Modeling evaporation from porous media influenced by a turbulent free flow

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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 and properties

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

In a preliminary work, the coupling of those two flow regimes has been performed [1, 3].

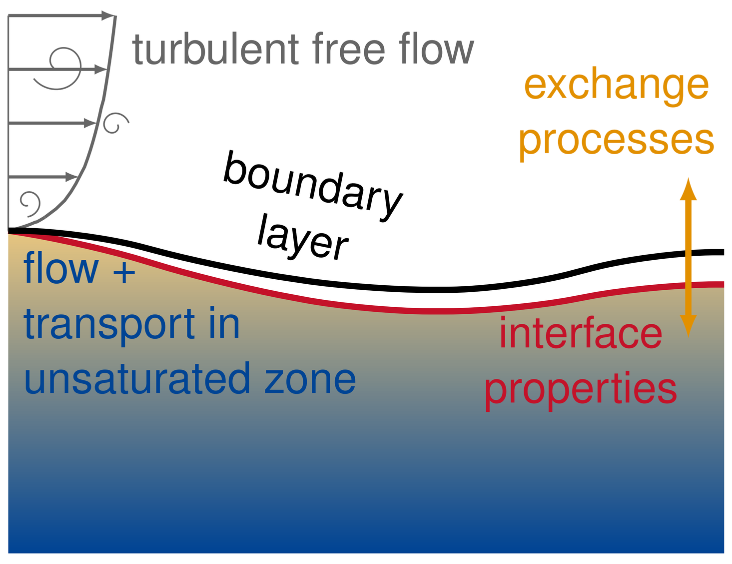

Figure 1: *Relevant processes for modeling evaporation from bare soil on a field scale.*

The main goal is to increase the predictability of evaporation rates under turbulent conditions. Within this work, the knowledge is transferred from laboratory to field scale.

Model concept

Coupling

Different methods for connecting and calculating the two domains.

	⇔	
• 1 domain, [2]		• 2 domains, [1, 3]
• 1 set of equations		• 2 different set of equations
• transition zone		• sharp interface

Models

Different methods and abstractions for modeling flow in the two domains.

