Machine Learning Applied to Parametric Analysis of CO_2 Migration During Geologic Carbon Sequestration in a Sandstone Reservoir

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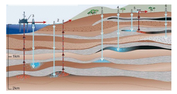
Fluid Flow Dynamics Uncertainties

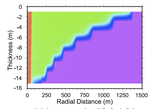
Carbon Capture and Storage (CCS)

- Capillary pressure
- Buoyancy
- Relative permeability
- Thermal
- .....

Computational simulations ⟷ Multi-component Multi-phase Fluid flow dynamics at reservoir scale



Cook (1999)

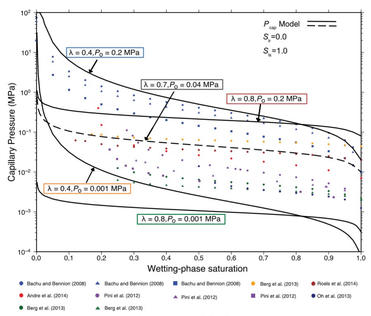


Wu et al. (2018)

To study the fluid flow dynamics, there are feedbacks between reservoir properties should be considered, and computational methods provide benefits to learn how the reservoir system will behave at a large scale.

Reservoir Properties and Parameter Variabilities

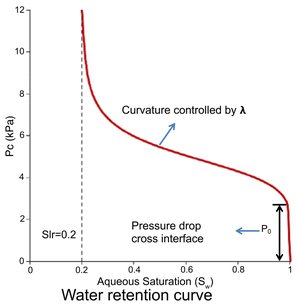
Capillary pressure



Wu et al. (2018)

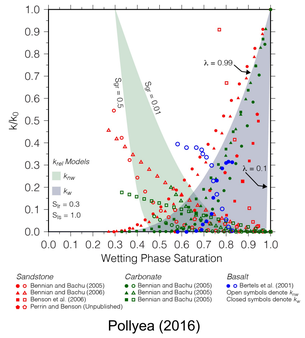
$$P_{cap} = -P_o([S^*]^{-\frac{1}{\lambda}} - 1)^{1-\lambda},$$

$$S^* = \frac{S_l - S_{lr}}{S_{ls} - S_{lr}}.$$



Water retention curve

Relative Permeability

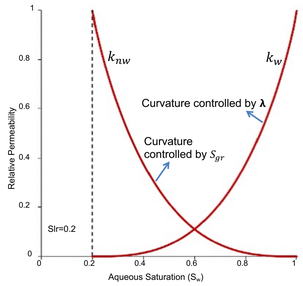


Pollyea (2016)

$$k_{nw} = (1-\hat{S})^2(1-\hat{S}^2),$$

$$\hat{S} = \frac{S_l - S_{lr}}{1 - S_{lr} - S_{gr}}.$$

$$k_w = \sqrt{S^*}[1-(1-S^{*\frac{1}{\lambda}})^{\lambda}]^2$$



Relative permeability curve

For different types of sandstone, capillary pressure and relative permeability measurements both show a large variability at a laboratory scale. To test the effect of these variabilities on fluid flow dynamics at reservoir scale, three parameters (grey) are picked to quantify the variabilities (same λ).

Model Setup

Objective

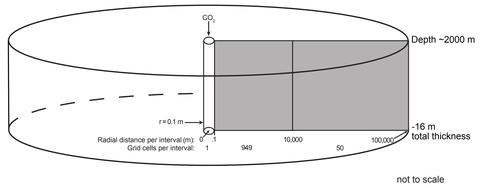
Understanding the effects of the capillary pressure and relative permeability variabilities:

- CO_2 plume geometry
- Fluid pressure perturbation

Method: Physics-based numerical simulation
Machine Learning method

- Machine learning increases the computation efficiency of computational simulations of CO_2 sequestration
- Predictions over large parameter space provide a more comprehensive understanding of parametric variability

Domain: a synthetic sandstone reservoir

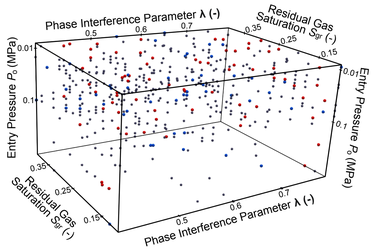


Supercritical CO_2 Injection
8.0 kg/s (229,023 MT/yr)
10 years

P_f = 20 MPa
T= 75 °C
C_{nacl} = 10,000 ppm
k = 4×10^{-13} m^2
Φ = 0.2

C_{nacl}, k, and ϕ from Berea Sandstone (S.Berg et al 2013)

