Submission code: QMX5Q7RPZN

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Implementation of Advanced Visualization Techniques for Evaluating Modeled Seismic Properties from Ensembles of Reservoir Models

Israel Dragone (DeepSoft), Mitsuo Luan Miyazato (Universidade Estadual de Campinas), Daine Rossi Rosa (Unicamp), Leonildes Soares de Melo Filho (Repsol Sinopec Brasil), Celmar Guimarães da Silva (Universidade Estadual de Campinas), Marcos Pilato (Deepsoft), Alessandra Davolio (Centro de Estudos de Energia e Petróleo (CEPETRO); Universidade Estadual de Campinas (UNICAMP)), Tahyz Pinto (Deepsoft), Pedro Vianna Mesquita (Deepsoft)

Implementation of Advanced Visualization Techniques for Evaluating Modeled Seismic Properties from Ensembles of Reservoir Models

Please, do not insert author names in your submission PDF file

Abstract

Reservoir modeling – a crucial step in oil field development – often demands the assessment of large ensembles of models. Visualization techniques that organize and display multiple models simultaneously on a single screen can significantly enhance the process of analyzing the ensemble and identifying its models' characteristics. This work presents the implementation of two visualization approaches within a widely used commercial subsurface platform. These visualization tools enable users to analyze ensembles of modeled seismic properties through two techniques: *Pixelization* and *Small Multiples* (*SM*). Both offer a unique overview of hundreds of models on a single screen, helping analysts to compare them with each other and with observed seismic data. The tools are fully integrated with the software's platform, allow typical 2D and 3D data objects as input, and are rendered in the platform's native 2D/3D windows. As an interactive tool, the user can alter visualizations on the fly to test different configurations, enhancing the quick evaluation of reservoir models against measured 4D seismic data and allowing more accurate monitoring decisions.

Introduction

Reservoir modelling plays a critical role in the development and management of oil fields, serving as the foundation for evaluating uncertainty, forecasting production, and guiding investment decisions. Dynamic reservoir models are representations of subsurface geology, fluid flow, and other reservoir properties' behavior over time, being essential for optimizing hydrocarbon recovery and minimizing economic and environmental risks. However, due to the inherent complexity and limited direct observability of subsurface systems, reservoir models must account for significant uncertainties. Ensemble-based modelling techniques address this challenge by generating multiple plausible realizations of the reservoir, each reflecting different assumptions and data interpretations.

Visualization techniques to study ensembles of models enable geoscientists and engineers to intuitively explore variability, identify trends and assess uncertainties. Furthermore, they can compare the reservoir responses to reference data, if available, and verify their accuracy and reliability. However, since a single ensemble can consist of hundreds of models, using basic visualizations that display only one model at a time becomes impractical for effective analysis. Therefore, approaches such as *Small Multiples* and *Pixelization* (Silva et al., 2019) are particularly useful for studying ensembles' characteristics and similarities with the observation, since they can show all models at once, on a single screen. Additionally, they offer unique perspectives of the ensemble, considering the distinct ways they arrange and display models within their structure.

In this work, we present the implementation of these visualizations within a plug-in for commercial subsurface software. The plug-in performs Petro-Elastic Modeling (PEMs) from reservoir simulations, generates seismic amplitudes through forward modeling, adds balanced noise, and computes volumes of 4D seismic data for amplitude and impedance attribute analyzes. These processes often create large ensembles, making the application of these visualization techniques particularly useful for the models' interpretation (Rosa et al., 2024). Finally, we demonstrate their applications by analyzing an ensemble of 100 models within the UNISIM-IV benchmark case (Botechia et al., 2022).

Visualization techniques

The *Pixelization* approach consists in generating a large heatmap-style image representing a reservoir property, where each cell corresponds to a specific spatial location of the reservoir. Each cell is subdivided into smaller sub-cells – each one representing an individual model from the ensemble. The layout of the cell is automatically optimized to preserve its aspect ratio while accommodating the number of models being displayed. When visualizing model data alongside observed measurements, the left half of the cell is colored according to the observed data. This split-color design creates a visual contrast that highlights differences and agreements between models and actual observations, as illustrated in Figure 1 (a and b). At first, the image resembles a conventional 2D heatmap of a reservoir property. However, it also reveals local patterns and behaviors that emerge from correlations between the ensemble of models and the observed data, as well as from the ordering of models within each cell. This model placement can be guided by various ranking strategies to emphasize specific features in the dataset.

