Assessing data error for 4D Seismic History Matching: Uncertainties from processing workflow

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). Most of the metrics for quantifying 4D seismic noise such as NRMS and Predictability (Kragh and Christie 2002) and 4D QCs (Saint Andre et al. 2013) are performed post-stack (although the noise attenuation is performed pre-stack) and they offer large ambiguities in 4D interpretation. Consequently, the post-stack analysis is not enough to characterize the seismic uncertainty properly as we cannot rely on one realisation for 4D seismic analysis. 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, the error bars and confidence levels on 4D seismic can be generated (Hatab et al. 2020). Most descriptions of 4D seismic error do not capture the full uncertainties in the seismic data or do not make the correct assumptions when looking at this error. Furthermore we should also recognise that the error may not only be on 4D seismic but can also be in the simulation model. Thus, to match the 4D seismic (observed) to simulation model (predicted), assessment of both error sources is required.

Here, we specifically address the data error component for the 4D seismic interpretation and 4D Seismic History Matching (SHM). The uncertainty on 4D seismic data has been estimated by generating multiple realisations of the post-stack volumes with different pre-stack processing workflows. The error associated with the variations of the processing parameters on the 4D seismic is then defined. After this, the far-angle stacks for all realisations were inverted and calibrated to obtain changes in saturation ($\Delta$SW$_{obs}$). There was only a slight match between the $\Delta$SW$_{obs}$ (4D seismic realisations) and those saturation changes ($\Delta$SW$_{pred}$) predicted by the legacy simulation model provided by operator, the mismatch being greatest in the central area of the reservoir. For comparison purposes the uncertainty in the legacy flow model is defined by creating multiple realisations of the model by varying the scenarios for the application of reservoir property multipliers (in our case, horizontal and vertical permeability). The $\Delta$SW$_{pred}$ is derived from each simulation model and in order to identify which $\Delta$SW$_{obs}$ matched with $\Delta$SW$_{pred}$, a Least Square Minimum (LSM) is evaluated to measure the match between each $\Delta$SW$_{obs}$ map and all the maps of $\Delta$SW$_{pred}$ from all the simulation models within the reservoir.

Method

The error in 4D seismic data is estimated by reprocessing the 3D pre-stack depth migrated gathers in time with alternative workflows. The re-processing is considering the wide variations of parameters and guided by the noise types and behaviour of gathers, followed by post-stack processing. As the sequence applied is identical for the base and the monitor, the 4D difference for each realisation remains valid. The 4D attributes were generated for qualitative interpretations, which are qualitatively similar but 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 which is time-consuming to undertake. Alternatively, we have generated error bars for the 4D seismic. The idea for generating the error bar is to provide a mean (average) of all realisations and then compute the error in the mean at each sample, which will be the error associated with the processing parameters variations at each sample. The relative error volumes define the expected percentage deviation of the seismic from their accepted value (Hatab et al. 2020).

After generating the 4D realisations, the far-angle stack volumes are inverted for the saturation change estimation (Figure 1). For this purpose a statistical wavelet is extracted from one of the 3D baseline realisations and, with available sonic and density well logs, the synthetic seismogram is generated for well to seismic tie and the low frequency impedance model is derived. By using the statistical wavelet for each 3D baseline and monitor, model-based coloured inversion (Lancaster and Whitcombe 2000) is
Figure 1 Schematic of assessing data error for 4D Seismic History Matching (SHM), uncertainties from processing workflows.

performed for each pair of realisations. The relative impedance output for these is differenced to obtain the observed impedance difference ($\Delta A_{I_{obs}}$) for all 4D seismic realisations. The predicted impedance ($\Delta A_{I_{pred}}$) has been obtained from the legacy simulation model using the petroelastic transform. The relation between $\Delta A_{I_{obs}}$ and $\Delta A_{I_{pred}}$ from the legacy simulation model is defined and then $\Delta A_{I_{obs}}$ for all observed realisations are calibrated. The $\Delta S_{W_{obs}}$ of observed realisations are obtained by using the relation between $\Delta S_{W_{pred}}$ and $\Delta A_{I_{pred}}$ from the legacy simulation model. The average $\Delta S_{W_{obs}}$ map for each observed realisation is generated between top and base reservoir, and compared to the average $\Delta S_{W_{pred}}$ from the legacy simulation model.

Figure 2. Average of reservoir saturation change maps from observed 4D seismic realisations from different processing flows. The central region of the reservoir does not match the predicted saturation change map from the legacy simulation model with any degree of accuracy.
The results show that \( \Delta S_{\text{SW}}^{\text{obs}} \) maps from observed 4D realisations are quantitatively different. However, none of the observed realisations match to \( \Delta S_{\text{SW}}^{\text{pred}} \) from the legacy simulation model, especially in the central part of the reservoir, as shown in Figure (2). Therefore, we have to assess the error in the model for better 4D seismic history matching.

**Figure 3 Left:** Average of predicted \( \Delta S_{\text{SW}} \) map from legacy simulation model showing the regions defined by polygons where permeability multipliers are changed to generate multiple simulation models for Seismic History Matching (SHM). **Right:** Least squares error between observed and predicted \( \Delta S_{\text{SW}} \) realisations.

The error in the legacy model is assessed by creating multiple realisations of the simulation model with differing scenarios for the multipliers of reservoir properties (in our case, horizontal and vertical permeability) at different regions defined by polygons as shown in Figure (3). The average of \( \Delta S_{\text{SW}}^{\text{pred}} \) map for each simulation realisation is generated between the top and base of the reservoir. In order to identify which \( \Delta S_{\text{SW}}^{\text{obs}} \) map gives the optimal match between the observed realisation and the simulation models, a Least Square Minimum (LSM) has been taken between each \( \Delta S_{\text{SW}}^{\text{obs}} \) map and all the maps of \( \Delta S_{\text{SW}}^{\text{pred}} \) from the available simulation model realisations.

The results indicate the mismatch between \( \Delta S_{\text{SW}}^{\text{obs}} \) from observed 4D legacy processing and \( \Delta S_{\text{SW}}^{\text{pred}} \) from all simulation models and also show the variations in \( \Delta S_{\text{SW}}^{\text{obs}} \) estimated for different observed realisations, due to the variations of the processing parameters. The \( \Delta S_{\text{SW}}^{\text{pred}} \) from multiple realisations of the simulation model are variable and a good match has been observed between simulation realisation-13 (SIM-13) and observed realisation-8 (OBS-8) which gave an optimal least square difference as shown in Figure (4). There are also two observed realisations giving a reasonable match with (SIM-14), which are OBS-2 and OBS-5.

**Conclusions**

Most descriptions of 4D seismic error for 4D quantitative interpretation (4D QI) do not capture the full uncertainties in the final seismic data volumes, or do not make the correct assumptions when looking at error. We may state that there is no single observed seismic realisation that we can rely on for 4D seismic interpretation and also that no single simulation model that can match the observed data. We show that by considering a range of realisations in both the seismic data and also the simulation model, that a better understanding of the match between observed and predicted seismic may be obtained. Our case studies serve to illustrate the value of capturing the correct uncertainties when using a complex 4D QI tool such as Seismic History Matching.
Figure 4 The comparison between the observed and predicted ΔSW of the legacy model and 4D seismic (top), better matching between observed 4D realisation (OBS-8) and (SIM-13) (bottom) and another possible good matching (OBS-5) and (SIM-14) (middle).

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References


