

Coupling TPSA geomechanics to OPM Flow

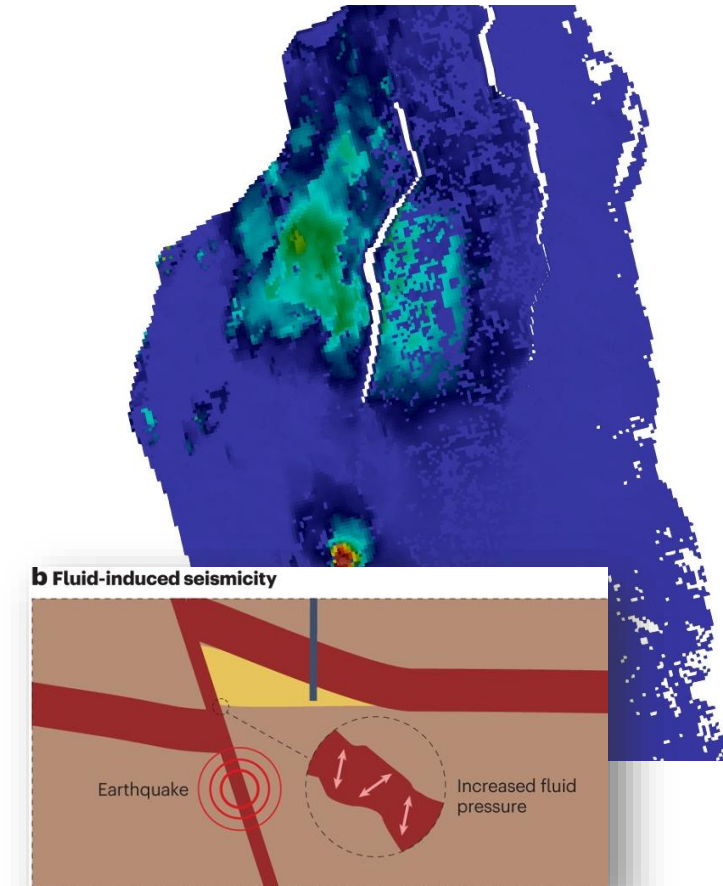
OPM Summit 2026, Utrecht

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Motivation

- Regional-scale CO₂ storage simulations with multiple injection sites
 - High pressure buildup with possible interference/communication
 - Typically 10⁶-10⁷ number of cells
- Potential geomechanical risks
 - Fault reactivation
 - Fracturing, injectivity problems, etc
 - (Micro-)seismicity
- Current workflows
 - Transfer of information between different software
 - Different grids between flow and geomechanics



Poroelectricity – Biot model



- Geomechanics – linear momentum

$$-\nabla \cdot (2\mu\varepsilon(u) + \lambda(\nabla \cdot u)I) + \alpha\nabla p = g$$

- Flow – mass conservation

$$\partial_t(cp + \alpha\nabla \cdot u) + \nabla \cdot K\nabla p = f$$

u : displacement
 p : pressure
 α : Biot const.

- Finite element methods
 - Pros: Flexible, numerous solvers
 - Cons: Corner-point grids difficult, sensitive to grid aspect ratios
- Finite volume methods
 - Pros: Same discretization as flow \rightarrow cell-centered variables
 - Cons: Larger stencils have been required

Two-point stress approximation (TPSA)

- Discretization of $\varepsilon(u) = \frac{1}{2}(\nabla u + (\nabla u)^T)$ at face?

$$n \cdot \nabla u = \frac{\partial u}{\partial n} \approx \frac{u^{i+1} - u^i}{h}$$

