Adaptive modelling of multi-phase flow

International Research Training Group nupus

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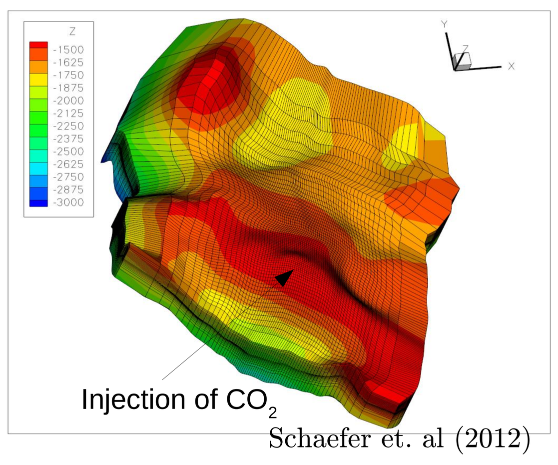
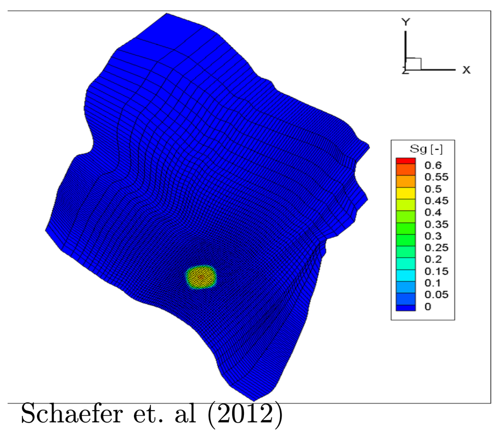
Motivation

Most simulations of multiphase flow scenarios require vast computer resources, due to the large time-span of interest and the huge size of the simulation domain. Such cases include:

- Remediation of contaminated soils,
- Geothermal applications,
- Sequestration of CO2 in the subsurface.



Schaefer et. al (2012)



Schaefer et. al (2012)

Only small parts of the domain are subject to complex physical processes or are of major interest:

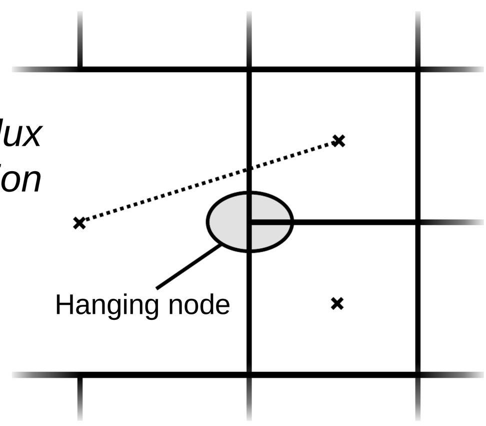
- Model complexity differs locally.
- Detailed refinement necessary locally.
  - ➡ Adaptive modeling beneficial!

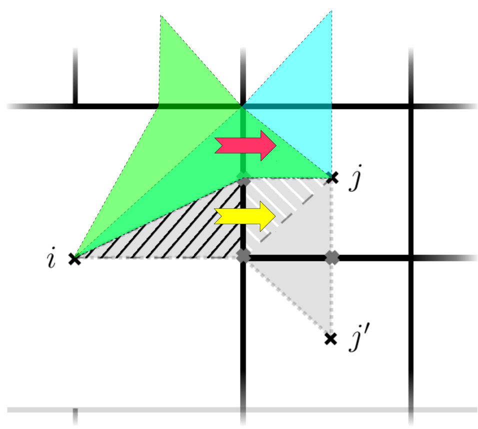
Adaptive Strategies

Adaptive grid

Refinement leads to hanging nodes: two-point flux approximation fails.

