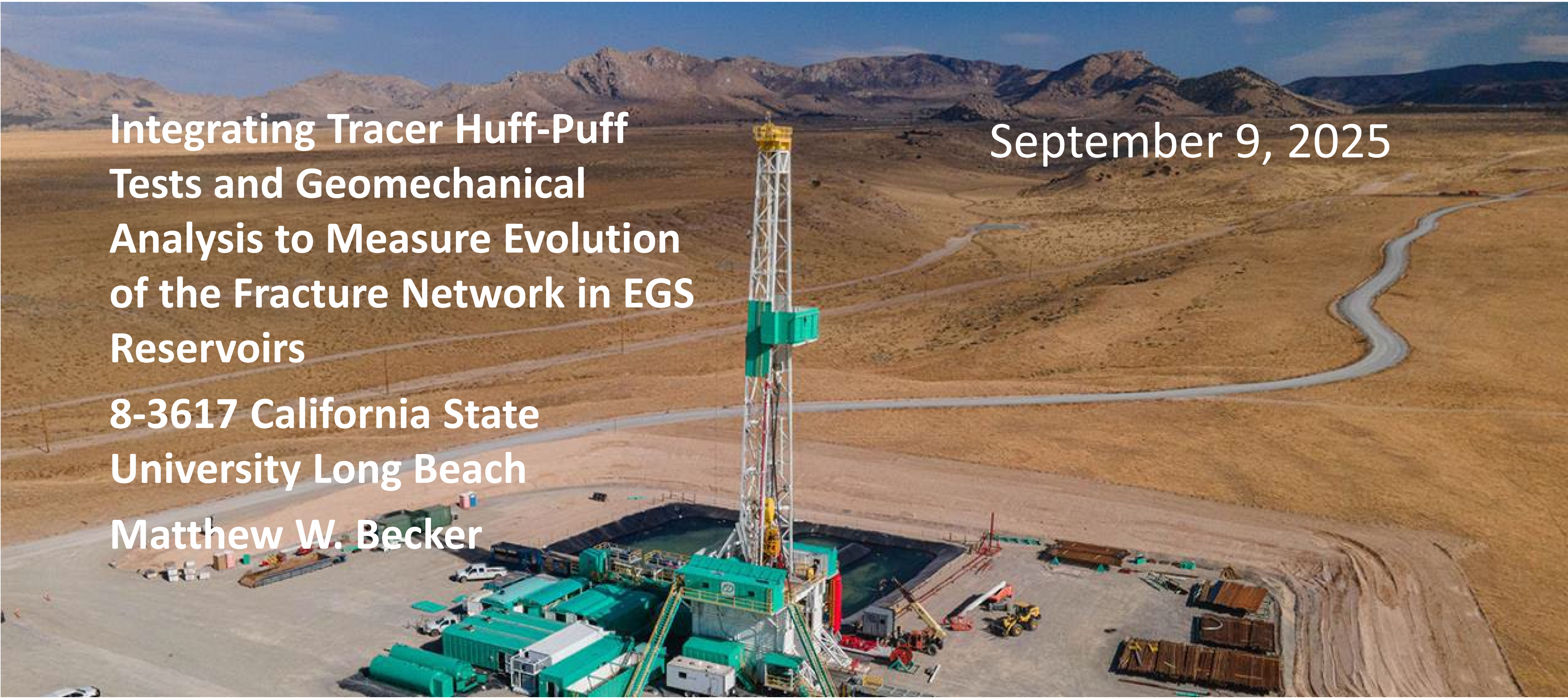
Utah FORGE– 2025 Annual R&D Workshop



Integrating Tracer Huff-Puff Tests and Geomechanical Analysis to Measure Evolution of the Fracture Network in EGS Reservoirs

8-3617 California State University Long Beach

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September 9, 2025

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8-3617 - Integrating Tracer Huff-Puff Tests and Geomechanical Analysis to Measure Evolution of the Fracture Network in EGS Reservoirs

