

QIQC: Using Seismic Inversion for Processing QC

Introduction

The success of seismic inversion projects relies heavily on the fidelity of the input data. Unfortunately, many processing decisions that are taken to enhance some aspect of the seismic image for interpretation purposes can have a detrimental effect on the use for workflows that rely on meaningful amplitude data. Furthermore, a lot of processing supervision and early testing is rather subjective and qualitative in nature. To address this, significant effort has recently been made to integrate inversion QCs at the early stages of processing.

In this paper we discuss the workflows we have established for two re-processing projects, where the fidelity of the data for seismic inversion was a crucial criterion for success. The added benefit of early inversions for processing QC is a tighter collaboration between the processing and inversion experts and the asset geophysicists in the earlier stages of the project, as well as improved results and significantly reduced turn-around time for the final inversion deliverables.

Both examples are from the Danish North Sea, the first is a 3D project, the other a re-processing of a multi-vintage 4D. In both examples running test inversions during the processing sequence revealed challenges that might not have been spotted if only the reflection data had been considered. Some areas where early inversion products can help are the impact of de-ghosting, spectral shaping, denoising, parametrisation, as well as parameter choices for Q-compensation, and the highlighting of remaining non-primary energy.

While these ideas are not new (see for example McHugo et al. [2013], Micksch et al. [2018], Hansen and Wagner [2020]), they are still rarely applied and we argue that for data used for inversion, the additional effort is warranted, ensuring data fitness, and thus ultimately better inversion results.

Method

It is crucial to ensure a fast turnaround of the test inversions, since the chance of influencing processing decisions erodes when the processing project needs to continue due to time constraints. Two important tools to address this point are repeatable automated workflows and setting up of the inversion project ahead of time as much as possible, identifying main areas of interest, key wells and clearly stating the questions that the resulting data should address. Our in-house 3D and 4D inversion tool (Cherrett et al. 2011, Micksch et al. 2014) is completely scriptable, making the inversion process highly repeatable.

The workflow that was used for both projects was to extract wavelets for each QC deliverable, as changes in the wavelet can be indicative of potential areas of concern. Afterwards, the data are inverted, keeping inversion parameters as constant as possible, to ensure comparability between deliverables. In addition, map extractions, or comparison of seismic AVO response compared to the synthetic response at wells are analysed.

In particular in 4D we found it useful to run test inversions that force a much stronger fit to the data than what would normally be considered good practice. This practice can highlight more subtle data problems effectively that otherwise might be rejected by the inversion algorithm.

One challenge of using seismic inversion for processing QC is the fact that virtually all inversion algorithms expect migrated data. However, many important decisions are taken before migration. We overcame this issue by running PSDM migrations in a focused test area for the 3D project and using post-stack migration in the 4D project.

3D Example: Greater Tyra Area

In the Greater Tyra Area (GTA), in the Danish Sector of the North Sea, a tie-back opportunity is currently being matured. It targets the Gas accumulations in the Tuxen formation, a lower Cretaceous shaly carbonate separated from the Chalk package by the shaly Rødby formation, which varies in

thickness between 15m to 25m. Another important target lies within the Hod formation, which is part of the main Chalk section and contains oil as the main reservoir fluid. The combination of a velocity reversal below the base of chalk and a subtle reflection due to small impedance contrasts between the Rødby and the Tuxen formation, makes mapping the top Tuxen reflection difficult, introducing significant uncertainties in the static model.

A decision was taken to re-process the Qmarine streamer data acquired in 2005 with a modern, improved processing workflow, including latest de-ghosting to widen the bandwidth and a new velocity model to optimise the imaging below the Chalk package. The objective of the reprocessing was to identify the optimum development concept for the Tuxen and Hod hydrocarbon accumulations. The previous processing provided a good product, therefore the expectations of the uplift in seismic image quality were modest, making the QC using inversion even more salient.

The structural interpretation relies strongly on products from seismic inversions. Normal reflectivity seismic is not sufficient to map the Top and Base of the primary Tuxen reservoir. The derivative of the relative acoustic impedance was found to allow the interpreter to interpret the top and base of the Tuxen reservoir confidently. Therefore, it was decided to implement a QC workflow during the re-processing that ascertains the optimal seismic products for the inversion. In a pre-defined key area, containing six wells of interest, early output sub-volumes at key steps of the processing sequence were produced. Depending on the question to be answered, the early outputs were either full stack or angle stack volumes. For the Quantitative Interpretation QC (QIQC), wavelets were extracted from the data for every volume, and test inversion performed for most of the deliverables. The data were PreSDM migrated, at the start of the project with a legacy velocity model, and once it was available, with the new updated velocity model. Tests were performed at ten decision points during the processing. A completely scripted workflow, from wavelet extraction and inversion and QC plot generation was the key to highly repeatable and comparable results and fast turnaround times. The inversion runs would usually require computer runtime of less than an hour and due to automated QCs, analyses of the results to aid processing decisions could be delivered within one to two working days. Figure 1 shows typical results from the inversion.

