Spatial model coupling - an efficient scheme to combine hydraulic and geomechanic simulations

International Research Training Group nupus

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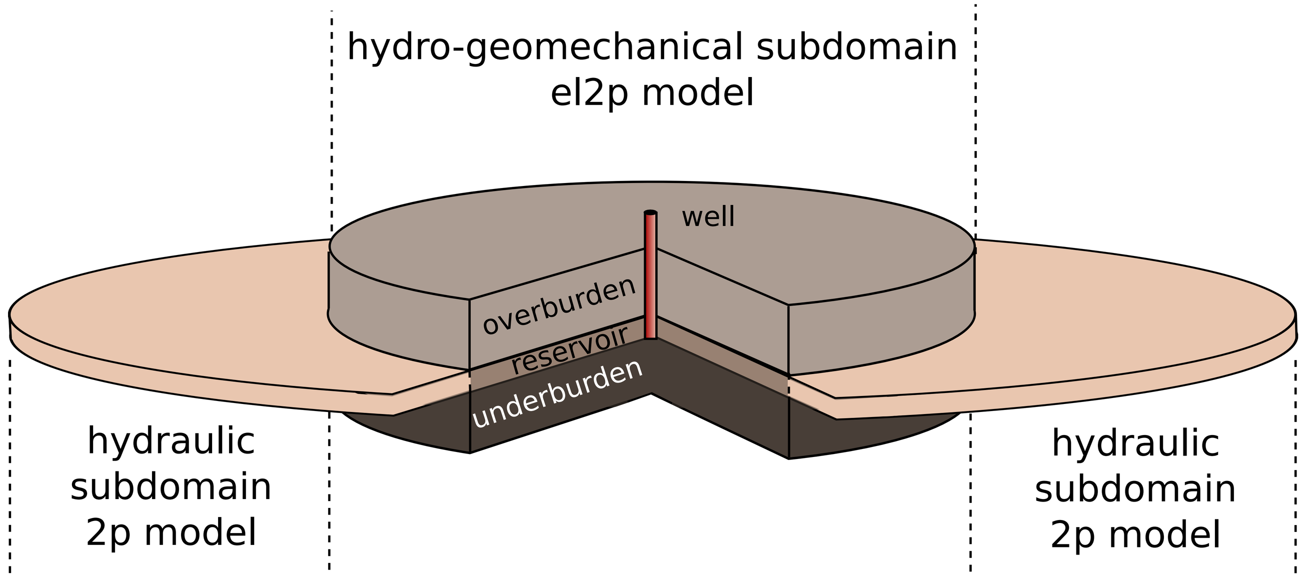
Motivation

Processes related to fluid injections into the subsurface take place on large temporal and spatial scales. The corresponding computational costs are high and can be reduced by adapting the model's complexity in time and space. Here, we present a spatial coupling approach with two subdomains [1]:

- Hydro-geomechanical model
  full model approach for the well vicinity (largest pressure build-up)
- Hydraulic model
  simplified model approach for the far-field (geomechanics are neglected)



We aim to demonstrate that such a coupling scheme could allow efficient simulations and an accurate description of the relevant processes at the same time.

Model concept

Balance equations

Hydraulic model (2p) - mass balance:

$$\phi \frac{\partial(\varrho_\alpha S_\alpha)}{\partial t} - \mathrm{div}\left\{\varrho_\alpha \frac{k_{r\alpha}}{\mu_\alpha}\mathbf{K}\left(\mathrm{grad}\, p_\alpha - \varrho_\alpha \mathbf{g}\right)\right\} = q_\alpha \quad , \ \alpha \in \{\mathrm{w}, \mathrm{n}\}.$$

Hydro-geomechanical model (el2p) - mass balance:

