Universität Stuttgart

A pseudo vertical equilibrium model for slow gravity drainage dynamics

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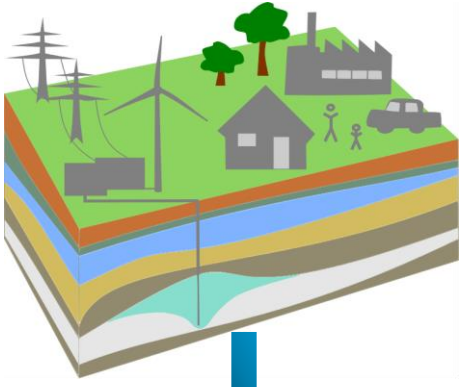
Motivation: Underground energy storage



Mechanical

Chemical

Thermal

Compressed air energy storage

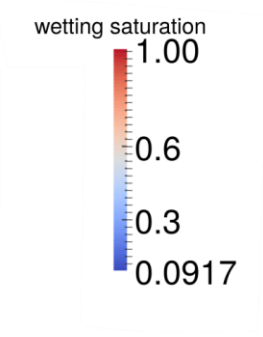
Hydrogen/SNG storage

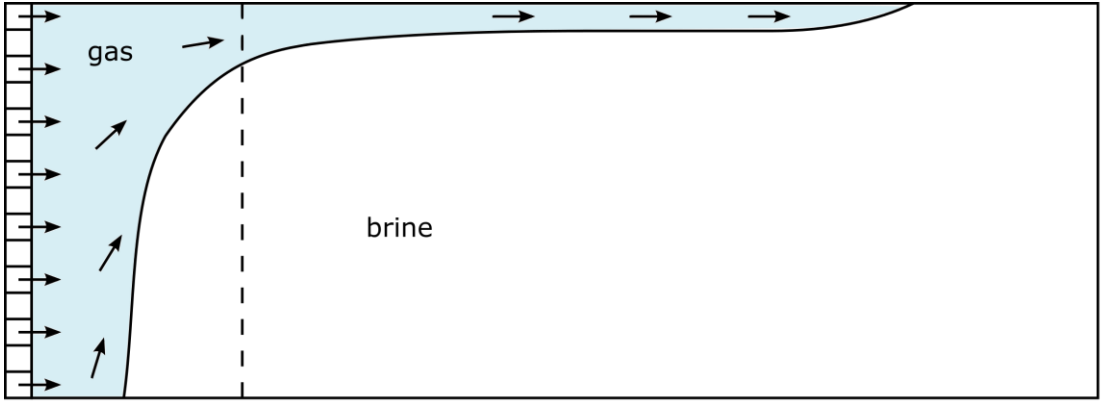
Hot/cold water storage

Vertical equilibrium model: Assumption

- Gas and brine are in vertical equilibrium

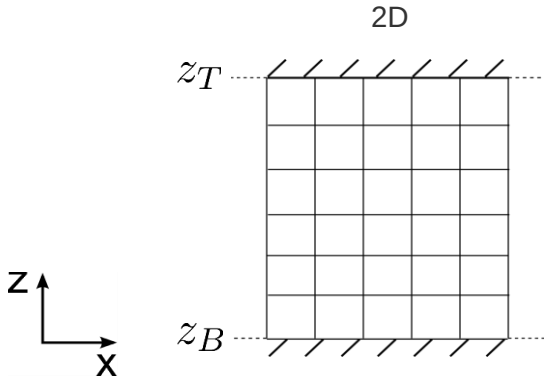
  ➡ Hydrostatic pressure profiles in the vertical direction

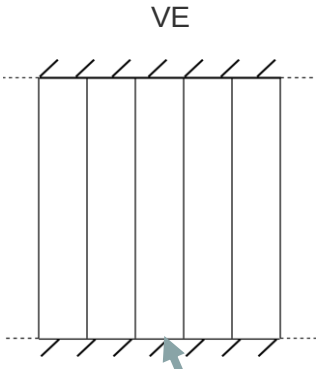




(Nordbotten & Celia, 2012)

