Physics Coupled Machine Learning Applications for Geological Carbon Storage

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SMART

Science-informed Machine Learning to Accelerate Real Time (SMART) Decisions in Subsurface Applications

Motivation and Objectives

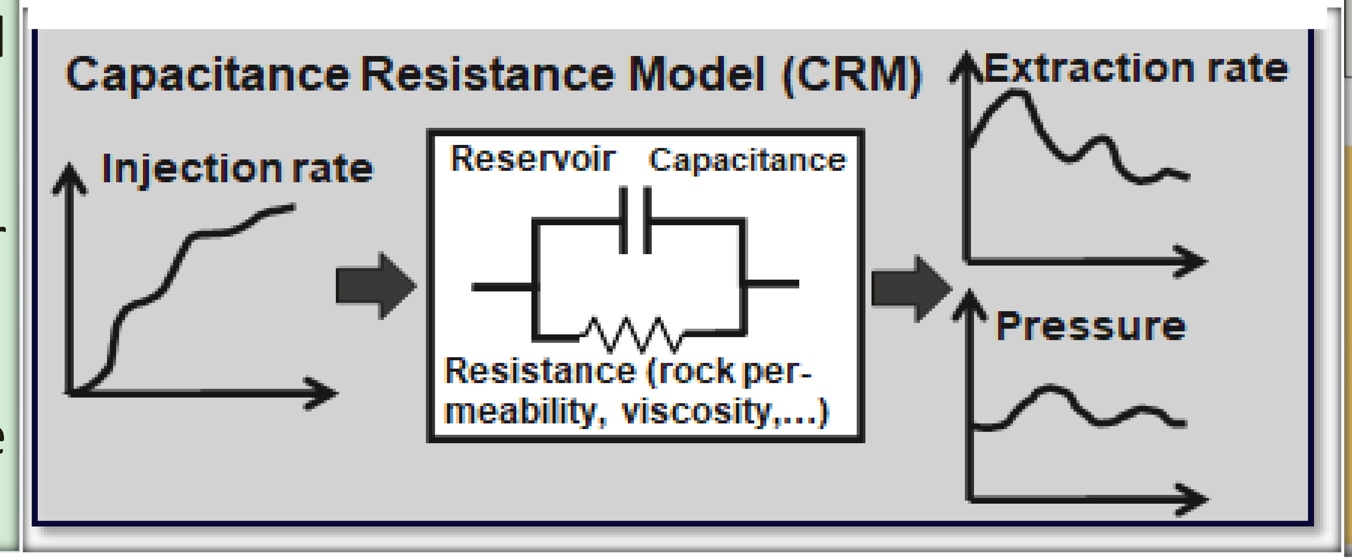
- CO_2 storage (CO_2 injection, brine extraction, pressure management) is a strategic design to meet the regulations based on the limited site characterization and dynamic reservoir responses for sequestration target.
- Coupled Capacitance & Resistance Model (CRM) and machine learning based upon machine learning techniques provide a bridge for operations and reservoir management for CO_2 storage.
- Demonstrating the synergy of physics coupled machine learning concept for CO_2 storage decision support.
- Potential to transfer the efforts learned from one datasets to another for the application purpose.

