Polynomial-Chaos-Expansion Based Metamodel for Computationally Efficient Data Assimilation in Closed-Loop Reservoir Management

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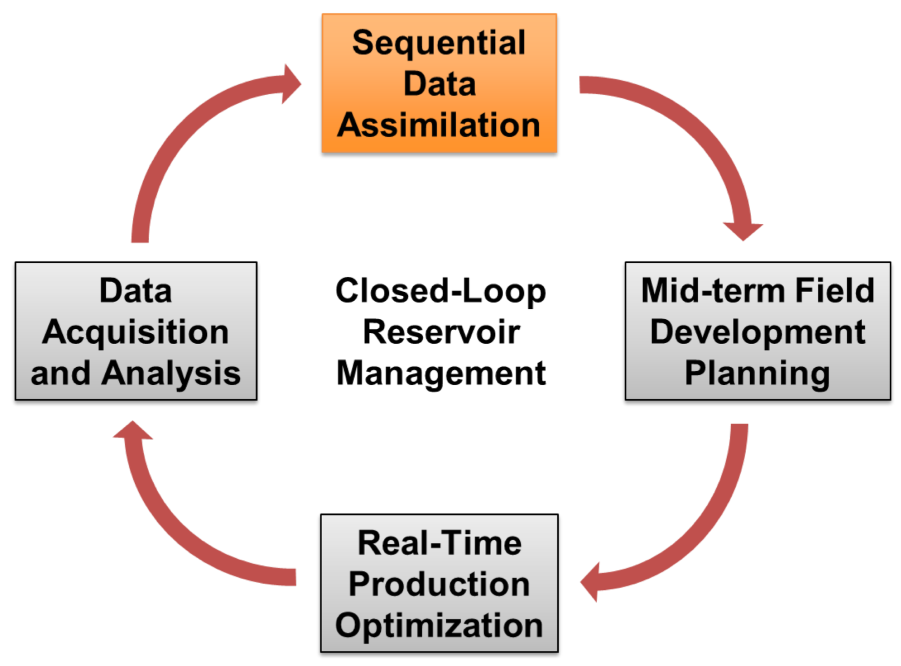
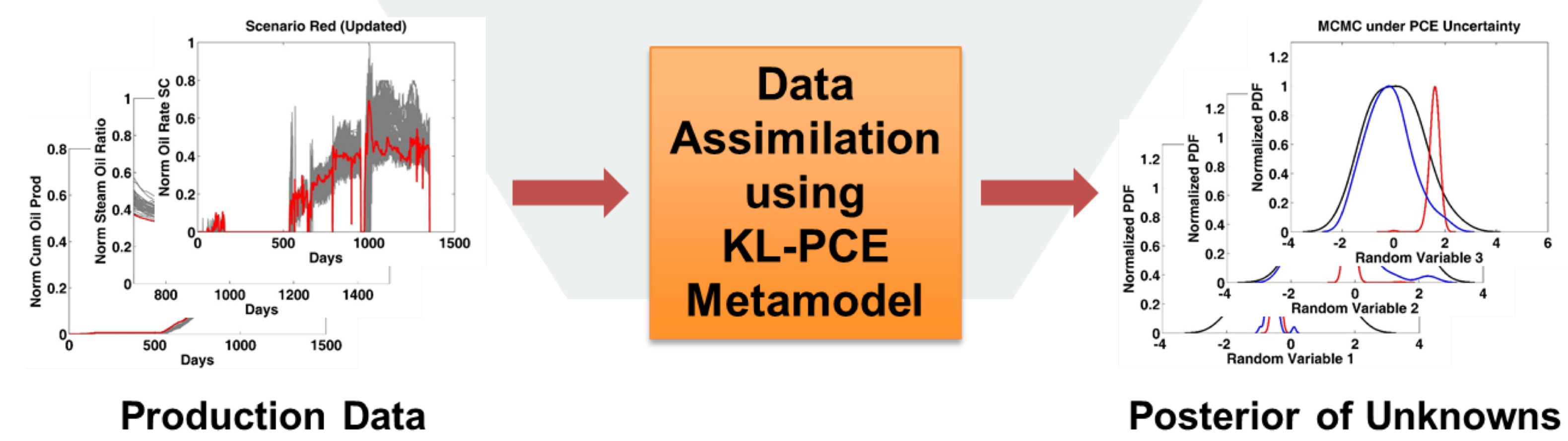
BACKGROUND

Data recorded in the digital oil fields can be sequentially assimilated in closed-loop reservoir management (CLRM) to estimate unknown reservoir parameters. However, millions of simulation runs may be required in the process, ultimately resulting into impractical computational cost.