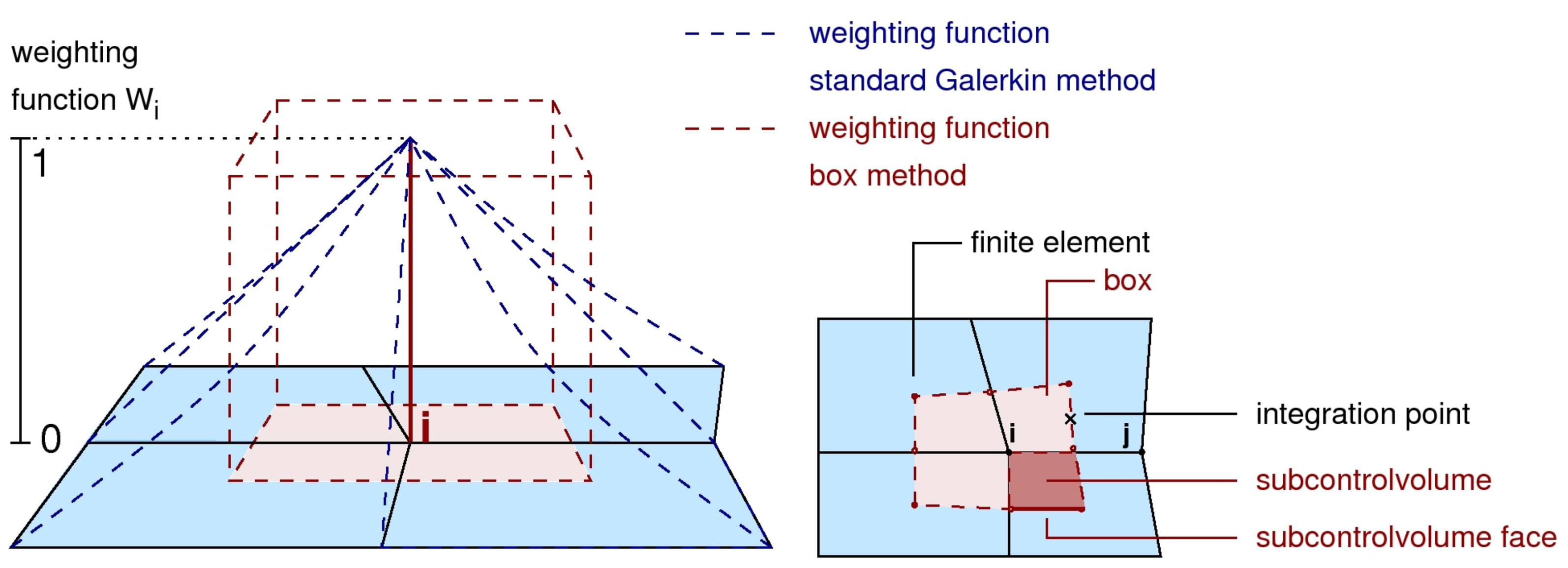
$$\frac{\partial(\phi_{\mathrm{eff}}\varrho_\alpha S_\alpha)}{\partial t} - \mathrm{div}\left\{\varrho_\alpha \frac{k_{r\alpha}}{\mu_\alpha}\mathbf{K}_{\mathrm{eff}}\left(\mathrm{grad}\, p_\alpha - \varrho_\alpha \mathbf{g}\right) + \phi_{\mathrm{eff}} S_\alpha \varrho_\alpha \frac{\partial \mathbf{u}}{\partial t}\right\} = q_\alpha \quad , \ \alpha \in \{\mathrm{w}, \mathrm{n}\}.$$

Momentum balance:

$$\mathrm{div}(\Delta\sigma' + \Delta p_{\mathrm{eff}}\,\mathbf{I}) - \phi\, S_{\mathrm{n}}\,(\varrho_{\mathrm{n}} - \varrho_{\mathrm{w}})\,\mathbf{g} = 0.$$

