A Proper Data Comparison for Seismic History Matching Processes

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Abstract

Seismic data usually has lower vertical resolution than reservoir simulation models so it is a common practice to generate maps of 4D attributes to be used as the observed data to calibrate models. In such a case, simulation results are converted to seismic attributes and a map is generated by averaging the corresponding layers. Although this seems to be a fair practice, here we show that this procedure can present some drawbacks and propose a new approach to ensure a proper data comparison.

The first step of the proposed procedure follows the traditional sequence where seismic attributes are generated by running a petro-elastic model (PEM) with reservoir simulation data, at the simulation scale. Then, instead of averaging the simulation layers, we propose to resample the simulation grid to a seismic grid and filter the seismic impedances to the seismic frequency. Lastly, we extract the map from the regular grid to be compared with the observed 4D seismic. This procedure is performed in the depth domain and allows a straight and fair comparison of the two dataset.

A synthetic dataset based on a Brazilian field produced through water injection is used to validate this procedure. This dataset is composed by a synthetic 4D seismic data (observed data) generated by a consistent seismic modeling and inversion and a set of reservoir simulation models (to be matched). We computed seismic impedance for each simulation model by applying a PEM and two maps were generated for each model: (1) by averaging impedance values throughout the corresponding layers and (2) by applying the proposed procedure. When these maps are subtracted from the observed data (error maps), as would happen in a quantitative seismic history matching, we note a relevant differences. In the dataset used, we observed that if the vertical resolution issue is not considered (Case 1) the error map presents a strong bias that would erroneously force a decrease on the water saturation to match the observed data in a seismic history matching. While the map generated in Case 2 presents the errors better balanced and related to actual water movement differences rather than being a consequence of scale and resolution issues.

The novelty of this work is a quick way to bring simulation data to seismic resolution without going through all seismic modeling process ensuring a proper data comparison, which can be promptly added in seismic history matching process.
Introduction

Time-lapse seismic technology is an essential tool for reservoir monitoring, as it can reveal important features about reservoir production such as fluid and pressures changes. 4D seismic data are used to calibrate reservoir simulation models improving model based decisions and causing great impact on field management. The use of these data to update reservoir simulation models can be done qualitatively or quantitatively. In both cases the final goal is to generate reservoir models that replicate the dynamic behavior observed on 4D signals. While qualitative approaches is performed by manual adjustments in the reservoir model, the quantitative integration follows a mathematically robust approach where the 4D seismic data is inserted as part of the objective function of a history matching procedure, as presented in Emerick (2016), Nóbrega et al (2018), Davolio and Schiozer (2018).

The addition of 4D seismic data quantitatively in a history matching procedure is challenging due to the different nature of seismic and reservoir simulation data. It is necessary to bring the data to a common domain (usually seismic impedances) as well as to a common scale (usually the simulation model grid). The error between the two dataset can be computed through quadratic deviations or using different metrics as discussed in the works Obidegwu (2015), Chassagne et al (2016) and Davolio and Schiozer (2018).

Due to the low resolution of seismic data it is a common practice to generate maps of 4D attributes (Falahat et al, 2013) and use them as the observed data to be matched in seismic history matching procedures. In this case, simulation results are converted to seismic attributes through a petro-elastic model (PEM) and a single map is generated by averaging the corresponding layers. Although this seems to be a fair practice, in this work we show that this procedure can present some drawbacks. By using a synthetic dataset based on a Brazilian field produced through water injection, we show how the low vertical seismic resolution can bias history matching procedures. Also, we propose a quick way to bring simulation data to seismic resolution without going through all seismic modeling process. In the procedure proposed we compare simulation and seismic data in the impedance domain, but we bring the impedance modeled from the simulation models to the seismic resolution. This procedure is performed in the depth domain and allows a straight and fair comparison of the two dataset.

Methodology

This work discusses the quantitative integration of 4D seismic data and reservoir simulation results, focusing on the effects of the difference on vertical resolution of the two data. Two procedures are compared: the traditional layer averaging of reservoir simulation results which are described in steps 1-2B of Figure 1 and a new procedure here proposed that consists of steps 1 to 4B of the same figure. Follow below a detailed description of these steps.

