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Cluster of Excellence in Data-integrated Simulation Science

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Toward a model hierarchy for underground gas storage: A compositional VE model

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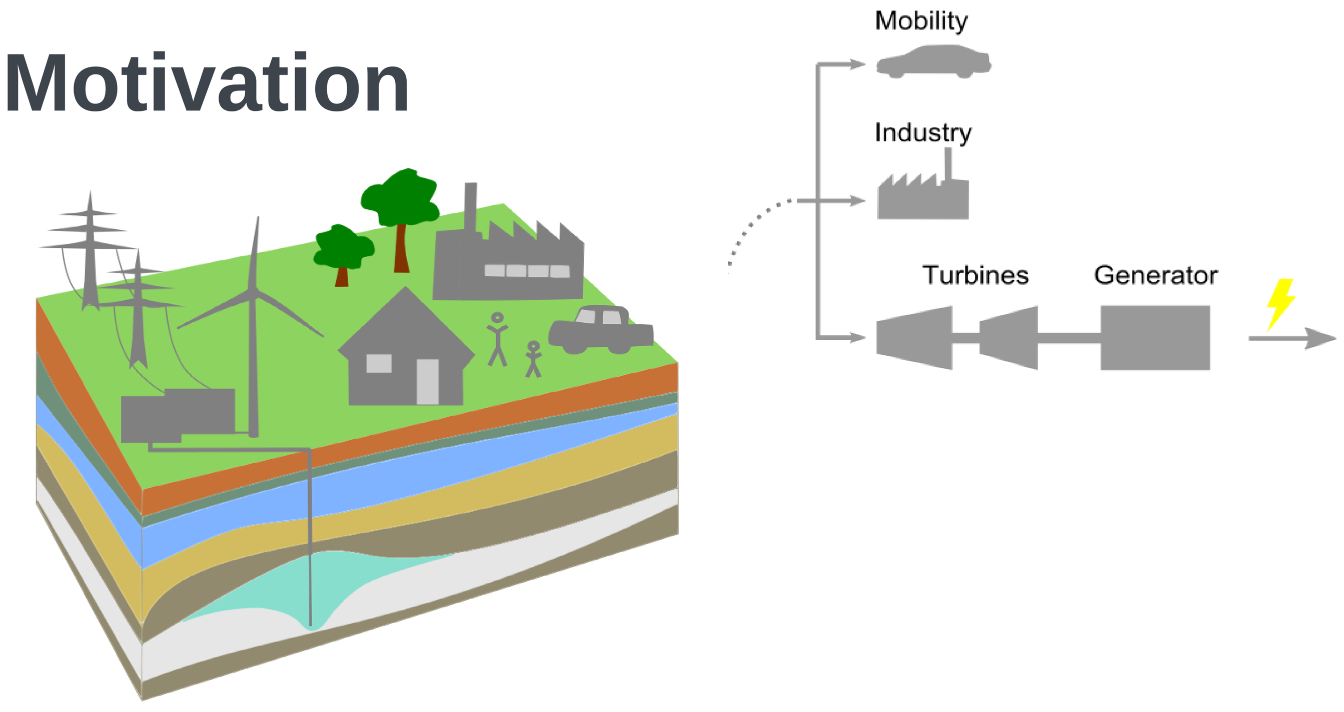
5-2a

