Universität Stuttgart

An adaptive multiphysics model coupling vertical equilibrium and full multidimensions for the simulation of underground gas storage

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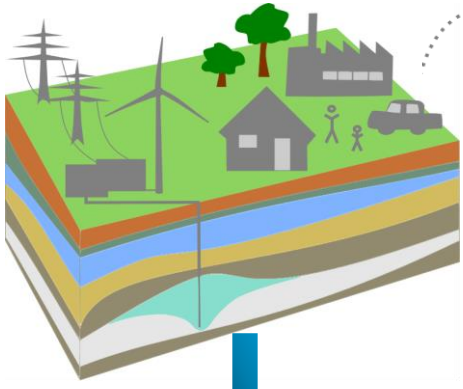
Underground energy storage



Mobility

Industry

Turbines

Generator

Mechanical

Chemical

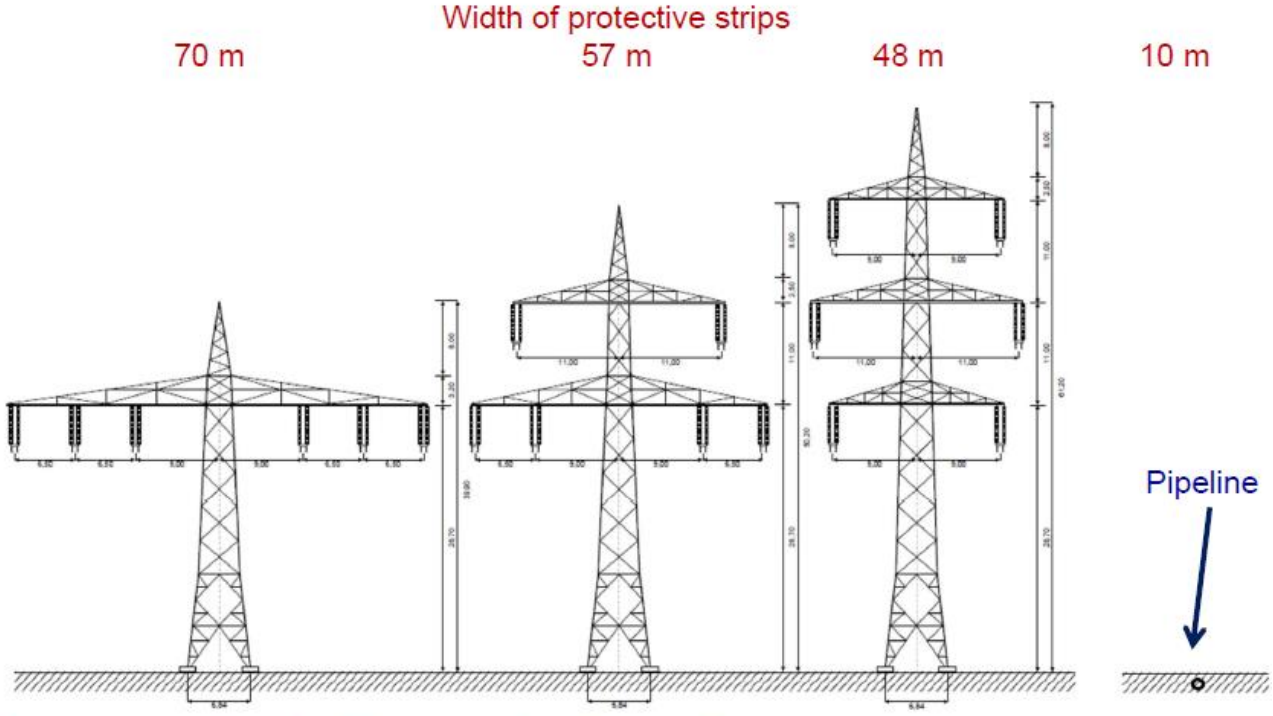
Thermal

Compressed air energy storage

Hydrogen/SNG storage

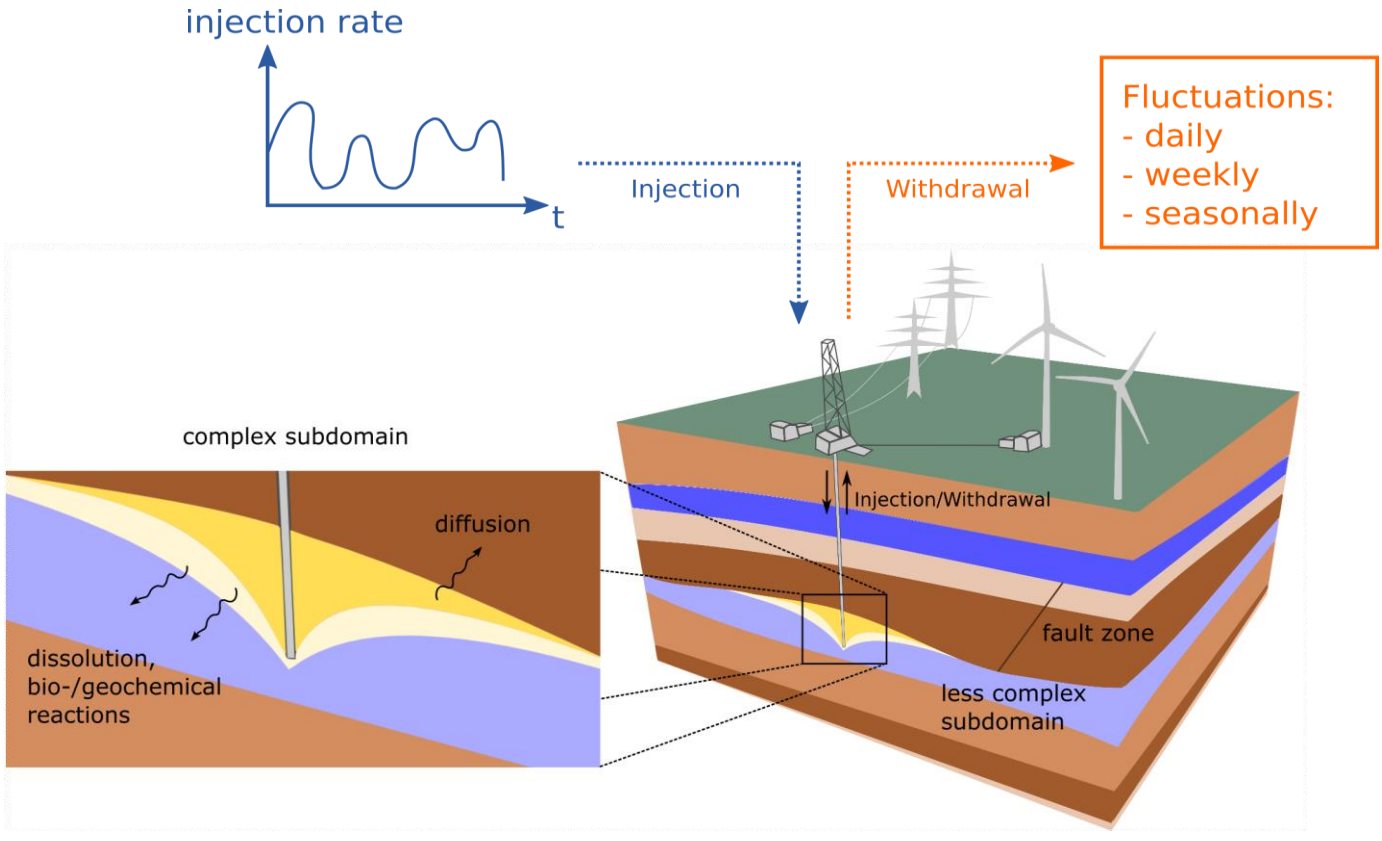
Hot/cold water storage

Transmission



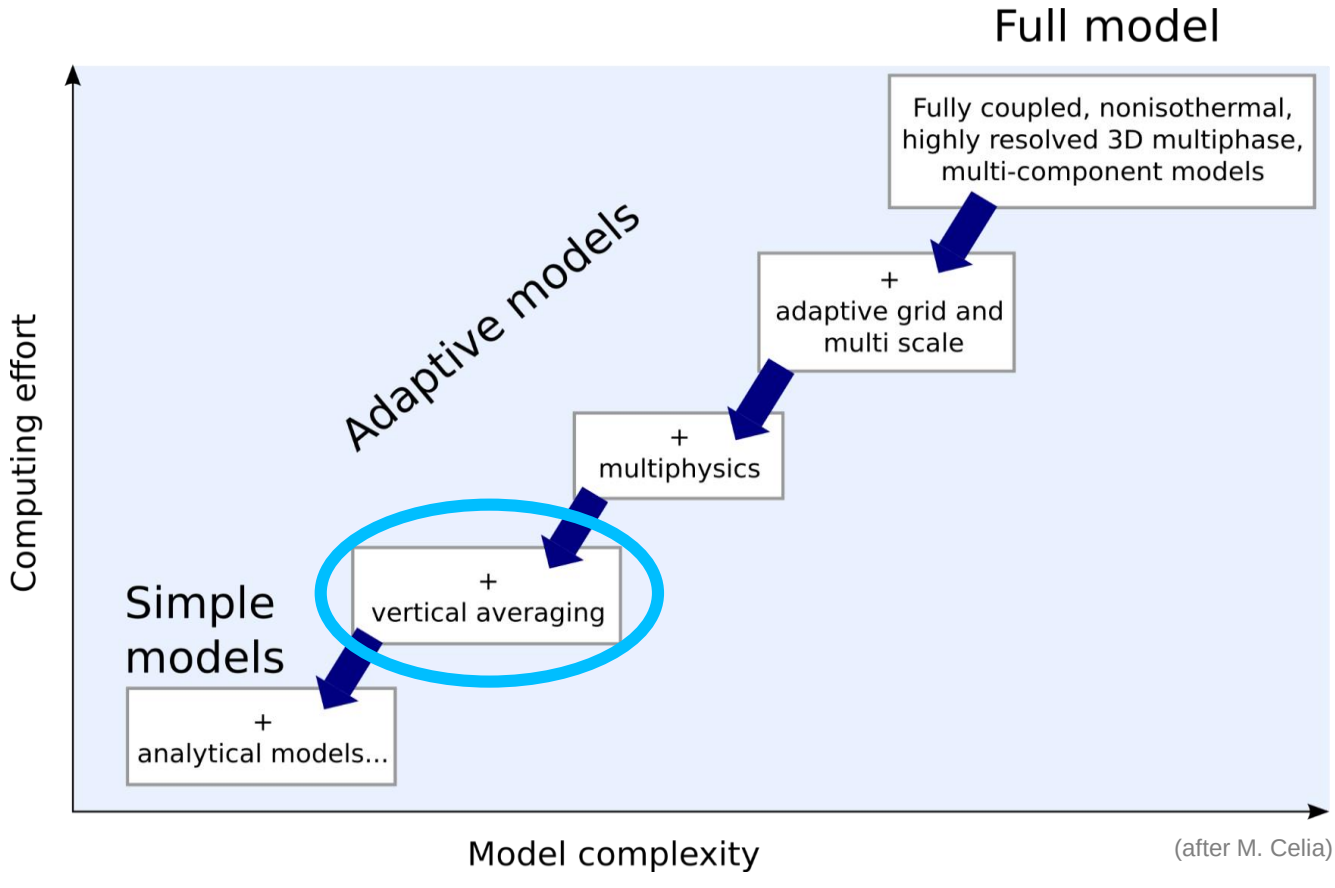
Picture of power poles from Hofman: Technologien zur Stromübertragung, IEH, http://nvonb.bundesnetzagentur.de/netzausbau/Vortrag_Hofmann.pdf

Gas storage: Modeling challenges



- Large domains and limited data
- Locally complex processes
- Dynamic boundary conditions

