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How turbulence and surface properties affect porous-medium / free flow exchange processes

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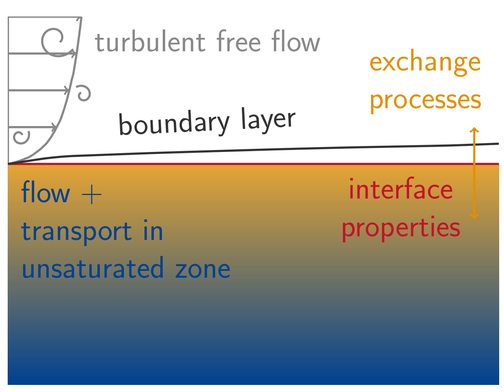
Motivation

This project focuses on understanding and modeling the relevant processes of evaporation. Evaporation is strongly influenced by the interaction of different physical processes:

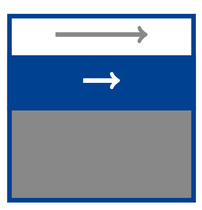
- in the free flow
- at the interface
- inside the porous medium



The main goal is to describe these processes and to simulate porous-medium flow with an adjacent free flow. The developed concept can be used for improving soil salinization simulations, analyzing water balance relations or technical applications, like fuel cells, or drying and cooling processes.

Concept

Porous Medium

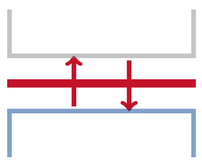


- REV concept
- Darcy's law
- two fluid phases (gas, liquid)
- two components (air, water)
- non-isothermal

Free Flow

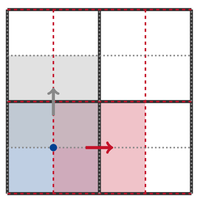
- laminar or turbulent (ν_t)
- Reynolds-averaged Navier-Stokes
- single fluid phase (gas)
- two components (air, water)
- non-isothermal

Coupling



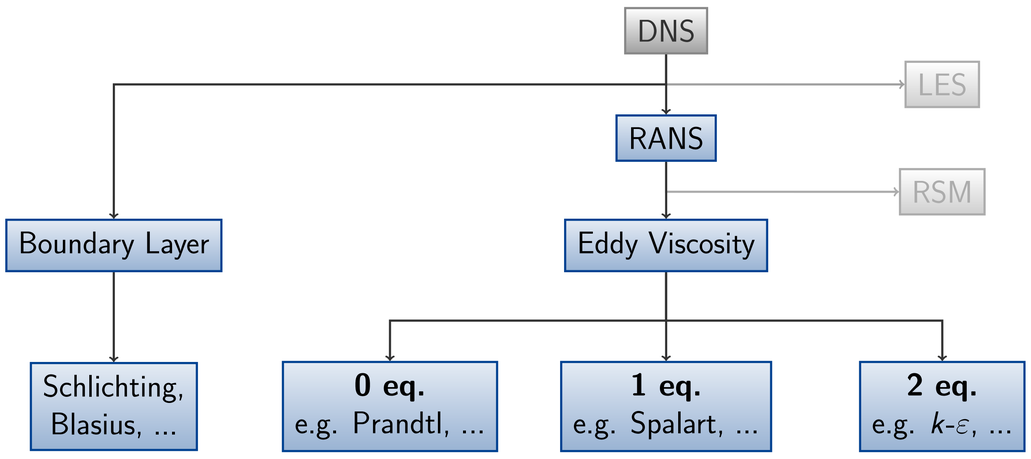
- local thermodynamic equilibrium
- continuity of fluxes
- extension of [5] to turbulent conditions
- wall functions for rough interfaces [4]

Implementation



- monolithic, fully implicit
- time: implicit Euler
- free flow: box, MAC
- porous medium: box, FV

