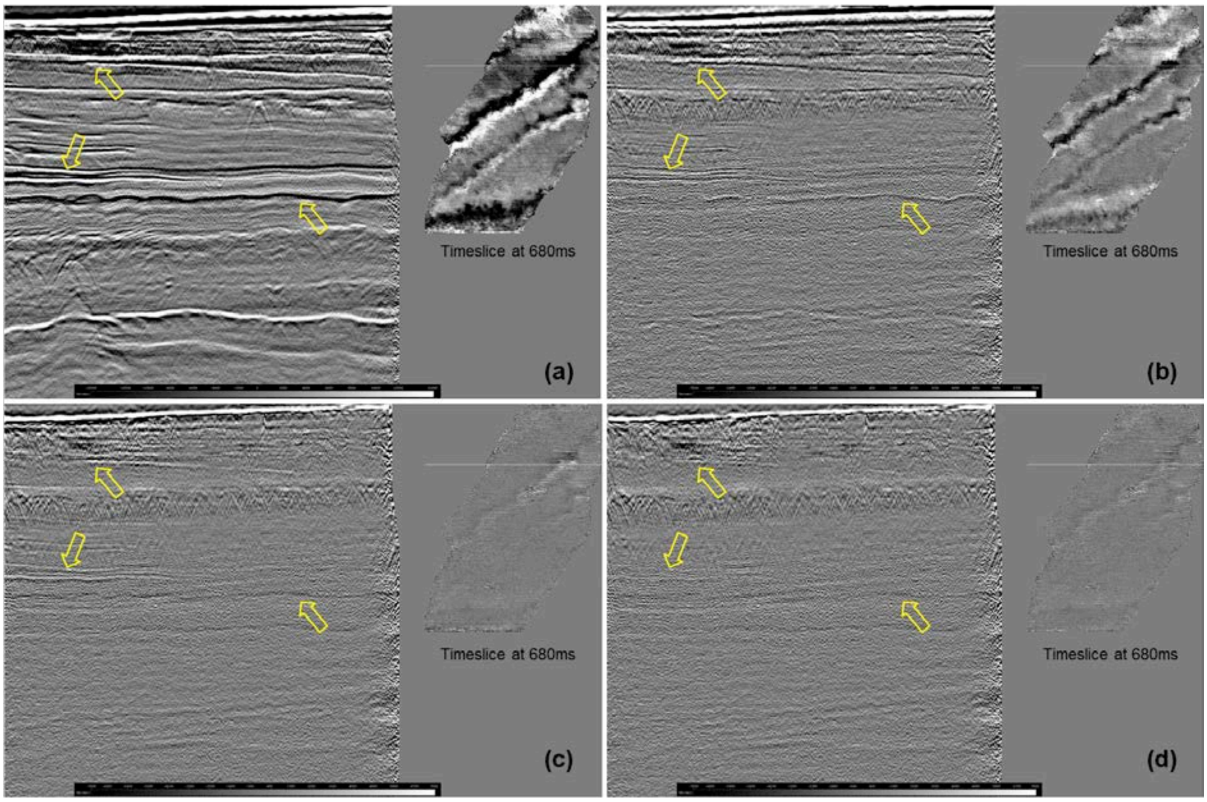

Figure 3 *Unmigrated stack (a) 3D base (b) raw 4D difference (c) 4D difference with data-driven daily average and (d) 4D difference with data-driven spatially varying water velocity correction. Amplitudes for (b) to (d) are increased by 6dB.*

Shot Coverage Variation

Due to differing reasons each of the PRM surveys to date has been completed with unique source coverage. This is shown in Figure 4.