- PI: Matthew Becker
- Organization: California State University Long Beach
- Presenters: Matt Becker (CSULB) Ahmad Ghassemi (OU)
- Subcontractor: Ahmad Ghassemi, Oklahoma University
- Total Project Funding $2,274,607
- Project Duration: April 1, 2024 to September 30, 2026 (2.5 yrs)

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Objectives and Purpose

- A key economic predictor for EGS projects is the *effective heat-exchange surface area* created through stimulation.
- One approach to measuring this area is to perform injection/backflow (huff-puff) tracer experiments.
- Traditional single solute tracer tests result in non-unique predictions, however, primarily because the interrogation volume is unknown.
- We will overcome the limitations by integrating multiple methods of interrogation:
  (1) hydraulic, (2) solute tracer, (3) heat tracer, and (4) geomechanical strain
- Results will be used to calibrate a thermal-hydro-mechanical-chemical (THMC) model
- Cost-benefit analysis will estimate the relative value of each of the four methods

Methods/Approach: Overview

- Test hydraulic (pressure), solute tracers, cold-water tracer, and geomechnical strain during huff-puff (injection/backflow) experiments
- Huff –puff conducted using injection and backflow
- Pressure will be recorded at the well head, solute tracer measured in the return flow, heat measured using FODTS, and strain measured FODAS/FODSS.
- All data will be used to calibrate a THM model augmented with solute transport (THMC) developed by Oklahoma University.

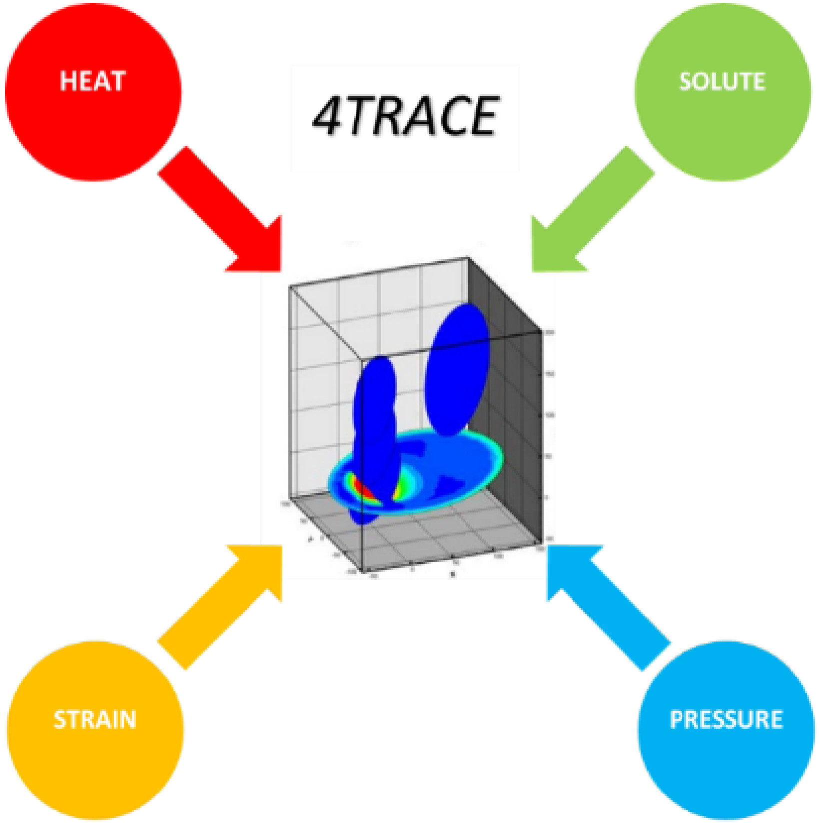

Figure 1. Schematic of the 4TRACE approach that integrates hydraulic testing, thermal and heat tracer testing, and DAS-measured strain.

