Stanford | Doerr
School of Sustainability
Energy Science and Engineering

Stanford Center for Carbon Storage

Affiliates Meeting — Nov. 19, 2024

GEOS
UPDATES

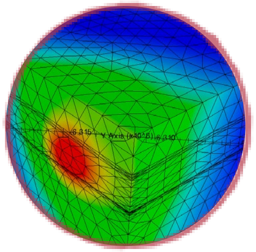
Herve Gross, PhD — TotalEnergies

CCUS Research & Development North America

GEOS

2018

LLNL, Stanford, TotalEnergies start the FC Maelstrom project

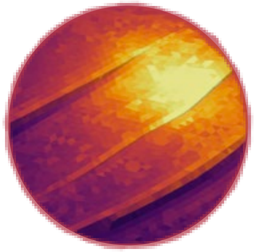


2019

Poroelastic simulation

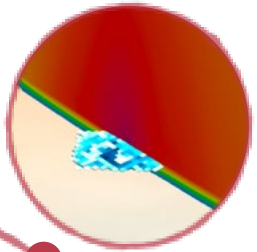
2020

CCS simulation on HI24L



2021

Fault models



2022

Northern Lights

2023

Chevron joins, Phase 2 starts

2024

2025

2026

2027

GEOS is a reference for multiphysics simulations for industry and regulators

GEOS: Multiphysics, exascale-ready, open-source simulator for CC

4,820 commits   77 contributors   C++   LPGL 2.1

- Ryan Aronson (Stanford, now at TotalEnergies)
- Andrea Borio (Politecnico di Torino)
- Quan Bui (LLNL, now at Blue River Technology)
- Tom Byer (LLNL)
- Nicola Castelletto (LLNL)
- Ben Corbett (LLNL, now at UNM)
- Andre Costa (Duke)
- Matthias Cremon (LLNL, now at META)
- Matteo Cusini (LLNL)
- Fan Fei (LLNL)
- Stefano Frambati (TotalEnergies)
- Andrea Franceschini (Stanford, now at UNIPD)
- Jacques Franc (Stanford, now at UPPA)
- Matteo Frigo (Stanford)
- Thomas Gazzola (TotalEnergies)
- Herve Gross (TotalEnergies)
- François Hamon (TotalEnergies)
- Brian Han (LLNL)
- Rasim Hasanzade (Chevron)
- Jian Huang (TotalEnergies)
- Tao Jin (LLNL, now at uOttawa)
- Dick Kachuma (TotalEnergies)
- Mohammad Karimi-Fard (Stanford)
- Mark Khait (TU Delft, now at SRT)
- Sergey Klevtsov (Stanford, now at NVIDIA)
- Antoine Mazuyer (TotalEnergies)
- Jie Meng (TotalEnergies)
- Daniel Osei-Kuffuor (LLNL)
- Victor Paludetto Magri (LLNL)
- Jeanne Pellerin (TotalEnergies)
- Margaux Raguenel (TotalEnergies)
- Guotong Ren (Chevron)
- Shabnam Semnani (UCSD)
- Randy Settgast (LLNL)
- Chris Sherman (LLNL)
- Hamdi Tchelepi (Stanford)
- Mike Thomadakis (Chevron)
- Bill Tobin (LLNL)
- Pavel Tomin (Chevron)
- Oleg Volkov (Stanford)
- Bin Wang (Chevron)
- Sohail Waziri (Chevron, now at Stanford)
- Xian-Huan Wen (Chevron)
- Josh White (LLNL)
- and many more . . .

Settgast, R. R., Aronson, R. M., Besset, J. R., Borio, A., Bui, Q. M., Byer, T. J., Castelletto, N., Citrain, A., Corbett, B. C., Corbett, J., Cordier, P., Cremon, M. A., Crook, C. M., Cusini, M., Fei, F., Frambati, S., Franc, J., Franceschini, A., Frig

Goal

How much CO_2 can we inject without activating faults?

