Use of Reduced-order Models for Improved Data Assimilation within an EnKF Context

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Abstract

A reduced-order modeling procedure is developed for reservoir simulation applications. The TPWL model represents simulation results for new geological models in terms of a linearization around previously simulated (training) cases. The high-dimensional state space and the parameter space are both projected into a low-dimensional subspace using proper orthogonal decomposition (POD) and Karhunen-Loève (KL) expansion. The resulting method is shown to achieve significant speedup for reservoir simulations with new geological parameters. The method is incorporated into an Ensemble Kalman Filter (EnKF) history-matching procedure. It enables EnKF to use many fewer (high-fidelity) reservoir simulations than would otherwise be required to avoid ensemble collapse.

Methods Studied

a. Trajectory Piecewise Linearization (TPWL)
   - Linearization of the governing equation
     \[ \ell = \ell + \left( \ell + \lambda \right) - \lambda \]
   - terms for the target simulation
   - terms from training simulation
   - training geology
   - Full order linear equation
     \[ \ell = \ell + \left( \ell + \lambda \right) - \lambda \]
   - terms for the training simulation
   - terms for the target simulation
   - training geology

b. Order Reduction of State Space
   - 2-D Gaussian field (45x45), \( \sigma \ln(\ell) = 5, \sigma \ln(\ell) = 1 \)
   - TPWL for EnKF-based History Matching
     - Case 1 uses 200 high fidelity (HF) models
     - Case 2 uses 50 HF models
     - Case 3 uses 50 HF + 150 TPWL models

Conclusions

- TPWL provides approximate simulation results for new geological models very efficiently.
- TPWL aided Ensemble Kalman Filter (EnKF) provides much better results than the standard EnKF with a small ensemble.
- Future work will focus on improving the accuracy and stability of the TPWL method.