58th ROCK MECHANICS / GEOMECHANICS SYMPOSIUM GOLDEN, COLORADO 23-26 JUNE 2024

Enhanced Geothermal Site Characterization using Generative Adversarial Network and Ensemble Method

Jichao Bao[1], Jonghyun Lee[1], Hongkyu Yoon[2]

[1]University of Hawaii at Manoa, Honolulu, HI, USA; [2]Sandia National Laboratories, Albuquerque, NM, USA

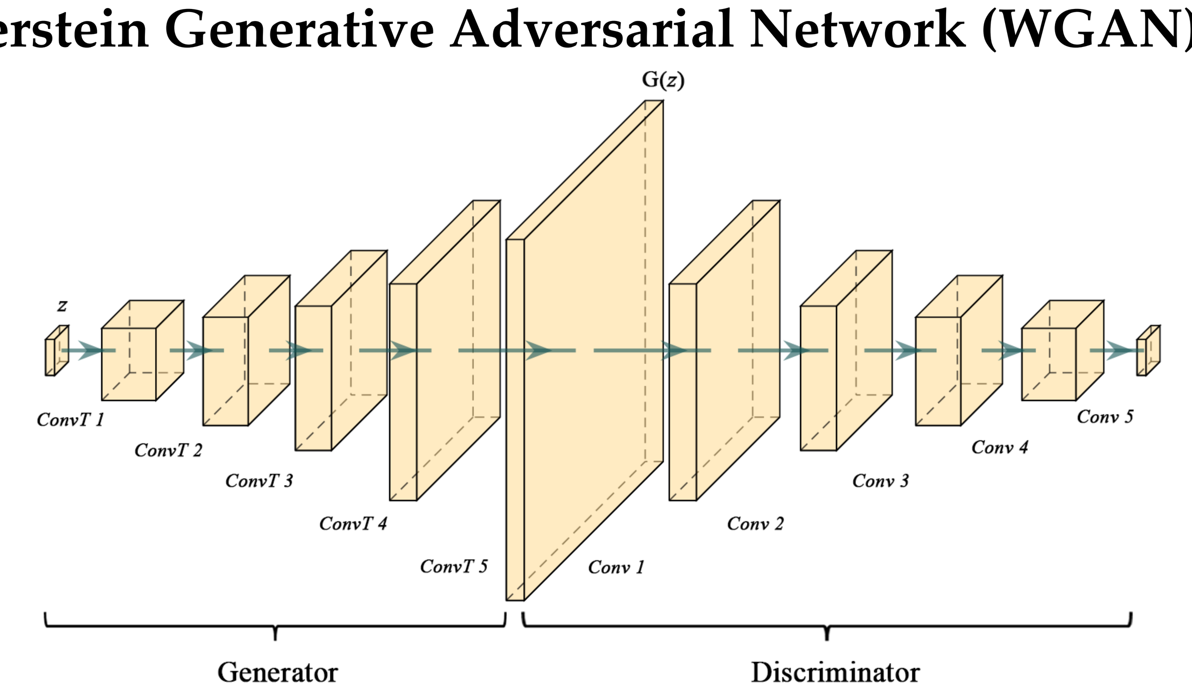
ARMA 24 – 0579

Overview

Characterizing the subsurface properties such as permeability is important for stimulation planning and heat production in enhanced geothermal systems (EGS). The geothermal sites are usually highly heterogeneous with complex structures such as faults and fractures, which are difficult to characterize. In this work, we use the Wasserstein Generative Adversarial Network (WGAN) to generate fractured images from the low-dimensional latent space. The ensemble method is then applied to the latent variables to characterize the permeability fields of fractured geothermal sites using temperature data.