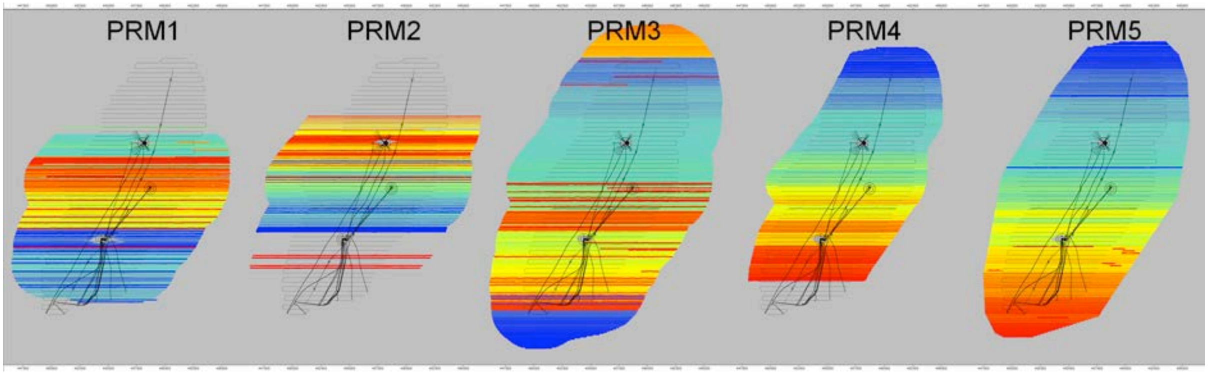

Figure 4 *Snorre PRM shot coverage variation overlaid on infrastructure (shown in black). Colour indicates acquisition sequence number.*

The source coverage of PRM1 and PRM2 (2014 spring and autumn surveys) were limited owing to an incomplete receiver array and weather conditions. The PRM3 (spring 2015) was acquired and completed according to the original pre-plot. In order to increase operational efficiency PRM4 and PRM5 (autumn 2015 and spring 2016) were acquired following a reduced source aperture pre-plot.

To account for these variations two scenarios were tested during the PRM3/PRM4 processing in order to harmonize the source coverage:

- A ‘cutting’ approach where the largest dataset (i.e. PRM3, the base survey) is reduced to the extent of the smallest dataset (i.e. PRM4, the monitor survey). This scenario requires that the base dataset is reprocessed with every monitor survey and will increase project turnaround.
- A ‘padding’ approach where data from the largest dataset (i.e. PRM3, the base survey) is used to pad the smaller dataset (i.e. PRM4, the monitor survey) to the extent of the largest one.

A significant advantage of the ‘padding’ route over the ‘cutting’ route is that it allows faster, single monitor processing: the base dataset (PRM3) does not have to be re-processed each time a new monitor becomes available. With the ‘cutting’ approach, one would end up with several versions of the base dataset, each one reduced to the extent of a given monitor dataset. Conversely a drawback of the ‘padding’ route is that a genuine 4D signal located in the vicinity of the outermost boundaries of the monitor dataset could be ‘diluted’ or ‘smeared’ as data from the base will be borrowed at the edges.

Following analysis of both flows on migrated volumes the ‘padding’ approach was selected as it provides faster processing turnaround and the 4D attributes (NRMS, RRMS etc.) were not significantly impacted (Thompson et al., 2016).

Conclusions

The described layback and data-driven water velocity corrections significantly reduce the 4D noise that can occur between successive surveys and can be derived in the context of a fast turnaround single monitor processing PRM set-up. Padding surveys acquired with a reduced pre-plot has proven to be the most pragmatic solution enabling simplified data management and fast processing turnaround; high quality 4D signal is obtained everywhere that is sufficiently far away from the edges of the padded monitor survey.

Acknowledgements

The authors wish to thank Statoil ASA and the Snorre licence for permission to publish this paper. We acknowledge the work of our colleagues involved with the Snorre PRM project, especially Ross Haacke, Henning Hoeber and Julian Holden.

References

Amini, A., Peng, H., Zhang, Z., Huang, R. and Yang, J., Joint Inversion of Water Velocity and Node Position for Ocean Bottom Node Data, [2016], *SEG International Exposition and 86th Annual Meeting*, 5490-5494.

Lacombe, C., Schultzen, J., Butt, S. and Lecerf, D. [2006], Correction for Water Velocity Variations and Tidal Statics, *68th EAGE Conference and Exhibition*, Extended Abstracts, P098.

Thompson, M., Anderson, M., Skogland, S.M., Courtial, C., and Biran, V.B., [2016] Time-lapse Observations from PRM at Snorre, *78th EAGE Conference and Exhibition*, Extended Abstracts, Tu LHR2 01.

Thompson, M., Pedersen, A.S, Anderson, M. and Skogland, S.M., [2016], A Novel Approach for Cost Effective PRM Seismic Operations at Snorre, *78th EAGE Conference and Exhibition*, Extended Abstracts, Tu LHR2 15.

Wang, K., Dunn, S., Ward, J. and Hatchell, P., [2015], Direct Measurement of Water Velocity and Tidal Variations for Improved 4D Repeatability in Marine Seismic Acquisition, *First Break*, **33**, 73-79.

Zietal, R. and Haacke, R. R., [2016], Measurement and Dynamic Wavefield Correction for Time-dependent Water-velocity Changes, *78th EAGE Conference and Exhibition*, Extended Abstracts, Tu LHR2 16.