Vertical equilibrium model: Governing equations





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

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

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

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

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

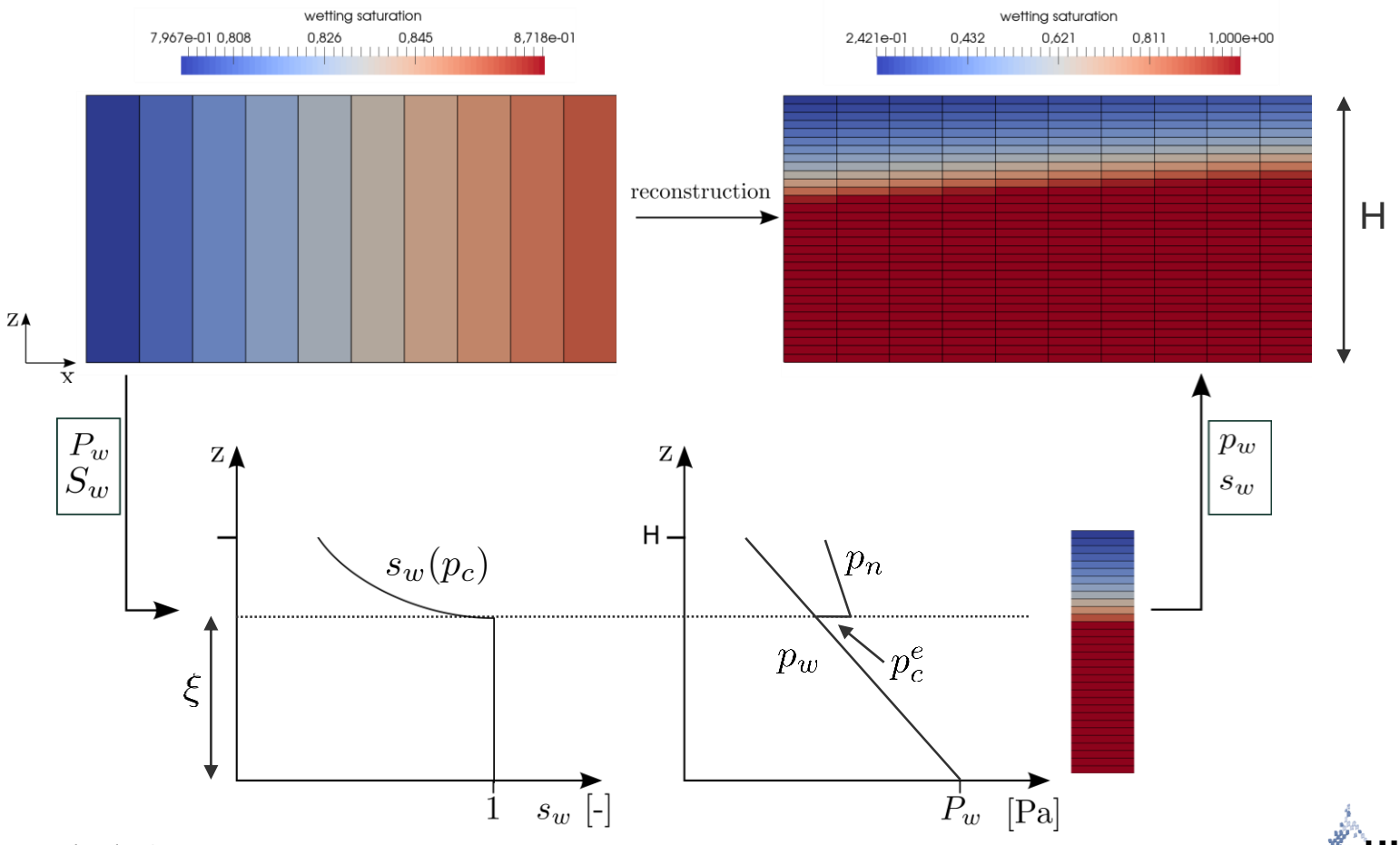
$$P_c(S_\alpha)$$

$$\sum S_\alpha = 1$$

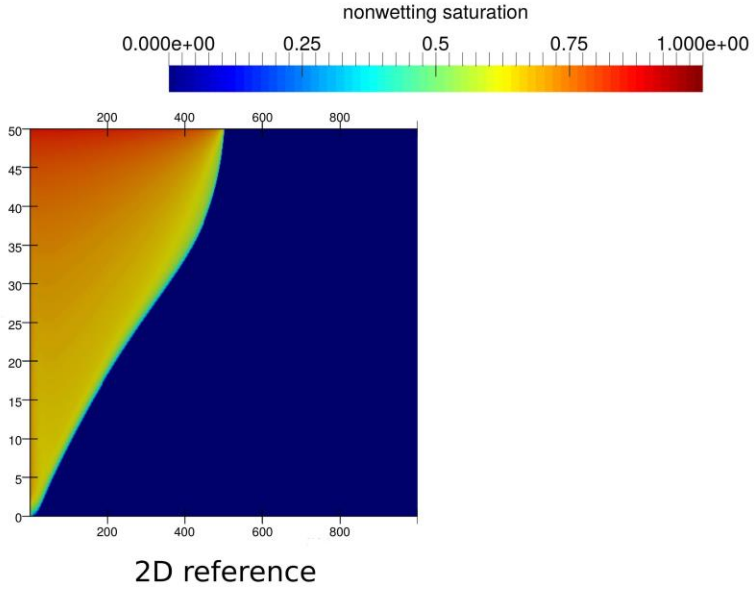
$$S_\alpha, \; P_\alpha$$

(Nordbotten & Celia, 2012)