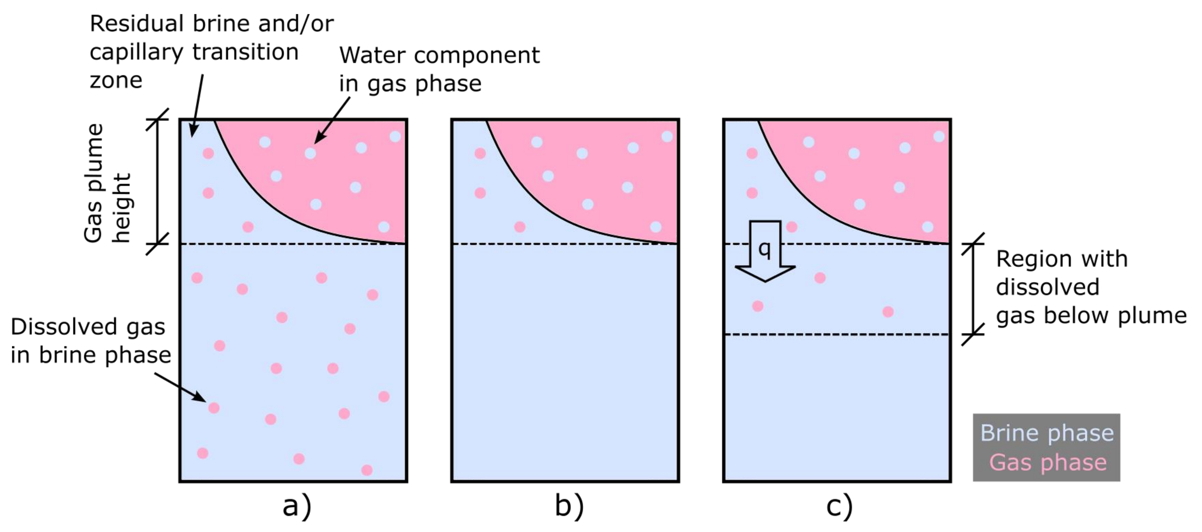
Motivation



Underground storage of synthetic gas from renewable energy

- Large domains and limited data require efficient models that adapt locally to varying domain/process complexity
- Our adaptive multiphysics model currently couples two models: a full-multidimensional model and a vertical equilibrium (VE) model, both for immiscible two-phase flow
- We extend the two-model hierarchy, e.g., to include compositional models for full multidimensions and vertical equilibrium

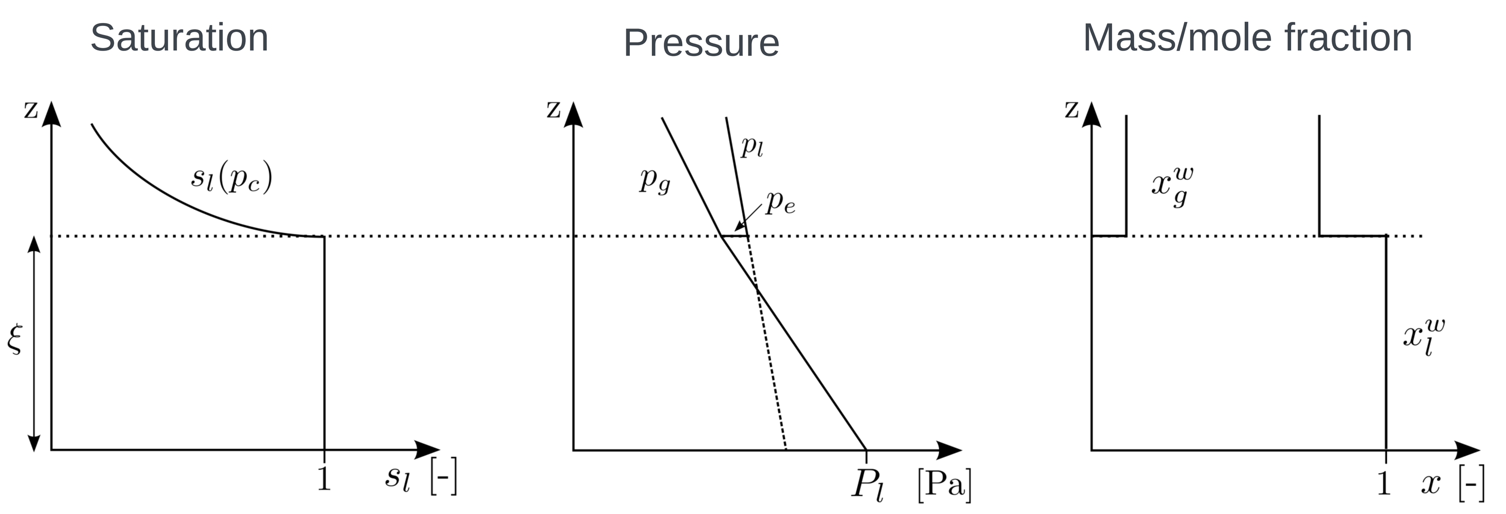
Conceptual compositional VE model



Full equilibrium Equilibrium in plume Transition state

We consider two phases (brine, gas) and two miscible components (water, gas)

Assumed vertical profiles



We neglect the influence of vertical pressure gradient on density and miscibility. Reference pressure is the pressure at the bottom.