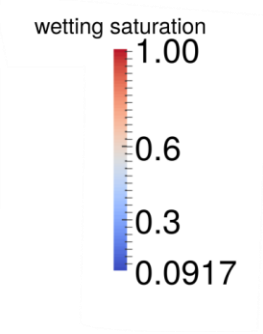
Model complexity

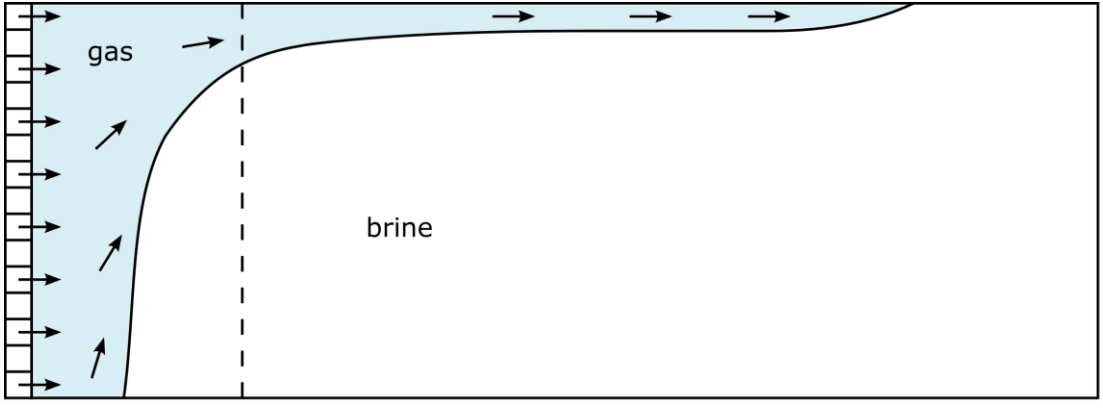


Vertical equilibrium model

Assumption: gas and brine are in vertical equilibrium

➡ Hydrostatic pressure profiles in the vertical direction

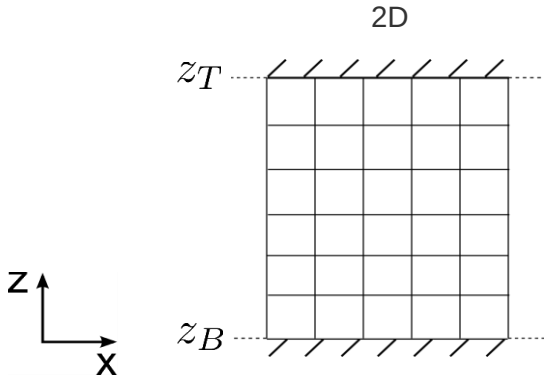


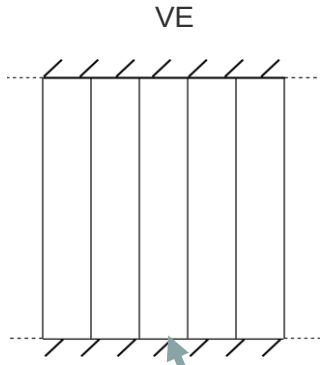


(Nordbotten & Celia, 2012)

Vertical equilibrium model

Governing equations





$$\frac{\partial}{\partial t}(\varrho_\alpha \phi s_\alpha) + \nabla \cdot (\varrho_\alpha \mathbf{u}_\alpha) = \varrho_\alpha \mathbf{q}_\alpha$$

$$\mathbf{u}_\alpha = -\mathbf{k}\frac{\mathbf{k_r}_{,\alpha}}{\mu_\alpha}(\nabla \mathbf{p}_\alpha - \varrho_\alpha \mathbf{g})$$

$$\frac{\partial}{\partial t}(\varrho_\alpha \Phi S_\alpha) + \nabla_{||} \cdot (\varrho_\alpha \mathbf{U}_\alpha) = \varrho_\alpha \mathbf{Q}_\alpha$$

$$\mathbf{U}_\alpha = -\mathbf{K}\frac{\mathbf{K_r}_{,\alpha}}{\mu_\alpha}(\nabla_{||} \mathbf{P}_\alpha - \varrho_\alpha \mathbf{G})$$