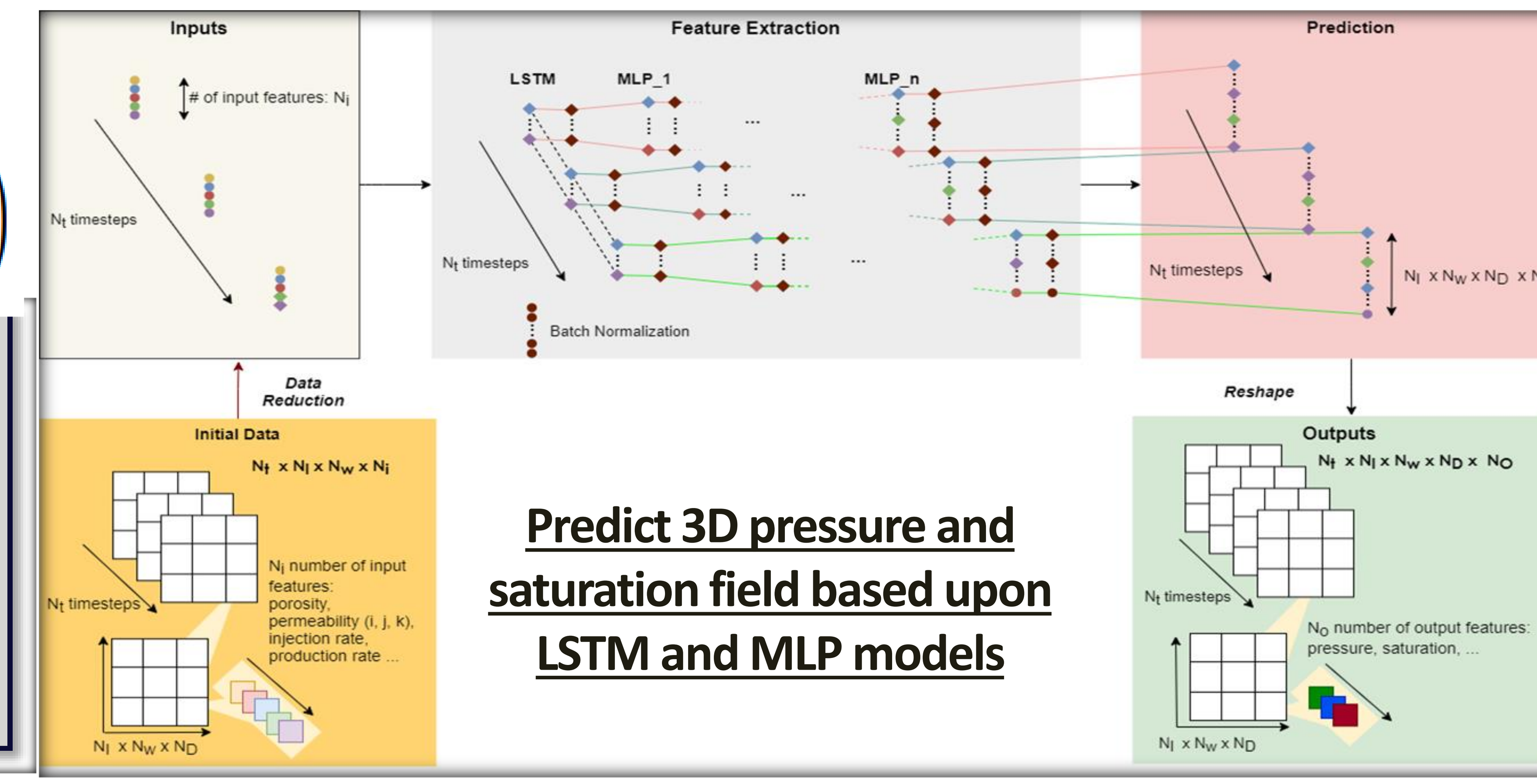
The Model Overview

Electric Circuit Borrowed Material Balance Principle

Capacitance & Resistance Model

$$q_k = q_{(k-1)} e^{-\frac{\Delta t}{\tau}} + \left(1 - e^{-\frac{\Delta t}{\tau}}\right)\left(f i_k - J\tau \frac{p_{wf}^{(k)} - p_{wf}^{(k-1)}}{\Delta t}\right)$$





Predict 3D pressure and saturation field based upon LSTM and MLP models

Adapted CRM Model

$$q_k = q_{(k-1)} e^{-\frac{\Delta t}{\tau}} + \left(1 - e^{-\frac{\Delta t}{\tau}}\right)\left(f i_k - J\tau \frac{p_{wf}^{(k)} - p_{wf}^{(k-1)}}{\Delta t}\right)$$

$$0 = \left(1 - e^{\frac{\Delta t}{\tau}}\right)\left(i - J\tau \frac{\Delta p}{\Delta t}\right)$$

$$J\tau \frac{\Delta p}{\Delta t}\left(1 - e^{\frac{\Delta t}{\tau}}\right) = i\left(1 - e^{\frac{\Delta t}{\tau}}\right)$$

$$c_t v_p \frac{\Delta p}{\Delta t} = i \quad (1) \qquad J\tau \frac{\Delta p}{\Delta t} = i \quad (2) \Rightarrow i = J\tau(\bar{p} - p_{wf})$$

