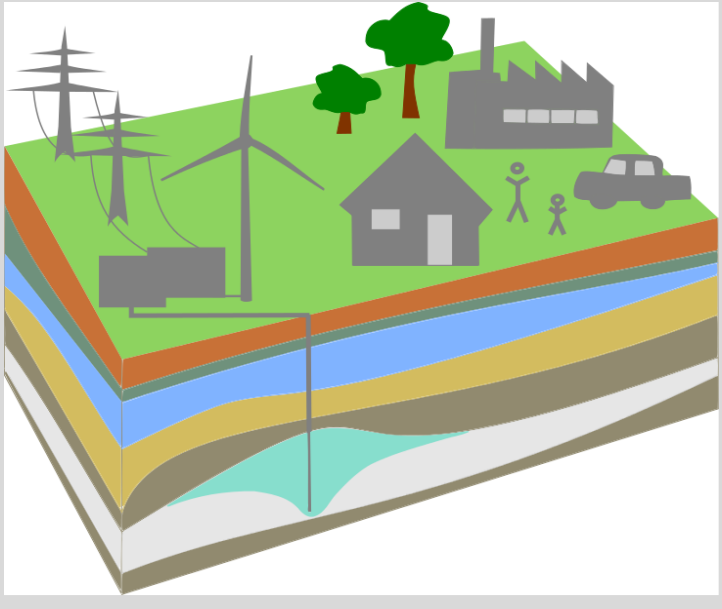
University of Stuttgart
Institute for Modelling Hydraulic and Environmental Systems
Department of Hydromechanics and Modelling of Hydrosystems