$$\int_{z_B}^{z_T} \ldots \, \mathrm{dz}$$

$$P_c(S_\alpha)$$

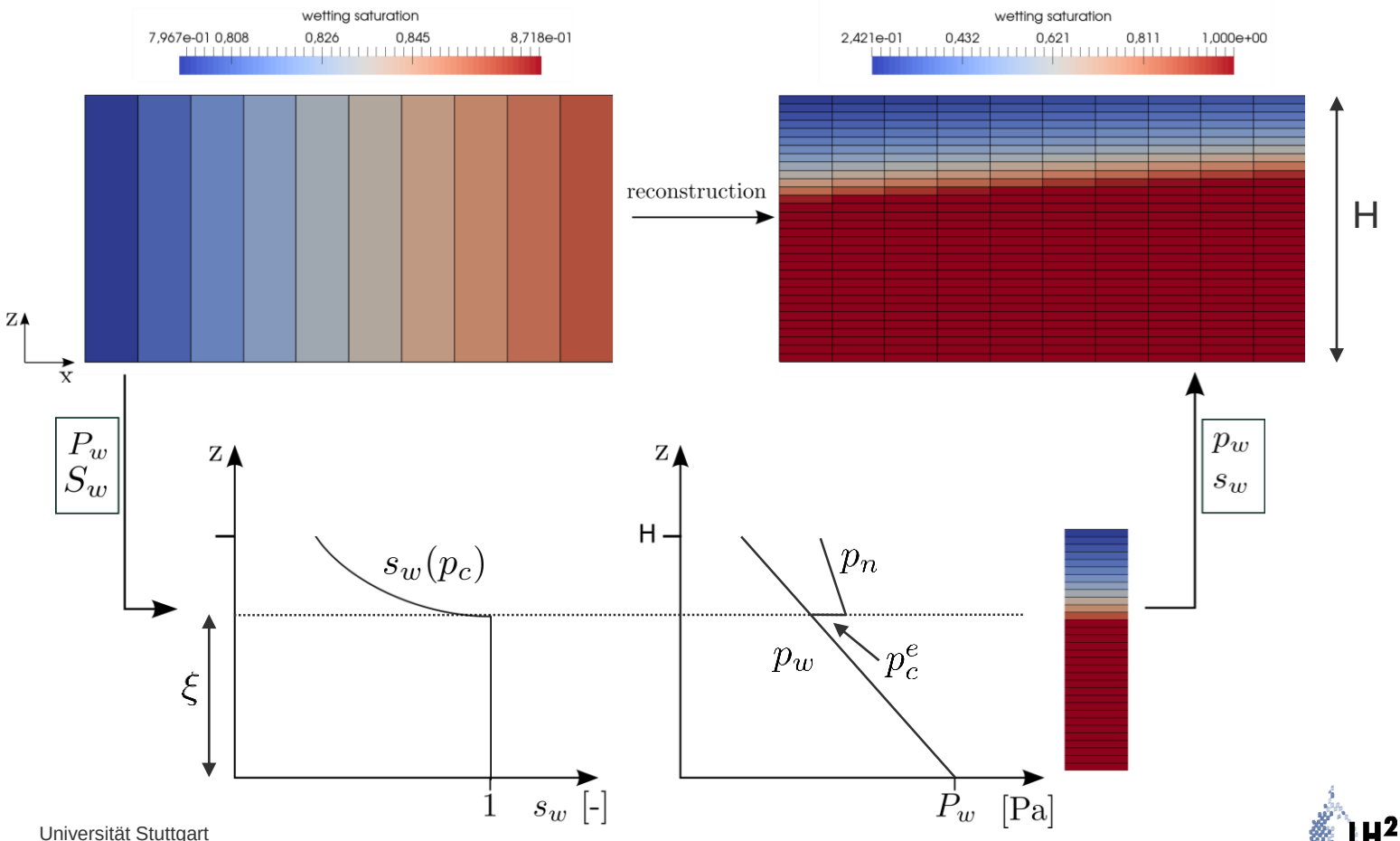
$$\sum S_\alpha = 1$$

$$S_\alpha, \; P_\alpha$$

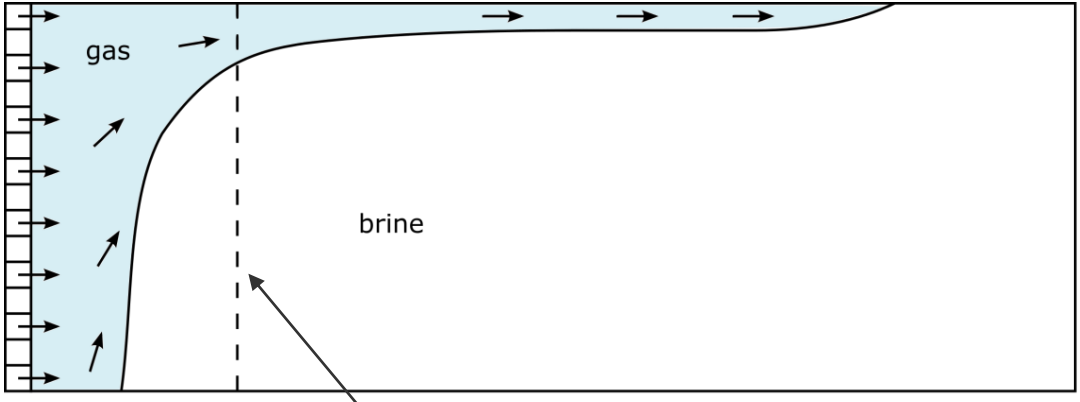
(Nordbotten & Celia, 2012)

