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RM19

Quantification of Uncertainties in Reservoir Models from Multi-fidelity Response Surfaces

V. Gervais* (IFPEN), A. Thenon (IFPEN) & M. Le Ravalec (IFPEN)

SUMMARY

To predict fluid flows in a reservoir and help decision-making for its development, engineers need to define representative models of this reservoir. Several workflows have been proposed that provide a set of reservoir models constrained to the static and dynamic data collected on the field. One of the main limitations is the computation time required by the fluid-flow simulations performed for each new model investigated during the process.

An alternative to reduce this computational time consists in building a meta-model to approximate the response of interest in the parameter space from a limited number of simulated values. This model can be substituted to the fluid-flow simulator at some steps of the workflow. Until now, meta-models were built from simulations performed on the same level of resolution. We propose here to investigate another type of meta-models, called multi-fidelity meta-models, which combine information obtained at several levels of accuracy. These models, rooted in cokriging, approximate the function on the fine level, using the values computed at every level. The tests performed on reservoir models considering grids with various spatial resolutions show that, compared to kriging, meta-models of equivalent or higher predictivity can be obtained within less simulation times.

Introduction

To predict fluid flows in a reservoir and help decision-making for its development, engineers need to define representative models of this reservoir. Several workflows have been proposed that provide a set of reservoir models constrained to the static and dynamic data collected on the field. One of the main limitations is the computation time required by the fluid-flow simulations performed for each new model investigated during the process.
An alternative to reduce this computational time consists in building a meta-model to approximate the response of interest in the parameter space from a limited number of simulated values. This model, also called response surface, can be substituted to the fluid-flow simulator at some steps of the workflow. Until now, meta-models were built from simulations performed on the same level of resolution, using for instance a Gaussian process regression (also referred to as kriging). We propose hereafter to investigate another type of meta-models able to handle information collected at various levels of resolution, called multi-fidelity meta-models.

Multi-fidelity meta-modeling

Multi-fidelity meta-modeling (Kennedy and O'Hagan, 2000) makes use of cokriging to combine information obtained at several levels of accuracy. More precisely, we consider a fine level of resolution – or high fidelity level - for which we need to approximate a function, and coarser levels of resolution for which the computation of the function value is faster, but also less accurate. The principle of the multi-fidelity approach then consists in building a meta-model approximating the function on the fine level, using the values computed at every levels. The aim is to get a model of good quality combining a restricted number of fine-level evaluations with many coarse-level evaluations.

Application to reservoir models

We consider a synthetic reservoir model derived from PUNQ-S3 (Floris *et. al*., 2001). Two levels of information are introduced. They differ from the spatial resolution of the reservoir grid used to perform fluid-flow simulations: a grid of 38×56×5 blocks provides the high fidelity production responses while a coarser grid of 19×28×5 blocks is used to get low fidelity production responses. For this test case, simulations with the coarse grid are on average three times faster than with the fine grid. Also, seven parameters related to the reservoir model are considered as uncertain: residual saturations, transmissivity multipliers and an aquifer parameter.
Multi-fidelity meta-models were built using the MuFiCokriging R package (Le Gratiet, 2013) to approximate the dynamic responses at wells, considering a model per well, property and time. The overall predictability of the resulting meta-models was estimated from an independent set of 150 reservoir models (confirmation runs) through the so-called Q2 coefficient. Kriging-based models were also considered for comparisons. The results obtained for the reservoir cumulated oil production and the water-cut at a well are presented in Figure 1, left and right respectively. We can see that using information from the coarse grid makes it possible to improve the predictability of the models (increasing Q2 coefficient). Also, models of equivalent or higher predictivity can be obtained within less simulation times.

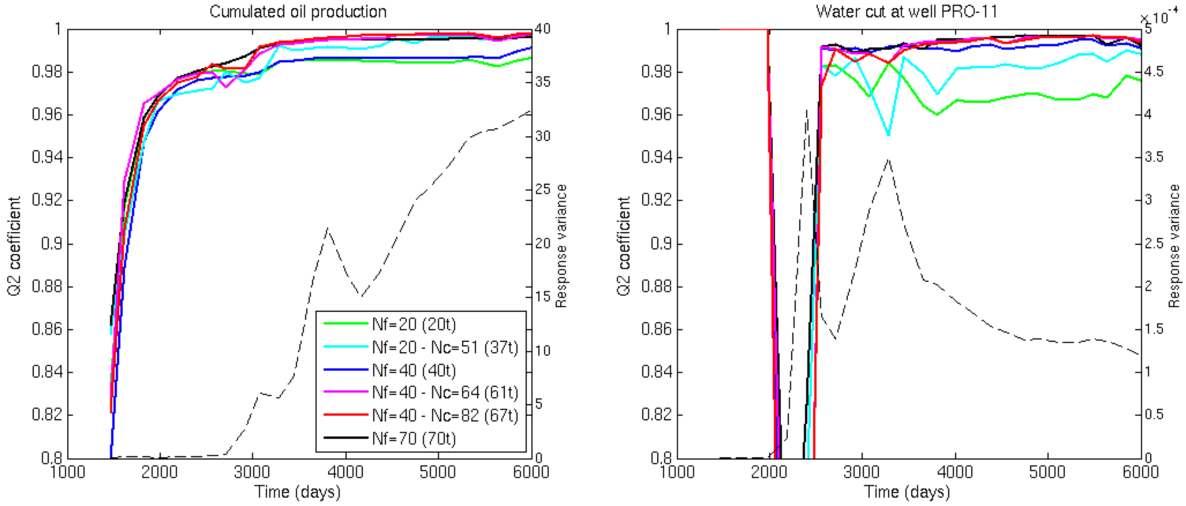

Figure 1 *Q2 coefficients computed for the cumulated oil production in the reservoir (left) and the water-cut at a well (right) at successive times of the production period. Nf denotes the number of fine-grid simulations and Nc the number of coarse-grid simulations used to build the meta-models. The total simulation time is given as a multiple of the time needed to perform a simulation on the fine grid (t). The dotted line shows the variance among the responses of the confirmation set.*

Conclusions

The results obtained so far with multi-fidelity meta-modeling on reservoir models are encouraging. Further tests should be performed on other cases and types of outputs. Also, we only considered here fixed designs of experiments. It would be interesting to investigate adaptive designs to improve iteratively the multi-fidelity meta-models.

References

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