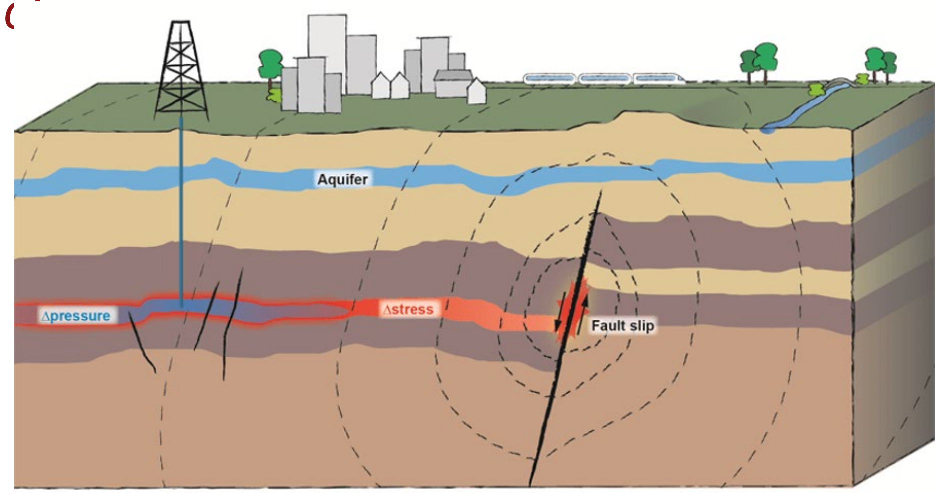
Method

Augmented Lagrange Multipliers

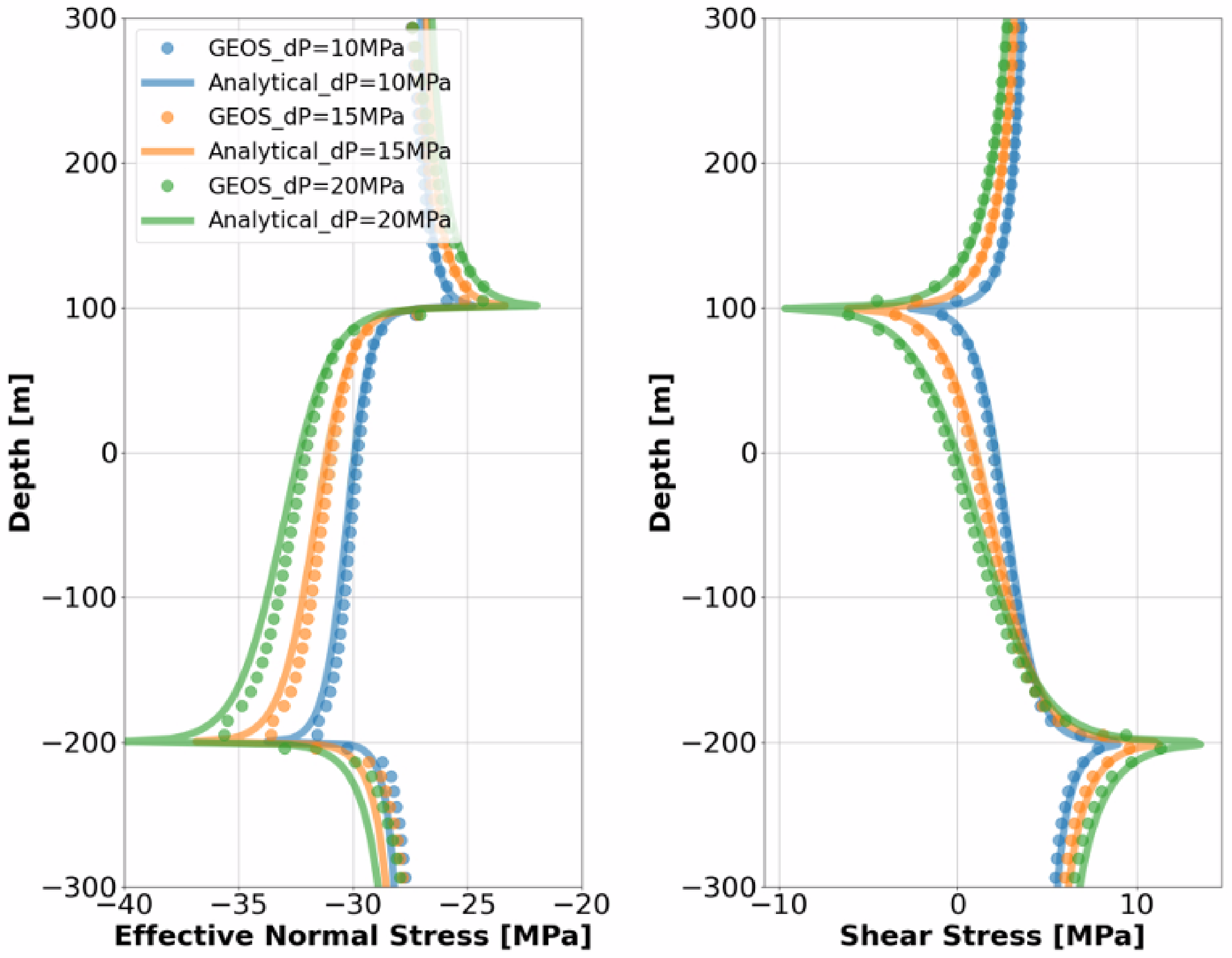
Results

Analytic validation, real field example

Solution: simulate the ***plastic*** *response of faults when stresses*



Muller et al.