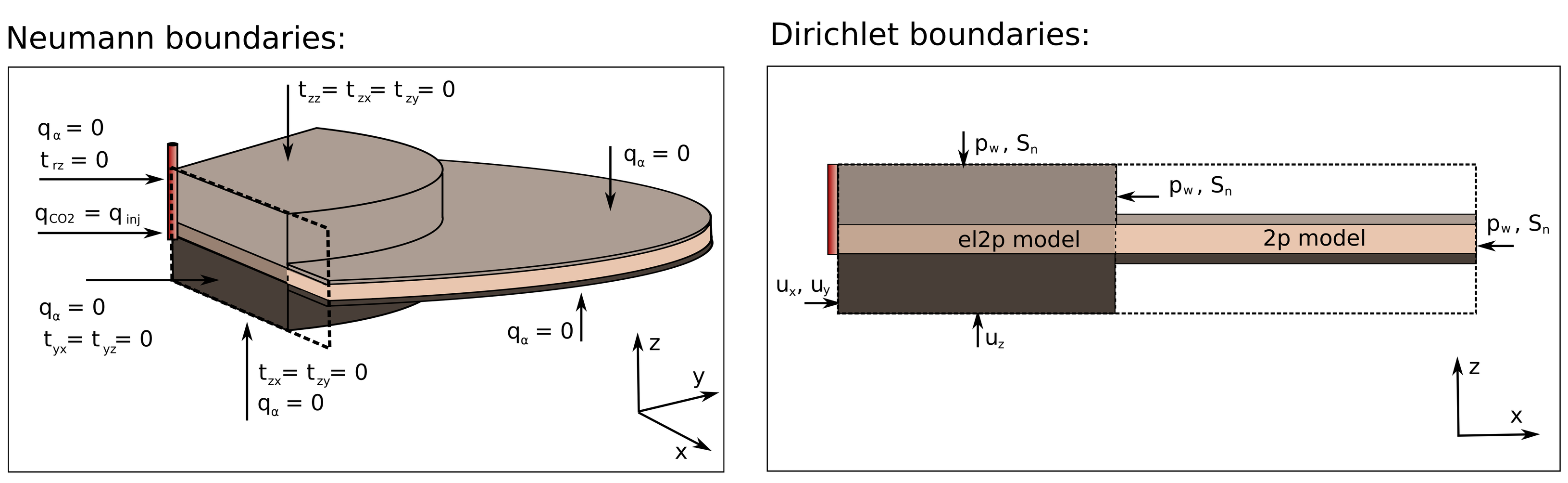
Discretization

The mass balance equations are discretized with the box method while the standard Galerkin finite element method is applied for the momentum balance equation. The different discretizations were chosen to avoid oscillations.



Coupling

Spatial model coupling of a hydro-geomechanical and a hydraulic model:



DuMu^x

Simulations are performed using the open-source simulator DuMu^x.

DFG

Support of the German Research Foundation is gratefully acknowledged.

Link to this poster.

