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GenAI4UQ: A Generative AI Framework for Accurate and Fast State Variable Forecasting in Geological Carbon Storage

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Forecasting reservoir pressure and CO_2 plume distribution in geological carbon storage (GCS) demands the efficient integration of monitoring data with reservoir simulations. Traditional inverse modeling methods often rely on restrictive linear or Gaussian assumptions, limiting their predictive accuracy for complex state variables. Moreover, simulating large-scale three-dimensional (3D) GCS problems is computationally expensive, making iterative runs in inverse problems prohibitive.

To address these challenges, we propose GenAI4UQ, a software package designed for inverse uncertainty quantification in model calibration, parameter estimation, and ensemble forecasting. Powered by a conditional generative AI framework, GenAI4UQ replaces computationally expensive iterative simulations with a direct, AI-driven mapping. Its capabilities include rapid ensemble generation, robust uncertainty quantification, and efficient use of computational and storage resources. The software's automated hyperparameter tuning further ensures accessibility for users with diverse expertise levels.

We demonstrate the effectiveness of GenAI4UQ in forecasting 3D pressure and saturation fields during a 30-year CO_2 injection period. Our method achieves low root mean square error (RMSE) values, accurately capturing spatiotemporal distributions of state variables. Remarkably, GenAI4UQ generates 100 ensemble forecasts of 3D state variables in just 10 seconds, highlighting its unparalleled computational efficiency. Ensemble averages closely align with ground truth values, and the model effectively captures variability and observational noise, ensuring reliable uncertainty quantification.

By enabling rapid parameter distribution estimation and model predictions for new observations, GenAI4UQ equips researchers and practitioners with a powerful tool for real-time decision-making in GCS applications. This generative AI-based approach provides a practical and efficient solution to the computational and predictive challenges in large-scale GCS applications.

The code is available at https://github.com/patrickfan/GenAI4UQ

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References

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