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A New Parameterization Method for Data Assimilation and Uncertainty Assessment for Complex Carbonate Reservoir Models Based on Cumulative Distribution Function

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> *"A proper parameterization scheme is crucial to ensure an effective and consistent data assimilation process, especially for complex geological systems."*

Introduction

One of the main challenges in the process of conditioning reservoir models to dynamic data (data assimilation) is related to the representation and updating of spatial properties in a geologically consistent way. The process is even more challenging for complex geological systems such as highly channeling reservoirs, fractured systems and super-K layered reservoirs. Therefore, mainly for highly heterogeneous reservoirs, a proper parameterization scheme is crucial to ensure an effective and consistent data assimilation process. This text presents some highlights of the paper of Maschio and Schiozer (2019), which proposes an innovative parameterization method for data assimilation and uncertainty assessment based on cumulative distribution function (CDF) focused on complex super-K layered reservoirs.

Methodology

The general methodology proposed in this work consists of an iterative process to generate a new set of images at each iteration. The main steps are:

1) Generate prior images. Before applying the approach proposed in this work, it is necessary to generate a set of prior realizations (or images) using any geostatistical modeling tool.
2) Run flow simulation and compute objective function.
3) Select images by region. In this step, the reservoir model is divided into flux regions. For each region, a set of best images is selected based on a cut-off value (NQD_R) of all OF corresponding to the wells belonging to that region. If the number of selected images (n) is lower than a pre-defined minimum (n_{min}), increase NQD_R until n is equal to n_{min}.
4) Generate CDF map, which means that a cumulative distribution curve is generated for each grid block based on the set of images selected in the previous step.
5) Generate frequency map. For each grid block i, compute the frequency ($f_i = n_i / N_{SI}$) of horizontal permeability values higher than a cut-off value (kx_{sk}), above which a given block is considered as a super-K block, where n_i is the number of images for which the block i pertains to a super-K and N_{SI} is the number of images selected for the corresponding region. In the example illustrated in Figure 1, 3 out of the 5 images for the highlighted block belong to a super-K, i.e. f = 0.6. The theoretical CDF for the block highlighted in Figure 1 is illustrated in Figure 2(a).
6) Generate new images of kx based on a cut-off value of f. The main innovative aspect of this work is focused on this step, where we propose a new sampling procedure based on a cut-off frequency (fc), used as a criterion to draw (kx_i^{new}) (new value of kx) from the CDF generated in Step 4, according to the following rule (see also Figure 2b).

$$\begin{cases} if\ \ f \geq f_c, & kx_{sk} \leq kx_i^{new} \leq kx_i^{\max} \\ if\ \ f < f_c, & kx_i^{\min} \leq kx_i^{new} < kx_{sk} \end{cases}$$

Note that the proposed procedure respects the limits stablished by the prior images. f_c is an input parameter (chosen by the user of the methodology) which reflects how likely a new block will be part of a super-K in the new image. In the example shown in Figure 1, if we consider, for instance, f_c=0.5, the highlighted block will be part of a super-K in new generated images because f>f_c. As there is no predetermined value for f_c, which in theory could range from 0 to 1, the purpose of this work is to treat it as an uncertain parameter, defining a probability distribution function (PDF).

7) Generation of new images for the other properties. For the other properties (excepting kx), the new value of each property (ppt_i^{new}) for the grid block i is generated according to the following criterion:

$$draw\ ppt_i^{new}\ from\ [ppt_i^{\min}, ppt_i^{\max}]$$

where ppt_i^{min} and ppt_i^{max} are minimum and maximum values of a given property for the block i. Thus, for each property, the algorithm scans the grid assigning one value to each grid block. This procedure preserves the trends between the properties. Suppose that there is a correlation between the permeability and the porosity. If the set of selected images (Step 3) has a trend of high permeability and consequently high porosity in a given region, the CDF curves generated from these images capture the trend, in such a way that the new images will preserve this trend.