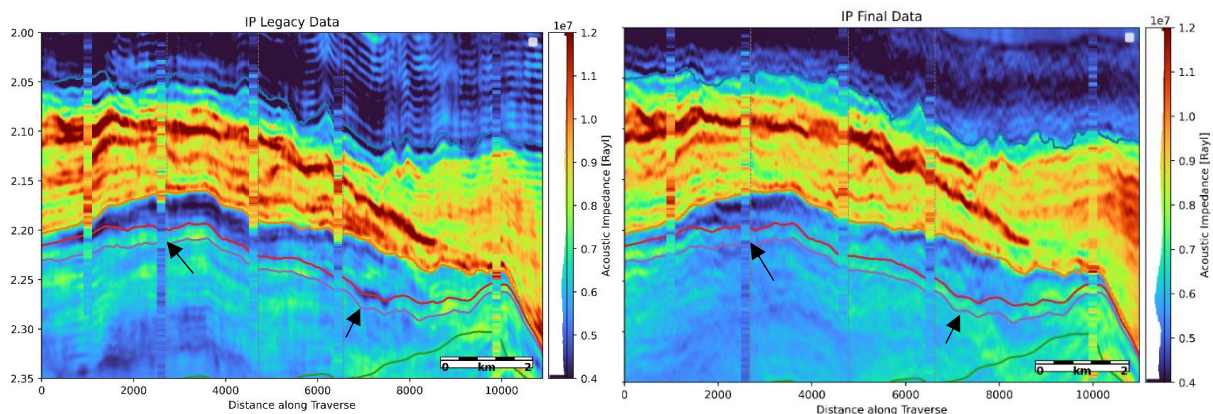


Figure 1 Comparison of the inversion results with the legacy data (left) and the final reprocessed data (right). The high impedance (hot) layer indicates the chalk package; the target is situated below. The events in the new results are, more in line with the well results (left arrow), more continuous (right arrow) and the spectrum is richer.

Comprehensive QC reports were produced during the inversion run, and the early results made available to the asset geophysicist for additional QCs. The early outputs could be used by the asset geophysicist for preliminary interpretations, and to gauge the differences between the new results and the legacy data and thus provide feedback to the processing team. Emerging changes to the reservoir model could be anticipated and prepared earlier. Key questions where the input from inversion was used were:

- Preferred post-migration de-noising parametrization
- Q-compensation parametrization
- Benefits of τ -p deconvolution
- Low frequency zero-phasing
- Effect of the new velocity model on the migrated data
- Benefits of post-migration Radon
- Effects of spectral shaping on the amplitude fidelity

4D Example: Dan/Halldan

The Dan and Halldan fields are Chalk fields in the Danish North Sea. The Dan Field is in production since 1972, the Halldan Field started production in 1999. Both fields produce from the Tor formation, and to a lesser extent from the overlying Ekofisk formation. After a recent acquisition of a new 4D monitor survey over both fields in 2023, it was decided to reprocess the entire suite of surveys jointly with a modern processing flow. Optimising the information obtainable from the surveys should help to understand reservoir behaviour, mature infill opportunities, and identify areas for well interventions. Six vintages from 1988, 1993, 2005, 2012, 2016, and 2023 were processed using the 2005 vintage as the base survey. The 1988 survey only covers the Dan Field, while the 1993 survey only covers the Halldan area.