Vertical equilibrium model: Reconstruction of fine scale solution



Vertical equilibrium model: The challenge



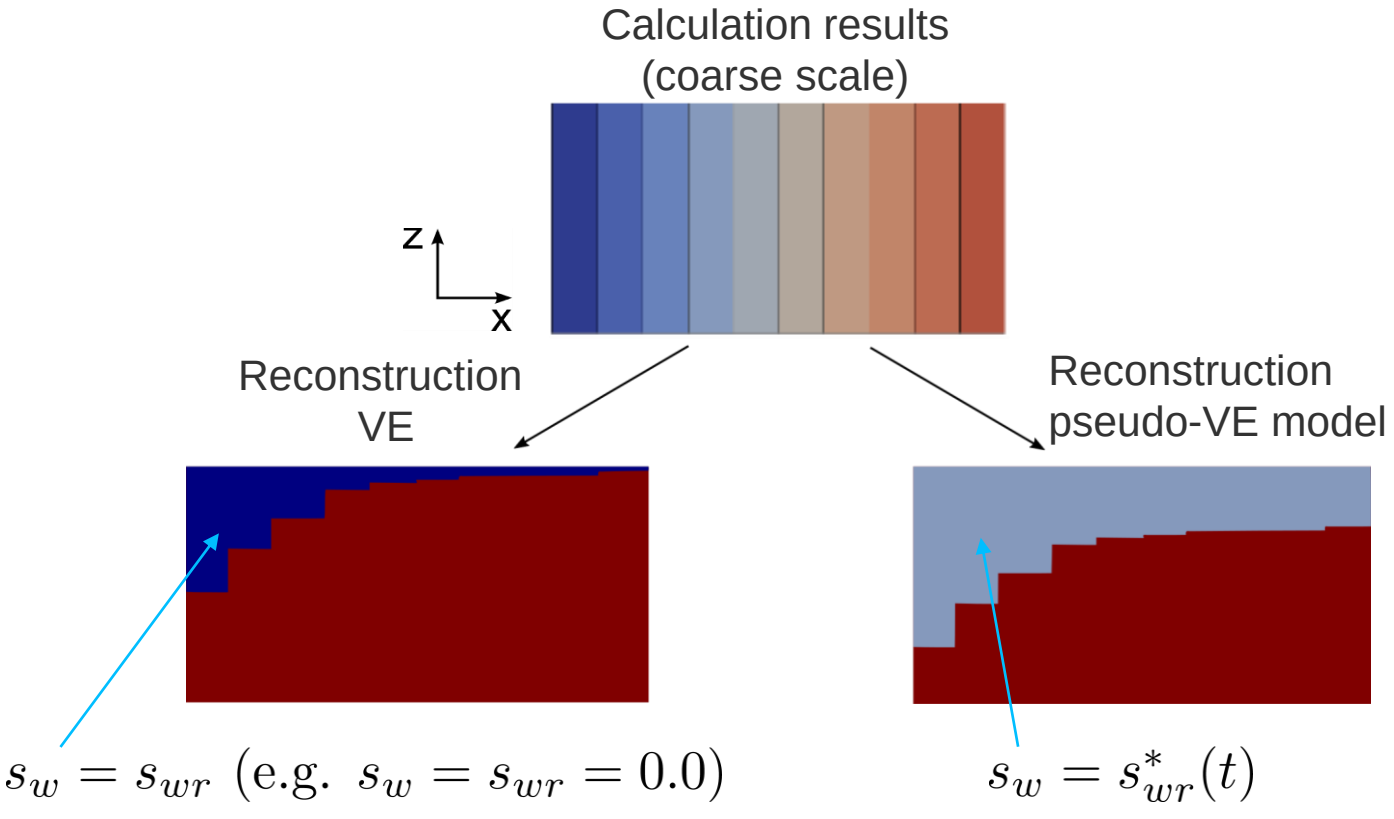
2D reference

?

$$t_{\mathrm{seg}} = \frac{H \phi \mu_{\mathrm{w}}}{k_{\mathrm{r,w}} k_{\mathrm{z}} (\varrho_{\mathrm{w}} - \varrho_{\mathrm{n}}) g}, \quad t_{\mathrm{seg}} << T_{\mathrm{sim}}$$