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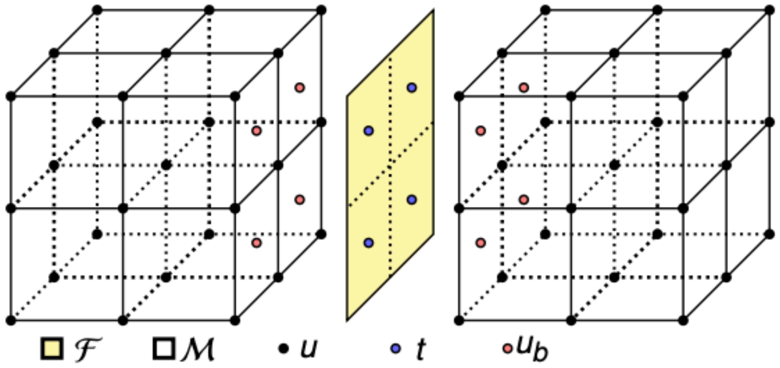
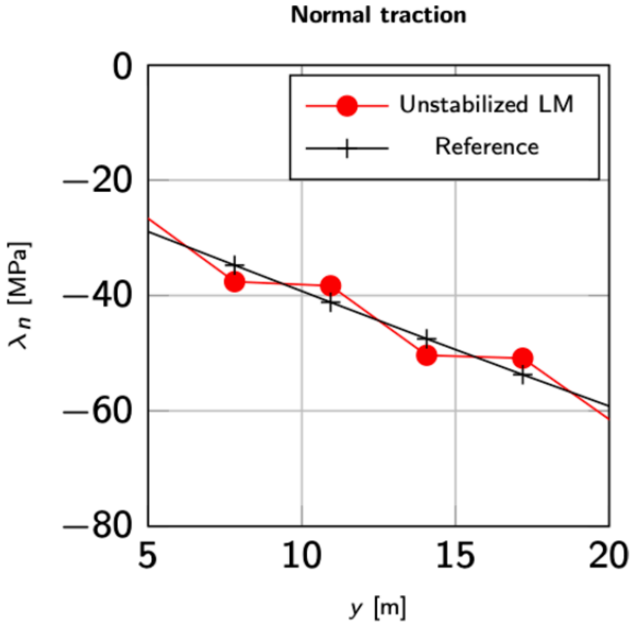


The discrete space of displacement:

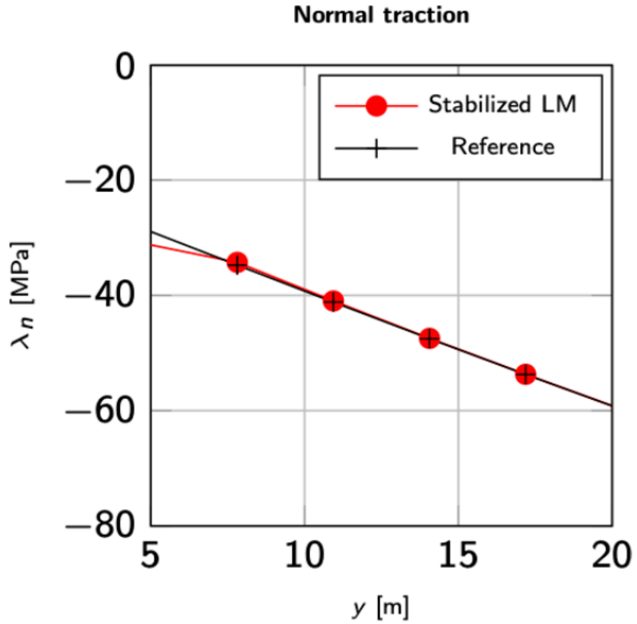
$$\mathcal{U}^n = \mathcal{U}^{n,1} \oplus \mathcal{U}^b, \quad \mathcal{U}^b = \text{span}\left\{[b_e]^d\right\}$$