Two-Point Flux Approximation (TPFA)



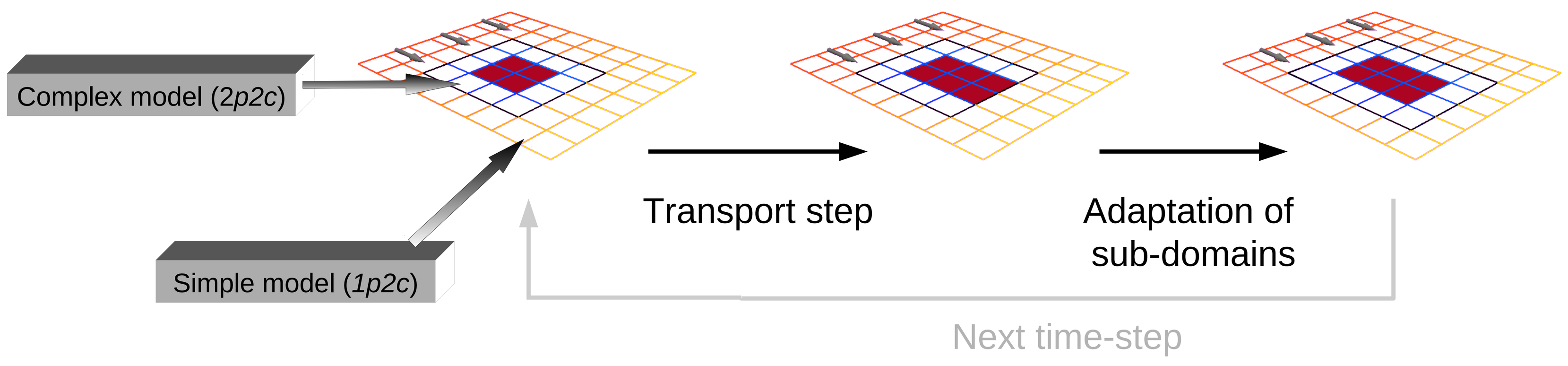


Multi-Point Flux Approximation (MPFA L-method)

Aavatsmark et. al (2008)

Multi-physics framework

Apply different numerical models locally according to their „sub-domain":

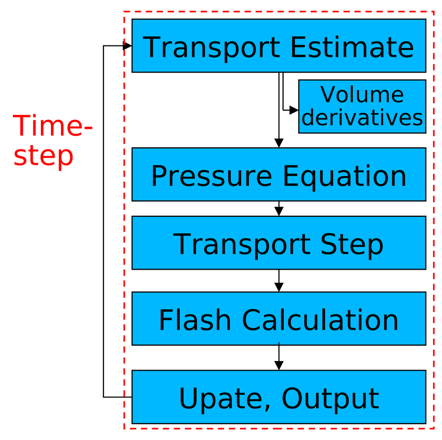


Numerical Model

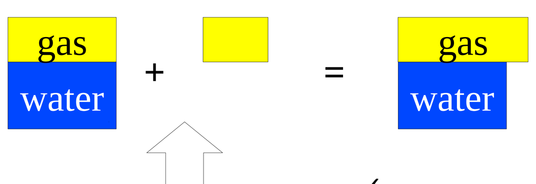
Implicit pressure equation

- Single phase:

$$c_\alpha \frac{\partial p}{\partial t} + \nabla \cdot \mathsf{v}_\alpha = \sum_\kappa \frac{1}{\varrho_\alpha} q^\kappa + \varepsilon,$$



- Multi-phase (volume balance):



$$c_{total} \frac{\partial p}{\partial t} + \sum_\kappa \frac{\partial v_{total}}{\partial C^\kappa} \nabla \cdot \left(\sum_\alpha X_\alpha^\kappa \varrho_\alpha \mathsf{v}_\alpha \right) = \sum_\kappa \frac{\partial v_{total}}{\partial C^\kappa} q^\kappa + \varepsilon,$$