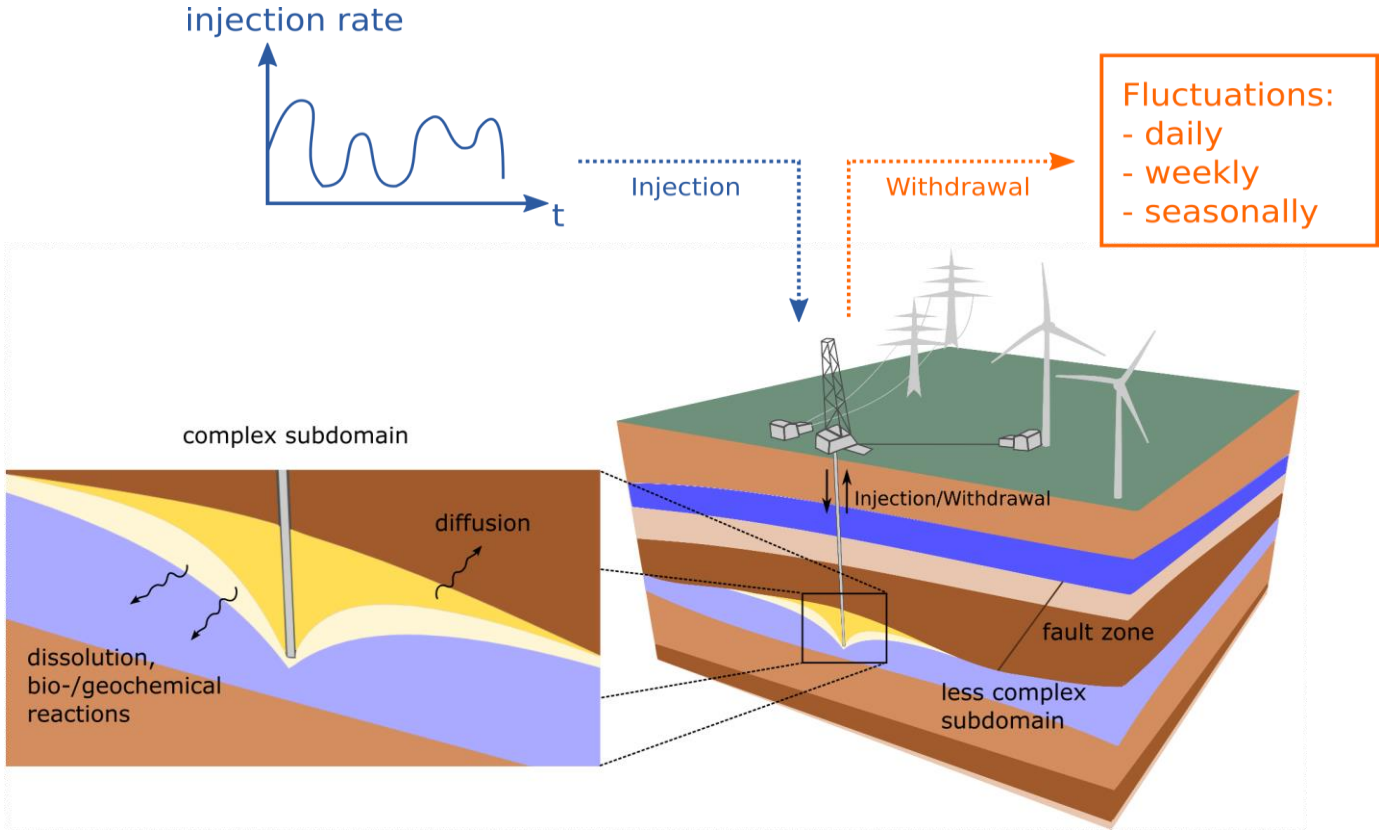


Adaptive coupling of a Full-Dimensional Multiphase model to a Vertical Equilibrium model