is enriched with **face bubble functions**

$$b_e = (1 - x_j) \prod_{k=1,k\neq j}^{d} (1 - x_k^2)$$



BEFORE
Without bubble functions:
stability issues



NOW
With bubble functions:
stable numerical solutions

Main contributor: Matteo Frigo, ESE, Stanford

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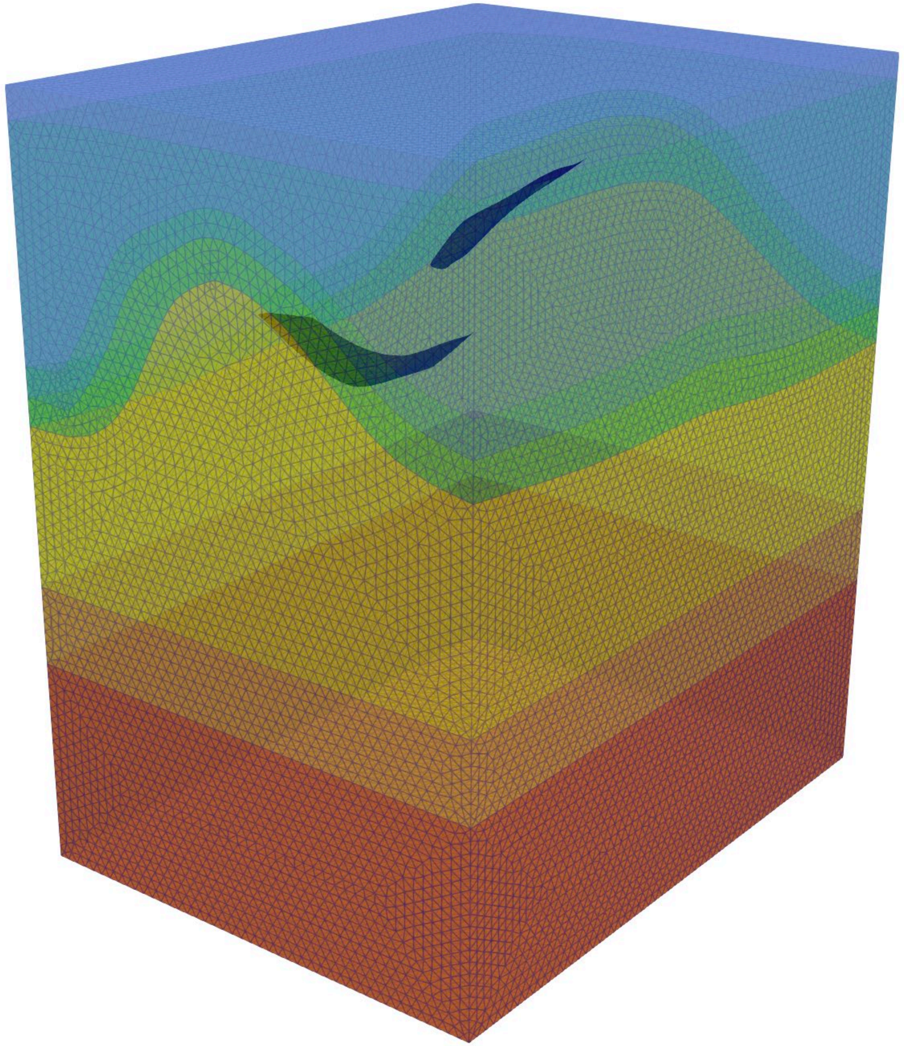
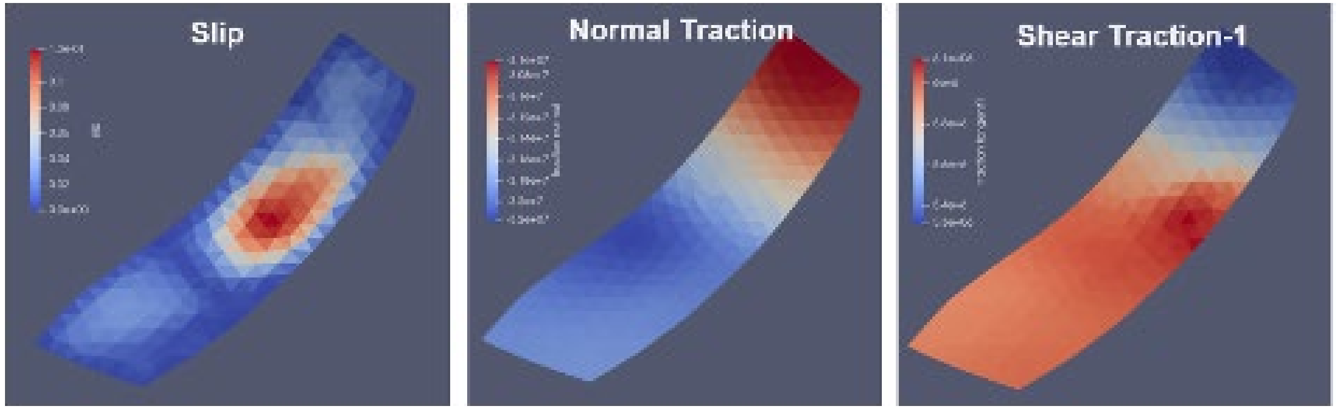