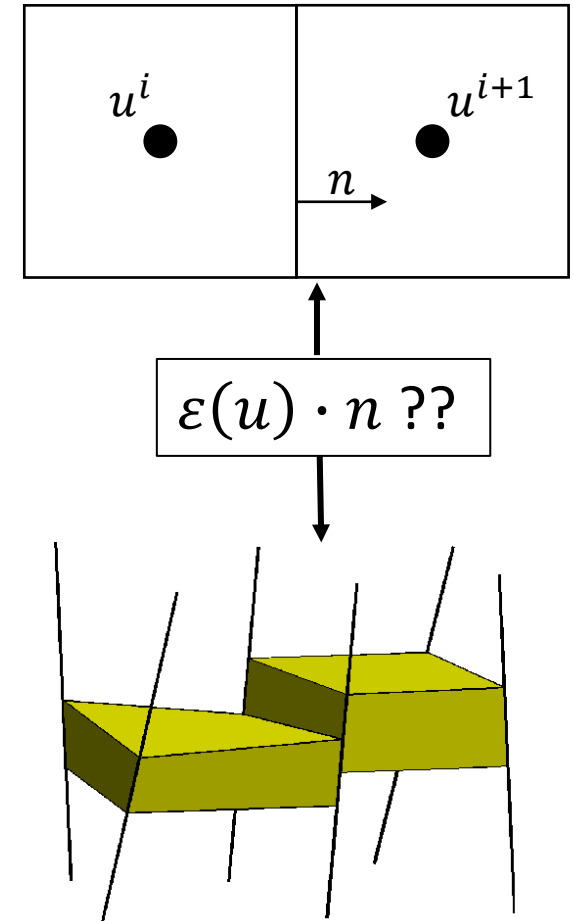
$$n \cdot (\nabla u)^T = \nabla(n \cdot u) \approx ?$$

- Solution*:

1. $r = \nabla \times u$, 3 dofs (per cell)

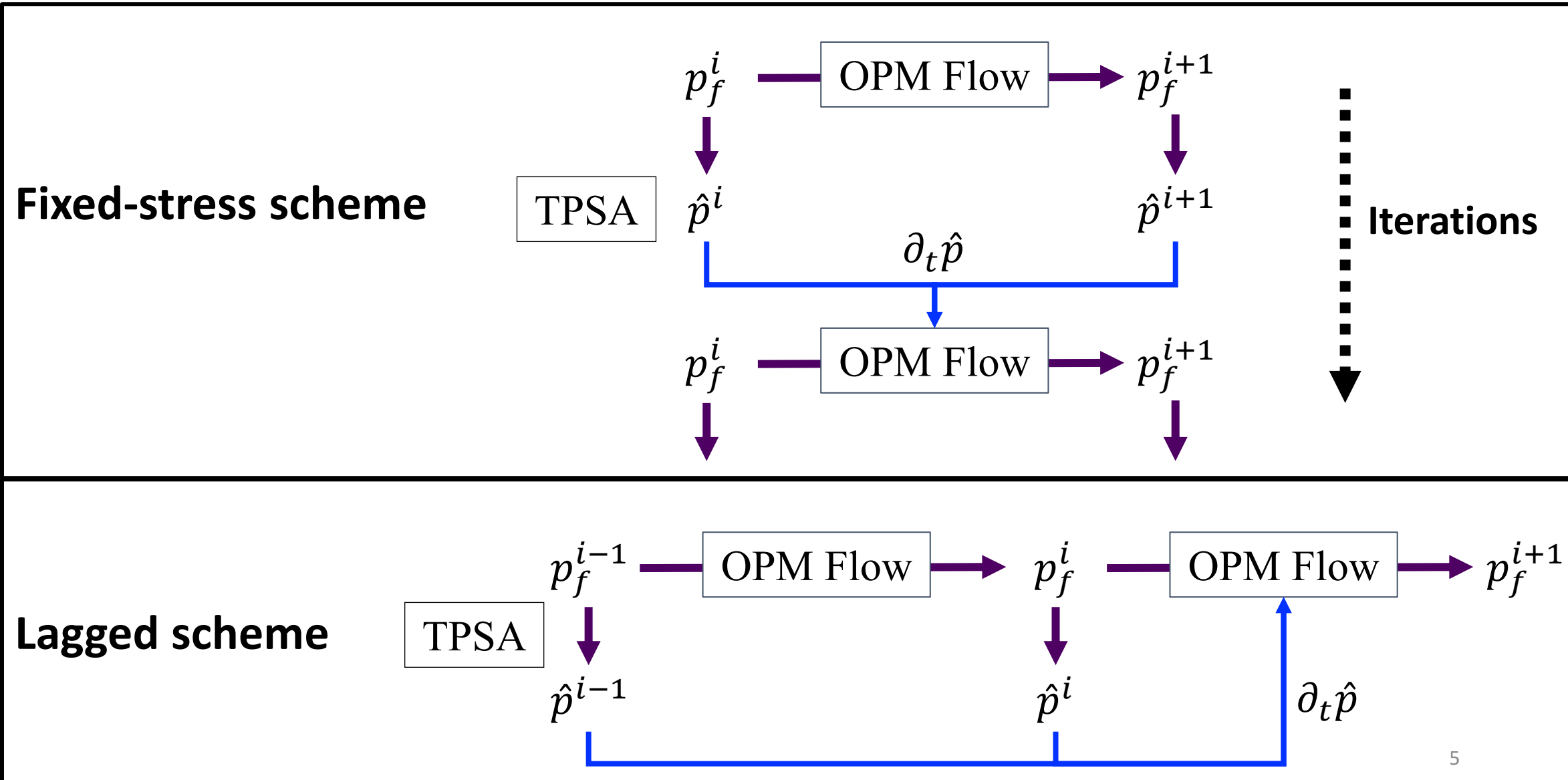
2. $p_s = \lambda \nabla \cdot u$, 1 dof (per cell)