Tools & Methods

C++, DuMu^X

Governing equations

Full multidimensional pressure and transport equation:

$$\frac{\partial \hat{v}}{\partial p}\frac{\partial p}{\partial t} - \sum_\kappa \frac{\partial \hat{v}}{\partial c^\kappa}\nabla\cdot\left(\sum_\alpha X_\alpha^\kappa \varrho_\alpha \boldsymbol{u}_\alpha\right) - \sum_\kappa \frac{\partial \hat{v}}{\partial c^\kappa} q^\kappa = \frac{\phi - \hat{v}}{\Delta t}$$

$$\frac{\partial c^\kappa}{\partial t} = -\nabla\cdot\left(\sum_\alpha X_\alpha^\kappa \varrho_\alpha \boldsymbol{u}_\alpha\right) - q^\kappa$$

with $\boldsymbol{u}_\alpha = -\boldsymbol{k}\lambda_\alpha\left(\nabla p_\alpha + \varrho_\alpha g \nabla z\right),\qquad \alpha = l,\, g$

and total specific volume $\hat{v}$, total component concentration c^κ, mass fraction X_α^κ, phase density ϱ_α, source/sink q^κ, porosity ϕ, intrinsic permeability $\boldsymbol{k}$, mobility λ_α, and graviational acceleration g.

Vertically integrated pressure and transport equation:

$$\frac{\partial \hat{V}}{\partial p}\frac{\partial p}{\partial t} - \sum_\kappa \frac{\partial \hat{V}}{\partial C^\kappa}\nabla_{||}\cdot\left(X_l^{\kappa,*}\varrho_l^* \boldsymbol{U}_l^* + \sum_\alpha X_\alpha^{\kappa,**}\varrho_{\alpha,**}\boldsymbol{U}_\alpha^{**}\right) - \sum_\kappa \frac{\partial \hat{V}}{\partial C^\kappa} Q^\kappa = \frac{\Phi - \hat{V}}{\Delta t}$$

$$\frac{\partial C^\kappa}{\partial t} = \nabla_{||}\cdot\left(X_l^{\kappa,*}\varrho_l^* \boldsymbol{U}_l^* + \sum_\alpha X_\alpha^{\kappa,**}\varrho_{\alpha,**}\boldsymbol{U}_\alpha^{**}\right) - Q^\kappa$$

with $\boldsymbol{U}_\alpha^* = -\boldsymbol{K}^*\Lambda_\alpha^*\left(\nabla_{||}p_{\alpha,B} + \varrho_\alpha^* g \nabla \xi_B\right)$ and

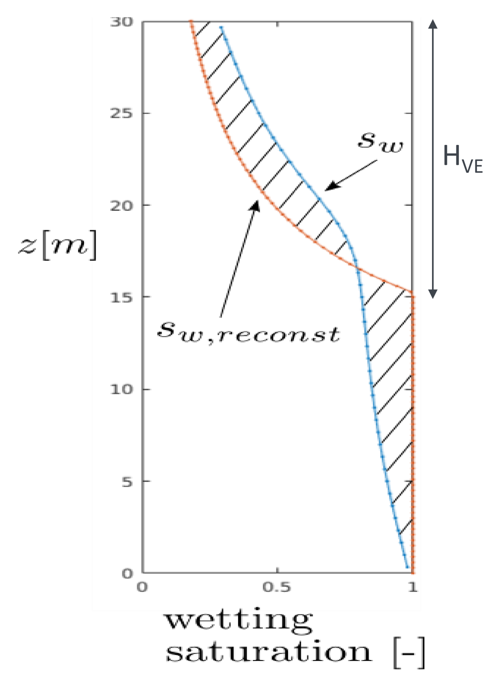
$\boldsymbol{U}_\alpha^{**} = -\boldsymbol{K}^{**}\Lambda_\alpha^{**}\left(\nabla_{||}p_{\alpha,T} + \varrho_\alpha^{**} g \nabla \xi_T\right)$

Capital letters denote integrated variables. Properties below the plume are denoted with superscript $*$, inside the plume with superscript $**$.

