Geophysical Research Abstracts
Vol. 13, EGU2011-11898, 2011
EGU General Assembly 2011

Use of Gaussian Process Emulators for Quantifying Uncertainty in CO2 Spreading Predications in Heterogeneous Geological Media

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The spreading and trapping behavior of carbon dioxide injected into a porous reservoir layer is highly dependent of the heterogeneity characteristics of the reservoir, and a proper description of the heterogeneity is therefore needed. The presence of the geological heterogeneity introduces uncertainty in estimating the parameter field, in particular the hydraulic conductivity field of the medium. This in turn, introduces uncertainty in the subsequent modeling prediction. Modeling of CO2 spreading and trapping in heterogeneous medium is a computationally demanding exercise, both due to the complex set of coupled equations to be solved as well as due to the large size of the domains to be modeled. For such systems, even the simulation of a single realization of the heterogeneous medium becomes a major effort and the application of the traditional Monte Carlo approach with multiple realizations is computationally prohibitive.

In this presentation we will explore an alternative approach based on so-called Gaussian process emulators (GPE). The basic idea of the approach is that the GPE produces a good approximation to the output of the full simulation, given the input parameters, but is much cheaper to run than the full simulation. In a traditional Monte-Carlo method the full simulation has to be run for a large number of realizations, whereas in the GPE approach a relatively small number of realizations of the full problem are run first to train the emulator. The trained emulator is then run for many realizations to produce the required output. The statistical properties of the output can be computed from the emulator runs and will give a good approximation to the properties that would have been computed from running the full simulation many times, but at greatly reduced computational cost.

The method is demonstrated for the case of CO2 spreading in a representative geology with the permeability modelled as a lognormal random field with an exponential correlation structure. A truncated Karhunen-Loève (KL) expansion of the logarithm of the permeability field is used so that the input to the calculation can be characterized by a finite number of parameters, which are the coefficients in the KL expansion. The total volume of CO2 injected by a give time is then a function of the KL coefficients and it is this quantity that is emulated. A Monte-Carlo simulation of this quantity is effectively achieved by running the emulator many times with the input parameters (the KL coefficients) drawn from the appropriate multivariate normal distribution.