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Developing a coupled numerical model for underground gas storage

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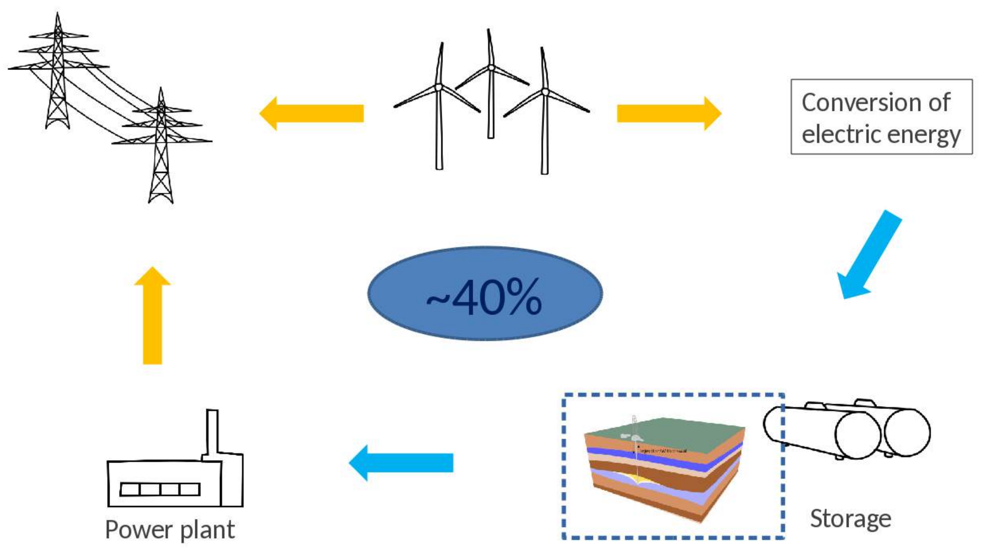
Motivation

One of the key technologies to reduce global greenhouse gas emissions is renewable electricity. However, renewable energy sources like wind or solar power experience intermittency as a combination of non-controllable variability and partial unpredictability. As a result, energy storage is an essential component of future energy systems that use large amounts of variable renewable resources.[1] Apart from pumped-storage hydropower, large scale energy storage is mainly provided by underground energy storage systems.[2]



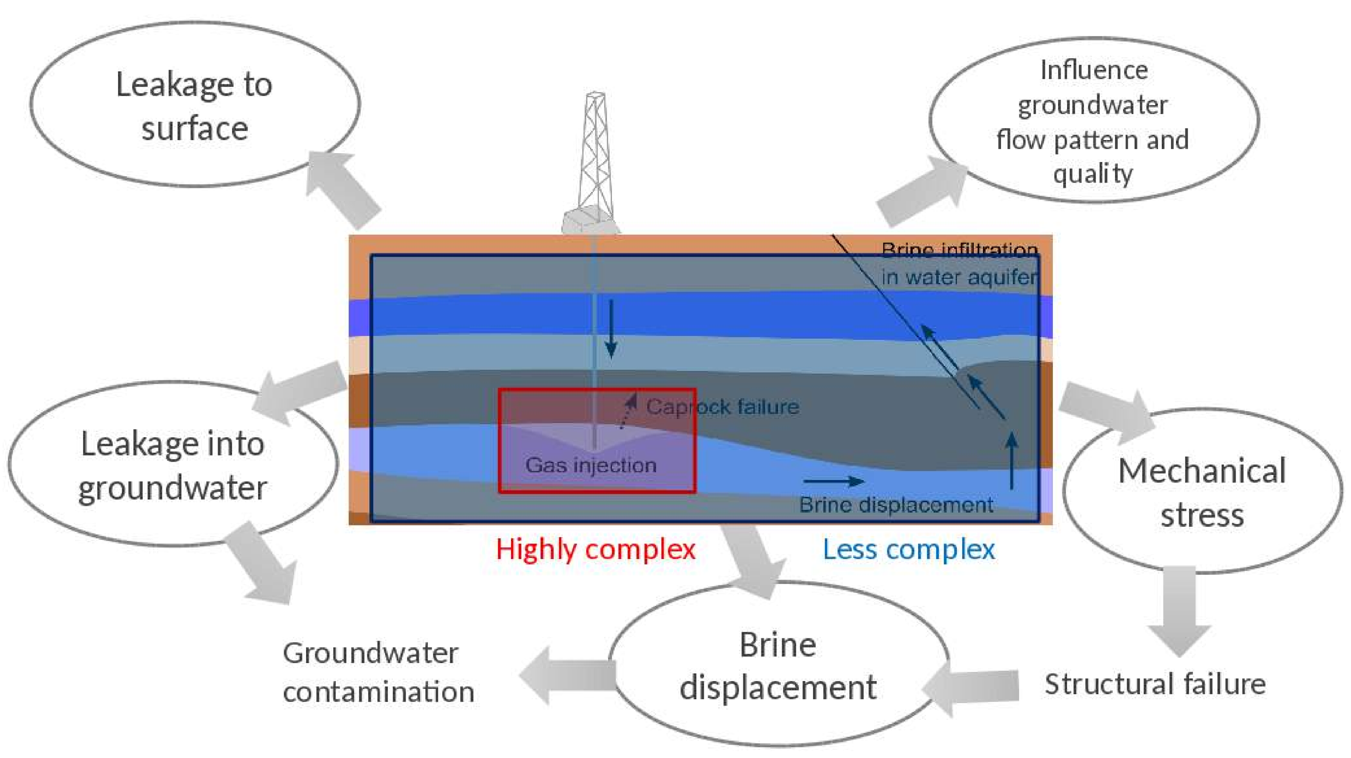
Simulating underground energy storage for risk assessment and planning purpose requires to address the following challenges:

- large domains
- locally complex (hysteresis, fingering, dissolution)
- dynamic boundary conditions

Within acceptable computational time this can not be achieved by standard three-dimensional multiphase multicomponent models due to limited computational resources. The main scope of this work is to increase efficiency of simulations by extending and combining various available methods in one domain.

Risks associated with underground gas storage

Various possible leakage pathways and harmful influences of gas storage on humans and the environment can be identified. The numerical model must be able to reproduce the underlying processes and mechanisms with a certain required accuracy.



Model equations

Mass balance equation:

$$\frac{\partial}{\partial t}(\varrho_\alpha \phi S_\alpha) + \nabla \cdot (\varrho_\alpha \mathbf{u}_\alpha) = \varrho_\alpha \psi^\alpha$$

$$\mathbf{u}_\alpha = -\frac{\mathbf{k} k_{r\alpha}}{\mu_\alpha}(\nabla p_\alpha - \varrho_\alpha \mathbf{g})$$

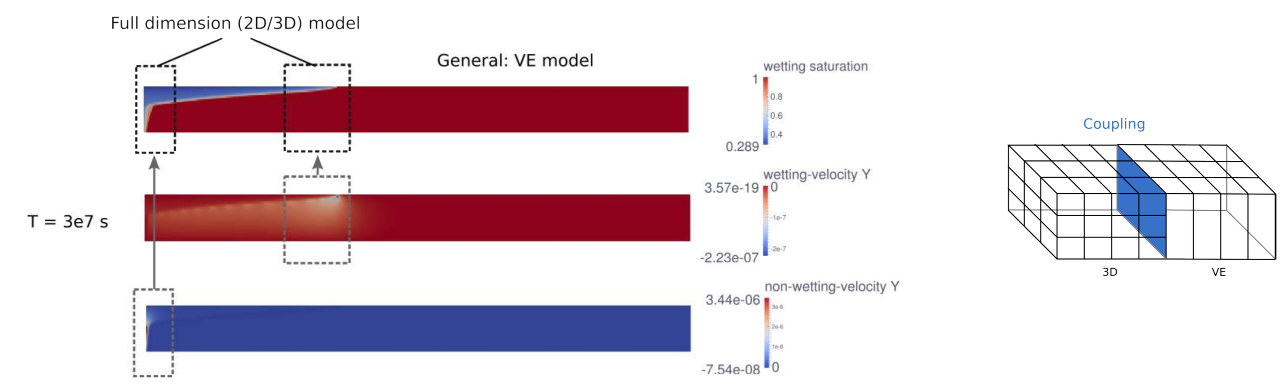
Integrated mass balance equation, with vertically integrated variables and pressure P_α at the bottom of the formation:

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

$$\mathbf{U}_\alpha = -\mathbf{K}\Lambda_\alpha(\nabla_{\parallel} P_\alpha - \varrho_\alpha \mathbf{G})$$

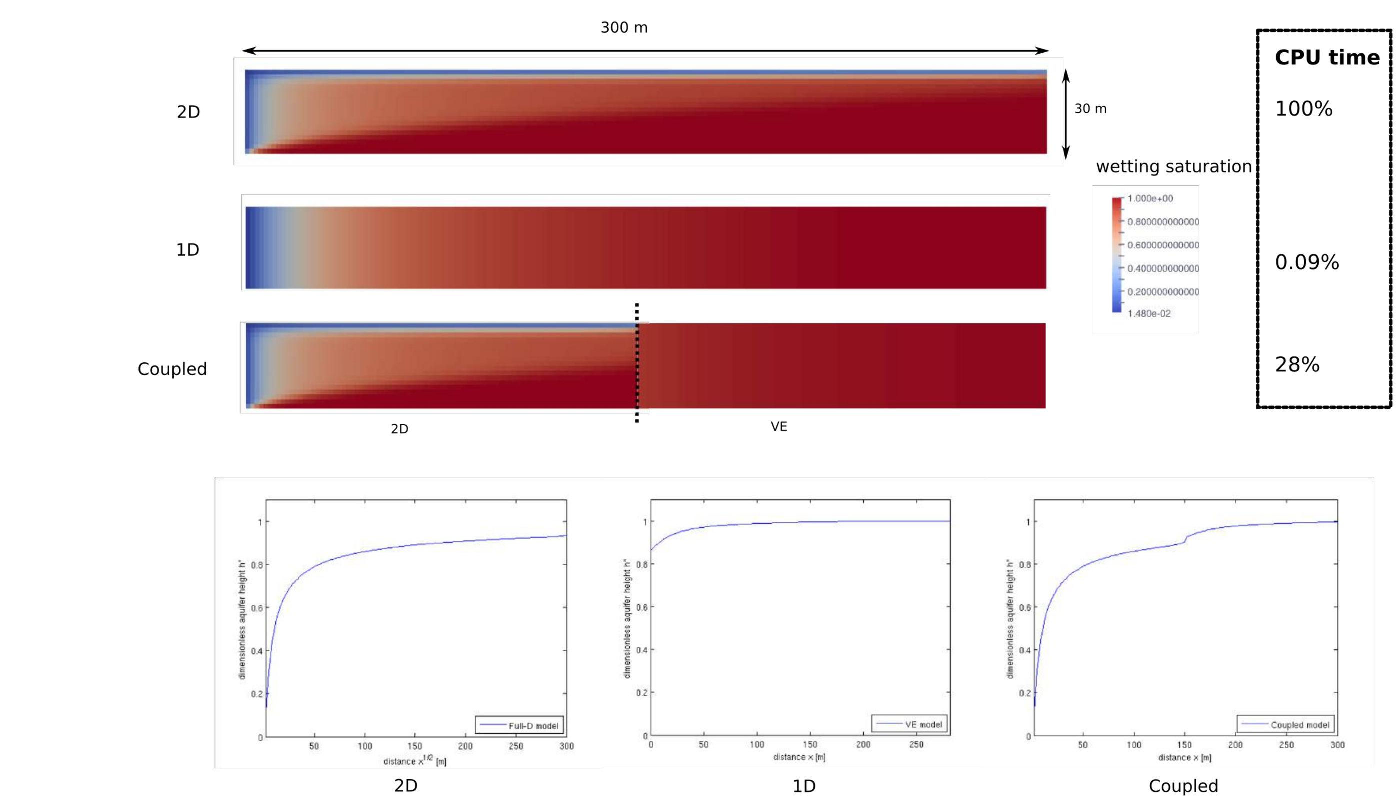
Coupling of a 3D to a VE model

A family of simplified models assumes that the two fluid phases have fully segregated due to buoyancy, and that the phase pressures have reached gravity-capillary equilibrium in the vertical direction (VE). However, there are a number of cases for which the VE assumption is inappropriate. A first step towards increased efficiency is the coupling of a vertically integrated modeling approach to a full dimension multiphase model.