The *Small Multiples* (*SM*) visualization offers a more straightforward approach in which all models of the ensemble are displayed simultaneously as small heatmaps, as illustrated in Figure 1c. Similarly to the Pixelization approach, the placement of the models in this window follows rankings and patterns that can be deliberately chosen by the analyst to provide a unique perspective of the ensemble. A good example of this is when using clustering to group the models based on their similarities (also shown in Figure 1c). This grouping facilitates a more targeted analysis of ensemble behavior and variability.

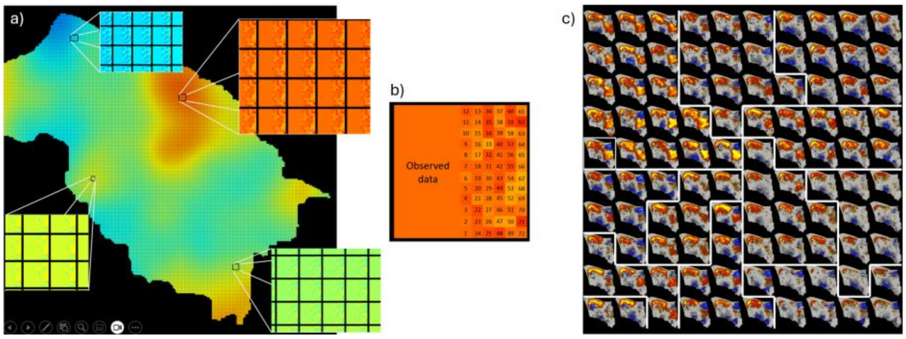

Figure 1: Schematic representations of the Pixelization (a and b) and SM (c) approaches. In the former, the highlighted cell (b) exemplifies a possible configuration where the observed data fills half of the cell, and each sub-cell on the right is indexed to an individual model in the ensemble, following some ranking. For SM, the models are shown as small heatmaps, that can be organized in clusters (as shown in c) or in other forms of ranking.

Both approaches use 2D data as input but can also show 3D data by converting it to 2D maps. In seismic cubes, for instance, traces can be calculated into a specific attribute, such as the Root Mean Square (*RMS)* amplitude or some other form of statistical mean (arithmetic, harmonic, etc.).

Implementation strategy

The visualization routines were implemented in C# and C++, making heavy use of the platform's SDK. Both visualizations are configured and stored as objects within the platform's input tree, which can be rendered as flat images on its native 2D/3D windows, using custom color tables. Their configuration is done through a common dialog, where the user inputs 2D or 3D model data directly from the platform's native objects, such as property surfaces or seismic cubes. For the latter, the plug-in offers the functionality to compute maps of attributes for seismic traces (RMS amplitude, arithmetic means, and others) as a preprocessing step. This computation can be applied to the entirety of the traces, or to a region defined between two depths or horizons.

To support model visualization, the tools offer options for applying *k*-means clustering (Forgy, 1965) to group ensemble models based on similarity, through metrics such as Euclidean distance, feature vectors (Silva et al., 2019), or *Structural Similarity Index Measure* (*SSIM*) (Zhou et al., 2004). The optimal number of clusters can be user-defined or automatically selected via silhouette score maximization (Rousseeuw, 1987). Models are ranked by their similarity to observed data, using *Root Mean Square Error* (RMSE), or Cross-Correlation. Structured layouts, including space-filling curves (Sagan, 1996), are adopted to organize models in the display. These strategies aim to improve interpretability and streamline comparative analysis within ensemble-based seismic modeling, thereby improving the user experience when evaluating them.

Results

In this section, we show these visualizations tools being used for analyzing RMS (calculated inside the reservoir) and dRMS (difference between the RMS at different time periods) maps, both extracted from synthetic seismic cubes generated with the UNISIM-IV benchmark case. Figure 2 illustrates the Pixelization technique applied to an ensemble of synthetic seismic cubes models. The left image is a 3D window showing the visualization mapped in the reservoir region and plotted with well data. The right image is a 2D window with the same visualization but zoomed in an area where there was a significant discrepancy between the observed seismic cube and the ensemble of models (black rectangle in the left image). This example highlights how Pixelization can help users in identifying regions where the ensemble could not fit the observed data.

