Introduction

Managing uncertainty in 4D quantitative interpretation is important for calibrating the production data and 4D seismic, pressure-saturation inversion, sim2seis analysis and closing the loop by Seismic History Matching (SHM). Repeatability and predictability metrics for quantifying 4D seismic noise such as NRMS and Predictability (Kragh and Christie 2002) have been the most widely used tools for analyzing 4D noise. Although routinely used, their output is sometimes not intuitive, they often lack sensitivity regarding the variations and they offer a large range of possible ambiguous interpretations.

The innovated attributes and 4D QCs (Saint Andre et al. 2013) to assess 4D data quality such as RMS ratio, Signal to Distortion Ratio (SDR), SDR versus NRMS cross plot, Noise Characterization Cross Plot, Relative Phase and Difference Time Shift Cube help to mitigate unambiguous interpretation and allow significant reduction for processing turnaround of full integrity 4D QCs. However, all these 4D metrics are generated post-stack (although the noise attenuation is performed pre-stack) and therefore we believe that post-stack analysis is not enough to characterize the seismic uncertainty properly as we cannot rely on one realization for 4D seismic interpretation.

Here, we derive new measure of uncertainty for 3D and 4D data, and apply these to the Volve processing workflow. We examine the implications for 4D quantitative interpretation. Our approach is to generate multiple realisations of the post-stack volumes with possible processing workflows for 4D seismic interpretation and to define the seismic error bars associated with acceptable variations of the processing parameters on 3D, 4D seismic, 3D and 4D AVO (intercept, gradient). We show how to use this error bar to reduce the uncertainties for reservoir property estimation.

Method

During processing, there are many possible routes that can be taken and even more variations of parameters within a set of sequences. The decisions for which sequence and which parameters we choose may be subjective and there can be many possible options (and final image). We then often use this image for quantitative interpretation with no concept of the uncertainty in that image (Williams, personal communication). For example, when we produce a stack from CMP gathers, then we compute the mean of every sample across the offsets (i.e. the stack is the average of all the traces within the CMP gathers). It is straightforward to compute the error in the mean at the same time so that we can output both a stack section and a section of the computed error for every sample and trace.

\[
stack(t) = \frac{1}{\text{fold}} \sum_{i=1}^{\text{fold}} \text{trace}_i(t) = \text{mean}(t),
\]

\[
\text{error in mean}(t) = \frac{1}{\text{fold}} \sqrt{\sum_{i=1}^{\text{fold}} [\text{trace}_i(t)]^2 - \text{stack}(t)^2}.
\]

The seismic error section provides a measure of the uncertainty or reliability of the stack for every sample and it can be useful but also be misleading since it computes absolute rather than relative errors. To produce the relative error, we simply divide the error trace by the envelope of the stack trace. To avoid the computation of Hilbert transforms to determine the envelope, we compute the RMS values of the amplitudes of the stack trace within a short time window. This will ensure that the percentage errors are always positive and there are no divisions by zero

\[
\text{relative error} = \frac{\text{Error in stack}(t)}{\frac{1}{N} \sum_{i=1}^{N} \text{stack}(t)^2}.
\]

Before starting 4D interpretation on the OBC legacy dataset (OBC-2002-Base, OBC-2010-Monitor) full, near, mid and far stacks are created over the Volve project. We have assessed whether or not these datasets are reliable for 4D QI, by generating 4D classical QCs as shown in Figure 1(a). The QCs show the datasets are very noisy, especially the near and far stacks and they offer a large range of
possible ambiguous interpretations. We have tried conditioning the 4D seismic volumes by re-processing the post-migration PSDM gathers in a conservative way – this forms one realization for 4D interpretation (Figure 2). Improvements were seen after reprocessing in the 4D signal and also 4D QCs such as NRMS, Predictability, and RMS ratio as shown in Figure 1(b and c). The output stacks are not satisfactory for 4D interpretation, meaning that we cannot rely on repeatability and predictability measures to judge whether or not the 4D data is reliable for 4D interpretation and there are many possibilities for the 4D realizations.