3-D Parameter Table

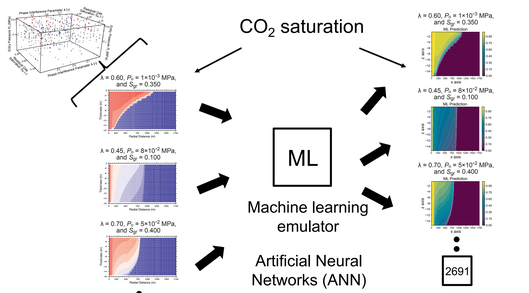


Parameter combinations of P_o, λ, and S_{gr}

460 Physics-based simulations (TOUGH3)

To explain the effects of capillary pressure and relative permeability, a simulation ensemble is produced for unique combinations of *Po*, *λ*, and *Sgr*. The results are then analyzed to quantify the variability in both CO_2 migration and fluid pressure perturbation. A total of 460 different parameter combinations are randomly selected from the 3- D parameter space.

Machine Learning Application



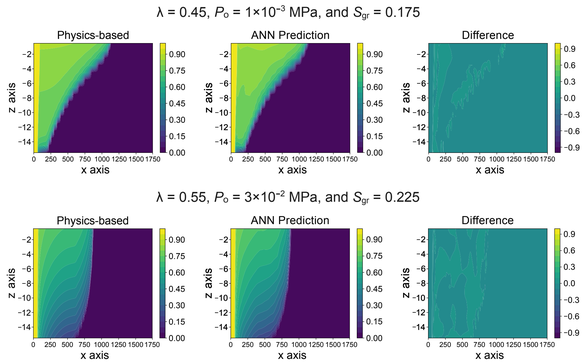
460 Physics-based simulations
Time: ~6 months

ML Prediction
~5 hours training
~10 minutes prediction

Results Analysis

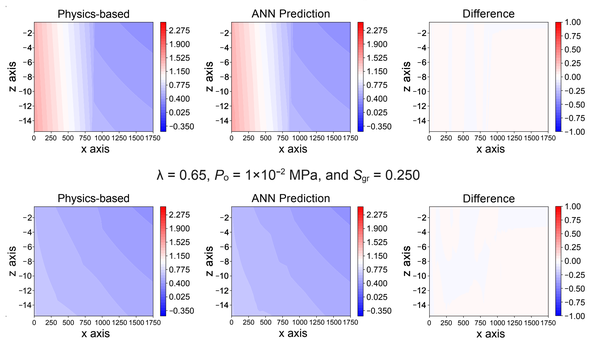
Testing Results Analysis

CO_2 saturation



Four different parameters combinations of capillary pressure and relative permeability models (*Po*, λ, and *Sgr*) are represented to analyze accuracy of ANN model prediction for CO_2 saturation and pressure perturbation.

Fluid pressure perturbation



The broad similarity between the physical and predicted images implies that the ANN model captures the salient aspects of the physics-based model.

Overall Accuracy

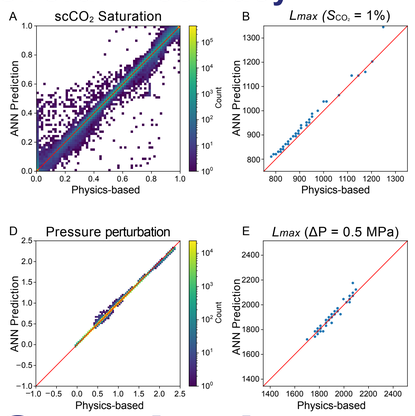


Fig A, D illustrate the comparison for each grid cell of the reservoir domain for 50 testing data. B presents the comparison on the maximum length of the plume when CO_2 saturation is 0.01 (boundary of the plume). E demonstrates the maximum length of pressure perturbation distribution when ΔP is 0.5 MPa.

ANN emulation methods provide excellent results for capturing the major distribution of both CO_2 saturation and fluid pressure change when trained on physics-based numerical simulations.

Conclusion

ML model offers an alternative method for simulating CO_2 sequestration across a high-dimensional parameter space

computational efficiency (460 vs. 2691)
run-time acceleration (6 months vs. 10 minutes)

ML model provides an immense potential for predicting fluid flow dynamics over an extended parameter range