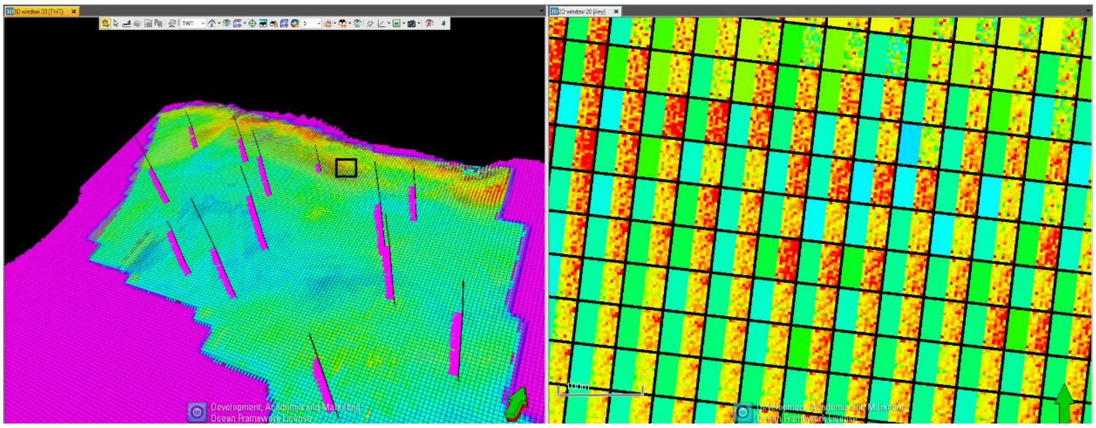

Figure 2: Screenshot of the Pixelization Visualization. The right image displays a zoomed-in view of the area marked by a rectangle in the left image.

The *SM* visualization is exemplified in Figure 3, where an ensemble of dRMS amplitude maps were clustered and displayed simultaneously. It is shown in a custom interactive window (c) in the platform that allows users to select and identify individual models using the mouse. Its main functionality, however, lies in the ability to dynamically display the currently selected model as a full-size heatmap in a 2D/3D window alongside it (b), as exemplified in Figure 3. Therefore, by also showing the observed data in a third window (a), the user can quickly view and switch between models in 2D/3D window by picking them on the *SM* window, and compare them visually with observed data, thereby enhancing the evaluation process.

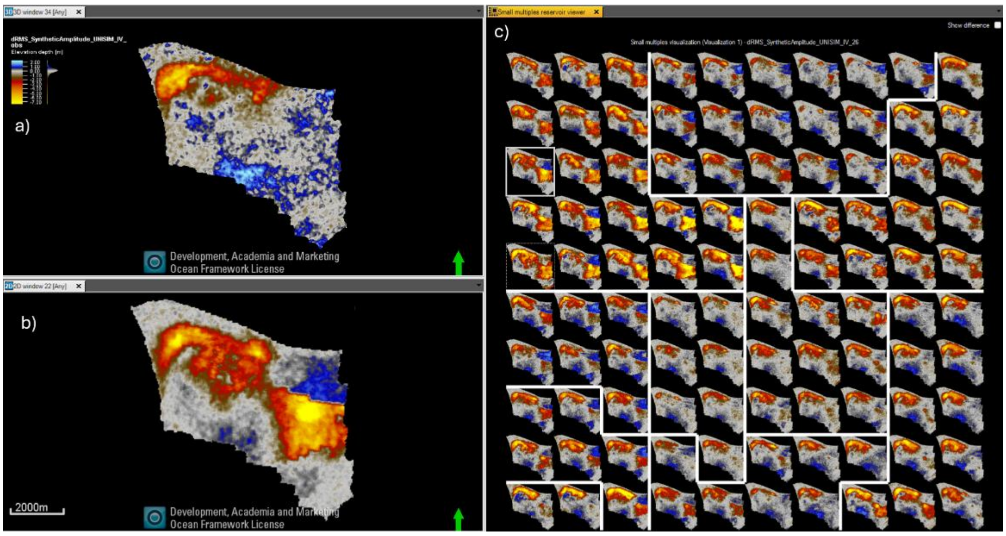

Figure 3: Screenshot of the *SM* visualization on dRMS amplitude maps, together with maps for the observed data (a) and the currently selected model (b) in the *SM* window (c).