Methods/Approach: Injection and Backflow

- Experiments are **ongoing** during the creation of this presentation
- We are injecting water from a surface tank into 16B and flowing back under reservoir pressure. Reservoir was charged during a 1-week recirculation tests by TTU
- TTU and CSULB jointly funded sequential recirculation/huff-puff tracer tests which involved the installation of coiled tubing with fiber in 16B.
- Neubrex is monitoring fiber (DTS, RFS-DSS, DAS)
- Resman is injecting and analyzing 5 uniquely identifiable solute tracers

Day	CSULB Activity	Rate (bpm)	Tot Inj Volume (bbl)	Return Vol (bbl)
1	Injection 1: Tracer 1	2.5	510	
1	Flowback 1	2.5		620
2	Injection 2: Tracer 2	2.5	695	
2	Flowback 2	2.5		920
3	Injection 3: Tracer 3	2.5	883	
3	Flowback 3	2.5		1220
4	Injection 4: Tracer 4	5	508	
4	Flowback 4	5		620
4	Injection 5: Tracer 5	7.5	508	
4	Flowback 5	7.5		770

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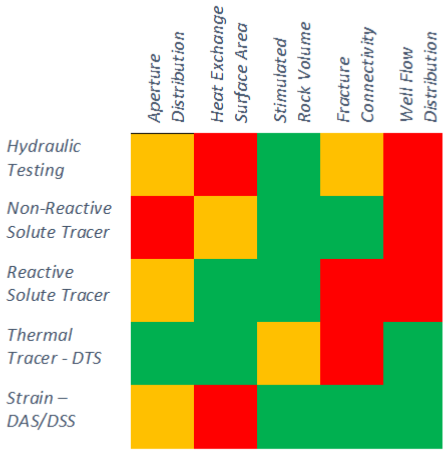
Methods/Approach: Integration of Tracers

- Each tracer has relative advantages in estimating fluid flow/reservoir parameters.
- We are using two approaches for evaluating the value of information
  1. Multiphysics forward modeling with simple reservoir conditions to evaluate a large range in model parameters and variables (CSULB)
  2. A calibrated THMC model calibrated to FORGE data to evaluate the value of information obtained from the 16B well tests (U. Oklahoma)



Matrix summarizing the relative strengths of interrogation methods. Red cells are poor estimators, yellow are potential estimators, and green are effective estimators

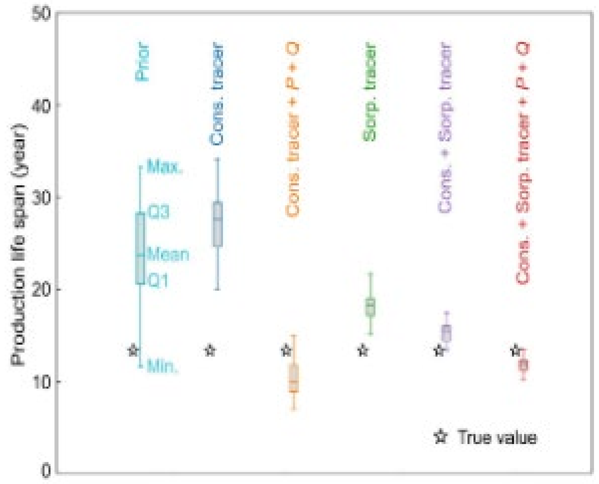


Figure 10 Production life span estimates in a single fracture using combinations of conservative tracer, sorptive tracer, pressure (P), and flow rate (Q). The estimation of the true value is improved with multiple data streams (after Wu et al, 2021).