1. Run simulation: perform reservoir simulation to compute pressure and saturation changes due to production.
2. Run PEM: perform a forward modeling to compute seismic impedances, for every cell of the simulation model through a petro-elastic model. So, seismic impedances are generated from simulation models at simulation grid ($\Delta IP_{SIM@SIM}$).
3. Extract maps of IP from the volume $\Delta IP_{SIM@SIM}$ by averaging the corresponding layers of the simulation model.
4. Transfer IP to a regular grid: transfer simulation models to a regular grid (seismic grid). Note that this seismic grid can be generated in depth avoiding depth-to-time conversion.
5. Filter IP to the seismic frequency: this step brings simulation estimated data to seismic resolution by applying a filter that excludes high frequencies ($\Delta IP_{SIM@SEIS}$).
6. Extract map of IP from the volume $\Delta IP_{SIM@SEIS}$ to be compared with the observed 4D seismic data $\Delta IP_{SEIS}$. 
Figure 1—Methodology proposed to estimate seismic attributes from reservoir simulation models taking into account resolution issues.

Application

"Observed" seismic data
A synthetic seismic dataset was built for 4D studies (Souza, 2017). The seismic data was generated with a high resolution simulation model called UNISIM-I-R (grid-cell size approximately [25, 25, 1] m). This fluid-flow model is part of the benchmark case UNISIM-I, built based on Namorado field, a sandstone reservoir in the Campos basin, Brazil (Avansi and Schiozer, 2015). The generation of synthetic seismic starts by estimating elastic attributes (P and S wave velocities and density) through a petro-elastic modeling that uses as input static and dynamic properties extracted from the high resolution simulation model (Figure 2a). The model is then depth-to-time converted and rescaled from the corner point grid to a regular seismic volume. The 3D volumes of seismic amplitudes are generated through a 1D convolution (Figure 2b). Finally, a colored inversion was applied to the synthetic seismic amplitudes, generating realistic estimations of P-impedance (Figure 2c).

3D modeling

For the 4D seismic modelling we considered two surveys, one base (pre-production) and one monitor (after 10 years of production). Figure 3 shows a map and a vertical section of the time-lapse difference for (a) P-
impedance generated from the PEM ($\Delta I_{PEM}$), (b) seismic amplitudes (Amp) and (c) P-impedance generated from the coloured inversion ($\Delta I_{INV}$). The strong 4D anomalies observed represent a hardening effect caused by water replacing oil. In this synthetic dataset $I_{PEM}$ can be seen as the true seismic information (i.e., if seismic data was perfect this would be the correct answer). As expected, we can observe some vertical resolution issues generated by 1D convolution (Figure 3b) that is also reflected in the inverted impedances (Figure 3c) which can be seen, for instance, in the regions pointed by the arrows in Figure 3. The high resolution of the simulation model allowed the generation of a very realistic synthetic seismic data. Also, this is a particularly interesting case for 4D studies because of the water saturation changes caused by an aggressive water injection strategy to maintain oil production.

4D modeling

![Figure 3](image)

**Figure 3**— Time lapse difference of: (a) P-impedance computed from PEM, (b) seismic amplitude and (c) P-impedance yielded from a coloured inversion. Left: map extracted along the solid black horizon. Right: vertical section along the inline highlighted in the map. The ellipses highlight a zone where the 4D signals loose resolution.

Simulation models

Besides the reference model presented in the previous section which represents the true earth model, UNISIM-I benchmark is composed by a set of simulation models built in a coarser grid (cell size approximately [100, 100, 8] m). For this work we select six of these models to show the impact of our procedure when computing the errors between observed and simulated 4D seismic data in a quantitative integration. The differences between the simulation models concern the reservoir uncertain properties which
include: rock compressibility, water-oil contact, PVT, relative permeability and grid properties (porosity, Net-to-gross and absolute permeability); for more details see Almeida et al (2018). As an example Figure 4 shows the permeability field of two of the models used and the corresponding water saturation changes.

A seventh model was used to better illustrate the application of the procedure here proposed, called the "Best" simulation model. This model corresponds to the reference model (UNISIM-I-R) after scale transference to the coarser simulation grid (cell size approximately [100, 100, 8] m), this means a very ideal scenario (assuming a perfect reservoir characterization). This simulation model does not make part of the benchmark, we included in this work just to understand the challenging of data comparison. This model was selected because it has a similar dynamic behavior when compared to the "true model", the only difference between them is related to scale differences. The next section shows the results for the seven models analyzed.