Acs et. al (1985)

with

$$\mathsf{v}_w = -\lambda_w \mathsf{K} \left(\nabla p_n - \nabla p_c - \varrho_w \mathsf{g} \right),$$
$$\mathsf{v}_n = -\lambda_n \mathsf{K} \left(\nabla p_n - \varrho_n \mathsf{g} \right),$$

$$C^\kappa = \sum_\alpha \varrho_\alpha S_\alpha X_\alpha^\kappa$$

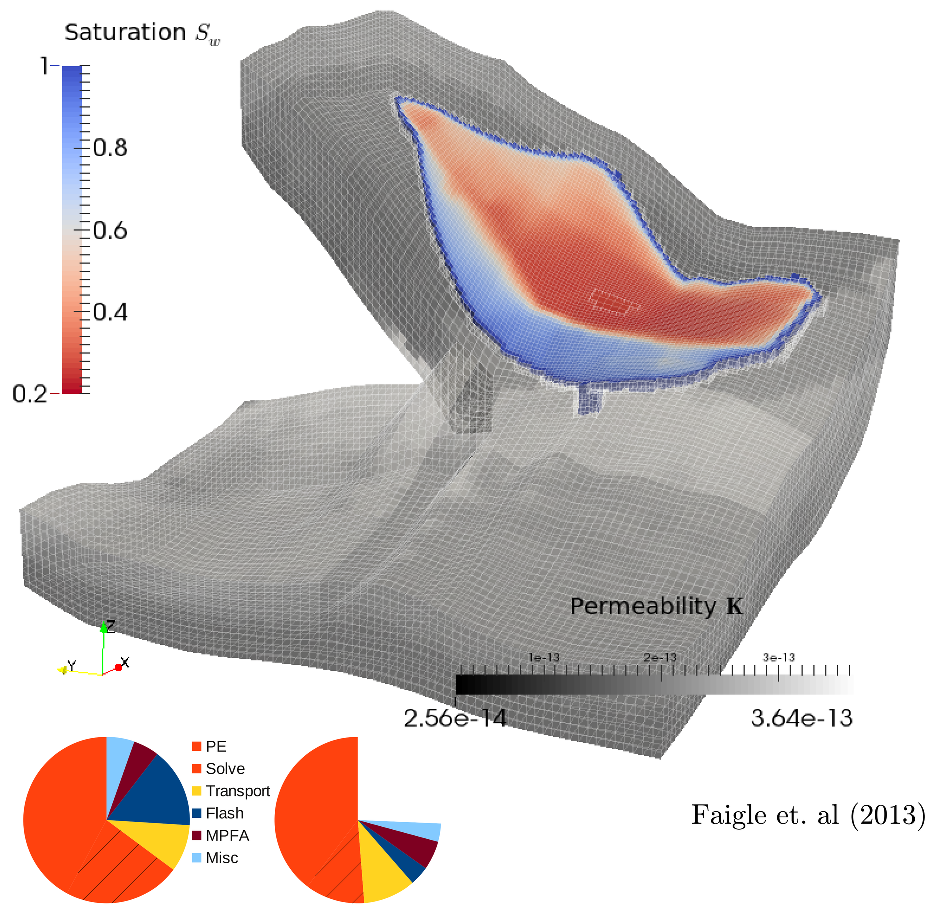
Explicit transport equation

$$\frac{\partial C^\kappa}{\partial t} = -\nabla \cdot \left(\sum_\alpha X_\alpha^\kappa \varrho_\alpha \mathsf{v}_\alpha \right) + q^\kappa.$$