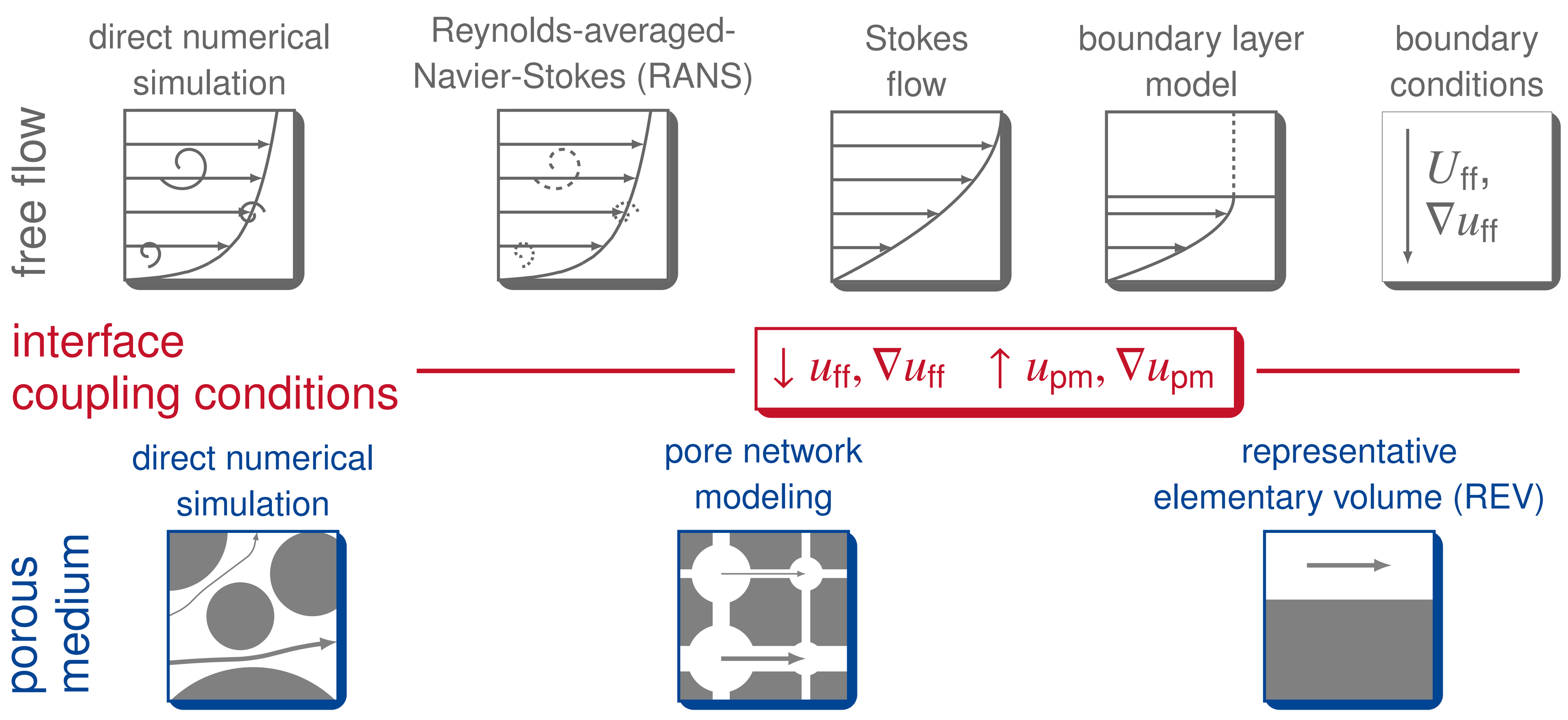

Figure 2: *Different methods for modeling free and porous-medium flow.*

Relevant processes

Main influence parameters and processes, considered in this work.

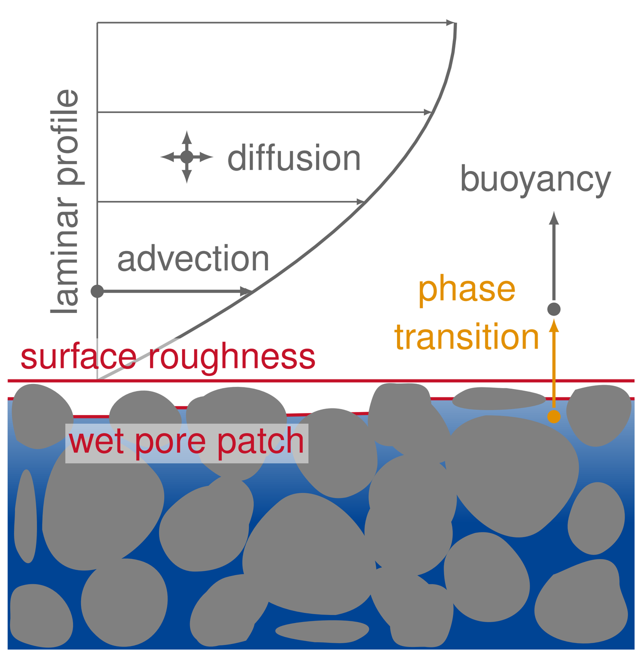

Figure 3: *Flow and transport in an isothermal, laminar flow.*

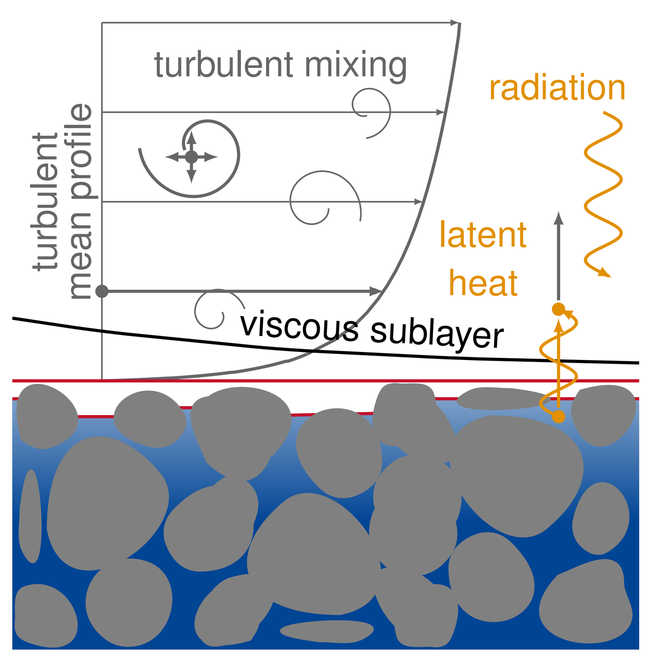

Figure 4: *Flow and transport in a non-isothermal, turbulent flow.*

Simulations are performed using the open-source simulator DuMu^x.