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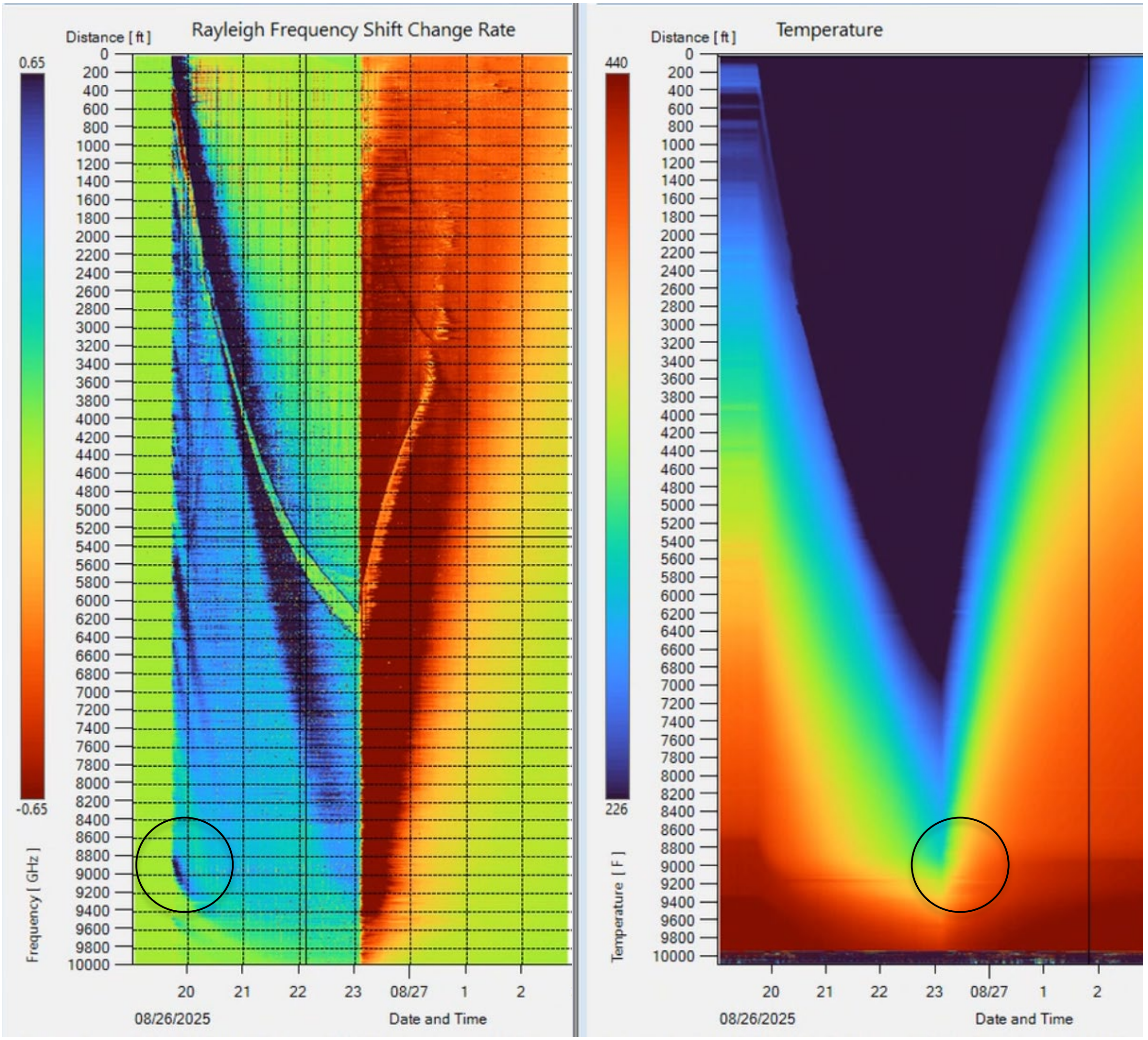
Technical Accomplishments and Progress

Field Experiments:

- Only real-time preliminary data are available from the field tests (ongoing)
- Quality of fiber data is excellent
- Thermal slug is about 65% slower than water slug as measured within the coiled tubing
- Strain and temperature effects are not yet decoupled



