# Enhancing Subsurface Fluid Flow and Solute Transport Modeling Through Machine Learning: A Study of Fractured Rocks Using FracNet

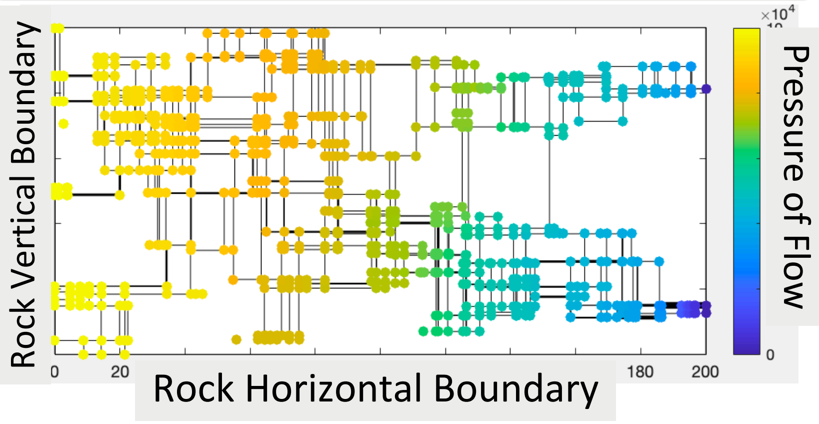
*Riddhi Bhagwat (riddhib@mit.edu), MIT Dept. of Electrical Engineering & Computer Science*
*Research Dept.: Juanes Research Group at MIT Civil & Environmental Eng.*

MIT Energy Initiative

## Introduction

Discrete Fracture Network (DFN) is **computationally expensive, which limits predictive accuracy**

### Flow in FracNet Simulated Rock Network:



**Juanes Lab Simulation Algorithm**

**Mapping fractured rock networks** allows us to better understand...

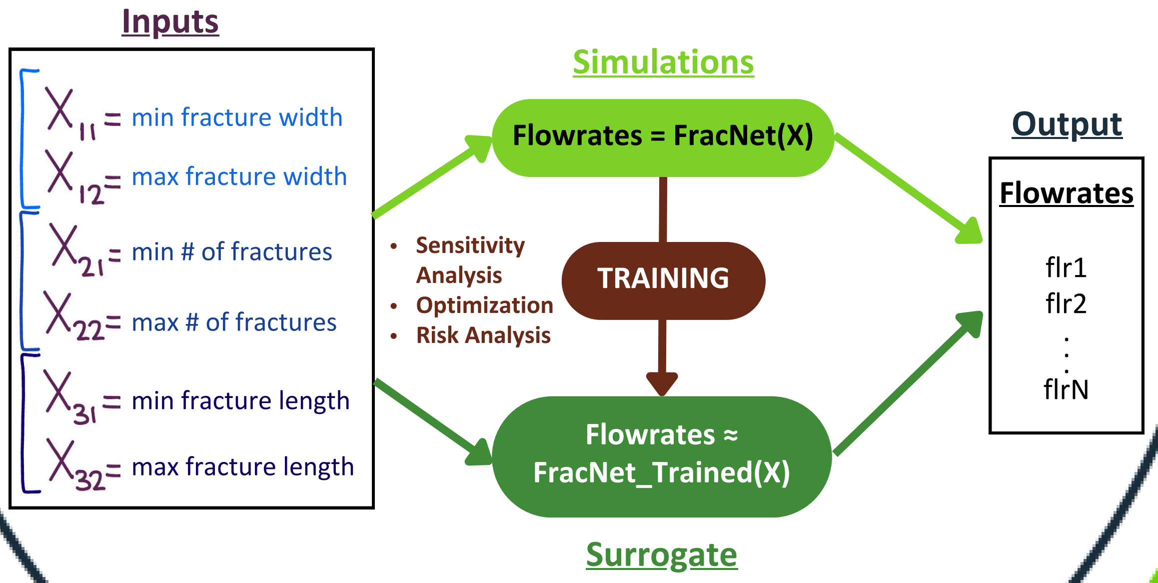
- Groundwater contamination
- CO2 storage
- Nuclear Waste Storage
- Improvement of Geothermal & Nuclear Energy Resources

**Research Question:**
How can we **better understand fractured rock networks** in a more **accurate and cost efficient** manner?

**Neural Network Benefit:** Much faster computation to run multiple cases quickly; helps assess uncertainty in forecasts of flow rates

## Highlights

- Achieved a **high throughput data visualization**
- Effectively determined **necessary ranges and variations across parameters** that influence flow rates
- Developed **deep-learning** neural network as a **surrogate model** (to the original simulation algorithm)



**Inputs**

$X_{11}$ = min fracture width
$X_{12}$ = max fracture width
$X_{21}$ = min # of fractures
$X_{22}$ = max # of fractures
$X_{31}$ = min fracture length
$X_{32}$ = max fracture length

**Simulations**

Flowrates = FracNet(X)

- Sensitivity Analysis
- Optimization
- Risk Analysis

TRAINING

Flowrates ≈ FracNet_Trained(X)