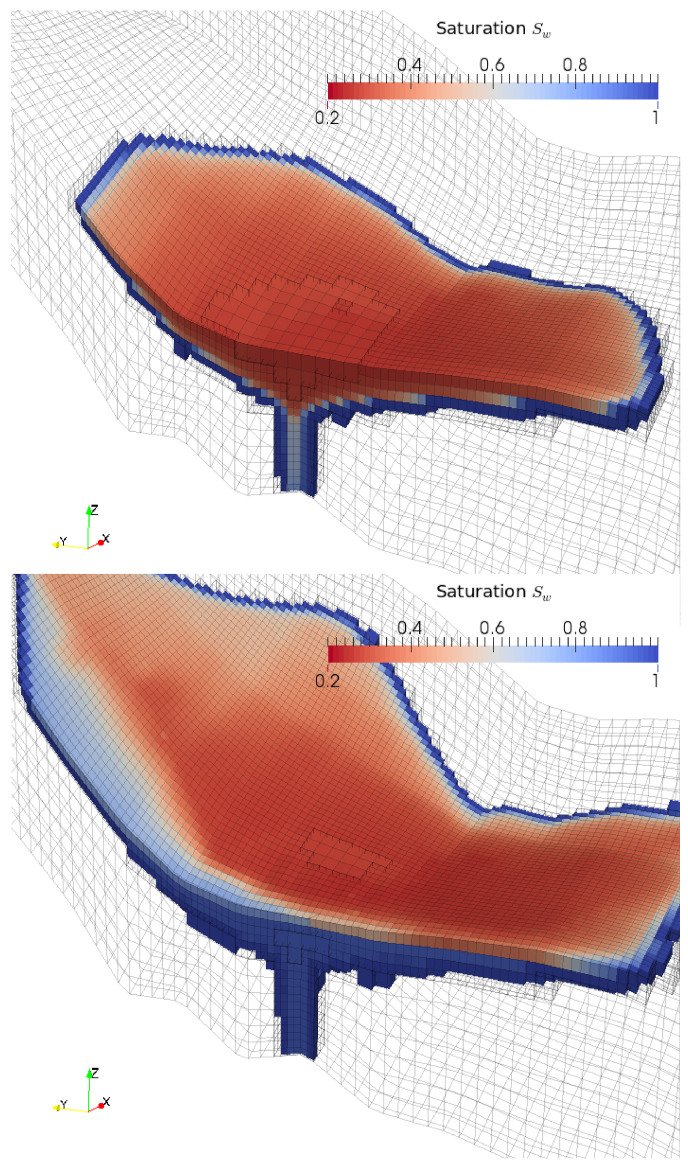
Large-Scale Examples

Johansen benchmark

- Injection of CO_2 over 25 years.
- Simulation time 50 years.
- Multi-physics and adaptive grid.



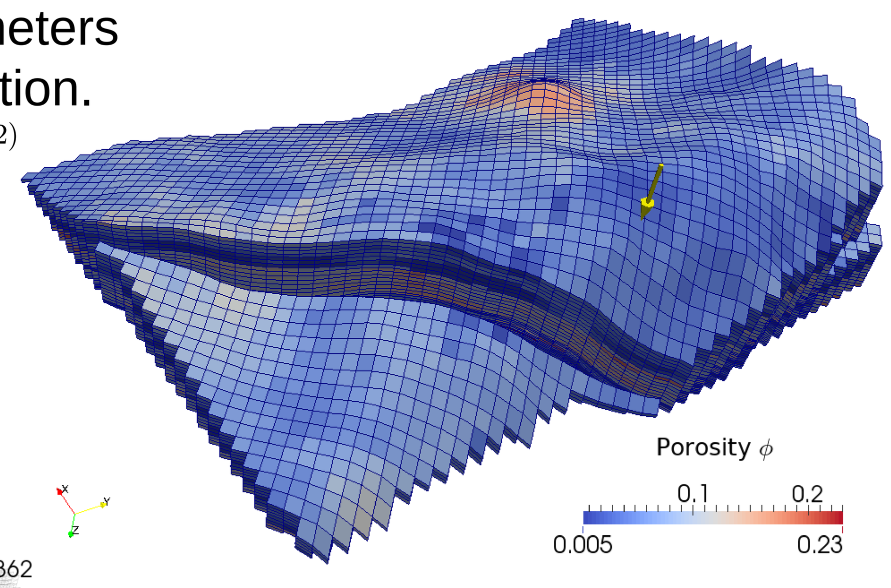
Faigle et. al (2013)