Figure 3 also exemplifies how k-means clustering is used to arrange models in a comprehensive way. In this case, the 100 models were clustered into 10 groups using the distances from their feature vectors. The observed data (a) reveal two dominant features that are consistent across all simulations: softening in the northwest region (shown in red/yellow) and hardening in the center-southern region (shown in blue). This visualization technique enables users to identify which groups and models that best capture these key features of the observed data. As for the models that do not match with it, this clustering might also help users to investigate the common reasons within the same group for this mismatch with reference data.

Conclusions

This work has demonstrated the potential of Pixelization and Small Multiples visualizations to enhance the ability to visually detect patterns and uncertainties in ensembles, by enabling the simultaneous and comprehensive analysis of seismic attributes derived from an ensemble of reservoir models. Their interactive features and flexible configurations further enrich the understanding of areas of match/mismatch between synthetic seismic data derived from reservoir models and measured 4D data, allowing users to intuitively explore data and adjust visualizations in real time.

Acknowledgments

This work was carried out in association with the ongoing project registered under ANP number 23095-3 as the “Seismic forward modeling tool for reservoir monitoring and CO2 injection and storage projects (RESSIM-FORM.CO2)” (UNICAMP/DeepSoft/Repsol Sinopec Brasil/ANP) funded by Repsol Sinopec Brasil under the ANP (Agência Nacional do Petróleo, Gás Natural e Biocombustíveis) rules. The authors are grateful for the support of the Center for Petroleum Studies (CEPETRO-UNICAMP/Brazil), the Department of Energy (DE-FEM-UNICAMP/Brazil), the Research Group in Reservoir Simulation and Management (UNISIM-UNICAMP/Brazil), the School of Technology (FT/UNICAMP/Brazil), Energi Simulation and CNPq. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior – Brasil (CAPES) – Finance Code 001. The authors would also like to thank SLB, CMG and GeoSoftware for the software licenses. In addition, a special thanks goes to Gilson Moura Silva Neto for providing the rock-physics models for the benchmark case.

References

- Forgy, E. W. *Cluster analysis of multivariate data: efficiency versus interpretability of classifications*. Biometrics, v. 21, n. 3, p. 768–769. 1965.
- Rosa, D. R., da Silva, C. G., da Silva Siqueira, K. R., de Andrade Miyazato, M. L., dos Santos, M. S., Pilato, M., ... & Davolio, A. (2024). A visual tool to analyze the matching quality between simulation models and 4D seismic data. In 4D Forum—Insight to Actions: A Global Forum, Galveston, Texas, November 4–6, 2024 (pp. 127-130). Society of Exploration Geophysicists.
- Rousseeuw, P. J. *Silhouettes: A graphical aid to the interpretation and validation of cluster analysis*. Journal of Computational and Applied Mathematics, v 20, p. 53-65, 1987.
- Sagan, H. *Space-Filling Curves*, Universitext, Springer-Verlag, 1994. doi:10.1007/978-1-4612-0871-6
- Silva, C., G.; Santos, A. A. S. & Schiozer, D.J. *Visualization of Ensembles of Oil Reservoir Models Based on Pixelization, Small Multiples and Reservoir Similarities*. Offshore Technology Conference Brasil, Rio de Janeiro, Brazil, 2019. doi: https://doi.org/10.4043/29788-MS
- Zhou, W.; Bovik, A.C.; Sheikh, H.R.; Simoncelli, E.P. Image quality assessment: from error visibility to structural similarity. *IEEE Transactions on Image Processing*, v. 13, n. 4, p. 600–612, 2004. doi:10.1109/TIP.2003.819861.
- Botechia, V. E., Correia, M. G., Rios, V. S., Davolio, A., Santos, S. M. G., Hohendorff Filho, J. C. V., & Schiozer, D. J. (2023). UNISIM-IV: Benchmark proposal for light oil carbonate reservoir with high CO_2 content. *Brazilian Journal of Petroleum and Gas*, 16(4).