Geophysical Research Abstracts
Vol. 15, EGU2013-3214, 2013
EGU General Assembly 2013

Chaos Expansion Based Bootstrap Filter To Calibrate CO_2 Injection Models

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Carbon dioxide (CO_2) storage in geological formations is currently being discussed intensively as an interims technology with a high potential for mitigating CO_2 emissions. Predicting underground CO_2 storage represents a challenging problem in a complex dynamic system. Any large-scale application of CO_2 storage requires a thorough risk analysis. Due to lacking information about distributed systems properties (such as porosity, permeability, etc.), quantification of uncertainties may become the dominant question in the risk assessment. Calibration on past production data from pilot scale test injection (called history matching) can improve the predictive power of the involved geological, flow and transport models. However, history matching is a very challenging task. Usually, brute-force optimization approaches for calibration are not feasible, especially for large-scale simulations. The current work deals with an advanced framework for history matching based on the polynomial chaos expansion (PCE). We will combine drastic but adequate stochastic model reduction with a brute-force but fully accurate Bayesian updating mechanism. Thus, we obtain a method for history matching that is both accurate and efficient, and allows a rigorous quantification of calibrated model uncertainty. The framework consists of two main steps. In step one, the original model is projected onto a response surface via a very recent PCE technique, called the arbitrary polynomial chaos (aPC). This projection is totally non-intrusive, i.e. is black-box compatible with commercial or open-source simulation codes. The aPC has the advantage that it can handle arbitrary distribution shapes of uncertain parameters. The distributions may change their shapes between updating steps, and may be incompletely known a priori. In our work, we set up a DuMuX-based model for a well-known pilot site operated in Europe. We parameterized geological uncertainty through permeability multipliers, and capture the dependence of the model on these multipliers with the response surface. Step two consists of Bayesian updating in order to match the reduced model to past or real-time observations of system behavior (e.g. past production data or pressure at monitoring wells during a certain time period). In this step we apply Bootstrap filtering on the response surface constructed in step one. Bootstrap filtering is a fully non-linear and Bayesian approach to the inverse problem in history matching, more accurate than Ensemble Kalman filters. As a specific methodological focus, ensuring that the expansion remains optimal even if the updated parameter values are far from their prior expansion, we will iterate between Step 1 and Step 2, so that the PCE expansion will be repeated successively. This may be interpreted as a high-order expansion equivalent to successive linearization.