Method

Wasserstein Generative Adversarial Network (WGAN)

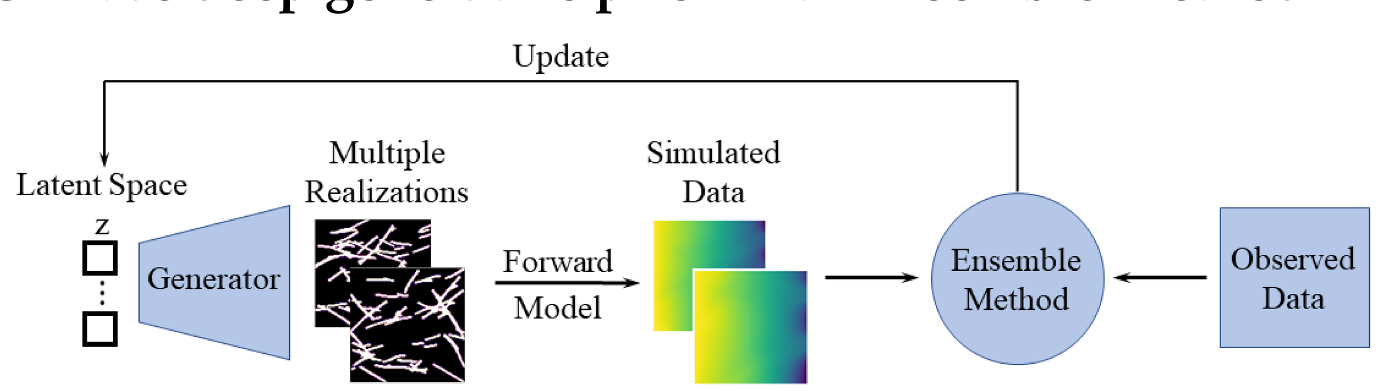


$$\min_{G}\max_{D\in\mathfrak{D}} E_{x\sim P_x}[D(x)] + E_{z\sim P_z}[D(G(z))]$$

Discriminator loss with gradient penalty for better training:

$$L_D = \underbrace{E_{z\sim P_z}[D(G(z))] - E_{x\sim P_x}[D(x)]}_{\text{original discriminator loss}} + \lambda \underbrace{E_{\hat{x}\sim P_{\hat{x}}}[(\|\nabla_{\hat{x}} D(\hat{x})\|_2 - 1)^2]}_{\text{gradient penalty}}$$

WGAN as deep generative prior with Ensemble Method



Latent variables z are updated as:

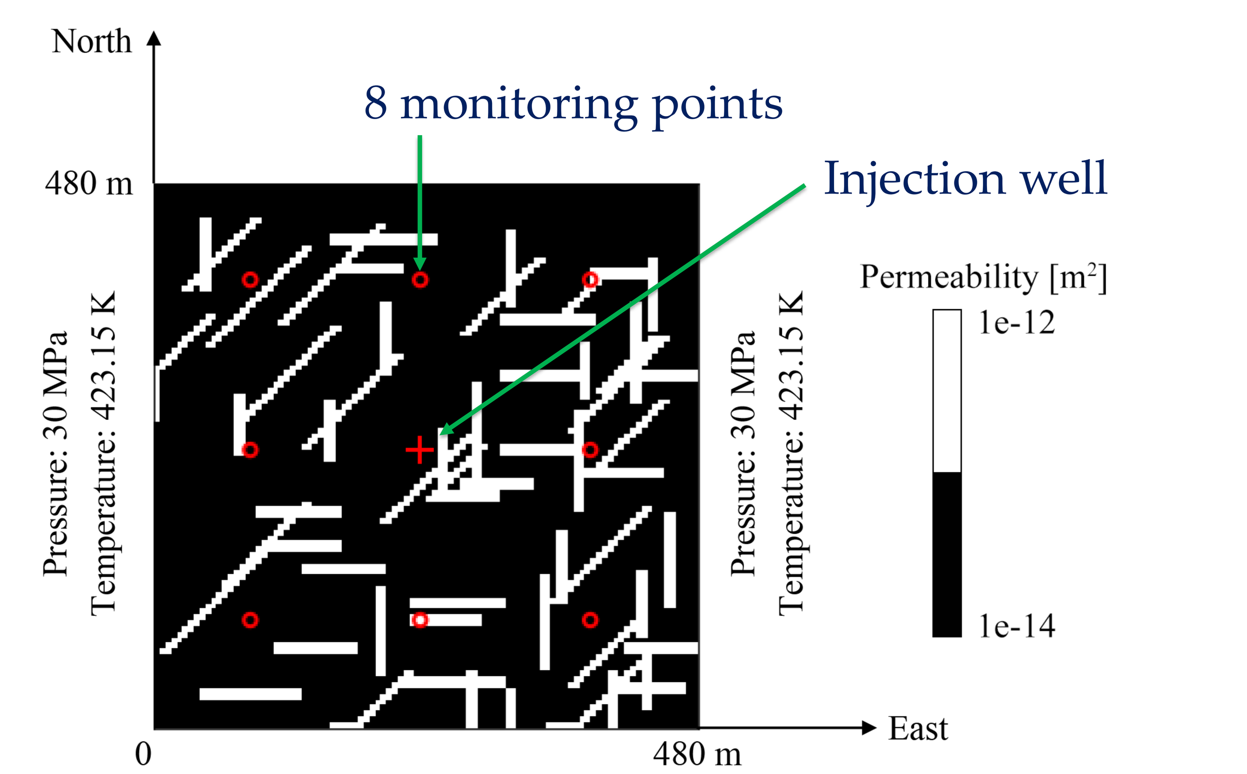
$$z_j^{i+1} = z_j^i + C_{ZD}^i\left(C_{DD}^i + \alpha_i C_D\right)^{-1}\left(d_{uc,j}^i - d_j^i\right), j = 1,\cdots,N_r$$