Beatrix Becker
Rainer Helmig
Bernd Flemisch
Bo Guo
Michael Celia

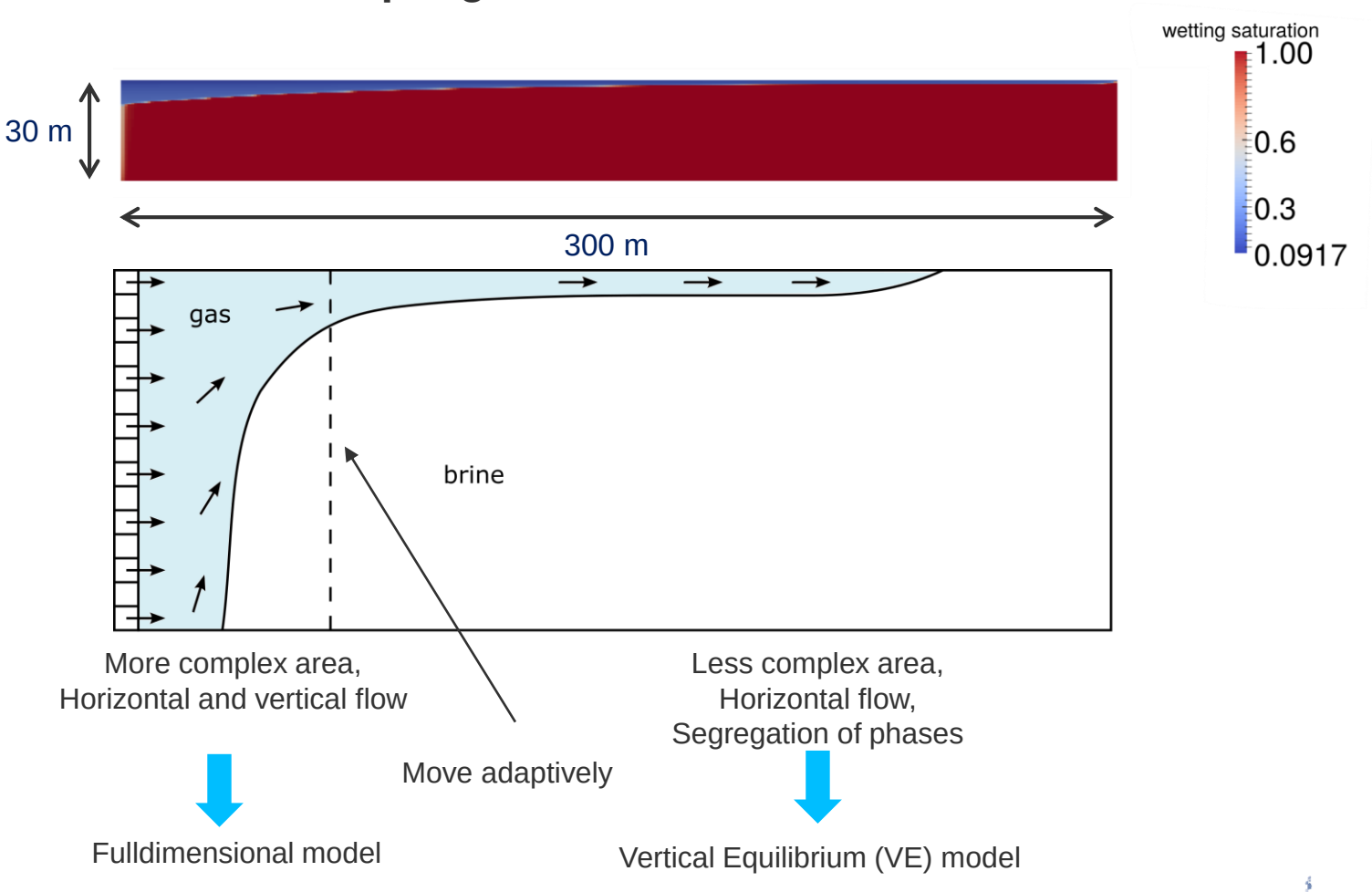
Nupus-Meeting 2016

Gas storage

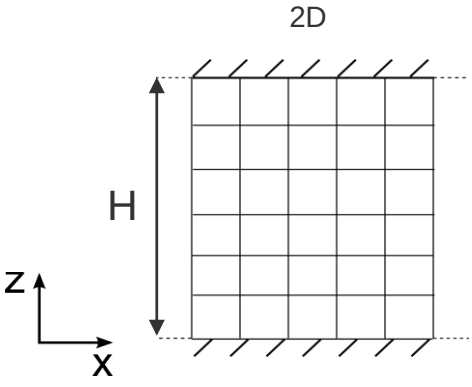


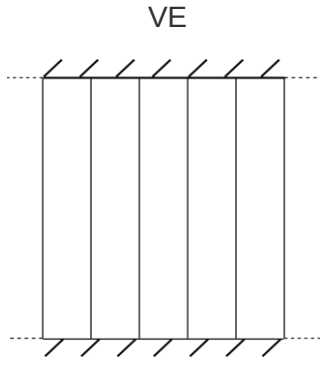
Large domain and limited data!

VE model and coupling



Vertical equilibrium model – governing equations





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

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

$$\frac{\partial}{\partial t}(\varrho_\alpha \Phi S_\alpha) + \nabla \cdot (\varrho_\alpha \mathbf{U}_\alpha) = \varrho_\alpha \mathbf{\Psi}_\alpha$$