Vertical equilibrium model

Reconstruction of fine scale solution



Model coupling



More complex area,
Horizontal and vertical flow

Less complex area,
Horizontal flow,
Segregation of phases

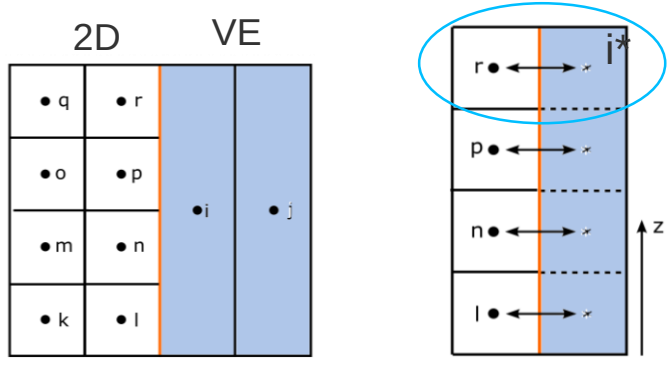
Move adaptively

Fulldimensional model

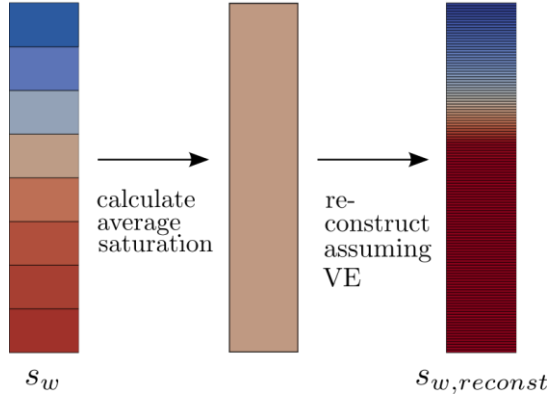
Vertical Equilibrium (VE) model

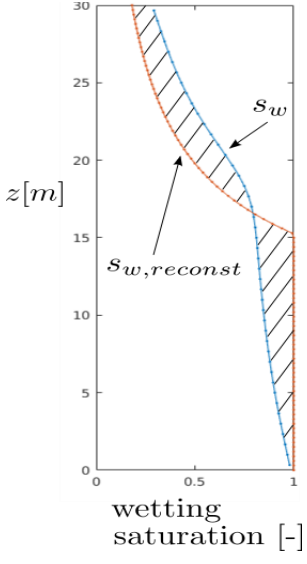
2D-VE coupling (IMPES)

Fluxes over boundary between subdomains



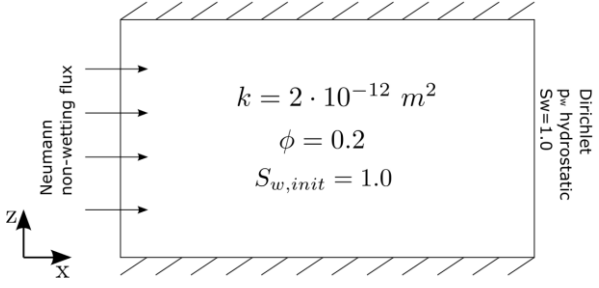
Switch criterion based on column profiles