- In total: 7 dofs (per cell), but sparse stencil!



Coupling Flow and TPSA

$$\begin{aligned}
 f_{Flow} &\leftarrow f_{Flow} - \alpha \lambda^{-1} \partial_t \hat{p} \\
 g_{TPSA} &\leftarrow g_{TPSA} + \alpha \lambda^{-1} p_f \\
 \hat{p} &:= p_s - \alpha p_f
 \end{aligned}$$



Implementation

- Structure same as Flow
 - Default properties in `TTagFlowProblemTPSA.hpp`
- Flow and TPSA coupling schemes in `BlackoilModelTPSA` (inherits `BlackoilModel`)
- Generic TPSA implementation
 - Problem: `FlowProblemTPSA` (inherits `FlowProblemBlackoil`)
 - Model: `TpsaModel`
 - Newton: `TpsaNewtonMethod`
 - Linearizer: `TpsaLinearizer`
 - Linear solver: `ISTLSolverTPSA`
- Executables
 - `flow_blackoil_tpsa`, `flow_onephase_tpsa`,
`flow_gaswater_dissolution_tpsa`
 - ... or use `flow`

Implementation

- New keyword for choosing solver and coupling scheme

```
RUNSPEC
...

MECHSOLV
-- Solver Scheme
   TPSA    LAGGED /
```

or

```
RUNSPEC
...

MECHSOLV
-- Solver Scheme           Min its. Max its.
   TPSA    FIXED-STRESS 1           5           /
```