(a)

(b)

(c)

*Figure 1* Comparison between NRMS, PRED and RMS amplitude map (between top and base reservoir of the 4D difference) and 4D difference. (a) legacy processing; (b) conservative reprocessing workflow; and (c) legacy 4D difference (left) and reprocessing conservative workflow, (right) realisation 3 in Figure 2.

The noise on the gathers has been analyzed with the most common examples being random noise on the near offsets, multiples on the far offsets and linear noise that behaves differently along the reservoir. Although the gathers are after PSDM migration, and Residual Move-Out (RMO) has been applied, the flatness of the gathers is unsatisfactory. The 4D realisations have been generated by reprocessing the post migration PSDM gathers in time with different possible processing workflows, considering the wide variations of processing parameters and guided by the noise types and behavior of gathers, followed by post stack processing as shown in Figure 2. The processing parameters for each realisation have been applied exactly the same to both base and monitor. We choose both a conservative and more aggressive variation in the processing parameters to illustrate an experienced, and less experienced processor.
Figure 2 The most possible 3D post migration co-processing workflow (applied to both base and monitor) to generate 4D realisations, based on the noise types analysed on 3D PSDM in gathers for base and monitor.

The 3D seismic for the base and monitor of all realizations are slightly different, not only in amplitudes but also in the timing, due to the change in the processing parameters for each realisation. As the processing sequence applied is exactly the same for the base and the monitor, the 4D difference for each realisation is still valid. 4D attributes are generated for all of the 4D realisations and although they indicate similar qualitative interpretations, they are quantitatively quite different. In order to assess the results to understand which realisation gives the best answer for quantitative interpretation, a separate 4D interpretation for each realisation may be required and that will be a time consuming process. Alternatively, we have generated error bars for the 3D (baseline and monitor), and 4D seismic as well as the 4D AVO error bar (intercept and gradient). The idea for generating the error bar is to get the mean (average) of all realisations and then compute the error in the mean at each sample, which will be the error associated with the mean in the processing parameters variations for each realisation at the each sample (error section) as shown in Figure 3. Also the relative error section has been computed that will be the percentage of these errors.

The 3D seismic realisations show differences in amplitudes as shown in Figure 4. The change in amplitudes will yield a change in impedance and, if the relation between the impedance and porosity is known, we can therefore invert the 3D seismic to get the porosity. The error in the porosity can then indicate the error in saturation and it can be used as a calibration point for sim2seis. Post stack inversion has been performed in order to get impedance of the 3D seismic realisations. The low-frequency model has been built using the available well data after tying the wells to the seismic. A statistical wavelet for each realisation has then been generated and inversion performed to get the impedance. The relation between the impedance and porosity has been defined and we can therefore get the mean of the porosity and the associated errors.

Conclusions

4D repeatability and predictability matrices for quantifying 4D seismic noise are sometimes not intuitive. They often lack sensitivity regarding the variations and they offer a large range of possible ambiguous interpretations. Although post migration conservative reprocessing shows a good uplift in improvement using NRMS, PRD and 4D signal over the legacy, the output stacks are not satisfactory for 4D QI. Therefore we cannot rely on one realisation for 4D quantitative interpretation. A multiprocessing approach is possible, to generate 4D realisations which are qualitatively similar but quantitatively different. The error bars can be generated by taking the mean for all the realisations and calculating the error in the mean at each sample along the seismic trace as well as relative error, due to processing parameter variations for all realisations. This can be done for 3D seismic, 4D, 4D AVO.
The error in 3D seismic amplitude leads to an error in impedance and a consequent, error in porosity is defined and used as a calibration point for saturation change.

**Figure 3** Error in mean section (left) and its corresponding histogram at top reservoir plus 20ms (right) of 4D differences for all realisations shown in Figure 2.

**Figure 4** Sum of positive amplitude of the 4D difference, between the top and base reservoir for selected realisations as shown in Figure 2. Realisation 1 (top left), realisation 3 (top right), realisation 7 (bottom left) and realisation 8 (bottom right).

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**References**