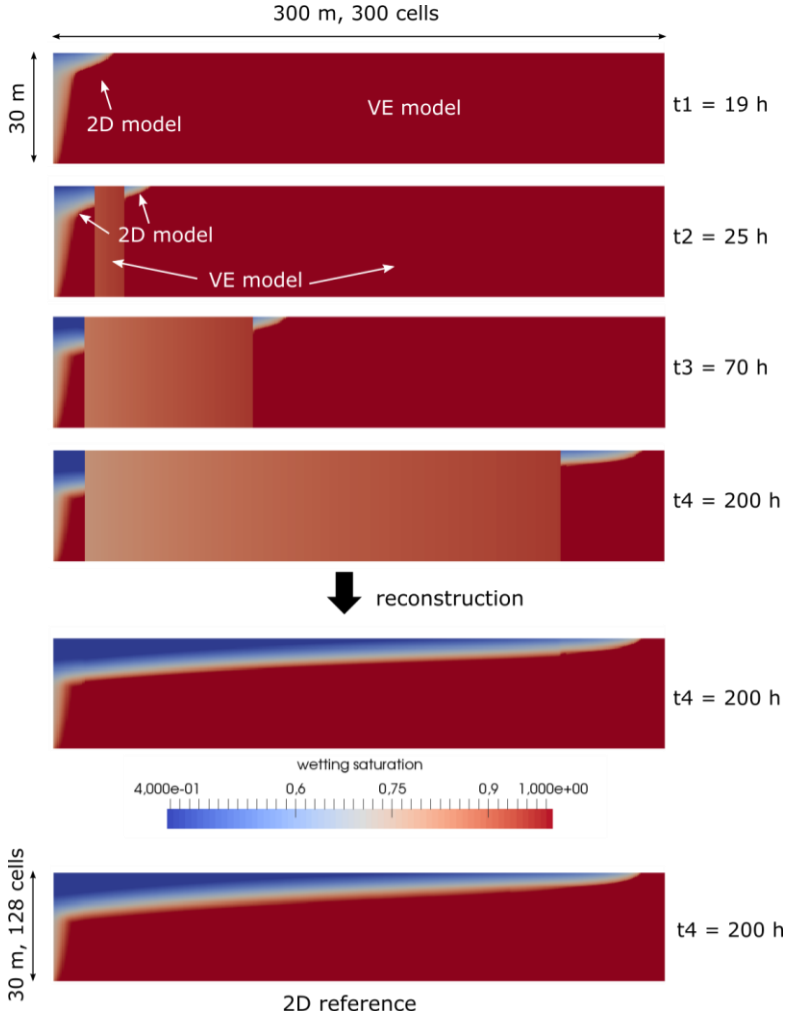


Results for VE-2D coupling

Adaptive coupling



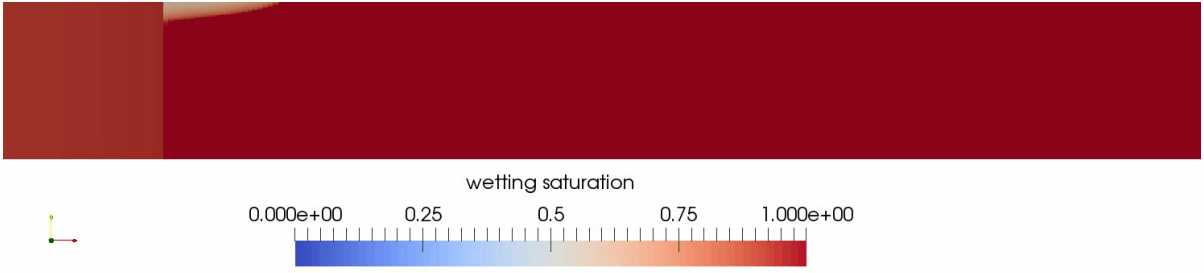
Brooks-Corey cap. pressure:
$\lambda = 2.0$, $p_e = 1\ bar$
Phase properties (CH_4, water):
$\varrho_n = 59.2\ kg/m^3$
$\varrho_w = 991\ kg/m^3$
$\mu_n = 1.2 \cdot 10^{-5}\ Pa\,s$
$\mu_w = 5.2 \cdot 10^{-4}\ Pa\,s$
Injection rate: $Q_{nw} = 552\ t/m/a$



