Geophysical Research Abstracts
Vol. 21, EGU2019-15910, 2019
EGU General Assembly 2019

Uncertainty Quantification for Basin Scale Heat Flow Models with a Physics-Based Machine Learning Approach

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In order to determine suitable locations for geothermal exploration, reliable predictions of the earth's subsurface temperature field are essential. For these predictions, it is necessary to consider the uncertainties of the involved parameters. However, with the current state-of-the-art simulations standard uncertainty quantification methods, such as Markov Chain Monte Carlo are computationally intractable for basin-scale models at high resolution. We thus require numerical methods that considerably accelerate the forward simulation to enable the use of uncertainty quantification approaches that can easily require up to a million forward simulations.

For this purpose, we introduce the reduced basis method, a physics-based machine learning approach. Our previous studies show that we obtain speed-ups of four to six orders of magnitude in comparison to standard finite element simulations.

One main advantage of the reduced basis method in contrast to other surrogate models is that we obtain temperature values at every point in the model and not only at the observation points. Consequently, we can generate uncertainty maps of the temperatures at the target depth of the geothermal wells for the entire extent of the basin.

We use the Brandenburg (Germany) model to illustrate the application and benefits of the reduced basis method for large-scale geological models. The numerical simulations are realized within the DwarfElephant package, an open-source high-performance application based on the Multiphysics Object Oriented Simulation Environment (MOOSE) developed by the Idaho National Laboratory. The DwarfElephant package offers a physics-independent and user-friendly access to the reduced basis method within a high-performance finite element library, allowing computations of spatially high dimensional models. In addition, we present how the method can be used for other inverse processes, such as automated model calibrations. Inverse problems are becoming rapidly extremely expensive computationally even without including all major sources of uncertainty. In that regard, the reduced basis method is very promising because it allows a significant reduction in computation time without introducing additional physical uncertainties.