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

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

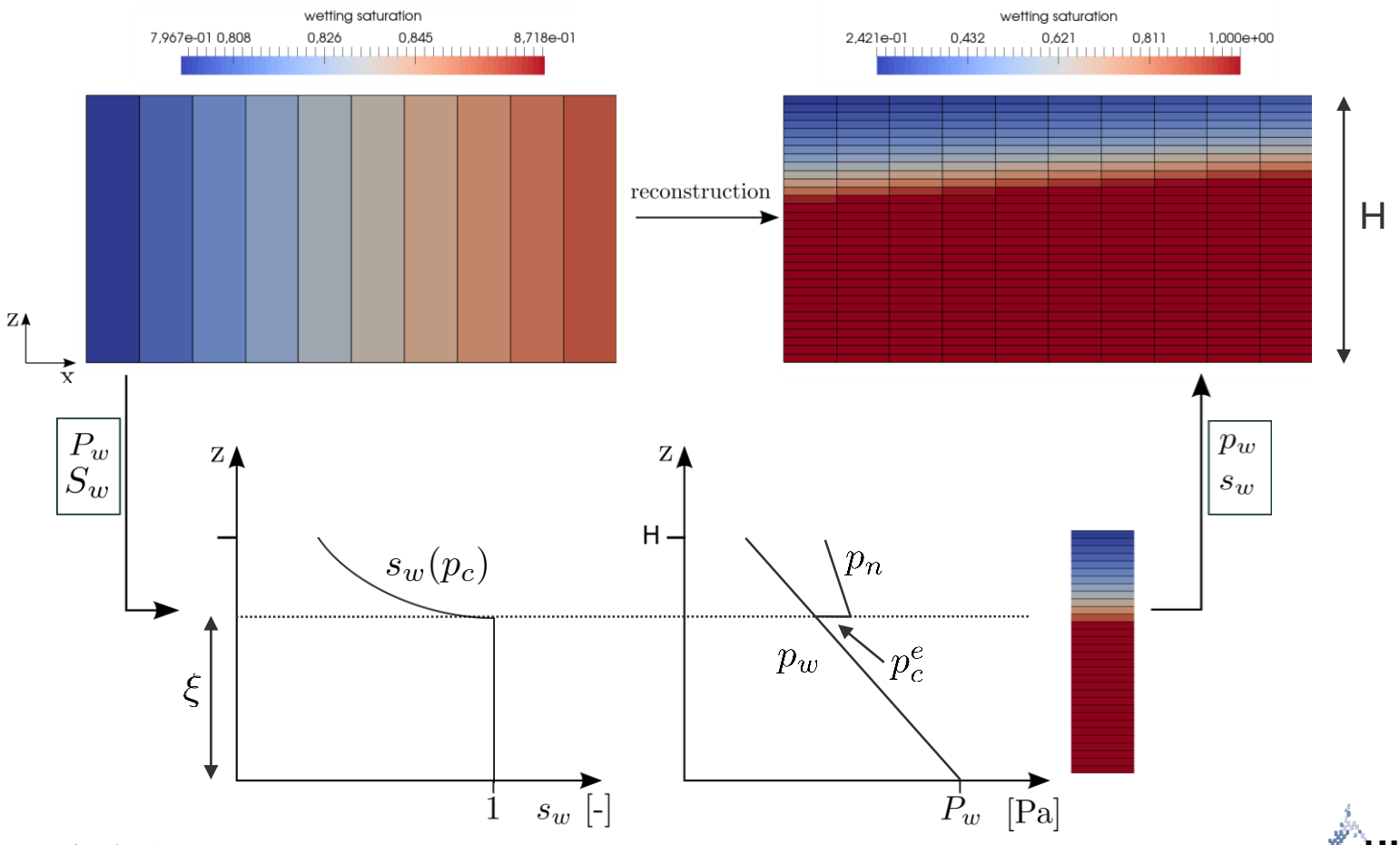
$$P_c(S_\alpha)$$

$$\sum S_\alpha = 1$$

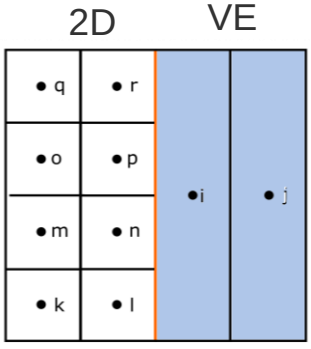
$$S_\alpha, \; P_\alpha$$

(Nordbotten & Celia, 2012)

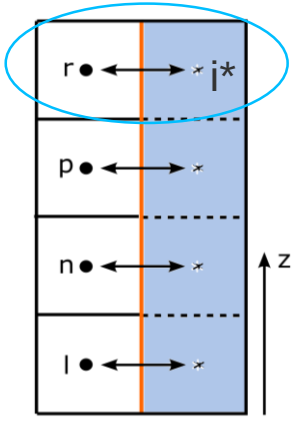
Vertical equilibrium model – reconstruction of fine scale solution



2D-VE coupling (IMPES)



Fluxes over boundary between subdomains?



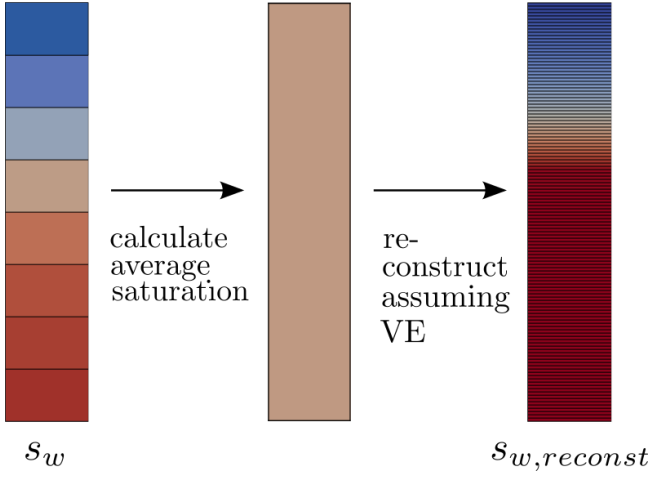
$$v_{tot,i^*r} = -k\lambda_{tot}\left(\frac{p_{wr}-p^*_{wi}}{\Delta x} + f_n\frac{p_{cr}-p^*_{ci}}{\Delta x}\right)$$