Courtesy of Jian Huang, Margaux Raguenel, Zoe Ternisien, TotalEnergies

Goal

Improve our understanding of CO_2 trapping

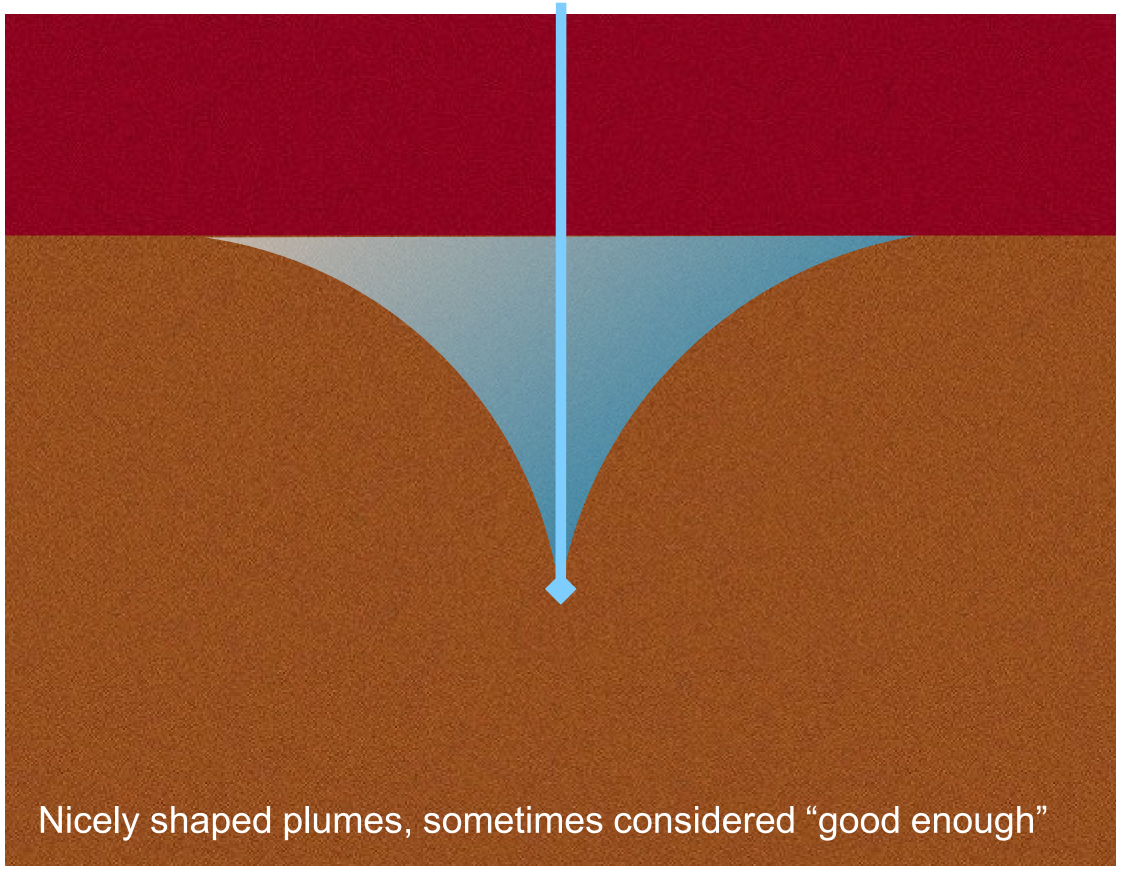
Method

Dissolution, residual trapping, diffusion, dispersion

Results

Analytic validation, real field example

If our model is like this :



Nicely shaped plumes, sometimes considered “good enough”

How can we predict this?

Fluid Flower during ECMOR, Oslo, Sept. 2024

Goal

Improve our understanding of CO_2 trapping

Method

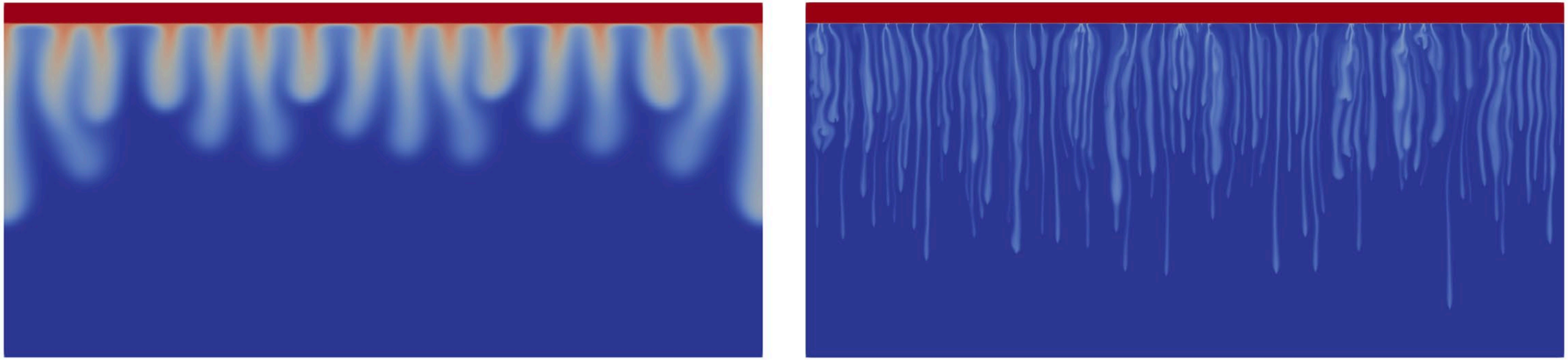
Dissolution, residual trapping, diffusion, dispersion

Results

Analytic validation, real field example

$$j_p = -(s_p \Phi D_p + E|u_p|)\nabla \chi^c{}_p$$

Diffusion + Dispersion



Reproduction of Riaz et al. gravitational dissolution instabilities. This experiment highlights the importance of the mesh resolution in capturing such phenomena.