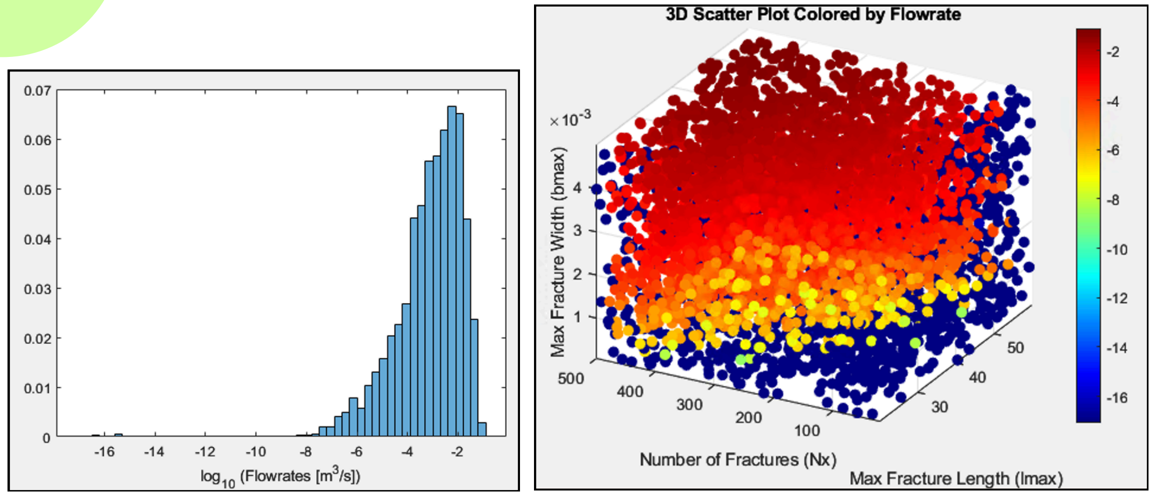
**Surrogate**

**Output**

**Flowrates**
flr1
flr2
:
flrN

## Results

### (N=5000) Dataset Visualization

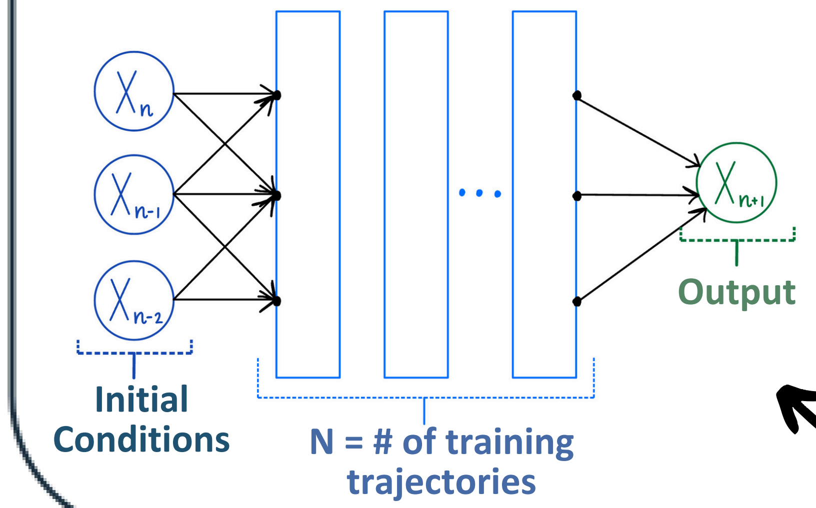


- Flow rate spans approx. **14.16 orders of magnitude**
- Suggests **disconnected backbone** in certain cases - reveals **network behavior**

## Materials & Methods

**Generated dataset** using original **simulation** algorithm (in **MATLAB**)

**Transformed** dataset into **training input** for **Python**-based **deep-learning** model

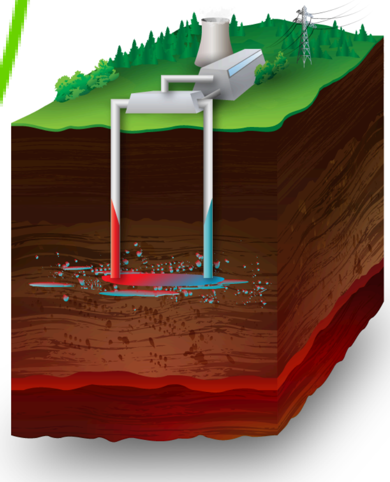


Built dataset using **FracNet simulation algorithm** developed by Juanes Lab at MIT

**flow modeling architecture** for solving ordinary differential equations - used to determine the **best structure for the neural network** to model the fluid flow through fractured rocks

Future work will involve **applying knowledge** to **enhancing the efficiency and output of geothermal, nuclear, and hydrothermal energy** resources

## Discussion & Applications



- Better allocate resources for **managing underground substance storage (CO2 and Nuclear Waste)**
- **Prevent groundwater contamination** by controlling solute flow and transport

References:

1. *Energy Graphic:*Encyclopedia, E. (n.d.). Geothermal Systems - Renewable Energy Sources - Energy Encyclopedia. https://www.energyencyclopedia.com/en/renewable-energy/geothermal-energy/geothermal-systems
2. *Flow Modeling:* Churchill, V., & Xiu, D. (2023). Flow map learning for unknown dynamical systems: Overview, implementation, and benchmarks. Journal of Machine Learning for Modeling and Computing, 4(2).
3. *Surrogate Modeling:* Lamoureux, Benjamin & Mechbal, Nazih & Masse, Jean-Remi. (2013). Selection and Validation of Health Indicators in Prognostics and Health Management System Design. 239-244. 10.1109/SysTol.2013.6693847.