d_{uc} is the perturbed observed data:

$$d_{uc} = d_{obs} + \sqrt{\alpha_i} C_D^{1/2}\epsilon_d, \epsilon_d \sim N(0, \boldsymbol{I}_{N_d})$$

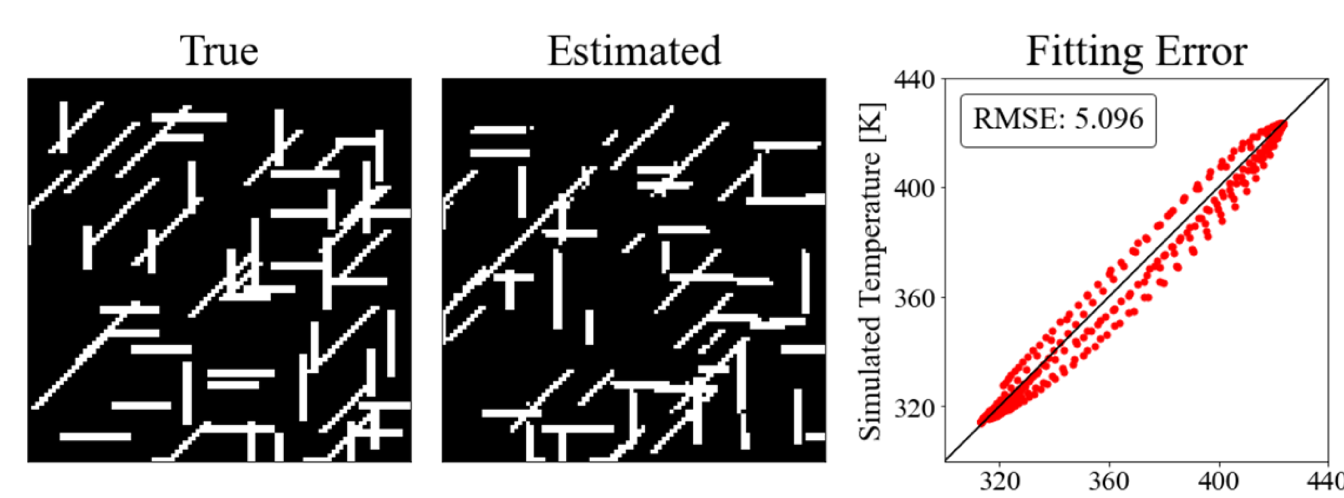
Synthetic Example

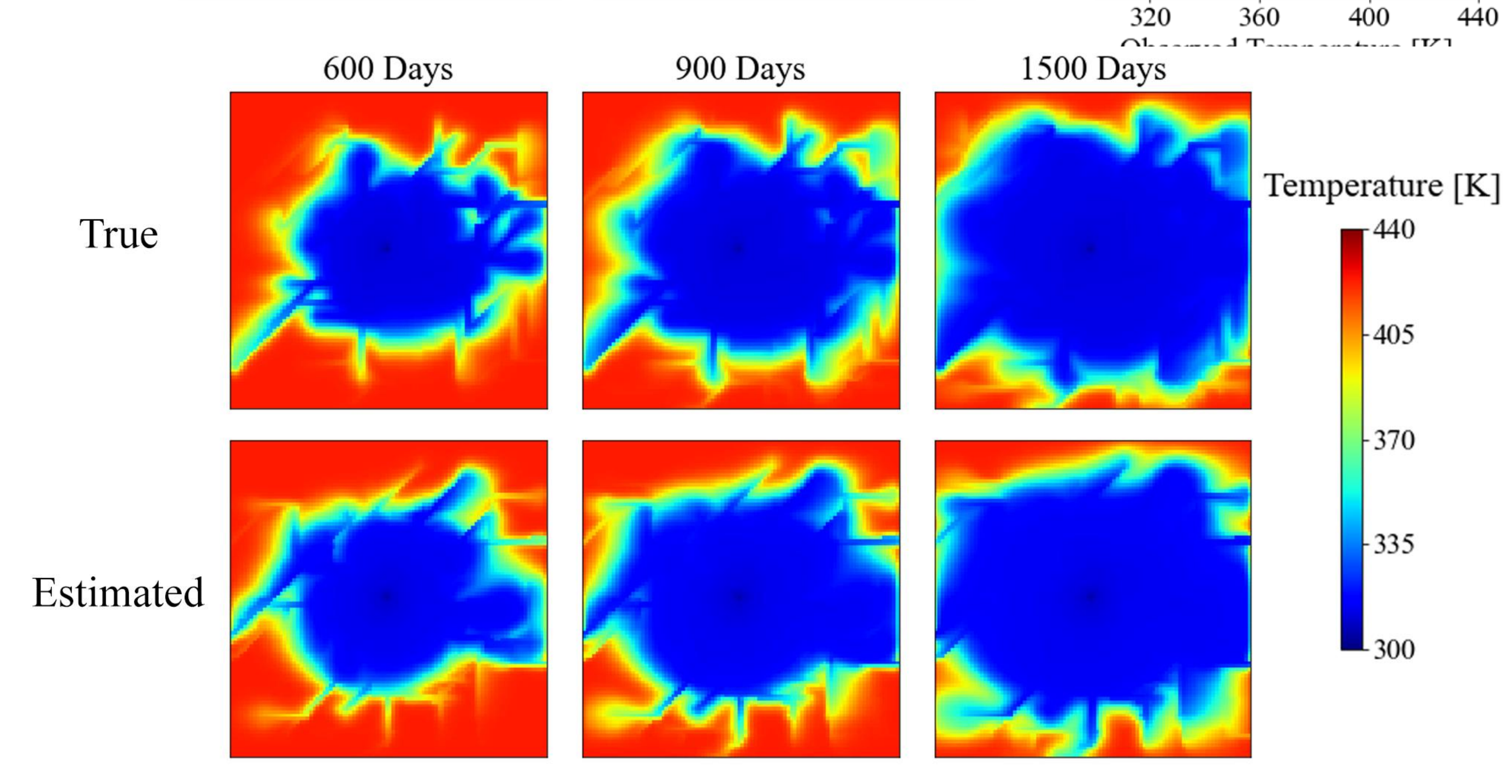