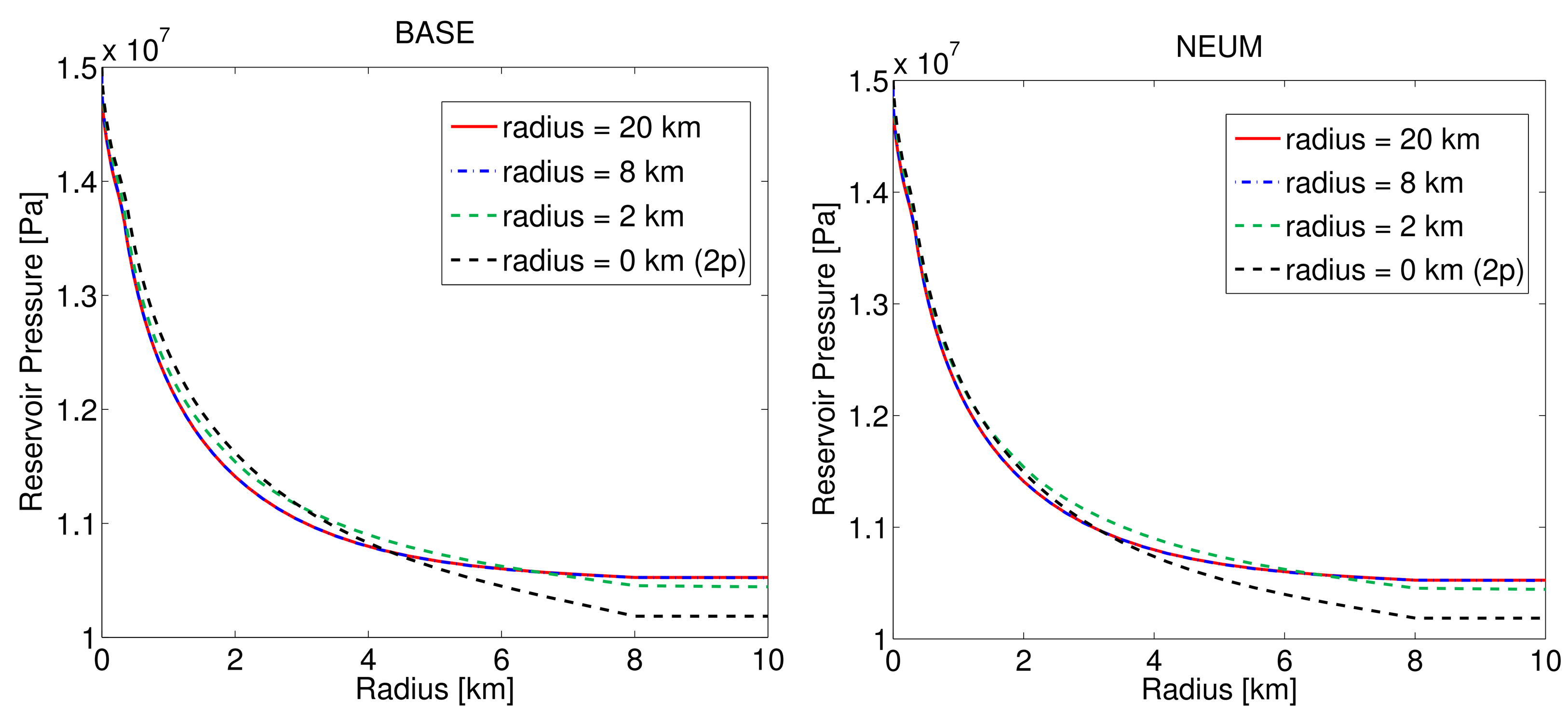
Numerical experiments

We tested the spatial coupling scheme for two CO_2 injection scenarios:

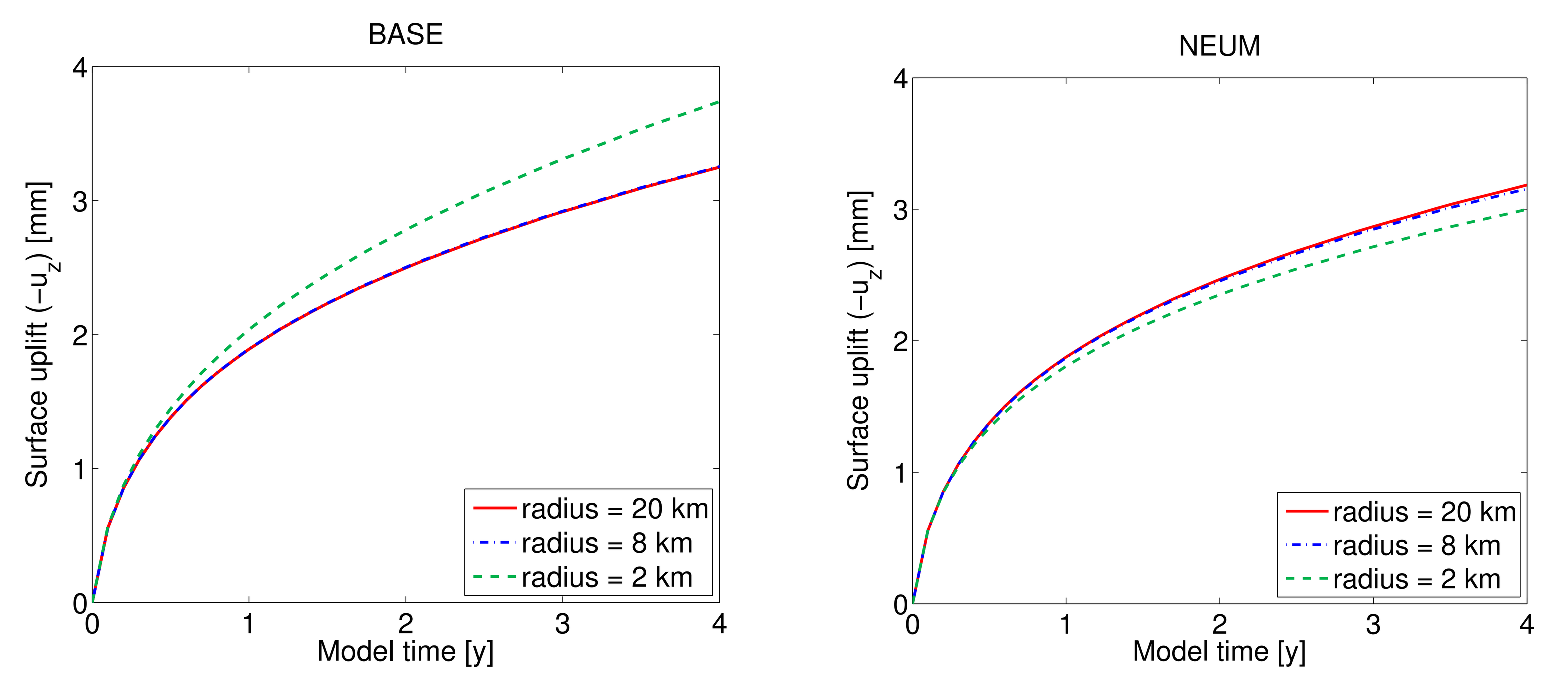
test case	description	injection rate [kg/s]	injection period [y]	radial *el2p* boundary condition
BASE	base case	0.17	4	Dirichlet $u_x = u_y = 0$ m, Neumann $\mathbf{t}_{rz} = 0$ Pa
NEUM	neumann boundaries	0.17	4	Neumann $\mathbf{t}_{rx} = \mathbf{t}_{ry} = 0$ Pa, Neumann $\mathbf{t}_{rz} = 0$ Pa