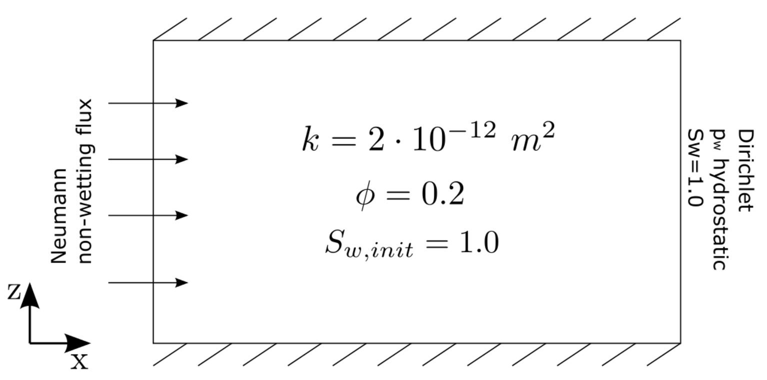
VE criteria

VE criteria are based on vertical profiles of parameters β, e.g., saturation or relative permeability.

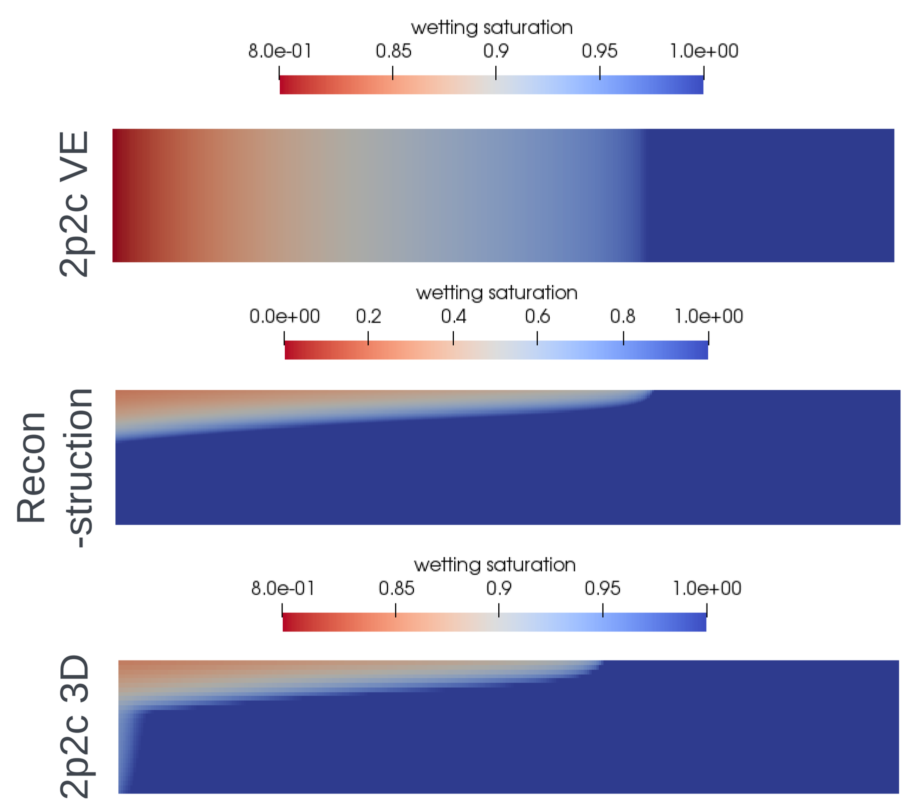
$$c_\beta = \frac{\int_0^H \|\beta - \beta^*\|\mathrm{d}z}{H_{VE}}$$



Preliminary results



Brooks-Corey cap. pressure:
$\lambda = 2, \quad p_e = 1bar$
Depth: $1000\ m$
Temperature: $53\ ^\circ C$
Injection rate: $q^{CH_4} = 552\ t/m/a$



References

[1] Gasda, S., Nordbotten, J., and Celia, M. Vertically averaged approaches for CO_2 migration with solubility trapping. Water Resources Research, 47(5), 2011.

[2] Nordbotten, J. M. and Celia, M. A.: Geological Storage of CO_2: Modeling Approaches for Large-Scale Simulation. John Wiley & Sons, 2012.

[3] Nilsen, H. M., Lie, K.-A., and Andersen, O. Robust simulation of sharp-interface models for fast estimation of CO_2 trapping capacity in large-scale aquifer systems. Computational Geosciences, 20(1):93–113, 2016.

Collaboration

- PN 5-2b: Development and analysis of the optimization framework
- TU Delft: Lab- and field-scale experiments of gas storage
- PN 5-1: Identification and description of global optimization spaces
- PN 1-5: Model hierarchy for porous medium / free flow interfaces