Model Setup



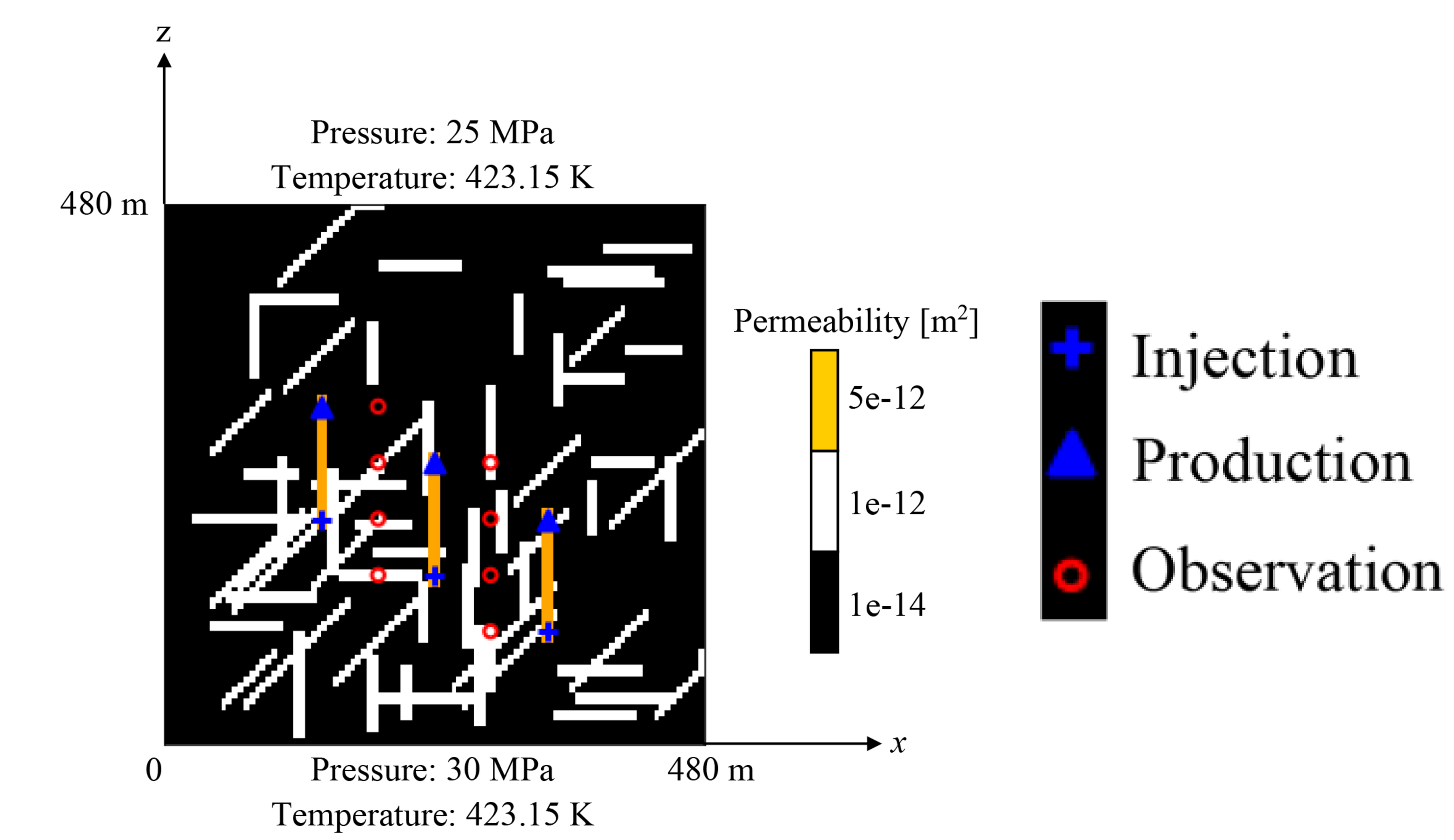
- 480 m × 480 m domain discretized into 96 × 96 grids (9,216 unknown permeabilities).
- 3× 3 = 9 latent variables z and 200 ensemble realizations.
- Constant pressure and temperature boundary conditions.
- 8 monitoring wells and 1 injection well.
- 0.001 m^3/s injection rate with constant temperature of 293.15 K.
- 1,500-day simulation using the Matlab Reservoir Simulation Toolbox (MRST).
- Temperature data were measured every 30 days.