Here, t_{ij} is a linearized traction vector, which represents the change in total stress in j direction at a face with normal direction i. The index r refers to a normal vector in radial direction.

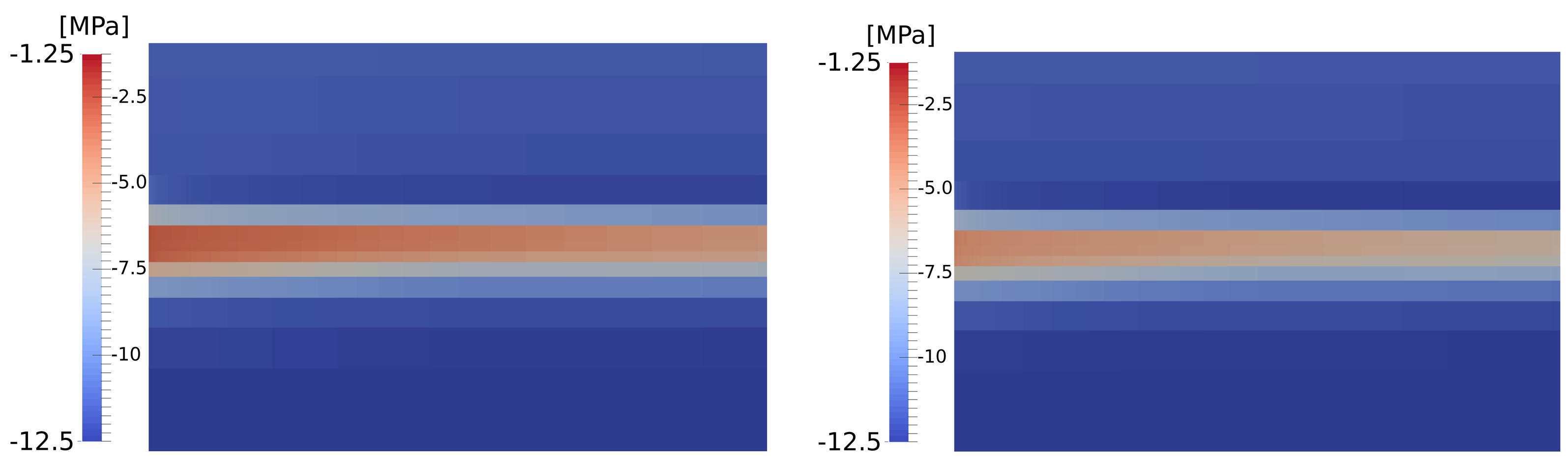
Reservoir pressure for different coupling radii after four years of injection



Surface uplift for different coupling radii above the injection



Pressure margin for shear and tensile failure after one year of injection



Outlook

- short-term
  cross-check the approach by inverting the spatial extent of the subdomains => large geomechanical model and smaller hydro-geomechanical model
- medium-term
  implement a phenomenological approach to calculate the stress reorganisation after failure occurs
- long-term
  include mechanics and hydraulics for fractures

References

[1] Darcis, M., Beck, M., Flemisch, B., Mūthing, S., and Class, H. (2014). Spatial model coupling applied to the simulation of CO2 storage scenarios. *Computational Geosciences*. Submitted.

[2] Helmig, R., Flemisch, B., Wolff, M., Ebigbo, A., and Class, H. (2013). Model coupling for multiphase flow in porous media. *Advances in Water Resources*, 51:52–66.