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Stochastic analysis of flow in porous media with sparse polynomial chaos expansion

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An efficient method for uncertainty analysis of flow through highly heterogeneous porous media is explored in this study, combining the Karhunen-Loève (KL) decomposition and a non-intrusive stochastic approach. The random log transformed hydraulic conductivity field is represented by the Karhunen-Loève expansion and the hydraulic head is expressed by a sparse polynomial chaos expansion.

Recently, classical solution schemes based on polynomial chaos expansions (PCE) have been accurately used to quantify uncertainty in groundwater flow and solute transport problems (Li and Zhang (2007), Fontaine et al. (2010), Fajraoui et al. (2011)). However, their major drawback is that the computational cost associated with blows up if many input variables are involved, say more than ten.

When dealing with random fields as it is the case in the present study, the discretization may lead to a significant number of truncated terms (i.e. the input variables). This number depends on the ratio of correlation length to the domain size. The smaller the correlation length the large number of terms is to be retained in the KL expansion, which makes the solution of the classical PCE unfeasible and the computational cost unaffordable.

In order to avoid this “curse of dimensionality”, the Sparse Polynomial Chaos Expansion (SPCE) developed by Blatman and Sudret (2011) is used herein. This method is based on an adaptive regression-based algorithm which automatically detects the significant coefficients of the PCE to be computed. As a consequence, a rather small number of the PCE coefficients is eventually retained (sparse representation), which may be obtained at a reduced computational cost compared to the classical “full” PCE representation.

A set of numerical experiments (1D and 2D) of flow in random porous media are performed with different spatial variability and correlation lengths featuring 10 - 100 input variables. Results show that the proposed scheme noticeably overperforms the classical strategy based on full PC expansions in terms of accuracy and efficiency.

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