Courtesy of Jacques Franc, Stanford (now at UPPA)

Goal

Improve our
understanding of

Dissolution,
residual trapping

Analytic
validation, real

1.

Goal

Improve our understanding of CO_2 trapping

Method

Dissolution, residual trapping, diffusion, dispersion

Results

Analytic validation, real field example

Goal

Model near-wellbore thermo-hydro-mechanics effects

Method

Plasticity models that depend on temperature

Results

Analytic validation, real field example

Huang, Jian, François Hamon, Matteo Cusini, Thomas Gazzola, Randolph R. Settgast, Joshua A. White, and Herve Gross. "Simulation of Multiphase Flow and Poromechanical Effects Around Injection Wells in CO2 Storage Sites." *Rock Mechanics and Rock Engineering* (2024): 1-24.

Nguyen-Sy, Tuan, Jian Huang, and Herve Gross. "Theory and analytical solutions to wellbore problems with hardening/softening Drucker-Prager models." *International Journal of Rock Mechanics and Mining Sciences* 182 (2024): 105878.

Su, Kun, Frédéric Bourgeois, Jian Huang, Ghislain Pujol, and Arthur Moncorgé . "Reference stress solution and benchmark of thermo-poro-elastic modelling of cooling effects induced by CO2 storage in depleted reservoirs." In *ARMA US Rock Mechanics/Geomechanics Symposium*. ARMA, 2024.

Model near-wellbore thermo-hydro-mechanics effects

Goal

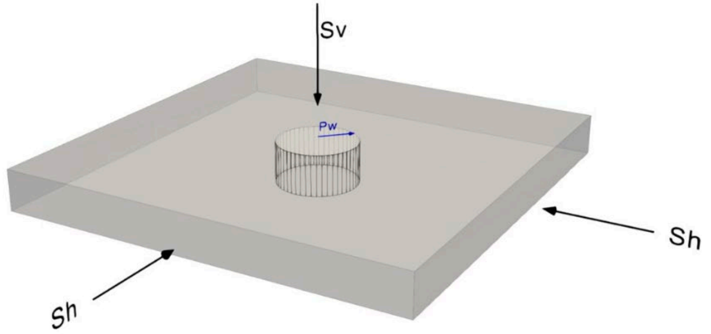
Plasticity models that depend on temperature

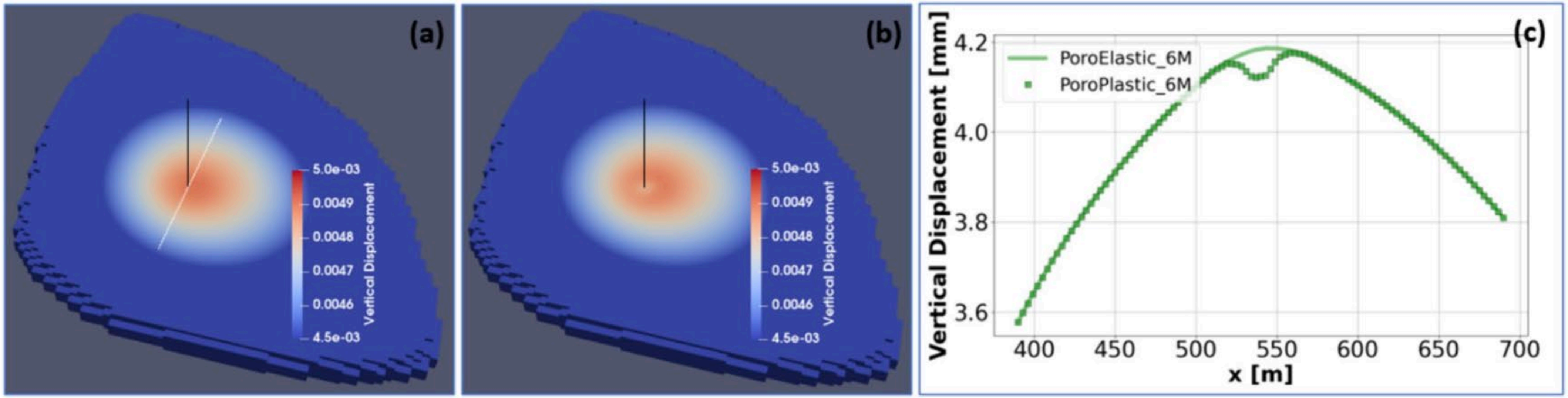
Method

Analytic validation, real field example

Results

Wellbore Contraction Problem with Plasticity using extended Drucker–Prager elastoplastic model to simulate irreversible deformations near a vertical well.