Preliminary results

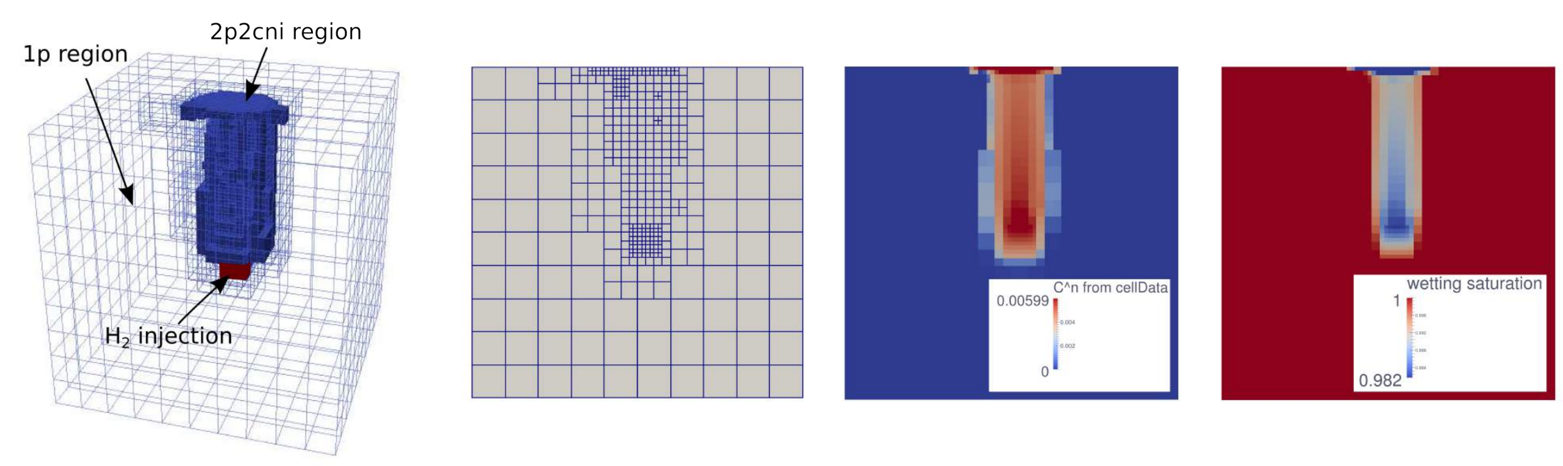
First results show an increase in computational efficiency.



Comparison of 2D injection scenario: 2D, 1D (VE-model) and coupled model

Outlook

Extending the concept to adaptive grids and applicability in multi-physics models [3].



Simulation of hydrogen injection; from left to right: multi-physics subdomains, refined grid (based on error estimation), total concentration of hydrogen, wetting saturation

References

[1] R. Socolow, R. Hotinski, J. B. Greenblatt and S. Pacala.
Solving the climate problem: technologies available to curb CO2 emissions. Environment: Science and Policy for Sustainable Development, 46(10), 8–19, (2004).

[2] I. Perez-Arriaga.
Managing large scale penetration of intermittent renewables. MITEI Symposium on Managing Large-Scale Penetration of Intermittent Renewables, Cambridge/USA, 20/04/2011, (2011).

[3] B. Faigle, R. Helmig, I. Aavatsmark and B. Flemisch.
Efficient multiphysics modelling with adaptive grid refinement using a MPFA method. Computational Geosciences, 1–12, (2013).