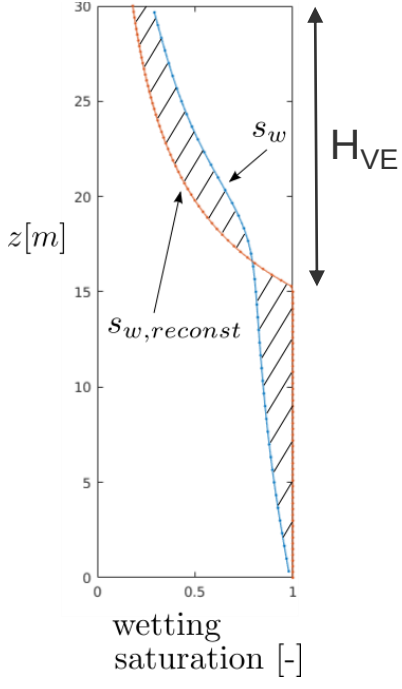
$$p^*_{wi} = P_{wi} - \varrho_w g z$$

$$p^*_{ci} = p_c(s^*_w)$$

$$\lambda_{tot}, f_n \quad \text{all depending on } \bar{s}^*_w$$

Applicability of VE models – criterion based on column profiles

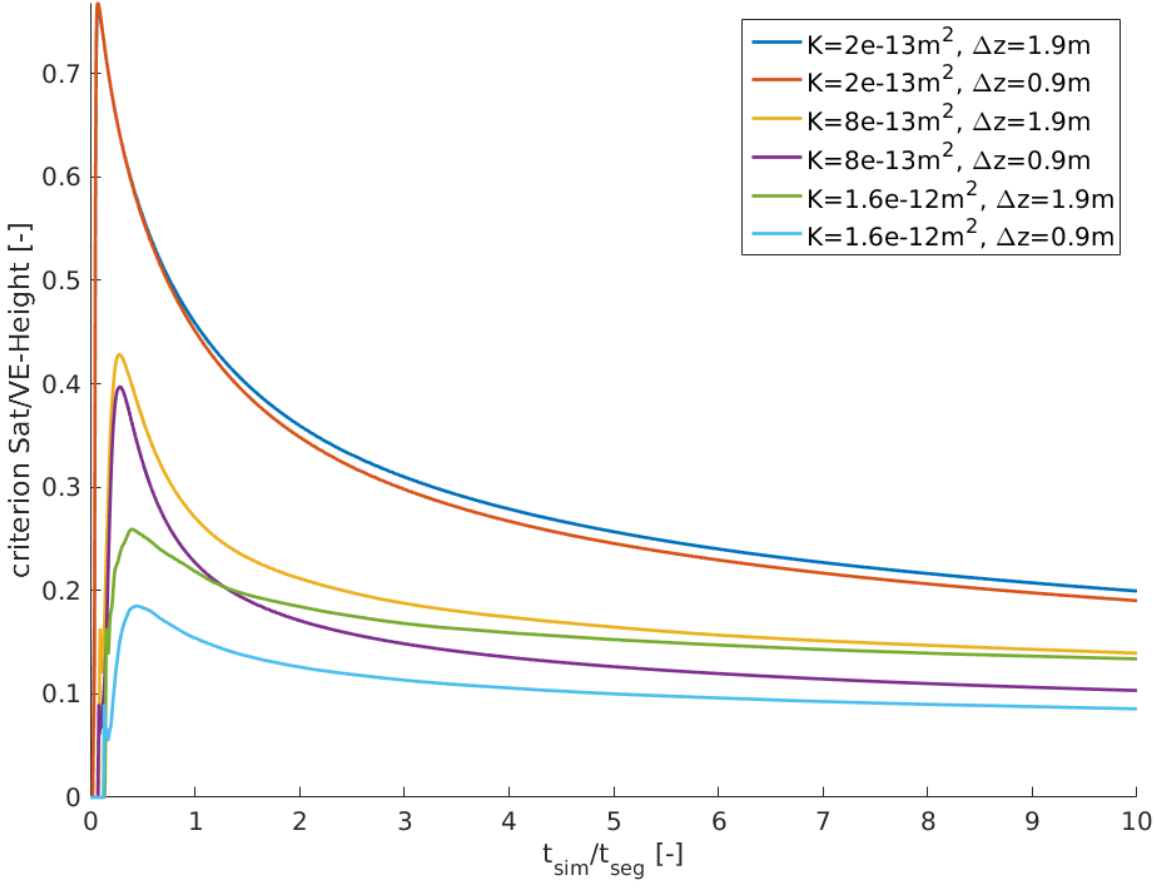




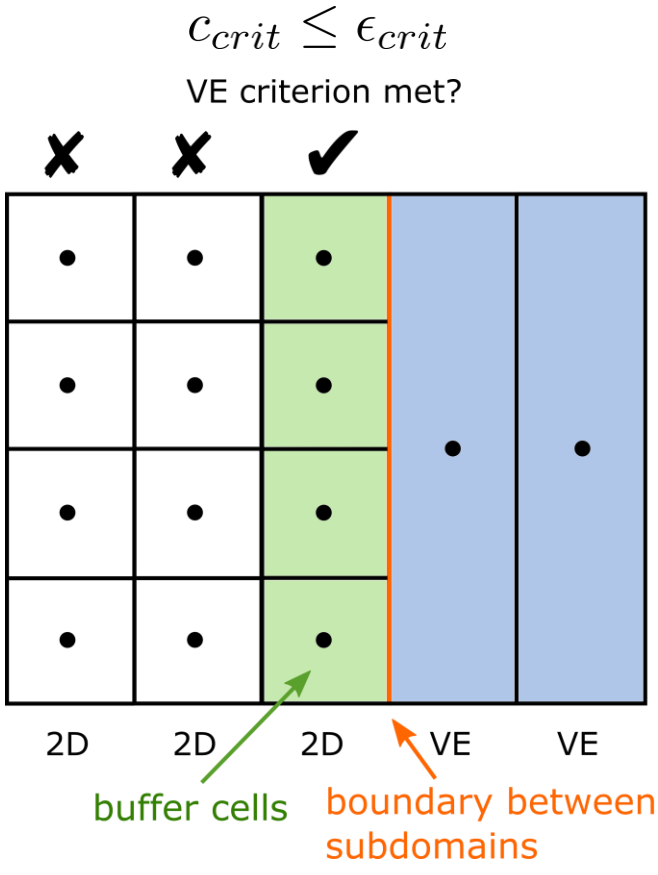
$$c_{sat} = \frac{\int_0^H |s_w - s_{w,reconst}| \mathrm{dz}}{H_{VE}}$$

