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Subsurface CO2 Leakage Detection Using Multi-stage Well Testing And Machine Learning

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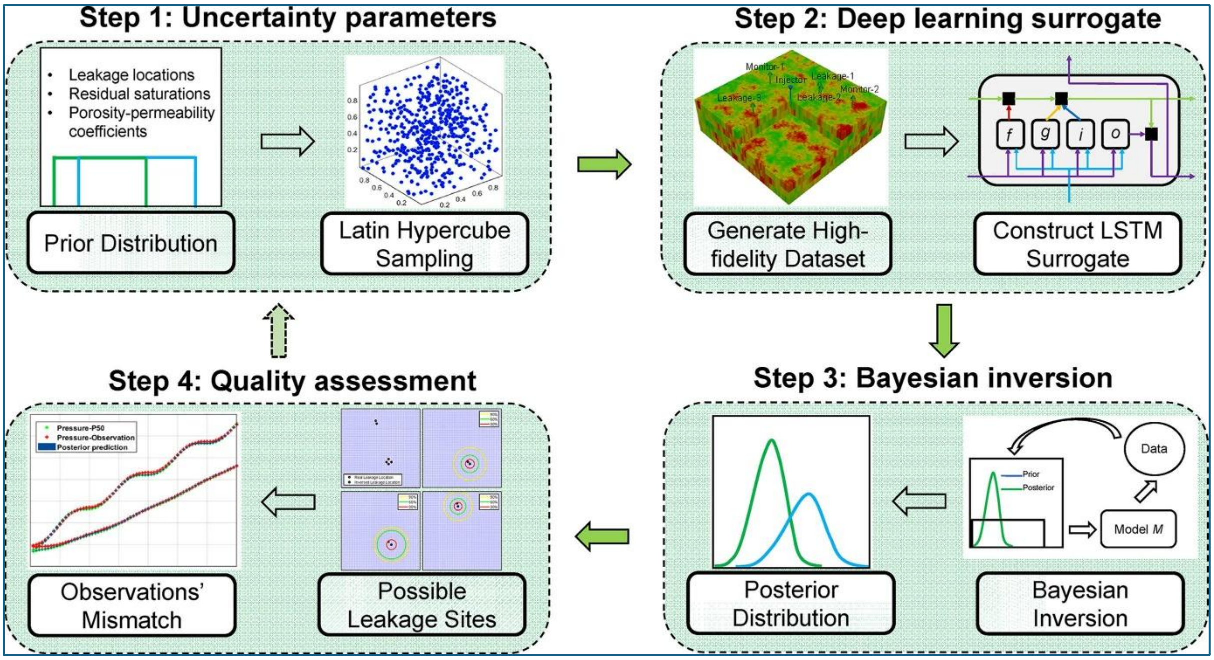
Objectives/Scope: The accurate and efficient localization of CO2 leakage in subsurface formations is critical to ensuring the security and success of geological carbon sequestration (GCS) projects. However, this task poses significant challenges due to the inherent uncertainties associated with subsurface environments. In this study, we propose a novel Bayesian framework, enhanced with deep learning techniques, to identify potential CO2 leakage sites. This framework leverages the multi-stage well-testing technique, measured at injection or observation wellbores, to enhance detection accuracy.

Methods, Procedures, Process: The proposed method involves two key steps: machine learning surrogate and Bayesian inversion. The machine learning surrogate efficiently replaces computationally intensive high-fidelity simulations, while Bayesian inversion determines the posterior distributions of potential CO2 leakage locations, utilizing the surrogate model as the forward simulation tool. These processes are seamlessly automated using Bayesian optimization, eliminating the need for labor-intensive trial-and-error approaches and significantly enhancing efficiency and scalability. The proposed workflow is illustrated in the attached Figure.

Results, Observations, Conclusions: The proposed framework is validated using a 3D geological model that simulates CO2 sequestration in a brine-filled reservoir. The results show that the Bayesian-optimized surrogate effectively captures the underlying dynamics of subsurface CO2-brine flow, while the Bayesian inversion algorithm accurately localizes potential CO2 leakage with high precision.

Novel/Additive Information: To our knowledge, this is the first implementation of a Bayesian framework for locating multiple CO2 leakage sites at the field scale. The proposed workflow offers a highly accurate and efficient real-time approach for detecting potential leakage locations, demonstrating significant promise for field-scale applications in geological carbon sequestration (GCS).


Step 1: Uncertainty parameters
Leakage locations
Residual saturations
Porosity-permeability coefficients
Prior Distribution
Latin Hypercube Sampling
Step 2: Deep learning surrogate
Generate High-fidelity Dataset
Construct LSTM Surrogate
Step 3: Bayesian inversion
Posterior Distribution
Bayesian Inversion
Prior
Posterior
Data
Model M
Step 4: Quality assessment
Pressure-P50
Pressure-Observation
Posterior prediction
Observations' Mismatch
Possible Leakage Sites