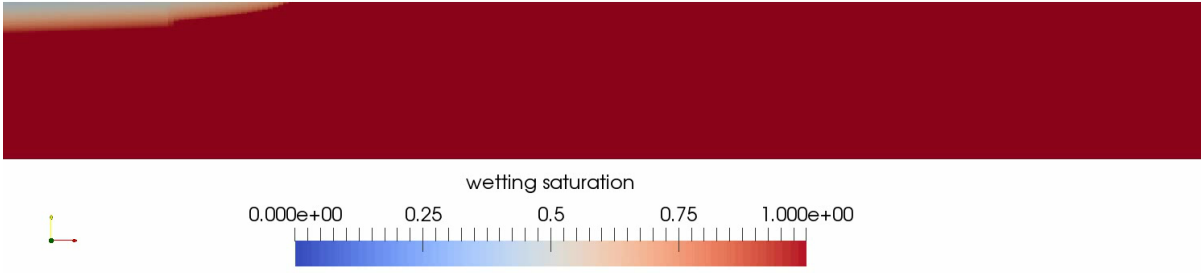
Results for VE-2D coupling

Adaptive coupling, example with low-permeability lense

Simulation result



Reconstruction

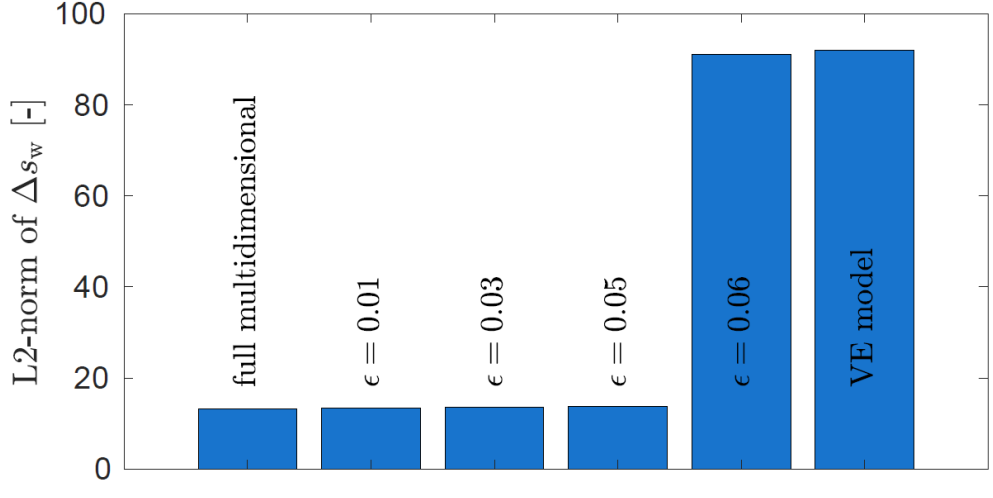


(Becker, 2017)

Efficiency of the multiphysics model

Efficiency:
Speed ✖ Accuracy

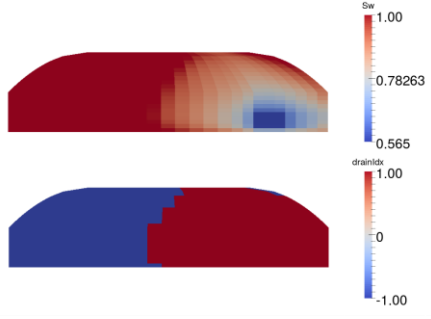
Model	relative average number of cells [-]	relative CPU time [-]
Full VE	0.008	0.003
Multiphysics $\epsilon_{\text{relPerm}} = 0.06$	0.04	0.02
Multiphysics $\epsilon_{\text{relPerm}} = 0.05$	0.11	0.05
Multiphysics $\epsilon_{\text{relPerm}} = 0.04$	0.12	0.06
Multiphysics $\epsilon_{\text{relPerm}} = 0.03$	0.19	0.12
Multiphysics $\epsilon_{\text{relPerm}} = 0.02$	0.3	0.18
Multiphysics $\epsilon_{\text{relPerm}} = 0.01$	0.41	0.22
Full multidimensional	1	1



Outlook

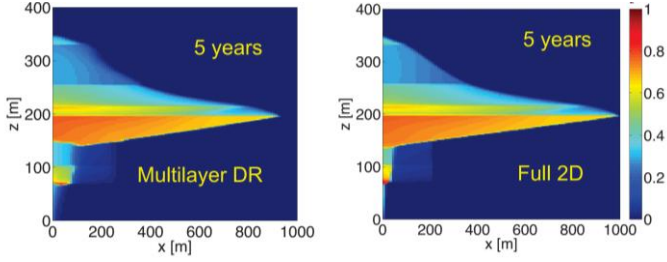
- VE model with slight compressibility

- Adaptive coupling I
  - Implement for vertical heterogeneity, 3D
  - Further tests, application of energy storage



- Adaptive coupling II
  - Combine with multi-layer coupling
  - VE model with non-isothermal effects
  - VE model with compositional effects

➡ include in adaptive coupled model



(Guo, 2016)

References

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Thank you!

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