Turbulence Model Hierarchy

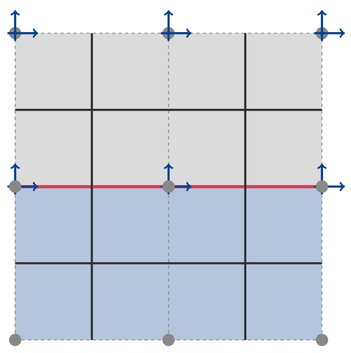


Discretizations

box – box

$q^{\text{if,ff}} = q^{\text{if,pm}}$

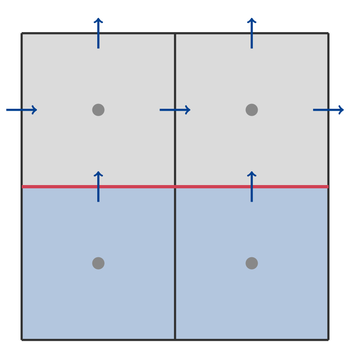
$u^{\text{if,ff}} = u^{\text{if,pm}}$



MAC – FV

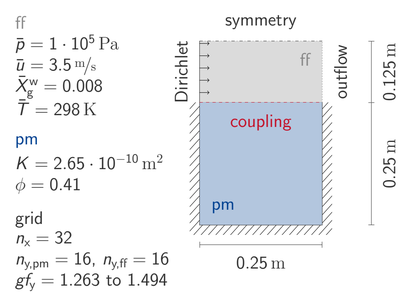
$q^{\text{if,ff}} = q^{\text{if,pm}}$
with $\nabla u^{\text{if,ff}} = ?$

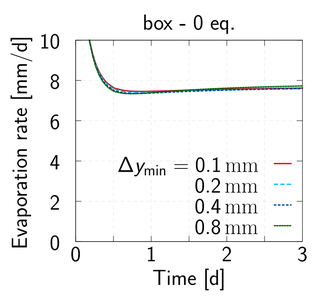
$u^{\text{if}} = ?$

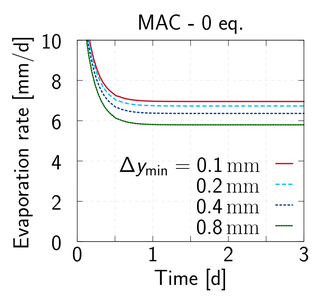


Results

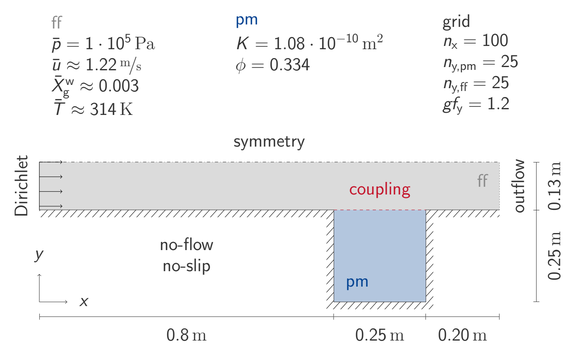
Convergence study, cf. [3]:

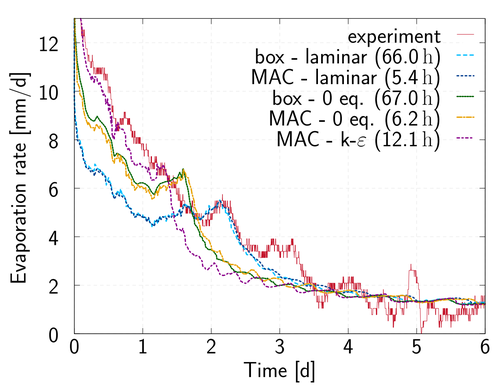






Comparison with experiments, [1, 2]:





Outlook

Analyze the influence of

- turbulent pumping
- discrete roughness elements
- heterogeneous porous media

Extend the model by

- a pore network model next to the interface
- local thermodynamic non-equilibrium

Literature

[1] Davarzani, H., Smits, K., Tolene, R. M., and Illangasekare, T. (2014). Study of the effect of wind speed on evaporation from soil through integrated modeling of the atmospheric boundary layer and shallow subsurface. *Water Resources Research*, 50:1–20.

[2] Fetzer, T., Smits, K., M., and Helmig, R. (2016). Effect of Turbulence and Roughness on Coupled Porous-Medium/Free-Flow Exchange Processes. *Transport in Porous Media*.

[3] Grüninger, C., Fetzer, T., Flemisch, B., and Helmig, R. (2016). Coupling DuMuX and DUNE-PDELab to investigate evaporation at the interface between Darcy and Navier-Stokes flow. in preparation.

[4] Kuznetsov, A. V. and Becker, S. M. (2004). Effect of the interface roughness on turbulent convective heat transfer in a composite porous/fluid duct. *International Communications in Heat and Mass Transfer*, 31(1):11–20.

[5] Mosthaf, K., Baber, K., Flemisch, B., Helmig, R., Leijnse, A., Rybak, I., and Wohlmuth, B. (2011). A coupling concept for two-phase compositional porous-medium and single-phase compositional free flow. *Water Resources Research*, 47(10):W10522.