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A computationally efficient Bayesian sequential simulation approach for the assimilation of vast and diverse hydrogeophysical datasets

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Bayesian sequential simulation (BSS) is a powerful geostatistical technique, which notably has shown significant potential for the assimilation of datasets that are diverse with regard to the spatial resolution and their relationship. However, these types of applications of BSS require a large number of realizations to adequately explore the solution space and to assess the corresponding uncertainties. Moreover, such simulations generally need to be performed on very fine grids in order to adequately exploit the technique's potential for characterizing heterogeneous environments. Correspondingly, the computational cost of BSS algorithms in their classical form is very high, which so far has limited an effective application of this method to large models and/or vast datasets. In this context, it is also important to note that the inherent assumption regarding the independence of the considered datasets is generally regarded as being too strong in the context of sequential simulation.

To alleviate these problems, we have revisited the classical implementation of BSS and incorporated two key features to increase the computational efficiency. The first feature is a combined quadrant spiral – superblock search, which targets run-time savings on large grids and adds flexibility with regard to the selection of neighboring points using equal directional sampling and treating hard data and previously simulated points separately. The second feature is a constant path of simulation, which enhances the efficiency for multiple realizations. We have also modified the aggregation operator to be more flexible with regard to the assumption of independence of the considered datasets. This is achieved through log-linear pooling, which essentially allows for attributing weights to the various data components. Finally, a multi-grid simulating path was created to enforce large-scale variance and to allow for adapting parameters, such as, for example, the log-linear weights or the type of simulation path at various scales.

The newly implemented search method for kriging reduces the computational cost from an exponential dependence with regard to the grid size in the original algorithm to a linear relationship, as each neighboring search becomes independent from the grid size. For the considered examples, our results show a sevenfold reduction in run time for each additional realization when a constant simulation path is used. The traditional criticism that constant path techniques introduce a bias to the simulations was explored and our findings do indeed reveal a minor reduction in the diversity of the simulations. This bias can, however, be largely eliminated by changing the path type at different scales through the use of the multi-grid approach. Finally, we show that adapting the aggregation weight at each scale considered in our multi-grid approach allows for reproducing both the variogram and histogram, and the spatial trend of the underlying data.