$$c_{relPerm} = \frac{\int_0^H |k_{rw} - k_{rw,reconst}| \mathrm{dz}}{H_{VE}}$$

Applicability of VE models – criterion values for one column

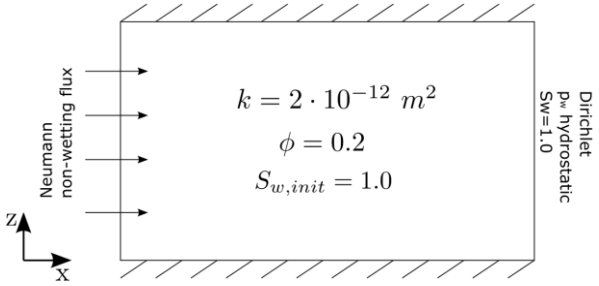


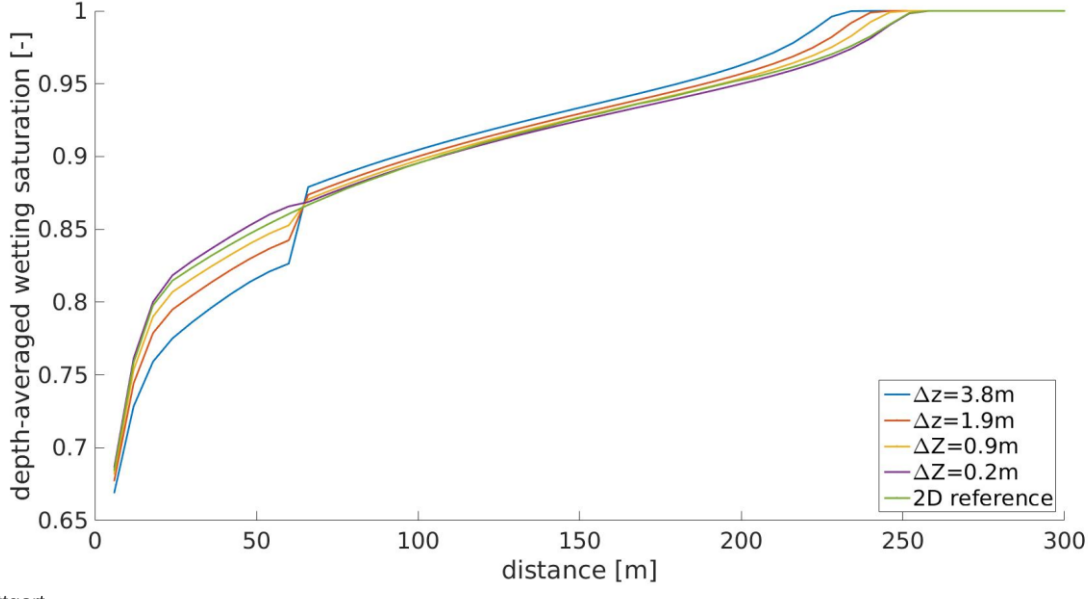
Buffer columns



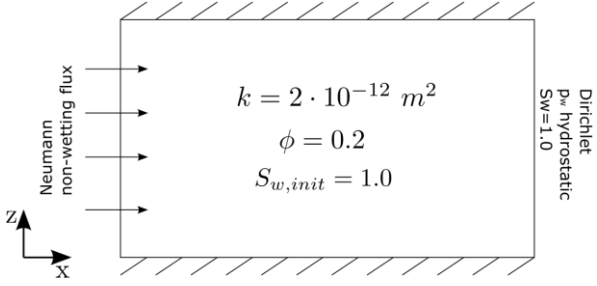
- A column stays a 2D column when the criterion is not met.
- A column is turned into a VE column when the criterion is met and the column is not a direct neighbor of a column where the criterion is not met.
- Buffer columns ensure that VE columns are turned back to 2D columns when necessary.

