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Uncertainty Quantification of geochemical and mechanical compaction in layered sedimentary basins

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Abstract

In this work we propose an Uncertainty Quantification methodology for sedimentary basins evolution under mechanical and geochemical compaction processes, which we model as a coupled, time-dependent, non-linear, monodimensional (depth-only) system of PDEs with uncertain parameters. While in previous works (Formaggia et al. 2013, Porta et al., 2014) we assumed a simplified depositional history with only one material, in this work we consider multi-layered basins, in which each layer is characterized by a different material, and hence by different properties. This setting requires several improvements with respect to our earlier works, both concerning the deterministic solver and the stochastic discretization. On the deterministic side, we replace the previous fixed-point iterative solver with a more efficient Newton solver at each step of the time-discretization. On the stochastic side, the multi-layered structure gives rise to discontinuities in the dependence of the state variables on the uncertain parameters, that need an appropriate treatment for surrogate modeling techniques, such as sparse grids, to be effective. We propose an innovative methodology to this end which relies on a change of coordinate system to align the discontinuities of the target function within the random parameter space. The reference coordinate system is built upon exploiting physical features of the problem at hand. We employ the locations of material interfaces, which display a smooth dependence on the random parameters and are therefore amenable to sparse grid polynomial approximations. We showcase the capabilities of our numerical methodologies through two synthetic test cases. In particular, we show that our methodology reproduces with high accuracy multi-modal probability density functions displayed by target state variables (e.g., porosity).

Keywords: Sedimentary basin modeling, Uncertainty Quantification, Random PDEs, Sparse grids, Stochastic Collocation Method

2010 MSC: 41A10, 65C20, 65N30

1. Introduction

Sedimentary basins occupy depressions of the Earth's crust where different materials may deposit along geologic times. Numerical simulation of compaction processes in sedimentary basins is relevant to a number of fields, e.g. for the characterization of petroleum systems in terms of hydrocarbon generation and migration [1, 2], understanding of large scale hydrologic behavior (e.g., compaction-driven flow or development of fluid overpressure) [3, 4, 5, 6, 7, 8, 9, 10, 11], or modeling the formation of ore deposits [12].

Modeling basin scale compaction requires to consider mechanical compaction due to the sediments overburden. Moreover, geochemical processes may also occur, due to chemical precipitation and/or dissolution

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