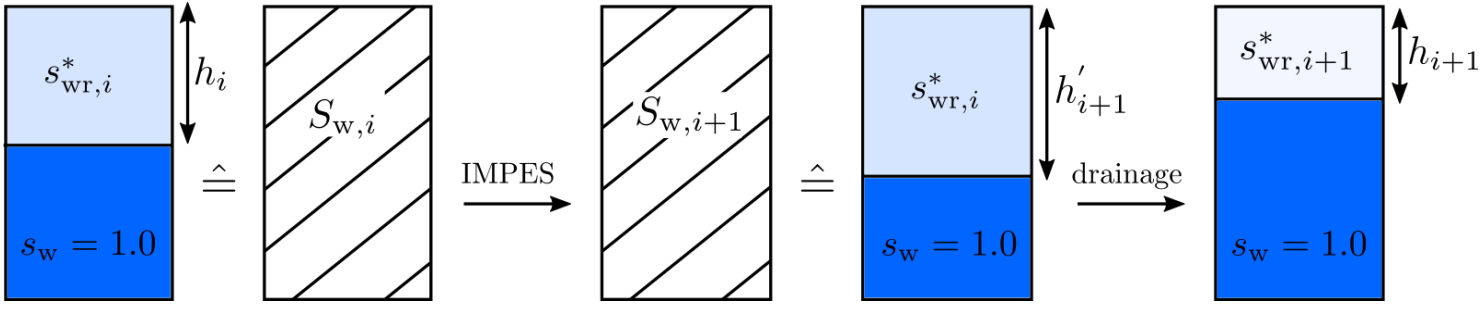
→ Vertical Equilibrium ✓

Pseudo vertical equilibrium model



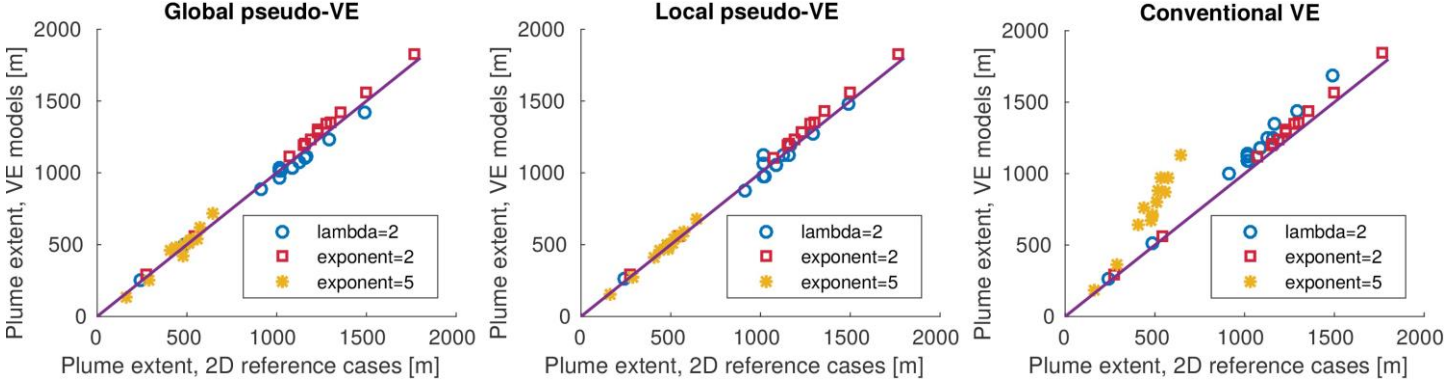
Pseudo vertical equilibrium model: Global and local model

- Global model: calculate average drainage out of plume
- Local model: calculate drainage out of plume in every grid column
- Initial pseudo-residual wetting phase saturation: 0.999



Results: Horizontal plume extent

- 15 test cases (varying permeability, entry pressure, porosity, fluids…)
- 3 relative permeability functions



