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Stochastic Collocation and Lagrangian Sampling for Passive Tracer Transport in an Aquifer with Random Permeability

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To a large extent, the flow and transport behavior within an aquifer is governed by its permeability. Typically, permeability measurements of an aquifer are affordable at few spatial locations only. Due to this lack of information, permeability fields are preferably described by stochastic models rather than deterministically. A stochastic method is needed to asses the transition of the input uncertainty in permeability through the system of partial differential equations describing flow and transport to the output quantity of interest.

The stochastic collocation method is an elegant and efficient tool for uncertainty quantification in subsurface problems. Several contributions (e.g., Li and Zhang, WRR, 2007) have successfully applied stochastic collocation-based frameworks for the flow problem. For the transport problem, however, Lin and Tartakovsky (AWR, 2009) have shown that an accurate solution via stochastic collocation is more challenging.

We propose a hybrid approach that utilizes stochastic collocation to solve the flow problem only and Monte Carlo-type sampling for transport: By means of stochastic collocation, we approximate the random flow field with a polynomial chaos expansion. Subsequently, a conventional Monte Carlo sampling technique is used for passive tracer transport. Here, the computational costs per flow field sample are very low thanks to the polynomial chaos expansion. In case of negligible pore-scale dispersion, the same holds true for a passive tracer transport sample, since a Lagrangian transport formulation can be employed. Our approach avoids problems related to the accurate collocation-based solution of the transport problem, while being significantly faster than full Monte Carlo. (Full Monte Carlo does not rely on a polynomial chaos expansion of the random flow field).

The proposed method is applied for passive tracer transport within a two-dimensional aquifer. A multi-point Gaussian logarithmic permeability field is assumed.