- **Injection cumulative-based pressure:**

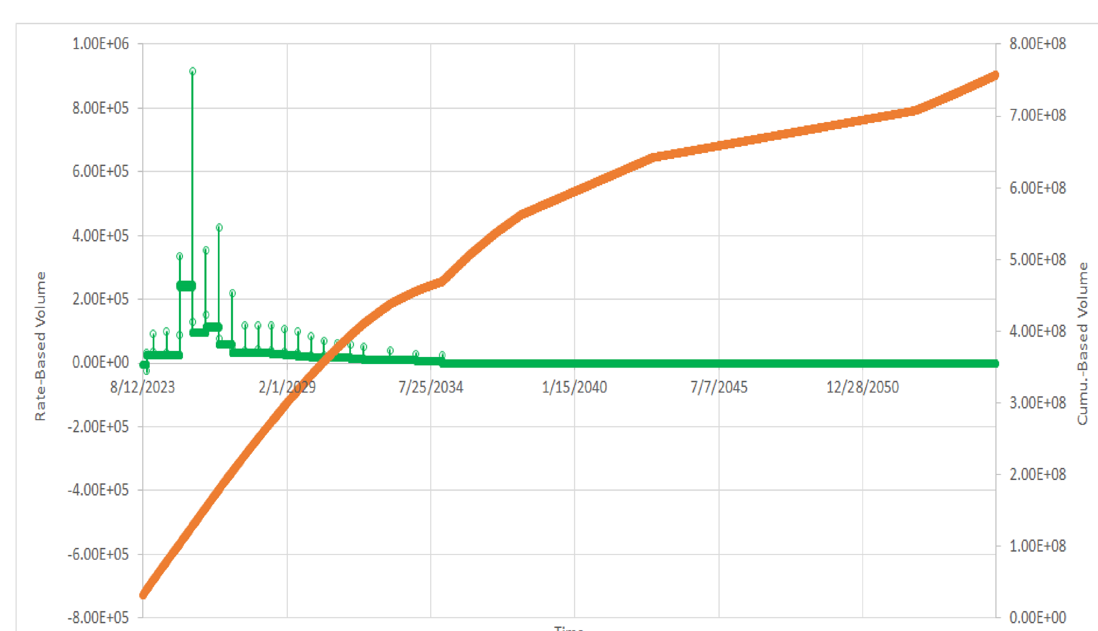
$$\boxed{c_t v_p \frac{\Delta p}{\Delta t} = i} \Rightarrow c_t v_p \Delta p = i\,\Delta t \Rightarrow c_t v_p \int \frac{\Delta p}{\Delta t} = \int i$$

$$\Rightarrow c_t v_p \sum_{t=0}^{t=n} \Delta p = \sum_{t=0}^{t=n} i \Rightarrow \sum_{t=0}^{t=n} \Delta p = \sum_{t=0}^{t=n} i/(c_t v_p)$$

- **Injection cumulative-based drainage volume:**

$$\boxed{c_t v_p \frac{\Delta p}{\Delta t} = i} \Rightarrow c_t v_p \Delta p = i\,\Delta t$$

$$\Rightarrow c_t v_p \sum_{t=0}^{t=n} \Delta p = \sum_{t=0}^{t=n} i \Rightarrow v_p = \sum_{t=0}^{t=n} i / \left(c_t \sum_{t=0}^{t=n} \Delta p\right)$$

