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Data-driven framework for history matching: application to carbon dioxide storage in geological formations

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CO2 storage in geological formations is currently being discussed intensively as a technology for mitigating CO2 emissions. The construction of accurate models of underground reservoirs and the reproduction of real flow behaviours using simulation is a very challenging task for the applied research. Once a virtual model has been established, the history matching to the real field becomes an extremely important issue in order to improve the confidence of prediction. First of all, the accuracy of the history matching depends on the quality of the established physical model including all aspects, such as seismic, geological and hydrodynamic characteristics, fluid properties etc. Secondly, the history matching procedure itself is very time consuming from the computational point of view. Even one single forward deterministic simulation may require parallel high-performance computing. This fact makes a brute-force optimization approach not feasible, especially for large-scale simulations. We propose an advanced framework based on a massive model reduction which consists of two main steps. Step one - the original full complex model is projected onto an integrative response surface via data-driven polynomial chaos expansion. This projection is totally non-intrusive and optimally constructed for available reservoir data, using a data-driven orthonormal polynomial basis. Thus, the integrative response surface keeps all nonlinearity of the initial model and incorporates all suitable parameters, such as uncertain parameters (porosity, permeability etc.) and design or control parameters (injection rate, depth etc.). Technically, the computational power for the construction of such a response surface depends on the number of modeling parameters and the expansion degree. However, according to the probabilistic collocation approach, only the minimum number of forward simulations is required, which makes the proposed framework very powerful in comparison to classical sequential approaches. Step two consists of the Bayesian update in order to match the simulation model to available measurements of state variables or other the real-time observations of system behavior, such as pressure at monitoring wells during a certain time period, etc. Practically, we apply particle filtering on the integrative response surface constructed at step one. First of all, particle filtering is a strong technique for the reduction of predicting uncertainty which takes into consideration the nonlinearity of the model. At second, Bayesian updating becomes an interactive task and can incorporate real time measurements due to the fact that even sequential simulation on the constructed polynomials is very cheap. To summarize, we propose a novel framework for history matching of reservoir behavior which takes into consideration the nonlinearity of the model and provides a cheap but highly accurate tool for the reduction of prediction uncertainty.