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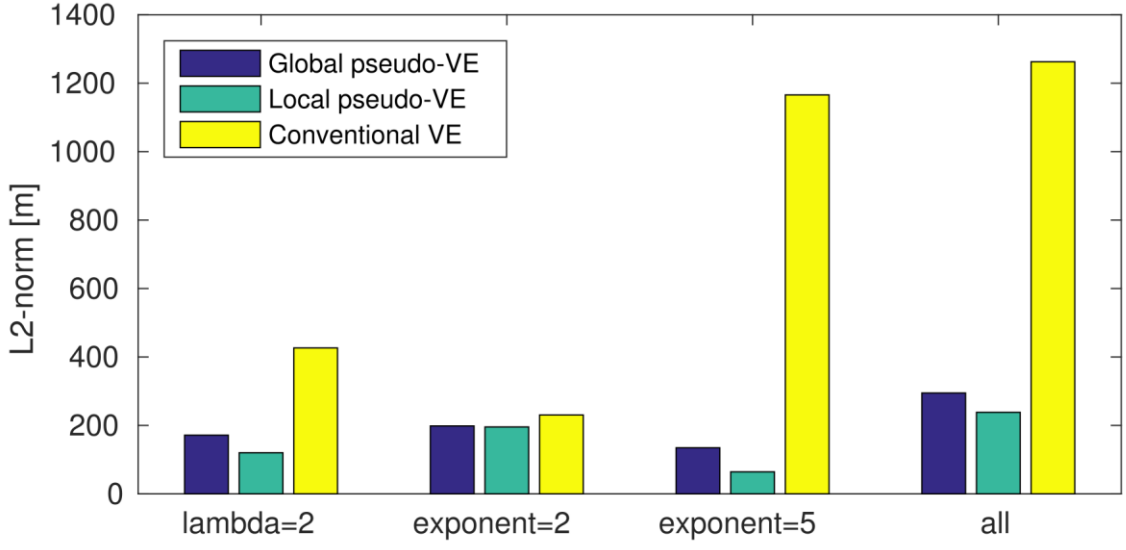
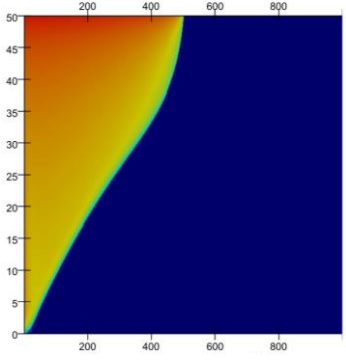
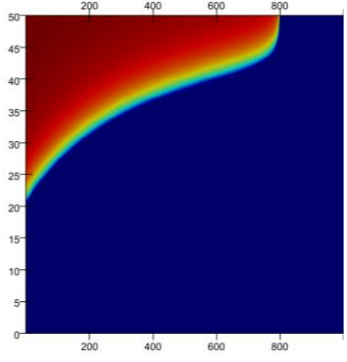


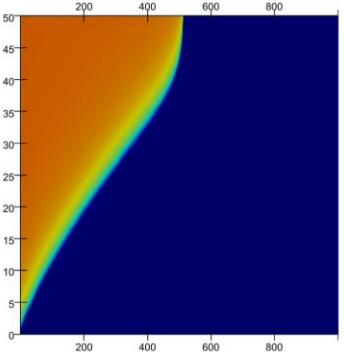
Results: Plume shape



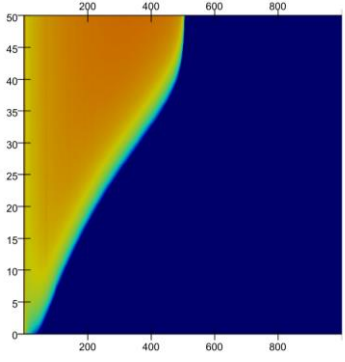
2D reference



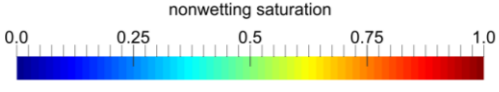
Conventional VE



Global pseudo-VE



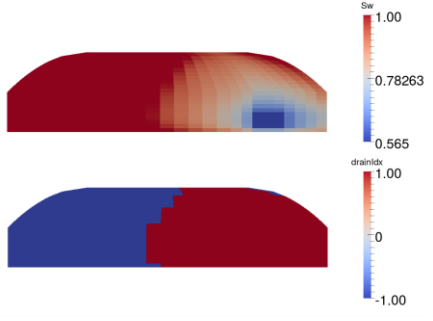
Local pseudo-VE



Outlook

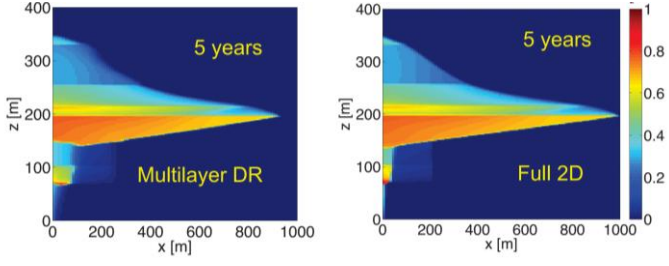
- VE model with slight compressibility

- 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



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Thank you!

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