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Impact of model and data resolutions in 4D seismic data assimilation applied to an offshore reservoir in Brazil

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Introduction

This text summarizes the paper published by Rosa et al. (2022b), which discusses the impact in data assimilation and production forecast of using grids with different resolutions as well as different 4D seismic maps in a real reservoir.

Time-lapse, or 4D, seismic data are an important source of information in reservoir studies, as they can reveal changes in elastic properties of the rocks that are due to variations in fluid saturations and pressure occurring during hydrocarbon production. In reservoir management, those changes are crucial to identify flow barriers and reservoir compartmentalization, injected waterflood and remaining oil. Due to their areal extension, 4D seismic data can be quantitatively incorporated in the calibration of reservoir models through simultaneous assimilation with well production data. The results are more accurate models that reflect observed dynamic changes at interwell locations.

The most common domain of integration from seismic to simulation are inverted impedances. They are obtained after the application of a seismic inversion, in which acquired amplitudes are used to calculate acoustic impedances of the rocks. In the assimilation process, they are compared to the ones calculated after applying a petro-elastic modeling to reservoir properties, and their differences are minimized.

Because of the lower resolution compared to simulation models, 4D seismic data are usually incorporated as maps calculated within specific intervals. The definition of those intervals depends on many factors, e.g., the reservoir thickness. Furthermore, the definition of grid size depends on the project´s objective and timeline, since the higher the number of blocks the higher the computational cost will be to simulate the models.

In this work, we evaluate the impact of using maps calculated over different intervals (i.e., the impact of adding a greater amount of seismic information) in data assimilation. Furthermore, we analyze the impact of using grids with different resolutions to simultaneously assimilate 4D seismic and production data in a real case, using the Ensemble Smoother with Multiple Data Assimilation (ES-MDA) method.

Methodology

The first step of the methodology involved calculating inverted 4D impedances from acquired 4D seismic data. These were then averaged to generate root mean square (RMS) maps considering different intervals within the reservoir. The resulting 4D impedance maps, along with production data, were used in different cases in the data assimilation process through ES-MDA. The available production data was divided into two parts: the first and most substantial part was used in data assimilation (treated as history), and the second and last part was used in the validation analysis. We also performed a long-term production forecast until the end of the field’s life to evaluate the uncertainties and differences in the estimates. This methodology was repeated for two grid systems with different resolutions.

Application and results

The current analysis was applied to a deep-water heavy oil reservoir, located at the Campos Basin (Southeast Brazil), named S field. Under a complex geometry setting, the reservoir is developed with 8 producers and 4 water injector wells for pressure maintenance. The available high-quality 4D seismic data was acquired in a PRM setting with different repeated surveys. This study considers baseline, acquired after production started, and monitor 3, acquired 851 days after the baseline survey. Strong softening signals are observed in the 4D seismic data at the earliest monitor surveys, which are due to gas going out of solution. Other main anomalies include hardening signals related to injected and aquifer water replacing oil.

We used two numerical models with corner-point grid geometries, named Grid1 and Grid2, with different resolutions (Table 1). More details on the creation of Grid2 are found in Maschio et al. (2021).

***Table 1**: Comparison of Grid1 and Grid2 resolutions.*

	Grid1	Grid2
Block size (X × Y × Z) [m]	50 × 50 × 1.5	150 × 150 × 3
Number of active grid blocks	405,306	27,113
Avg. time to simulate 1 model [min]	93	2

We ran the Bayesian 4D seismic inversion using as input the amplitude differences of monitor 3 minus baseline. The results were the mean of the ratio of acoustic impedances of monitor 3 divided by the baseline, here called RIPP (more details are found in Rosa et al. 2022a). Although it is a thin reservoir (~25 m of thickness), the high-quality seismic data allowed an improvement in the vertical resolution of inverted results, enabling the calculation of maps at intermediate layers between reservoir top and base. Therefore, two assimilation cases were considered for each grid: the production data was assimilated simultaneously with a single map from top to base (Figure 1); or with two intermediate maps (from top to middle, and from middle to base), after removing unreliable data (Figure 2). We also performed data assimilation using only well data for comparison purposes.

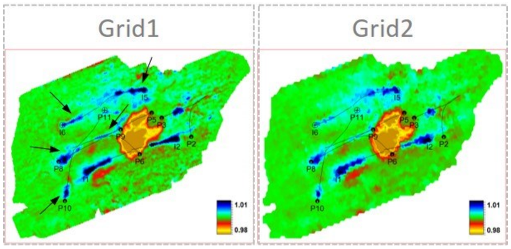

***Figure 1**: Observed RIPP maps in the simulation scale of Grid1 and Grid2, to be used in case of assimilating one map in the top-base interval. The black arrows indicate the main differences between the maps.*

The data assimilation was carried from 0 up to 2298 days, and the models were updated using BHP data for producers and injectors and oil rates for producers, as well as 4D impedance maps. A general analysis of well matching is shown in Figure 3. For all considered cases, we plot the percentage of models from the total ensemble (y-axis) against maximum NQD simultaneously considering all wells objective functions (x-axis). The errors are greater for Grid1 than for Grid2, but still the quality of the fit in Grid1 is very good. The higher error can be explained by the fact that the inversion problem is more complex and more nonlinear in Grid1 than in Grid2. We also note that assimilating seismic (WS1, WS2_SL_ex) improved the well matching compared to only assimilating production data (W), in both grids.