Synthetic Case Results

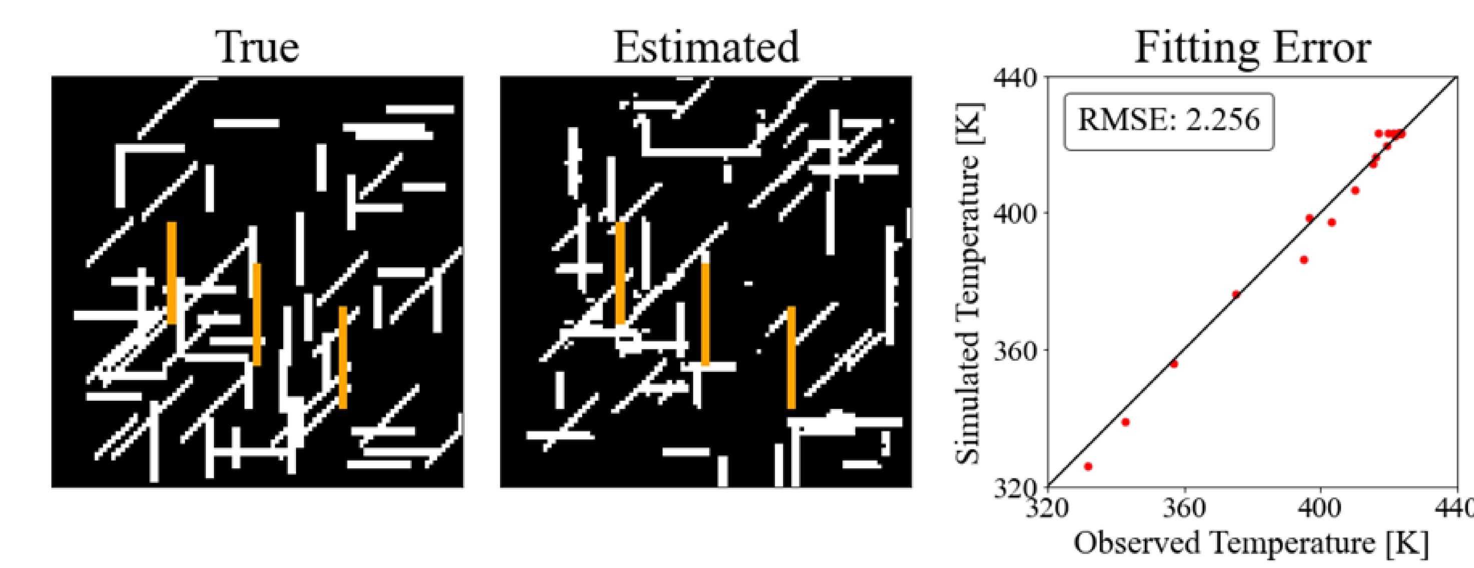




FORGE site-based 2D Application



Three *line* structures (yellow lines) are determined as induced fractures by stimulations connecting the injection and production wells.



7-day simulation with 0.01 m^3/s injection and production rates, temperature data were measured every day.

Conclusion

- Computational cost reduction (less than 1,000 MRST simulations) with WGAN priors (96 × 96 permeabilities to 3 × 3 latent variables).
- Coupling WGAN with ensemble method to deal with heterogeneous and non-Gaussian fractured fields.
- Captured important permeability features (i.e., fractures) with reasonable prediction accuracy.

Acknowledgment

This work was supported by a R&D award (5-2557) as part of funding provided by DOE EERE Geothermal Technologies Office to Utah FORGE and the University of Utah under Project DE-EE0007080 Enhanced Geothermal System Concept Testing and Development at the Milford City, Utah Frontier Observatory for Research in Geothermal Energy (Utah FORGE) site.