Goal

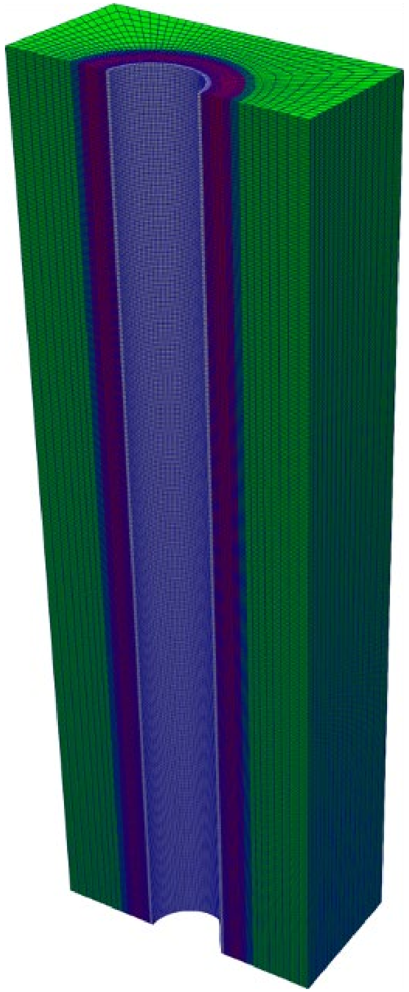
Use basin-scale models for long-term pressure and stress interferences