Although not shown here, by visually comparing RIPP maps of posterior models and observed data we note that assimilating seismic data also granted a better 4D seismic matching. Furthermore, the impact of assimilating two maps (WS2_SL_ex) proved positive, allowing the (vertical) separation of dynamic effects, e.g., the gas trapped in the lower interval, being closer to the observed data.

The validation analysis was performed considering the period from 2299 up to 2359 days, and the long-term forecast was performed until the end of field’s life. Figure 4 shows cumulative oil production curves for the field, of the

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"The choice of grid resolution may depend on the project's objectives. The coarser grid may be more appropriate for short-term studies, while the most refined grid may be better for long-term decisions."

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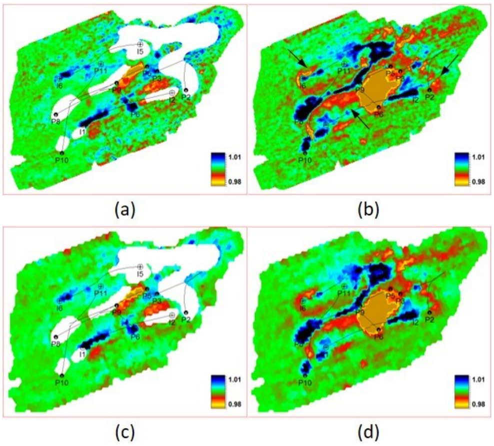

***Figure 2**: Observed RIPP maps in the simulation scale of Grid1: (a) top-middle and (b) middle-base; and Grid2: (c) top-middle and (d) middle-base intervals. The seismic data are not assimilated in the blank regions given the presence of artifacts.*

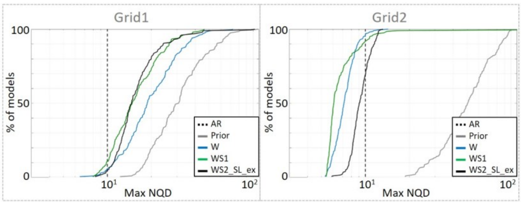

***Figure 3**: Maximum NQD for all well objective functions (flow rates and BHP for all wells), against the percentage of models for prior (grey) and posteriors of W (blue), WS1 (green) and WS2_SL_ex (black) cases, considering Grid1 (a) and Grid2 (b). The dashed line represents NQD values of 10.*

filtered models (NQD<15). Assimilating 4D seismic (WS1 and WS2_SL_ex) produced closer estimates to observed data than the W case, in the assimilation and validation periods in Grid1. In Grid2, this is also observed with the WS1 case, thus showing more appropriate results, while W and WS2_SL_ex cases produced more pessimistic estimates.

Conclusions

Well production misfits between posterior models and observed data were significantly reduced when assimilating seismic and production data simultaneously for both grids, showing even smaller errors than the cases that assimilated production data only. Furthermore, the addition of further 4D information at intermediate layers (WS2_SL_ex cases) generated posterior models that were able to predict reservoir behavior, such as the gas trapped in the deeper interval.

The Grid2 models presented lower production data misfits compared to Grid1. However, Grid2 models showed to be insensitive to the different seismic data used as input, presenting alike posterior models. In the production forecast results, Grid2 showed less variability. Grid1 showed greater potential to generate distinct models when different seismic data are used, and presented higher variance in production forecast.

The choice of grid resolution may depend on the project's objectives. The coarser grid may be more appropriate for initial studies and short-term forecast, since it is more than ten times faster. On the other hand, the most refined grid may be better for life-cycle final decisions, once it has a

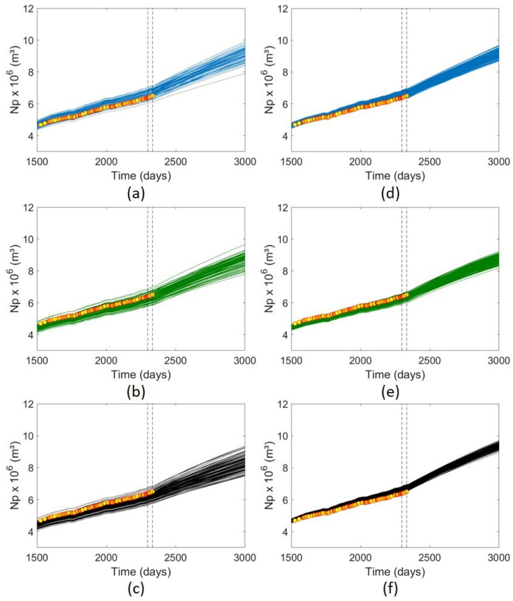

***Figure 4**: Cumulative oil production for the field, corresponding to filtered models (NQD<15). Grid1: (a) W, (b) WS1, and (c) WS2_SL_ex. Grid2: (d) W, (e) WS1, and (f) WS2_SL_ex. The vertical dashed lines limit the data assimilation and validation periods.*

better chance of representing models' uncertainties and provides higher variability and a higher chance to forecast reservoir behavior.

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Reference

Rosa, D. R., Schiozer, D. J., & Davolio, A. (2022b). Impact of model and data resolutions in 4D seismic data assimilation applied to an offshore reservoir in Brazil. Journal of Petroleum Science and Engineering, 110830 (https://dx.doi.org/10.1016/j.petrol.2022.110830).

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