OBJECTIVES

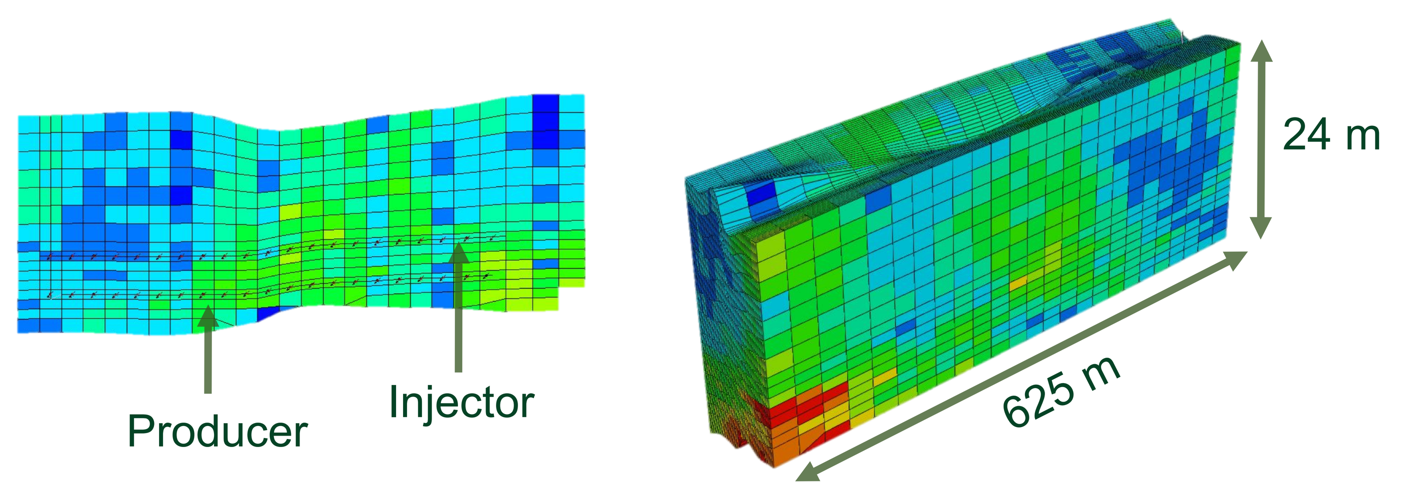
Data-driven meta/surrogate/proxy models provide an alternative solution to alleviate the issue of high computational cost. In this research, the primary objective is to develop an accurate and computationally efficient polynomial chaos expansion (PCE) based metamodel. It can be incorporated in state-of-the-art data assimilation frameworks as a forecast model and can handle a large number of input variables through parameterization.



SAGD FIELD CASE STUDY

Numerical Experiments

A field-scale 3D model, representing a segment of the steam-assisted gravity drainage (SAGD) reservoir located near Fort McMurray, Alberta is considered.