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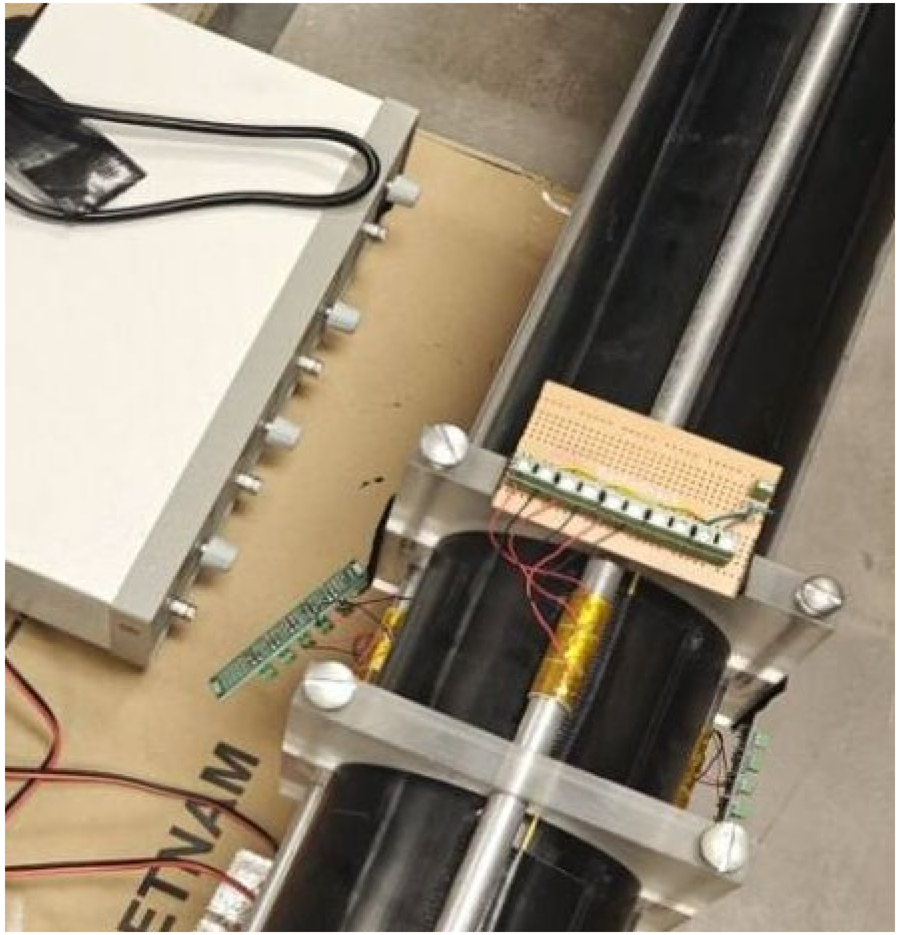
Technical Accomplishments and Progress

Lab Experiments:

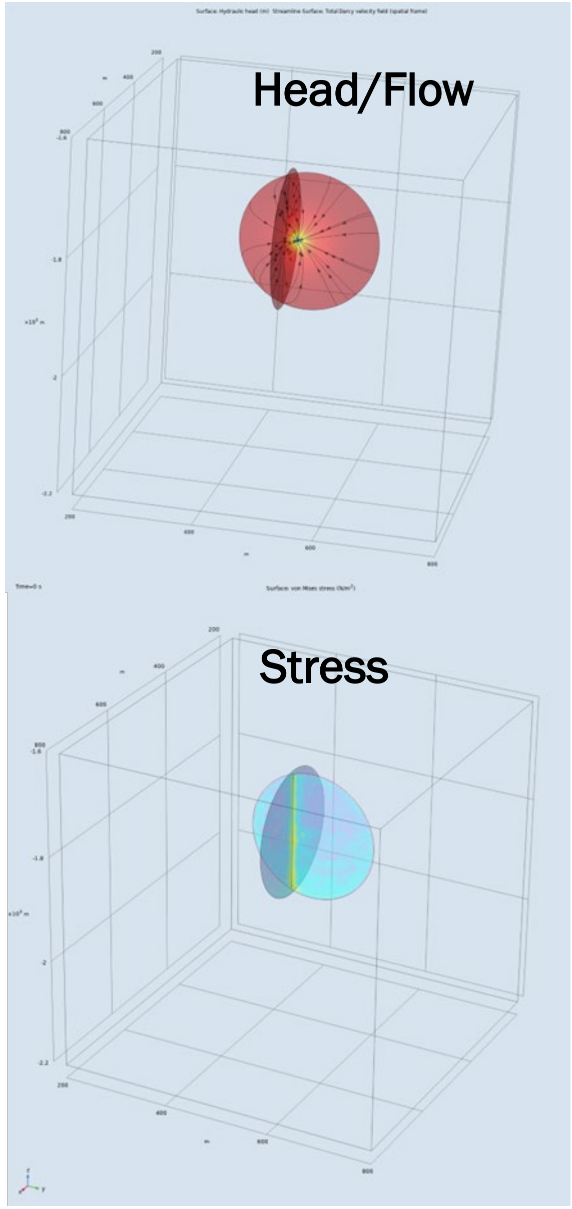
- Fiber slip is a concern for coiled tubing deployment
- There has been some recent work in fiber slippage, but the focus is seismic, higher frequency
- We will look experimentally at fiber frictional coupling at mHz-Hz frequencies
- Strains are observed with DAS fiber