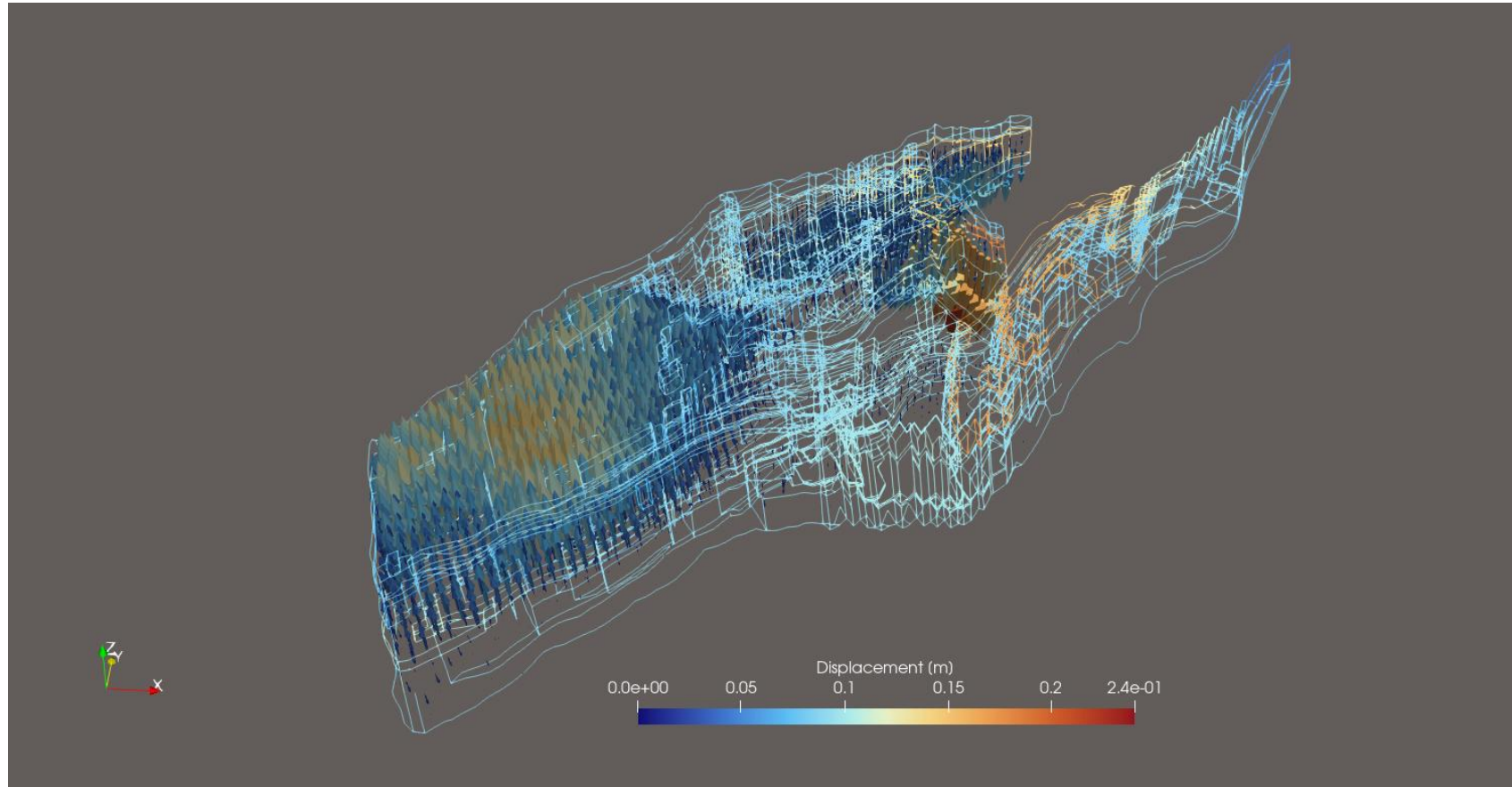
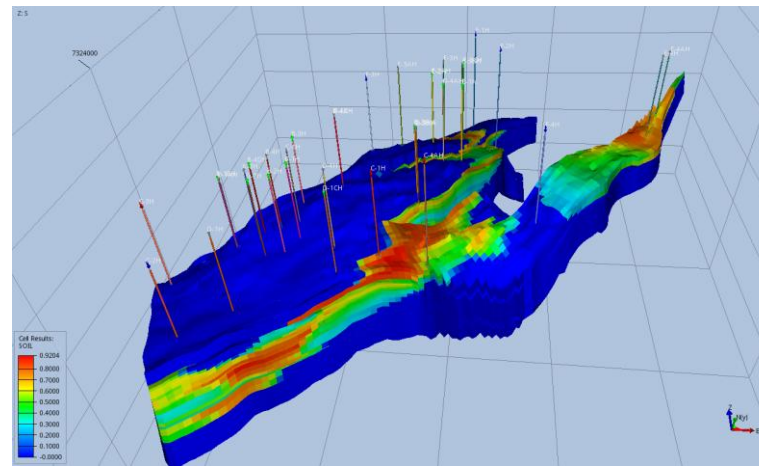
- Visualization:
 - Restart files for ResInsight (`--enable-opm-rst-file=true`)
 - VTK for Paraview (`--enable-vtk-output=true`)
 - Only displacement, other outputs (stress, strain,...) in progress
- OBS parallel:
 - TPSA may need overlap cells even for zero transmissibility faces
 - Use `--edge-weights-method=uniform` in worst case