The prime challenges for the processing are the shallow water depth of the survey area of about 40m, which prevents mapping the seafloor with primary reflections, and the infrastructure in the survey area which necessitates undershoots and oblique line acquisition. Due to the lack of a water bottom reflector, the suppression of acquisition striping was one of the main concerns during the processing, as well as the handling of the undershoot areas. The first test inversions were performed before imaging in the processing sequence, using post-stack migrated volumes. The overburden geology in the Dan/Halldan area is not very complex, therefore, post-stack migration was deemed a good approach to obtain QC data early in the processing sequence. The early QCs served as a baseline for the de-striping efforts and were also able to demonstrate that the processing flow was suitable for shallow marine seismic. Earlier processing efforts included a receiver-side de-ghosting, which introduced strong 4D artefacts, particularly a low frequency banding due to phase instabilities. For this processing sequence it was therefore decided not to include a de-ghosting. The early QCs were performed to confirm that the new products do not suffer from those problems. Later QCs concentrated on the handling of the destriping and the undershoot areas. The size of the area of interest led to computation times of about 12 hours per QC run, which meant that a highly automated workflow was required to keep the turnaround times short. Test inversions were performed at six critical points of the project:

1. After initial denoise and demultiple (post stack migrated data)
2. After pre-migration destriping
3. QC Undershoot matching
4. QC of the raw PreSDM migrated data
5. QC of the post-image flow
6. Final inversions

Figure 2 shows extractions after the first and the final inversion of the top reservoir unit. The acquisition striping, clearly visible in the North-West corner in the extraction of the early inversion is essentially gone in the final deliverables, and the signal in the undershoot area in the centre of the extraction is significantly more coherent in the final results. In addition to an inversion run with conventional parametrisation, another run was performed that overfitted the data. The resulting deliverables highlight artefacts more strongly that could otherwise potentially be overlooked.

Conclusions

The early inclusion of quantitative interpretation methods for processing QC resulted in processing products better suited for inversion and led to a significantly shortened timeline for the final inversion

process. The inversion products lend themselves to early interpretation and resulted in a strong involvement of the asset geophysicists in the projects during processing.

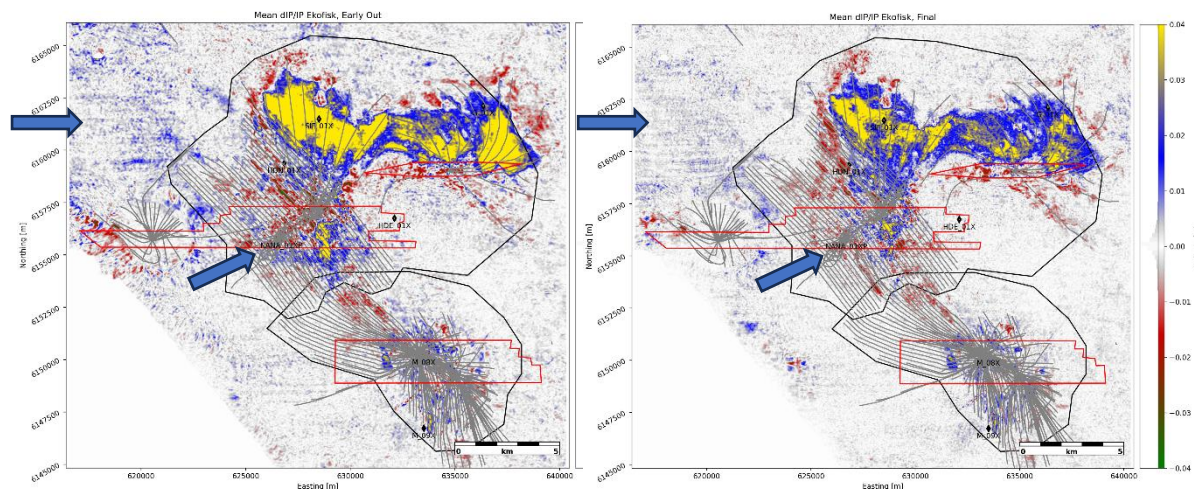


Figure 2 dIP/IP extraction of the top reservoir layer after the first inversion (left) and the final inversion (right). In the North-West area, a clear improvement of the de-stripping can be seen (EW artefacts). In the centre area, the improved handling of the undershoot areas (red polygons) provides a more consistent signal.

In addition to the choice of optimal processing parameters, the QC inversions also revealed other insights, not originally perceived as problematic. In the 3D project, the well-tie and inversion process for example highlighted subtle timing differences induced by different parameters for Q compensation. Furthermore, wavelet extraction using a scripted and therefore exactly repeated method proved to be an excellent QC to assess phase stability.

The detailed QCs made it easier to communicate the particular challenges of the reprocessing projects, in the GTA example this is a thin reservoir layer below the thick and fast chalk package, and in the 4D case the handling of acquisition striping and undershoot areas. The close collaboration between the asset, the QI and the processing geophysicists was a key component for the success of the projects.

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