Results for VE-2D coupling – stationary boundary

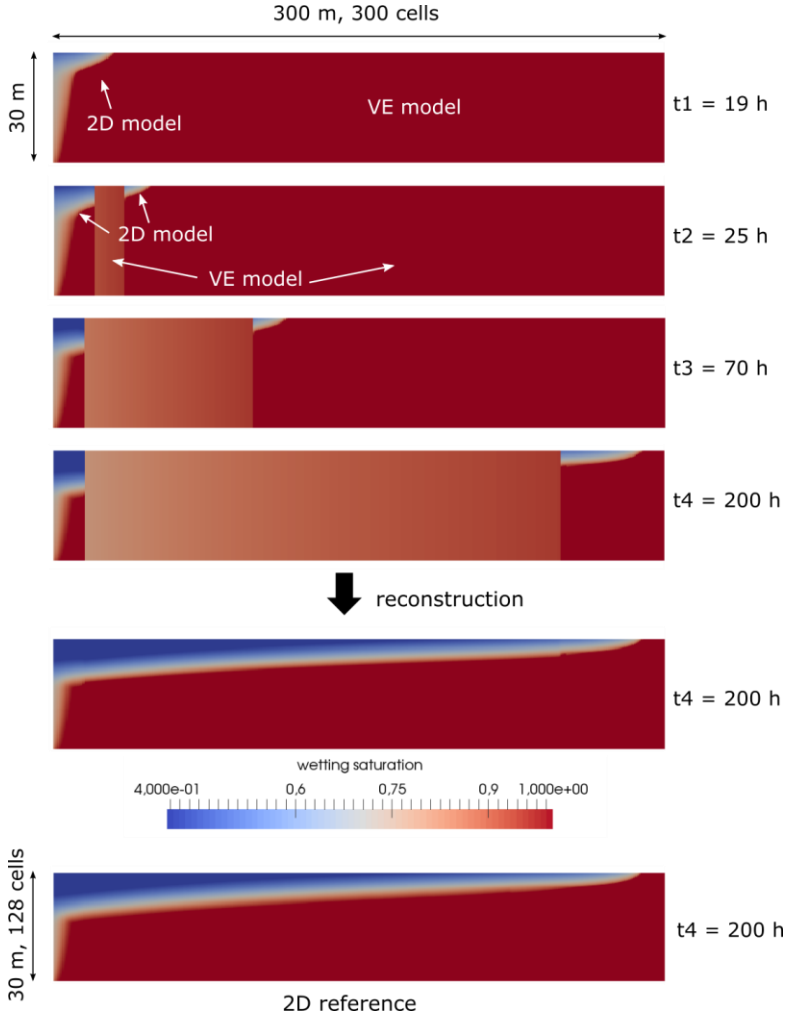




Results for VE-2D coupling – adaptive boundary

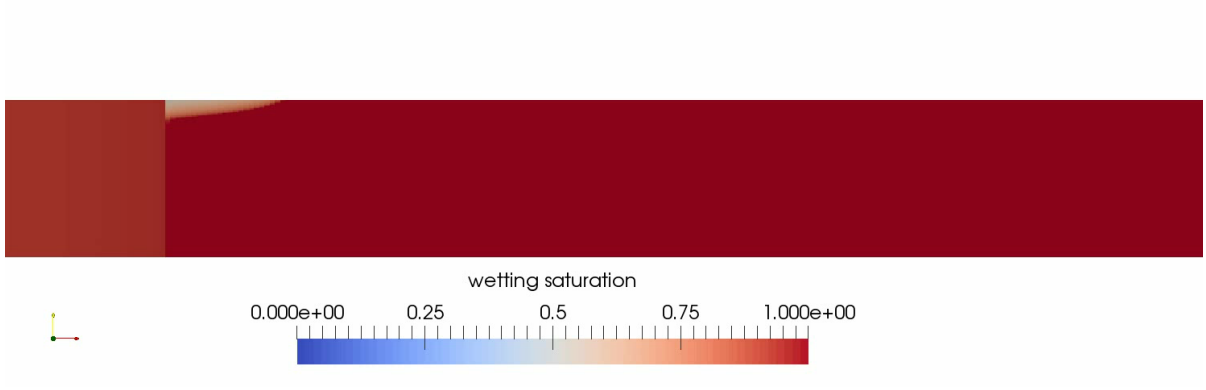


Brooks-Corey cap. pressure:
$\lambda = 2.0$, $p_e = 1\ bar$
Phase properties (CH_4, water):
$\varrho_n = 59.2\ kg/m^3$
$\varrho_w = 991\ kg/m^3$
$\mu_n = 1.2 \cdot 10^{-5}\ Pa\,s$
$\mu_w = 5.2 \cdot 10^{-4}\ Pa\,s$
Injection rate: $Q_{nw} = 552\ t/m/a$