Technical Accomplishments and Progress

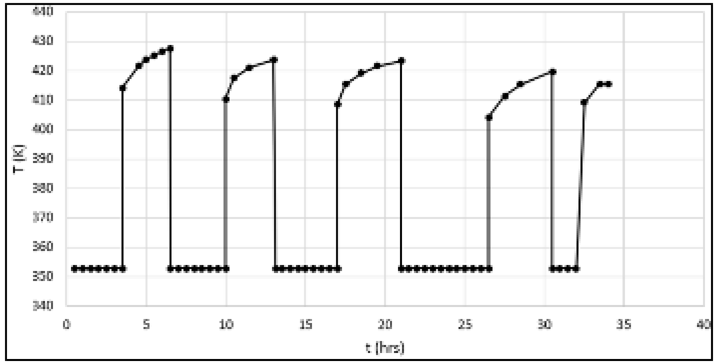
Simulations:

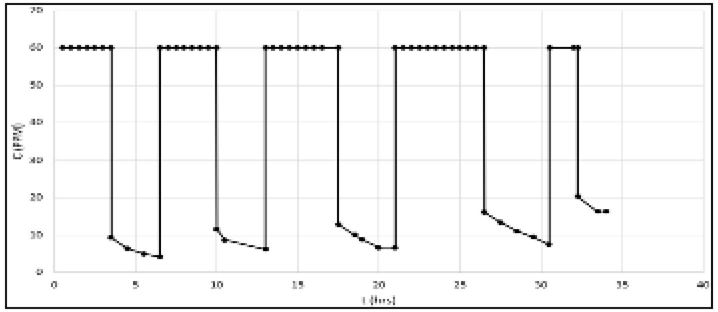
- Using Multiphysics simulations (COMSOL) we have begun to develop forward synthetic models
- Simple models and customizable physics interfaces allow for flexibility in test design and value of information
- This modeling is different than OU models which are calibrated to parameters and employ a DFN



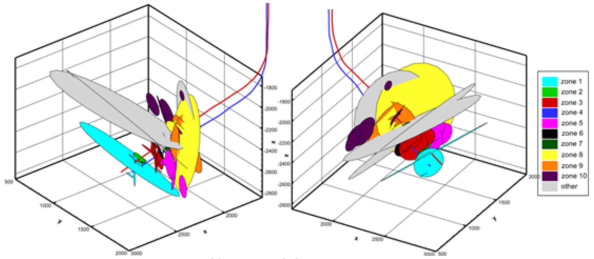
Technical Accomplishments and Progress

- Oklahoma University is developing DFN with heat and tracer transport based upon prior information from microseismic epicenters and geological modeling
- These models will be calibrated to experimental data but have been used initially to design tests and demonstrate, numerically, that we can expect useful experimental results.