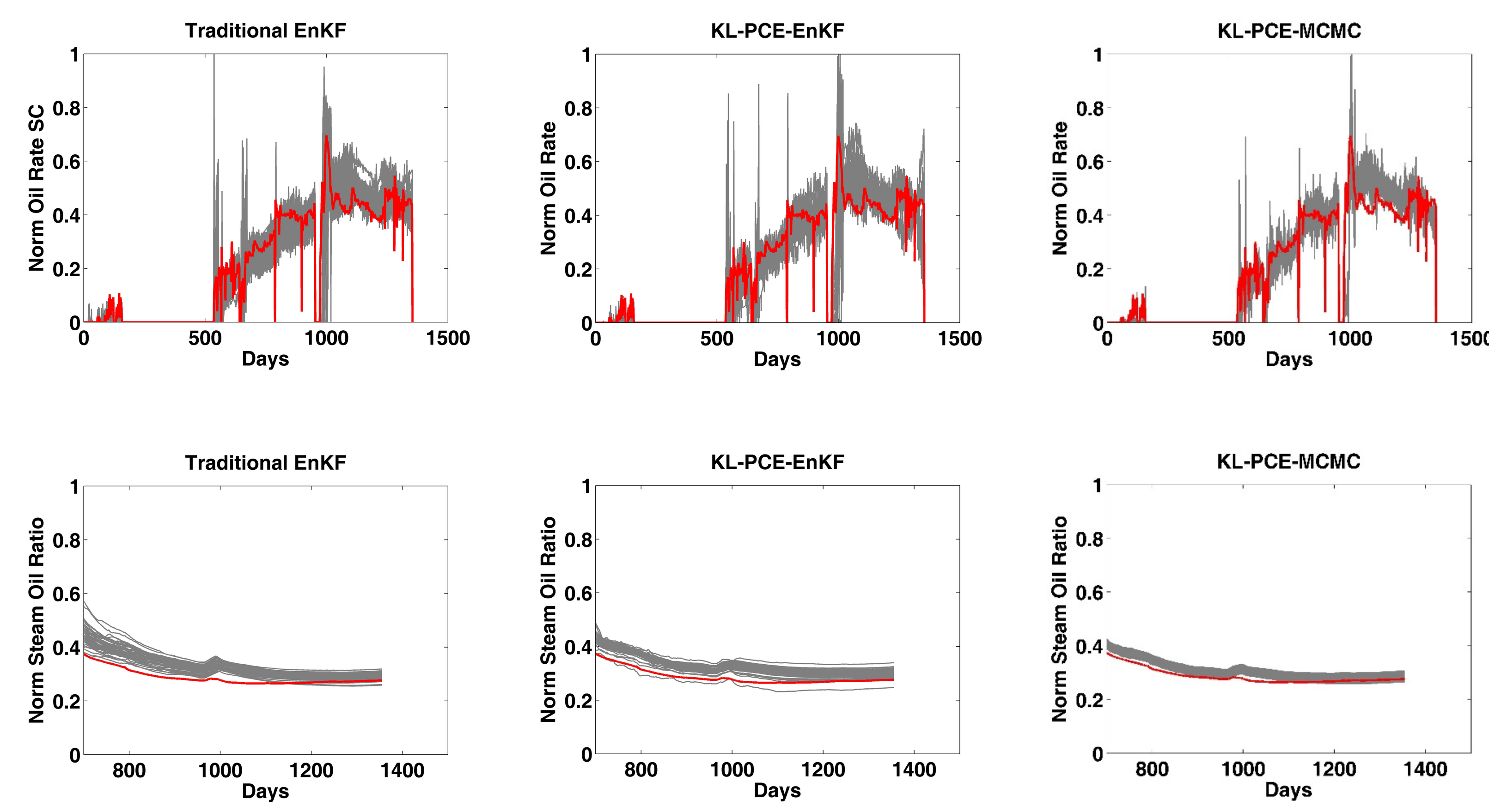
Model parameters (permeability of each grid block) are represented using 3 eigen values and corresponding random variables in Karhunen-Loeve parameterization.

A 2nd order polynomial chaos with 3 stochastic variables (ξ) and Hermite polynomials is constructed. Probabilistic collocation method is used to compute PCE coefficients.

$$y = y_0 + y_1 H_1(\xi_1) + y_2 H_1(\xi_2) + y_3 H_1(\xi_3) + y_4 H_2(\xi_1) + y_5 H_2(\xi_2) + y_6 H_2(\xi_3)$$
$$+ y_7 H_1(\xi_1) H_1(\xi_2) + y_8 H_1(\xi_2) H_1(\xi_3) + y_9 H_1(\xi_1) H_1(\xi_3)$$

Three numerical experiments are performed: 1) Ensemble Kalman Filter (EnKF) with reservoir simulator, 2) PCE metamodel with EnKF, and 3) PCE metamodel with Markov chain Monte Carlo (MCMC).

Results



Numerical Experiment	Simulation Runs	Execution Time (sec)
Traditional EnKF	400	4.573×10^5
KL-PCE + EnKF	10	3.051×10^2
KL-PCE + MCMC	10	6.073×10^3

CONCLUSIONS AND FUTURE WORK

Conclusions:

1) Using PCE metamodel, significant reduction in computational cost is achieved without compromising the data assimilation results.
2) EnKF can provide reliable estimations of model parameters and observations using PCE based forecast model.
3) MCMC is more robust than EnKF against forecast model uncertainty as it provides accurate posterior distributions.

Future Work:

1) Evaluation of various machine learning techniques with latest data assimilation methods to understand their performance under various conditions and sources of uncertainties.
2) Application of PCE metamodel for the long-term robust optimization of reservoir operations.

FES PROJECT OVERVIEW

Project T07-C02

Reservoir management and advanced optimization for thermal and thermal-solvent based recovery processes using scaled models and machine learning

Activities:

The project aims to improve the heavy oil reservoir operations through multiscale and multi-objective optimization, scale-up methods, and machine learning. Quick real-time optimization and application of big data analytics will be considered for optimum resource allocation at various stages of a reservoir lifecycle.

Impact:

Outcomes of the research will be essential for low cost and energy efficient steam/solvent assisted oil recovery processes. Advanced workflows will allow the data-driven real-time decision making, optimal steam usage, and GHG benefits.

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