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Experiment

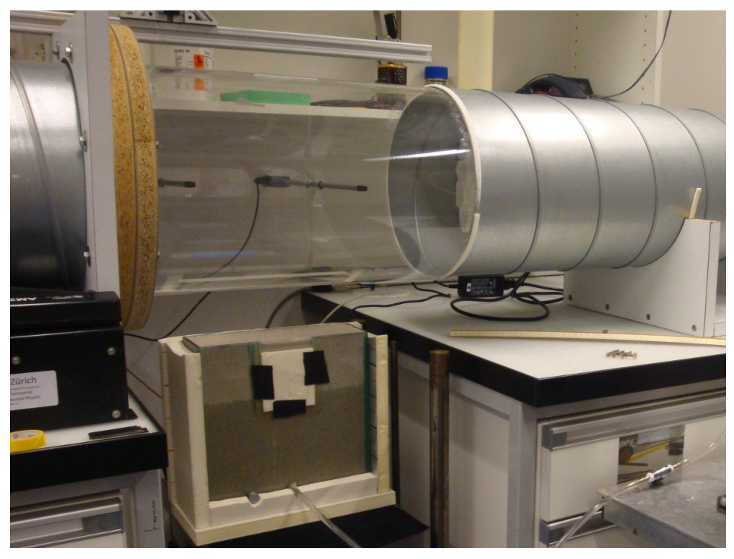
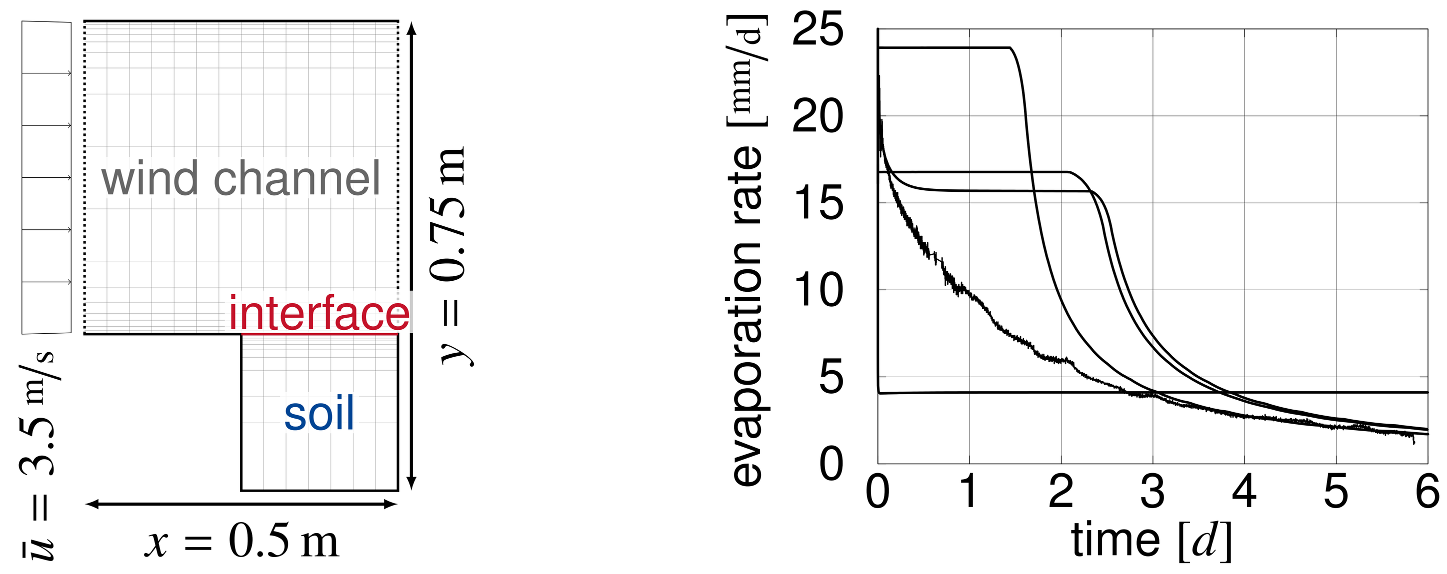


Figure 5: *Setup of the experiments done in cooperation with ETH Zürich, [4].*

free flow		
wind speed	u	3.5 m/s
wind profile		constant
porous medium		
conductivity	K	$3.2 \cdot 10^{-10}\,\mathrm{m}^2$
porosity	ϕ	0.4
min. grain diameter	d_{min}	0.3 mm
max. grain diameter	d_{max}	0.9 mm

Table 1: *Parameters of the experiment.*



– experimental data – RANS μ_t – RANS μ_t, D_t, λ_t, non-isothermal
– Stokes non-isothermal – RANS μ_t, D_t

Figure 6: *Setup of the corresponding simulations and the calculated evaporation rates.*

Results

- turbulent free flow improves results
- viscous sublayer is important
- wet pore patch influences evaporation rate

Challenges

- 3D effects
- pressure oscillations
- high computational effort
- no grid convergence

Outlook

Model concept

Goal: Stable discretization and fast solution for turbulence flow over more complex geometries.

- implementation of k-ω turbulence model and wall functions
- staggered grid for structured and unstructured grids
- multiple timestepping methods
- mortar elements at coupling interface
- coupling and testing of different model concepts
- extension to 3D

Experiment

Goal: Validation of the model concept.

- Lattice Boltzman simulation for flow in a soil sample
- more detailed wind channel experiments

Field scale

Goal: Simulation of real problems on larger scales.

- upscaling of results and parameters
- including new processes and parameters occurring on field scale
- reduction of model complexitiy

Literature

[1] K. Baber, K. Mosthaf, B. Flemisch, R. Helmig, S. Müthing, and B. Wohlmuth. "Numerical scheme for coupling two-phase compositional porous-media flow and one-phase compositional free flow". *IMA Journal of Applied Mathematics*, 77, 2012.

[2] H. C. Brinkman. "A calculation of the viscous force exerted by a flowing fluid on a dense swarm of particles". *Applied Scientific Research*, 1, 1949.

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

[4] E. Shahraeeni, P. Lehmann, and D. Or. "Coupling of evaporative fluxes from drying porous surfaces with air boundary layer: Characteristics of evaporation from discrete pores". *Water Resources Research*, 48, 2012.