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Linearized uncertainty propagation, geostatistical inversing, and data-worth analysis in heterogeneous aquifers

O.A. Cirpka (1), W. Nowak (2), and C.M. Bürger (3)

(1) Swiss Federal Institute for Environmental Science and Technology (EAWAG), Dübendorf, Switzerland (olaf.cirpka@eawag.ch),
(2) Universität Stuttgart, Institut für Wasserbau, Stuttgart, Germany (wolfgang.nowak@iws.uni-stuttgart.de),
(3) Universität Tübingen, Center for Applied Geoscience, Tübingen, Germany (claudius.buerger@uni-tuebingen)

First-order second-moment methods of uncertainty propagation require quadratic matrix-matrix multiplications of the covariance matrix of parameters and the sensitivity matrix of the quantities of interest with respect to all parameters. In a discretized numerical groundwater flow and transport model, the number of parameters is in the order of the number of grid cells ($\approx 10^5 - 10^6$). Thus, efficient methods are needed to perform the calculations. For this purpose, we embed the domain into a larger periodic domain and apply Fourier-transformation techniques for matrix-matrix multiplications. This allows us computing cross-covariance matrices within seconds, rather than hours, on a standard PC. The original technique requires stationarity of the covariance function. Many cases of nonstationarity can also be treated, since they either can be traced back to stationary counterparts (e.g. zonal stationarity) or lead to covariance matrices consisting of a sum of a easy-to-handle matrices (e.g. conditional covariance matrices).

We apply the technique to the quasi-linear geostatistical approach of inverse modeling, e.g., in the inference of the log-conductivity distribution from head measurements. We use it also for uncertainty propagation *per se*, e.g., in the assessment of the hydraulic reliability of funnel-and-gate designs in heterogeneous media or in the computation of the travel-time variance at a control plane. Optimal points for additional sampling can be determined by computing the expected variance reduction by conditioning.