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Model reduction in coupled groundwater-surface water systems - potentials and limitations of the applied proper orthogonal decomposition (POD) method

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The complexity of many groundwater-surface water models often results in long model run times even on today's computer systems. This becomes even more problematic in combination with the necessity of (many) repeated model runs for parameter estimation and later model purposes like predictive uncertainty analysis or monitoring network optimization. Model complexity reduction is a promising approach to reduce the computational effort of physically-based models. Its impact on the conservation of uncertainty as determined by the (more) complex model is not well known, though. A potential under-estimation of predictive uncertainty has, however, a significant impact on model applications such as model-based monitoring network optimization. Can we use model reduction techniques to significantly reduce run times of highly complex groundwater models and yet estimate accurate uncertainty levels?

Our planned research project hopes to assess this question and apply model reduction to non-linear groundwater systems. Several encouraging model simplification methods have been developed in recent years. To analyze their respective performance, we will choose three different model reduction methods and apply them to both synthetic and real-world test cases to benchmark their computational efficiency and prediction accuracy. The three methods for benchmarking will be proper orthogonal decomposition (POD) (following Siade et al. 2010), the eigenmodel method (Sahuquillo et al. 1983) and inversion-based upscaling (Doherty and Christensen, 2011). In a further step, efficient model reduction methods for application to non-linear groundwater-surface water systems will be developed and applied to monitoring network optimization.

In a first step we present here one variant of the implementation and benchmarking of the POD method. POD reduces model complexity by working in a subspace of the model matrices resulting from spatial discretization with the same significant eigenvalue spectrum. The subspace is generated by sampling full-model variation via snapshots in time, which requires only a few runs of the complex model. In theory, straight-forward POD methods are only applicable to linear problems. To test the limits of the POD method, we apply it to a complex non-linear synthetic groundwater model using MODFLOW and compare the loss of model accuracy to the accuracy of the complex model. Success of the applied POD method is evaluated by estimating the tradeoff between reduction of computing times and the deterioration of simulation accuracy. Preliminary results have shown that run time reductions of two orders of magnitude are possible while retaining acceptable precision levels.

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