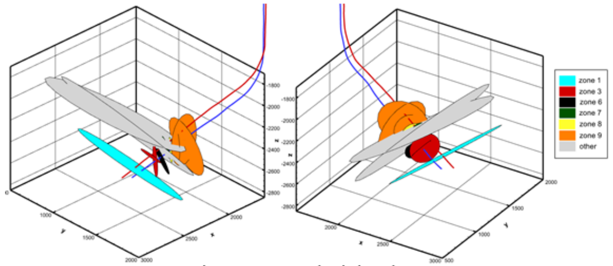




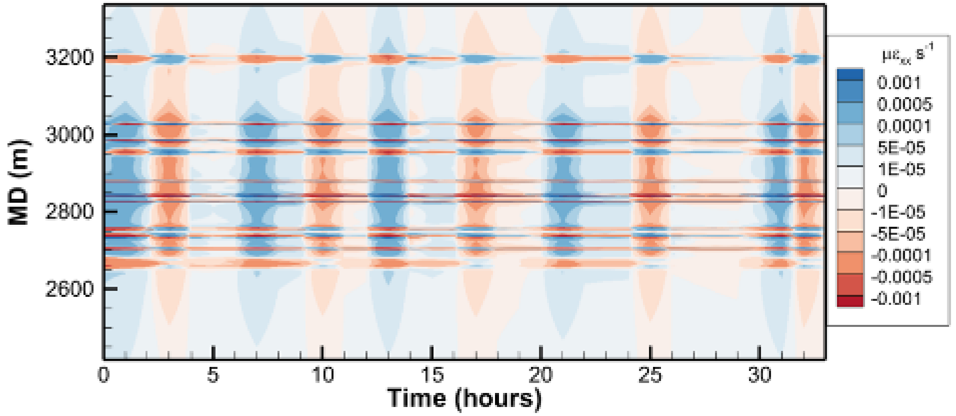
- The fracture network has been simplified by removing fractures that are hydraulic dead ends.



Initial DFN consisting of 49 fractures.



Filtered fractures used in this simulation.



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Technical Accomplishments and Progress

Actual Milestone/Technical Accomplishment	Date Completed
Task 0: Project Management and Planning: Rebudget and new project management plan approved (M0.1)	Q2 2024
Task 1: Forward Modeling Data collected (M1.1), forward modeling completed (M 1.2)	Q3 2024
Task 2: Design and Procurement: Experiments planned, vendors contracted, laboratory experiments built (M 2.2) GNG #1 Forward modeling for experiment design PASSED	Q4 2024
Task3: Numerical Model Refinement Add tracers to THMC model, benchmark against transport codes (OU)	Anticipated Q2 2025
Task 4: Conduct Experiments Experiment successfully underway at FORGE	Anticipated Q2 2025

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Technological Advancement and Data Dissemination

- The successful installation of coiled tubing was demonstrated in 16B
- Huff-puff tests have been demonstrated as feasible using an injection/backflow approach, provided the reservoir is pressurized
- Rayleigh Frequency Shift Distributed Strain data show very high resolution in both time and space, and sensitivity to strain and temperature
- More products to come soon as experiments conclude at end of August.

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Future Directions

- After completion of field experiments and processing of data, efforts will turn to:
  - Modeling of data
  - Uncertainty Analysis
  - Cost Benefit and Value of Information
  - Workflow Report
- We are currently on track to make these milestones on time within a quarter.

Task 5 – Modeling of Results
Sub Task 5.1 – History match results (OU)
Milestone 5.1 – SMART – History match of 4Trace results
Sub Task 5.2 – Forward model thermal breakthrough (OU)
Milestone 5.2 - Uncertainty analysis of inverted models
Sub Task 5.3 – Cost/benefit analysis (OU)
Milestone 5.3 - Cost benefit preliminary results
Sub Task 5.4 – Workflow analysis
Milestone 5.4 - Workflow report
Task 6 – Final Report

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Summary

- We conducted successful experiments at Utah FORGE during the last week of August, 2025.
- Data have not been processed but we tested according to plan and fiber, pressure, temperature data look good
- We have no tracer breakthrough yet from Resman.
- Moving forward we will focus on interpretation of data and developing a huff-puff workflow for estimating thermal breakthrough.

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