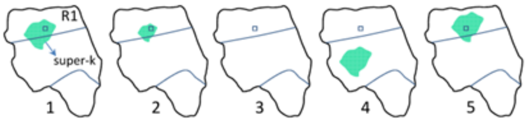

Figure 1: *Illustration of the procedure proposed to generate frequency map based on selected images of kx.*

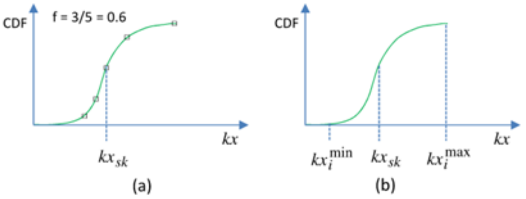

Figure 2: *(a) Illustration of f computation, (b) sampling according to a super-K cut-off value.*

Application and Results

The proposed method was applied to the UNISIM-II-H benchmark case, a complex carbonate reservoir model built based on a combination of Brazilian Pre-salt characteristics and the Ghawar field information available in the literature. To update the PDF of the parameter f_c, the IDLHC (Iterative Discrete Latin Hypercube) method, proposed by Maschio and Schiozer (2016), was used. Four iterations of the IDLHC method were carried out with 500 images generated at each iteration (total of 2500 reservoir simulations being 500 corresponding to the prior images).

Figures 3a and 3b present two images of kx comparing one of the prior images (a) and one of the images generated with the proposed method (b). Firstly, it is possible to note that the image generated by the proposed method has similar characteristics when compared with the prior image. Note that the histograms corresponding to the prior image (c) and the proposed method (d) are practically identical. This shows that the proposed method is consistent and preserves the characteristic of the prior model, in this case, a bi-modal distribution.

Figure 4 shows cross sections depicting rock type and water saturation front (3257 days) for one of the prior models (a and c) and for one of the posterior models (b and d). It is possible to observe that in the prior model, the water front does not reach the producer PROD2, while in the posterior model the water reaches PROD2 due to the presence of more super-K. A comparison of water rate for these models is depicted in Figure 4e, which shows that PROD2 is well-matched in the posterior model and very far from the historical data in the prior model. This analysis shows that the proposed method adjusts (automatically) the distribution and size of super-K for a proper data assimilation.

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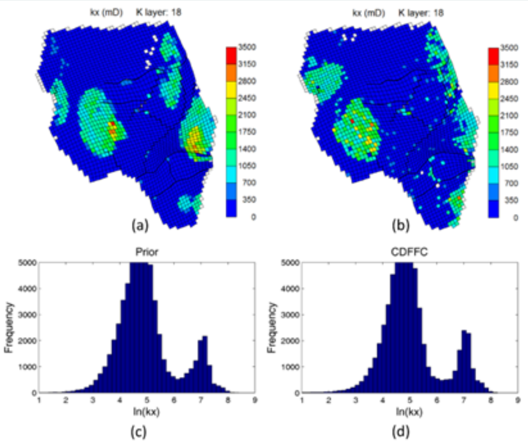

Figure 3: *Horizontal permeability (kx) and ln(kx) histograms comparing: prior (a and c) and the proposed method (b and d).*

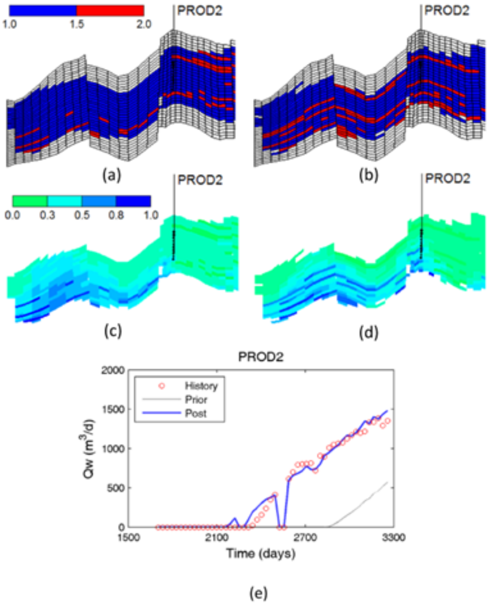

Figure 4: *Cross sections depicting rock type and water saturation front (3257 days) for one of the prior models (a and c) and for one of the posterior models (b and d). Water rate for PROD2 is shown in (e).*