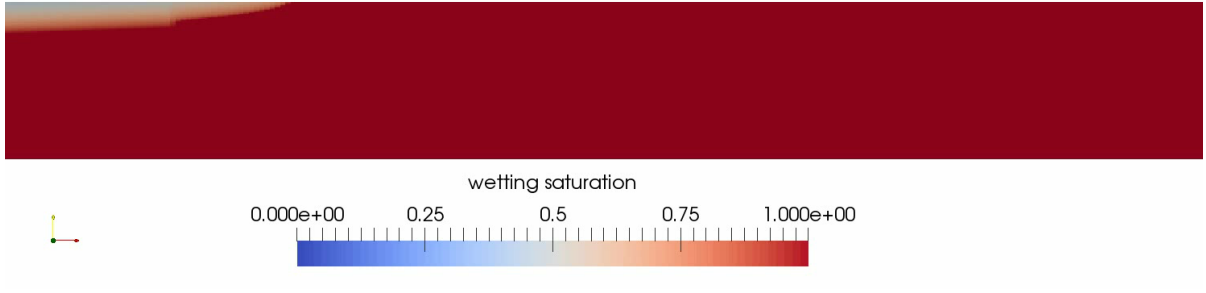


Results for VE-2D coupling – adaptive boundary with heterogeneity

Simulation result

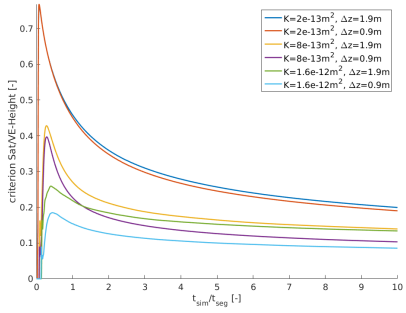


Reconstruction



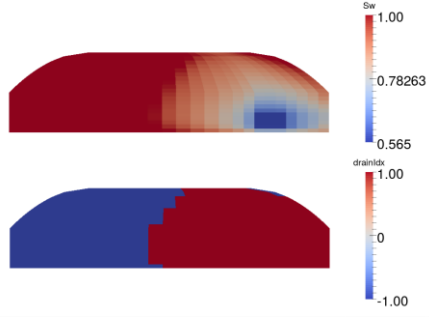
Summary

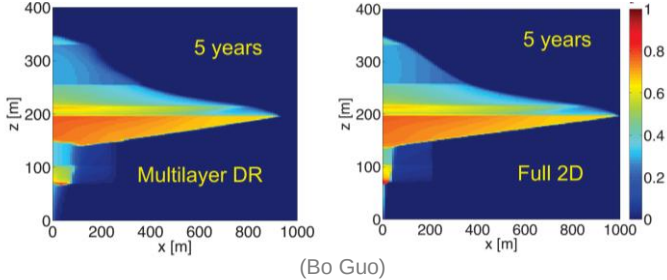
- Adaptively coupled 2D-VE model
- Criterion for applicability of VE model



Future work

- Adaptive coupling
  - Further tests
  - Implement for vertical heterogeneity, 3D
- Hysteresis
  - Relevance for gas storage?
  - Stability
- Combine with multi-layer coupling





(Bo Guo)

References

- Court, B., K. W. Bandilla, M. A. Celia, A. Janzen, M. Dobossy, and J. M. Nordbotten (2012), Applicability of vertical-equilibrium and sharpinterface assumptions in CO2 sequestration modeling, Int. J. Green. Gas. Con., 10, 134–147.
- Guo, B., Bandilla, K. W., Doster, F., Keilegavlen, E. and Celia, M. A. (2014). A vertically integrated model with vertical dynamics for CO2 storage, Water Ressources Research, 50.
- Nordbotten, J. M., Celia, M. A. (2012): Geological Storage of CO2: Modeling Approaches for Large-Scale Simulation. John Wiley & Sons.
- Papafotiou, A., Sheta, H., & Helmig, R. (2010). Numerical modeling of two-phase hysteresis combined with an interface condition for heterogeneous porous media. Computational Geosciences, 14(2), 273-287.

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Thank you!

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