Geophysical Research Abstracts
Vol. 21, EGU2019-10668, 2019
EGU General Assembly 2019

Quantification of parametric uncertainty and calibration of basin-scale depositional models

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The study is geared towards the development of a strategy to manage uncertainty arising from the variety of parameters embedded in three-dimensional multi-lithology stratigraphic models which allow modelling the development and formation of large scale stratigraphic sequences. These models are associated with a high computational cost due to (a) the richness and complexity of processes included and (b) the large number of input parameters which are typically affected by uncertainty.
Here, we design and implement a procedure which enables us to perform (a) a preliminary screening leading to the delineation of the most influential model parameters, (b) a global sensitivity analysis yielding the relative contribution of uncertain model parameters to key (statistical) moments of model output and (c) model calibration.
Quantities of interest forming the output of a stratigraphic modeling application include thickness of depositional sequences and spatial distributions of sediments, the latter being categorized in terms of a set of lithological fractions (e.g. siliclastic and carbonate sediments). Our approach starts by focusing on the selection of the most influential parameters, identified within the space of the model parameters. We do so by relying on the joint use of Morris indices and Principal Component Analysis (PCA) and by considering model parameters as independent and identically distributed (iid) random variables, uniformly distributed across a given support, whose width is assessed on the basis of literature information and modelers' experience.
The resulting reduced parameter set is then used for the construction of a surrogate (or reduced complexity) model mimicking basin scale deposition and grounded on the Polynomial Chaos Expansion (PCE) technique. This step enables us to (a) evaluating model output quantities of interest at an affordable computational cost and (b) obtain directly the Sobol Indices, which provide a quantification of the relative contribution of each model parameter to the variance of target outputs.
The surrogate model is the basis for model calibration, which is conducted by way of the Particle Swarm Optimization (PSO) technique. This yields the full (posterior) probability density function of the selected model parameters, thus allowing a complete characterization of the way uncertainty is propagated from unknown model parameters to target outputs through conditioning on available observations.
The procedure outlined above is applied to a synthetic test bed, considering input parameter effects on variables of the system such as local sediment compositions (in terms of fractions of sand, shale, and carbonates) and thickness of the basin. Our study allows assessing the potential of this procedure to (1) identify important model parameters, (2) analyze spatially distributed sensitivities to a variety of uncertain parameters in a complex sedimentological environment and (3) identify parameter combinations compatible with a given set of observations typically available in basin-scale exploration campaigns (i.e. vertical distributions of volumetric fractions and sediment thickness in deep exploration boreholes). Current developments include application of the procedure in a full field scenario.