Figure 5 shows NQDS for produced water rate for the prior (gray) and the posterior (blue, fourth iteration) models. There was a significant reduction in the NQDS amplitude for the majority of the wells. The water rate, the most critical function, is well-matched for practically all producer wells. Cumulative distribution curves showing reduction of uncertainty in cumulative oil production (Np) in the forecasted period are depicted in Figure 6. Note that there is a significant reduction of variability from the prior to the posterior models. It is also possible to see that the posterior models properly encompass the reference model.

Other details can be found in the complete version of the paper.

Conclusions

An innovative parameterization method for data assimilation and uncertainty assessment was proposed, based on cumulative distribution function (CDF) focused on complex layered reservoirs. We proposed a new sampling procedure based on a cut-off frequency which properly represents the spatial distribution of super-K in the reservoir model. The specific findings are:

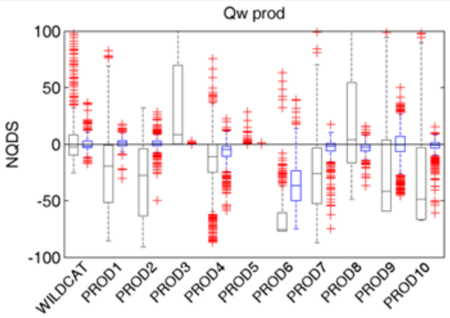

Figure 5: *NQDS for produced water rate for the prior (gray) and the posterior (blue, fourth iteration) models.*

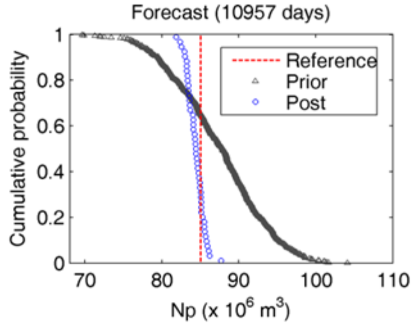

Figure 6: *Cumulative distribution curves showing reduction of uncertainty in cumulative oil production (Np) in the forecasted period.*

- The results showed that the new method preserves the prior characteristics of the model. It captured the bi-modal behavior of the permeability distribution, honoring the prior modeling and properly representing the spatial distribution of the super-K layers.
- The proposed method preserves the trends close to the wells, respecting the well data, which is important to preserve the consistency of the model.
- Proper data assimilation was possible with the parameterization method proposed in this paper. Good data matches were obtained and the uncertainty in the production forecast was reduced in a consistent way. The filtered models after data assimilation encompassed the reference model.

References

[1] Maschio, C.; Schiozer, D. J. 2019. A New Parameterization Method for Data Assimilation and Uncertainty Assessment for Complex Carbonate Reservoir Models Based on Cumulative Distribution Function. Journal of Petroleum Science and Engineering, 183 (106400), 1-18. https://doi.org/10.1016/j.petrol.2019.106400

[2] Maschio, C.; Schiozer, D. J. 2016. Probabilistic history matching using discrete Latin Hypercube sampling and nonparametric density estimation. Journal of Petroleum Science and Engineering, 147, 98-115. https://doi.org/10.1016/j.petrol.2016.05.011

About the author: Céllio Maschio is graduated in Mechanical Engineering from UNESP, holds a MS and a PhD degree in Mechanical Engineering from UNICAMP. He is a researcher at UNISIM/CEPETRO/UNICAMP since 2001 developing research and leading projects focused on history matching.

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