Results

The "Best" simulation model

Figure 5 shows the map and a cross section of IP outputted from step 2B (ΔIP_{SIM@SIM}) using the "Best" simulation model. Although the static properties (porosity, permeability and so on) are the same as the reference model, some differences are observed in the water movement due to the coarser grid (compare Figures 3a and 5).
Figure 5—ΔIP estimated for the "Best" simulation model following steps 1-2B of the traditional approach (ΔIP\textsuperscript{SIM@SIM}).

Figure 6 shows the map of IP outputted from step 4B of the proposed procedure and a vertical section that highlights the vertical resolution effects. Note that a qualitative analysis of the results allows the identification of the proper data comparison here proposed as the best option, as Figure 6 is clearly closer to Figure 3c than Figure 5.

Figure 6—ΔIP estimated for the "Best" simulation model following steps 1-4B of the proposed approach (ΔIP\textsuperscript{SIM@SEIS}).

It is important to note that the filtering process changes the magnitude of the 4D changes. Therefore for a quantitative comparison of the observed (ΔIP\textsuperscript{SEIS}) and simulated data (ΔIP\textsuperscript{SIM@SEIS}) normalization is required which is shown in Figure 7. The right side of Figure 7 shows the error maps between observed and simulated data for both cases, note that there are relevant differences yielded from the two procedures. In the traditional approach the error map presents a strong bias that would erroneously force a decrease on the water saturation to match the observed data in a seismic history matching. While the error map generated from the proposed approach presents better balanced errors which are related to actual water movement differences rather than being a consequence of scale and resolution issues.
Other simulation models
The methodology was applied to other six simulation models extracted from the UNISIM-I benchmark case (two of them are shown in Figure 4) following a fair construction considering realistic uncertainties in reservoir properties as presented by Avansi and Schiozer, (2015). These models present different dynamic behavior as a consequence of different modeled static properties. Figures 8 and 9 show the normalized $\Delta IP_{SIM@SIM}$ maps for the six models and the corresponding error map (when compared to $\Delta IP_{SEIS}$ map illustrated in Figure 7), respectively. Note that the bias to decrease water saturation is also observed in these models. However, when the proposed procedure is applied ($\Delta IP_{SIM@SEIS}$) the errors are better balanced, as shown in Figures 10 and 11.
One should observe that the magnitude of the $\Delta I P_{SIM@SEIS}$ in Figure 10 is lower than the maps of Figure 8, this is a consequence of the filtering process. The differences between the errors of Figures 9 and 11 are partially due to these differences in magnitude (since the error is a simple map subtraction), but not mainly. The main difference comes from the actual shape of the 4D anomalies. To better illustrate this fact Figure 12 shows a zoom-in in a highlighted zone of the reservoir; a visual analysis of these images shows that the shape of the 4D anomalies of $\Delta I P_{SIM@SEIS}$ is closer to the observed data. We also generated the corresponding binary images of these images through the application of a clustering algorithm (Figure 13). Figures 12 and 13 clearly show that the use of $\Delta I P_{SIM@SEIS}$ provides a more reasonable matching with the observed 4D seismic data.

The change in the magnitude of the 4D signals after the filter suggest the use of different metric to estimate the errors between them such as binary images, or other metric that evaluate the shape rather than the actual values.
Final remarks

The results presented here highlight a probable bias that can be created in seismic history matching by the differences in vertical resolution of simulation models and seismic data. Although we show relevant evidences of this possible bias (to wrongly force a decrease in the amount of water of the simulation
Another point to mention is the use of synthetic data. Although the generation of seismic data followed the standard practices of synthetic modeling, the use of a 1D convolution is not enough to model all effects of wave propagation on seismic signals. For real data the problem can be more complex and the application of the proposed procedure needs to be validated, or adapted for these cases.

Conclusion
This work discussed the effects of different vertical resolution of seismic and reservoir simulation models on seismic history matching procedures. We showed with a realistic synthetic case that the traditional model averaging to generated maps to be compared with 4D seismic data can introduce bias in seismic history matching. Alternatively, we propose a quick procedure to mitigate it by bringing reservoir simulation to seismic resolution before performing the data comparison. The case studied showed promising results, encouraging the continuation of this study with real data.

Figure 13—Binary images computed through a clustering algorithm applied to the images of Figure 12.

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Reference