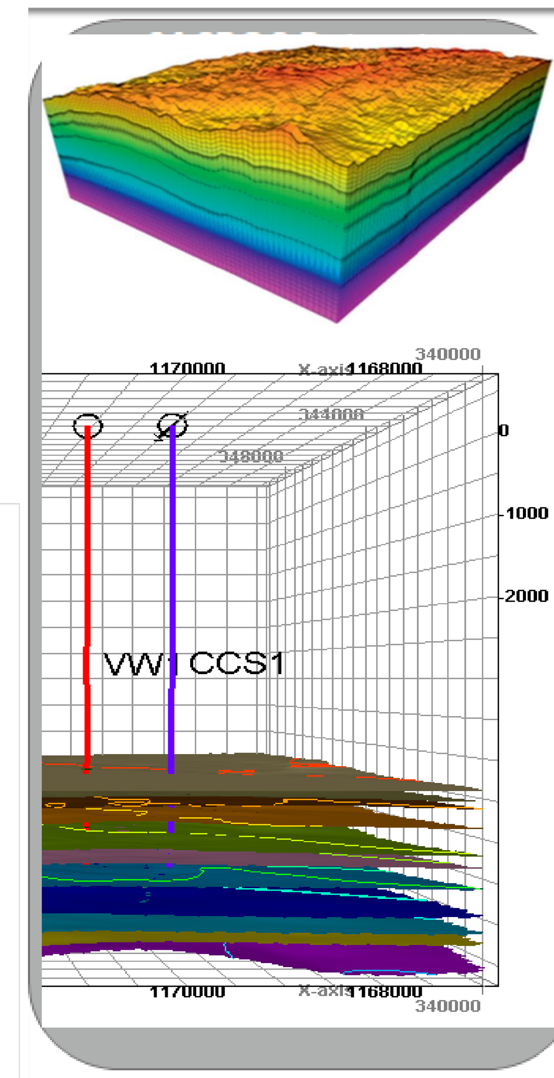


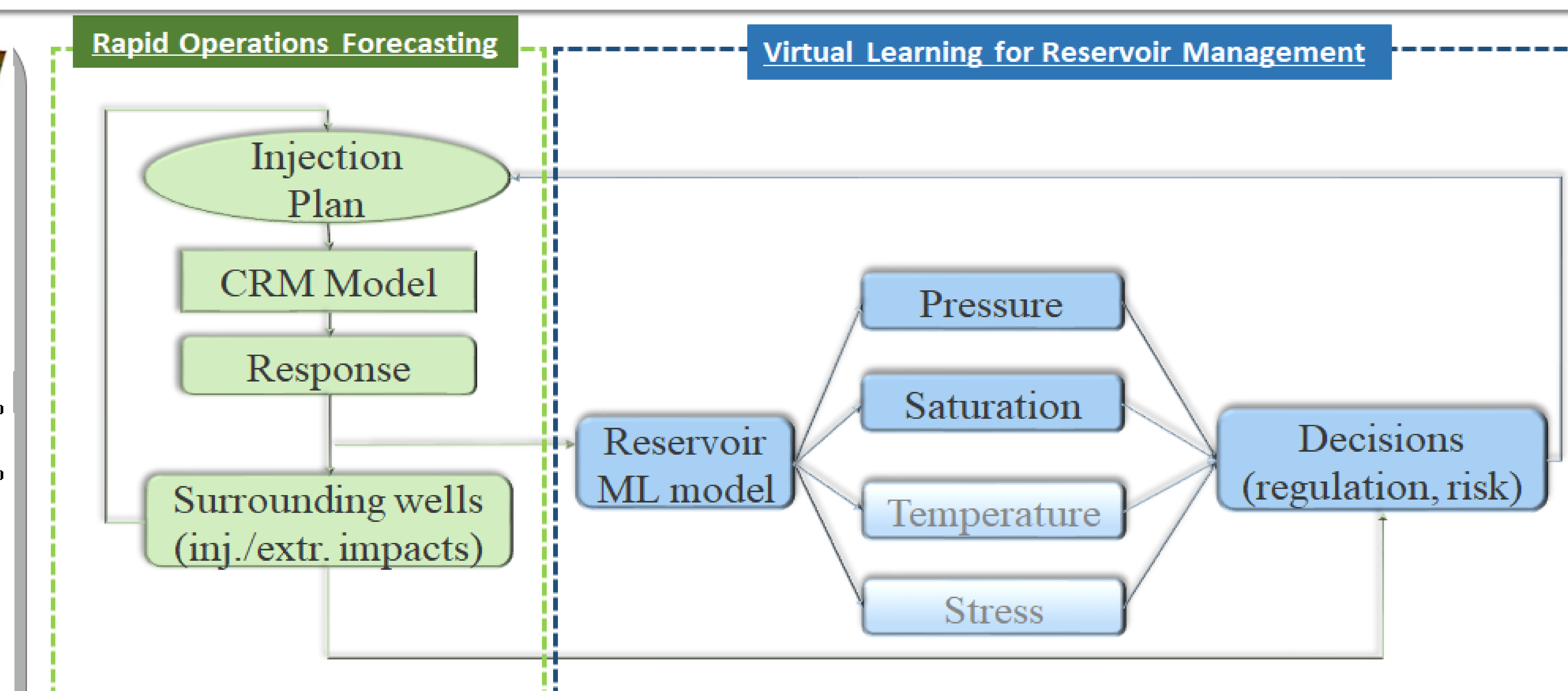
Rate-based and cumulative-based drainage volume

- **Injection rate-based drainage volume:**

$$\boxed{c_t v_p \frac{\Delta p}{\Delta t} = i} \Rightarrow v_p = \frac{i}{c_t \frac{\Delta p}{\Delta t}}$$

Coupled Workflow





- Rapid HM & forecasting
- Monitoring design

Injection/extract exploration

What-if scenarios/studies

Reservoir management

Operation optimizations

Remarks

- This study illustrates a physics coupled machine learning method for CO_2 storage application, particularly, providing insights of reservoir pressure build-up and drainage volume understanding over CO_2 injection.
- The adapted CRM model for CO_2 injection is driven from the classic form of the model to find out the relationships between injection and the reservoir pressure build-up and drainage volume.
- Such insights also can be used as constraint/s for machine learning to guide the training and testing.
- More cross validation and benchmark testing is still on-going.

Disclaimer

This project was funded by the United States Department of Energy, National Energy Technology Laboratory, in part, through a site support contract.

References

[1] Tao, Q., Bryant, S., Optimizing CO2 Storage in a Deep Saline Aquifer with the Capacitance-resistance Model, Energy Procedia, Volume 37, 2013, Pages 3919-3926, ISSN 1876-6102,

https://doi.org/10.1016/j.egypro.2013.06.290.

[2] Liu, G., Wu, X., Shih, C., Vasylkivska, V., Bromhal, G., Physics-Coupled Machine Learning Toolset for Geological Carbon Storage Evaluation and Performance Analysis (November 10, 2022). Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16) 23-24 Oct 2022, Available at SSRN: https://ssrn.com/abstract=4273411 or http://dx.doi.org/10.2139/ssrn.4273411