Example - Norne



```
RUNSPEC
...
MECH
MECHSOLV
TPSA /
```

```
GRID
...
BIOTCOEF
113344*0.87 /
SMODULUS
113344*3.5 /
LAME
113344*4.0 /
```

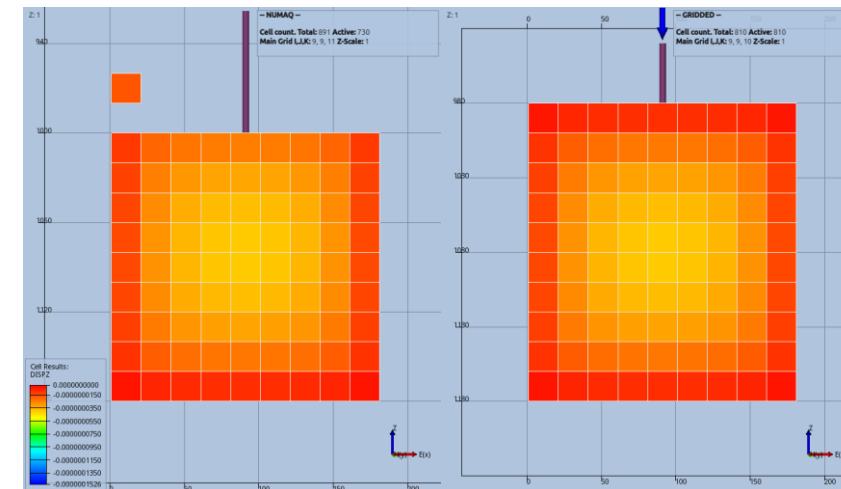


Some ongoing work

- AMG preconditioner
 - Serial version works, issues in parallel
- (Over-, under-, side-)burden
 - Extend reservoir grid
 - Approximate with numerical aquifer
 - Robin boundary conditions
- Thermal simulation
 - Straightforward (?) → additional pore volume term
 - ECMOR 2026, Portugal (with `opm-flowgeomechanics`)

$$P := \begin{bmatrix} \text{AMG}_V(M_{11}) & & & \\ & M_{21} & & M_{22} \\ & M_{31} & & \text{AMG}_V(M_{33}) \end{bmatrix}^{-1}$$

Boon et al, Computat. Geosc. (2026)



NUM AQUIFER

GRIDDED

Acknowledgments



The MuPSI project (Multiscale Pressure-Stress Impacts on fault integrity for multi-site regional CO₂ storage) is awarded through the Clean Energy Transition Partnership (CET-P) project number CETP-FP-2023-00298, with funding provided by the RCN Research Council of Norway, Scottish Enterprise, NWO Dutch Research Council, AEI-Agencia Estatal de Investigación, and US DoE, with contributions from Storegga Ltd, Equinor ASA, Norske Shell AS, and EBN Capital BV.



References



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Boon, W., Gasda, S., Sandve, T.H., and Tveit, S. (2026): *Solving Biot poroelasticity by coupling OPM Flow with the two-point stress approximation finite volume method*, Computat. Geosc. (In press)