Method

Improve numerical scalability and portability

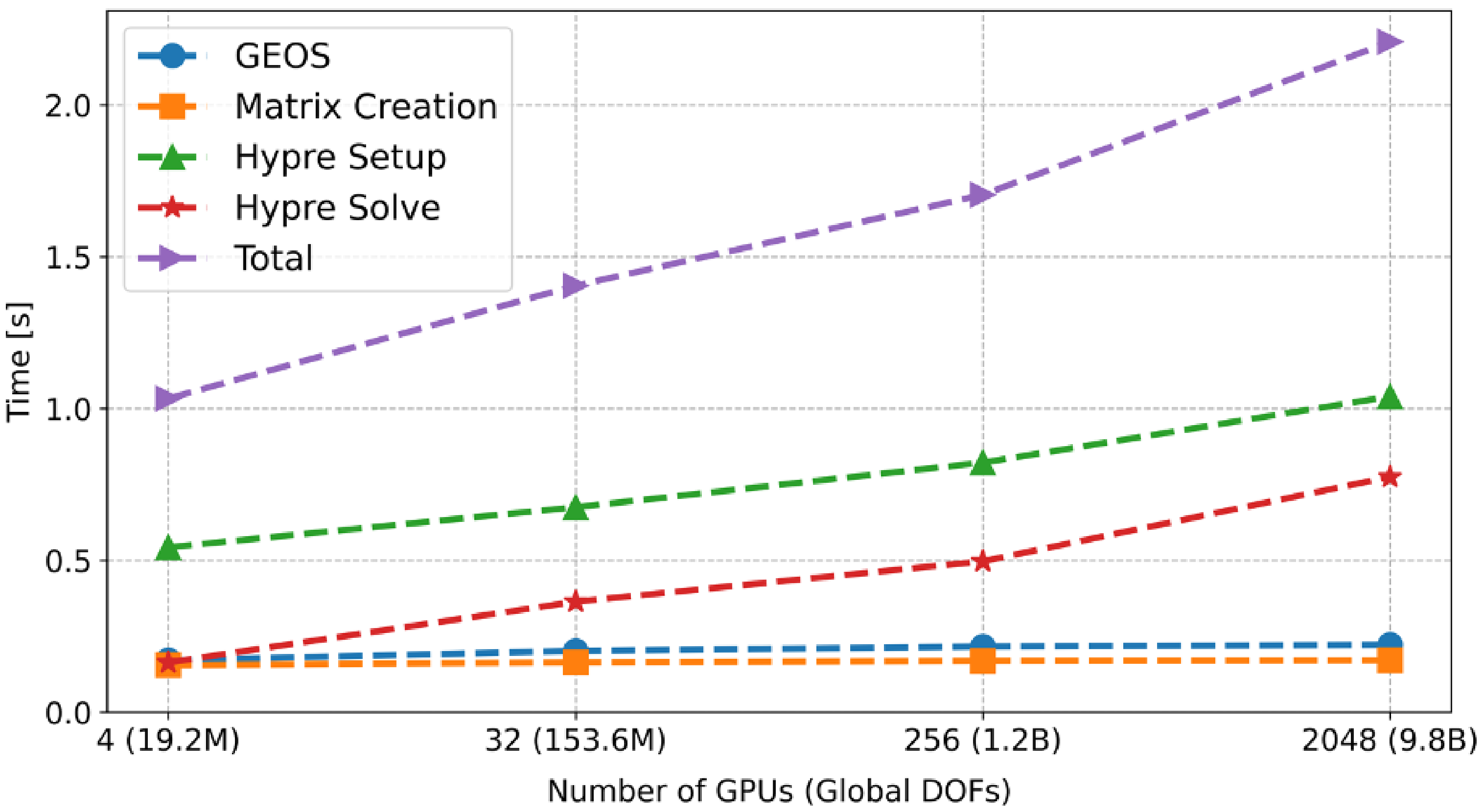
Results

Analytic validation, real field example



Average execution time per Newton timestep

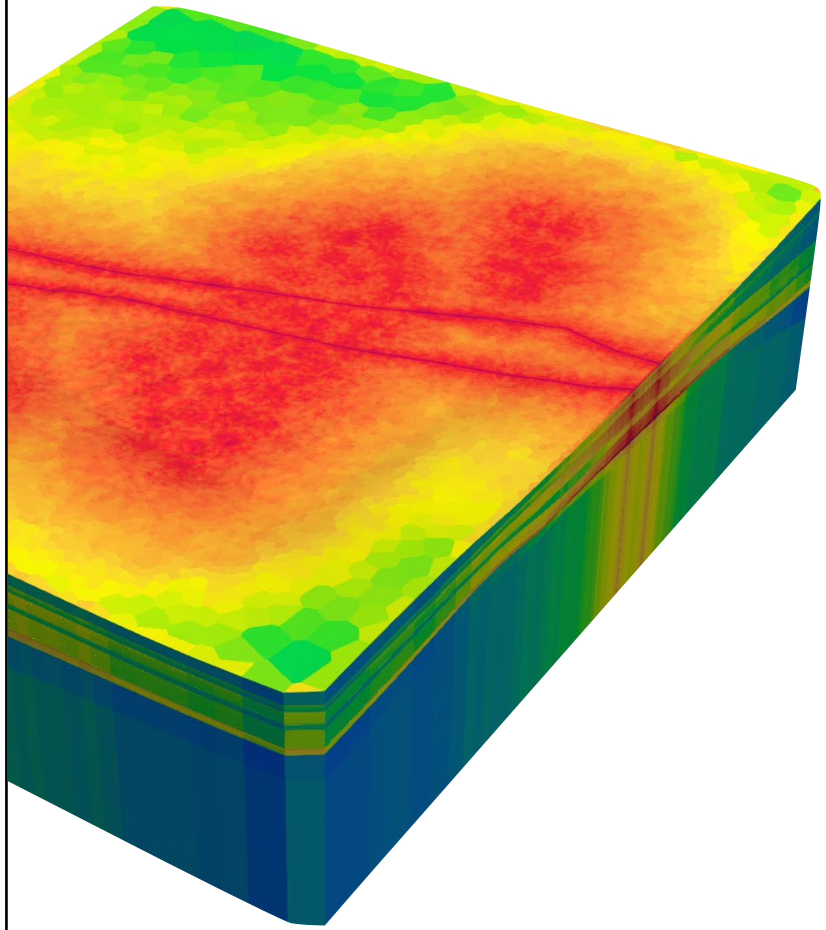
Frontier system (1.19 ExaFLOPs, 37,888 AMD MI250X GPUs)



Ryan Aronson, TotalEnergies, Victor Magri, Nicola Castelletto, Randy Settgast, LLNL.

Results

Analytic validation, real field example



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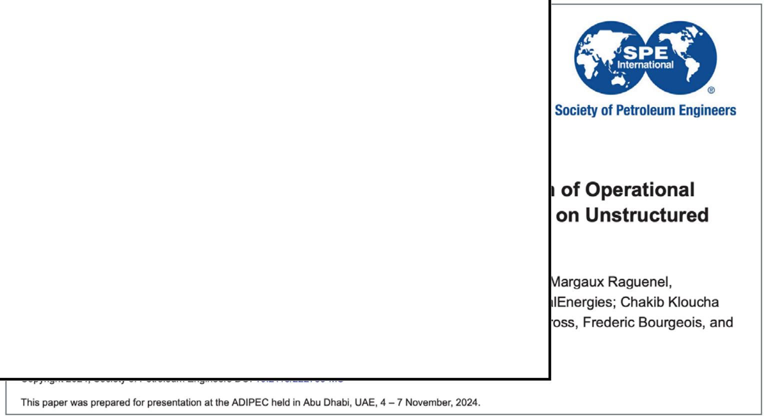

What is coming up?

2023 — 2024 — 2025 — 2026 — 2027 — 2028

WORK PACKAGE 1

Computational infrastructure

I/O stabilization, in-situ visualization, on-prem and cloud portability, scale study with large models (1G cells), support uncertainty quantification workflows.

WORK PACKAGE 2

Multilevel solution schemes

Combine all faults/fracture solvers, improve non-linear solvers and coupling strategies, improve multilevel support

WORK PACKAGE 3

Constitutive Relationships

Near-well geochemistry, Induced seismicity, thermal modeling, hydrogen storage capabilities, geophysical solvers for surveillance and monitoring

WORK PACKAGE 4

Use cases and applications

Support integration effort and train engineers to improve the user experience with GEOS

“Ask not what GEOS can do for you…”

Find out more

www.geos.dev

Download the code

https://github.com/GEOS-DEV/GEOS

Email me

herve.gross@totalenergies.com