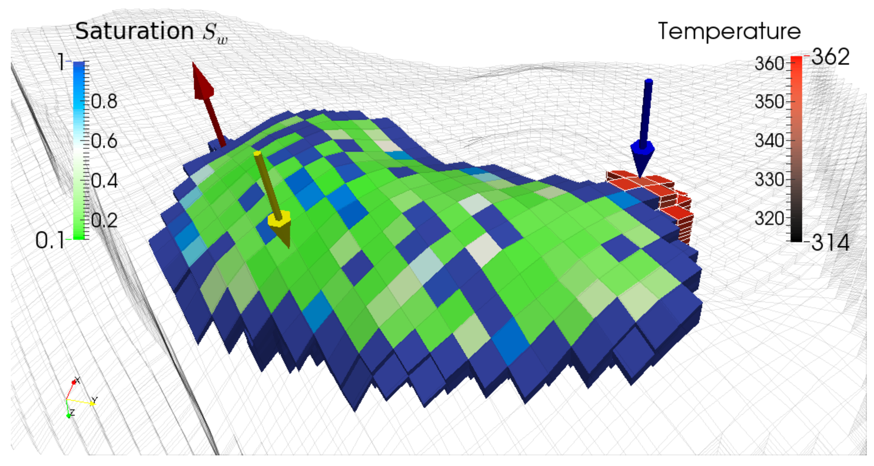
CO2-injection and geothermal usage

- Strongly heterogeneous soil parameters because of heavily fractured formation.

Jamal et. al (2012)

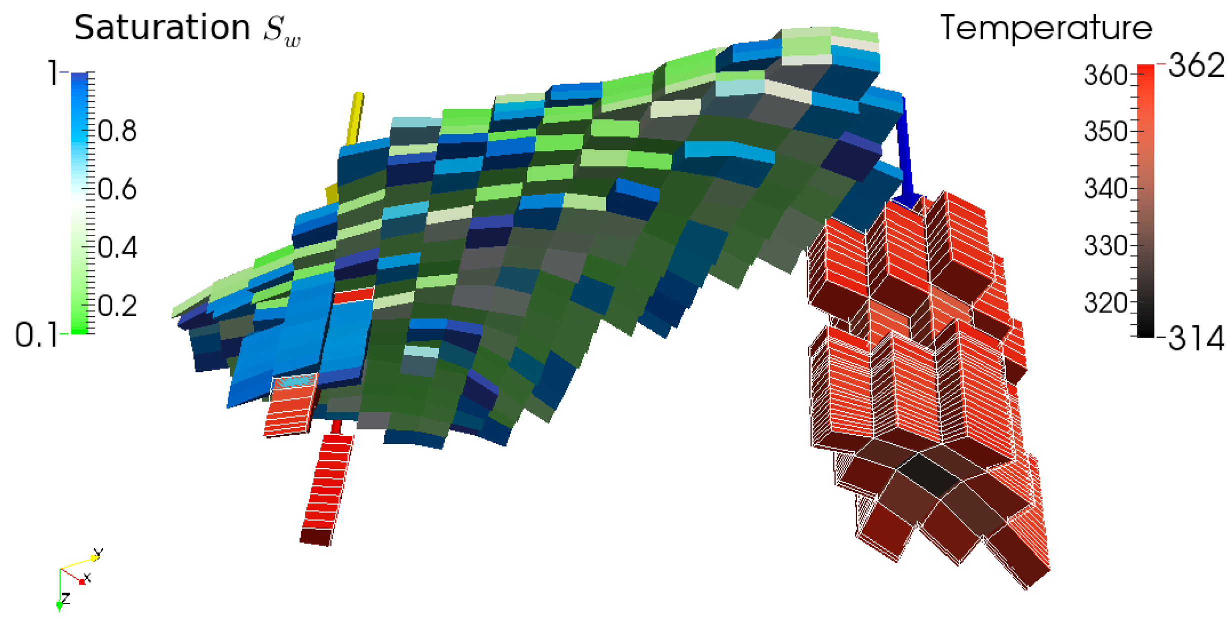


- Complex physics: Non-isothermal conditions including compositional compressible two-phase flow. Interacting processes within one domain.



Multi-physics with 3 Models:

- 1p2c with linear T
- 2p2c with linear T
- Full 2p2cNI



Future Work

- Simulation of the Tensleep formation on an adaptive grid.
- Further application of the framework, for example on a large-scale remediation scenario emplying the 3p3c multi-physics model.
- Increase numerical stability: improve time-stepping.
- Combination with multi-scale methods to up-scale soil parameters.

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