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

The main goal is to describe these processes and to simulate porous-medium flow with an adjacent free flow.

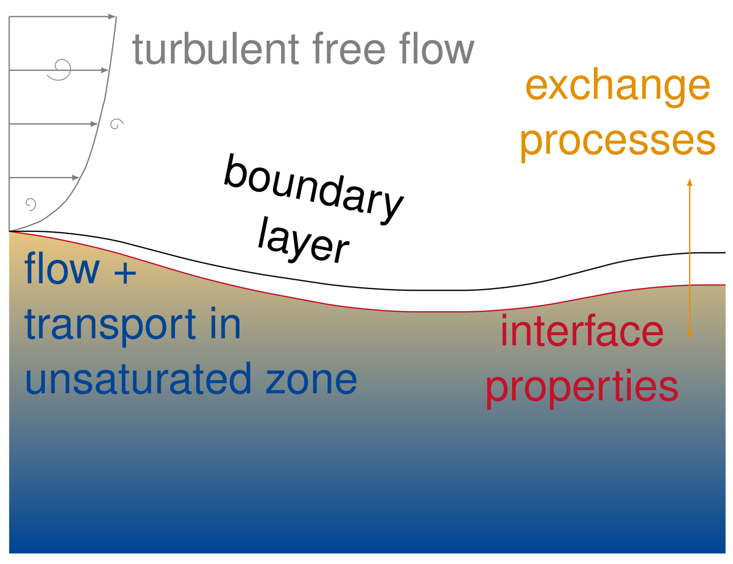

Figure 1: *Relevant processes for modeling evaporation from bare soil.*

The developed concept can be used for improving soil salinization simulations, analyzing water balance relations or other technical applications.

Model concept

It is aimed to develop a numerically **stable** model, which is able to simulate **turbulent free flow** and **exchange processes** with the porous medium.
The porous medium is modeled by the Darcy equation, extended to two-phase, two-component flow.

Free Flow Model

Reynolds-averaged Navier-Stokes equation:

$$\frac{\partial(\varrho\bar{\mathbf{v}})}{\partial t} + \nabla\cdot(\varrho\bar{\mathbf{v}}\bar{\mathbf{v}}) - \nabla\cdot([\mu+\mu_t]\nabla\bar{\mathbf{v}}) + \nabla p - \varrho\nabla\mathbf{g} = 0$$

$k-\varepsilon$ equations:

$$\frac{\partial\varepsilon}{\partial t}+\nabla\cdot(\varepsilon\bar{\mathbf{v}})-\nabla\cdot\left(\frac{\nu_t}{\sigma_\varepsilon}\nabla\varepsilon\right)-C_{1\varepsilon}\frac{\varepsilon}{k}2\nu_t\overline{S_{ij}}\cdot\overline{S_{ij}}+C_{2\varepsilon}\frac{\varepsilon^2}{k}=0$$

$$\frac{\partial k}{\partial t}+\nabla\cdot(k\bar{\mathbf{v}})-\nabla\cdot\left(\frac{\nu_t}{\sigma_k}\nabla k\right)-2\nu_t\overline{S_{ij}}\cdot\overline{S_{ij}}+\varepsilon=0$$

Eddy viscosity: $\mu_t = \varrho\nu_t = \varrho C_\mu k^2/\varepsilon$

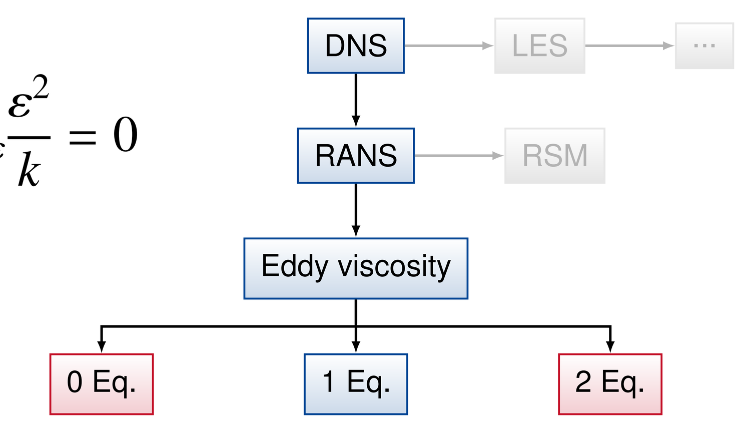

Figure 2: *Turbulence model hierarchy.*

Special treatment of those equations is needed in the viscous sublayer close to the wall [5, 3]. There, analytic wall functions will be applied as extended boundary conditions.

Discretization

Cell Centered Finite Volume

Staggered Grid

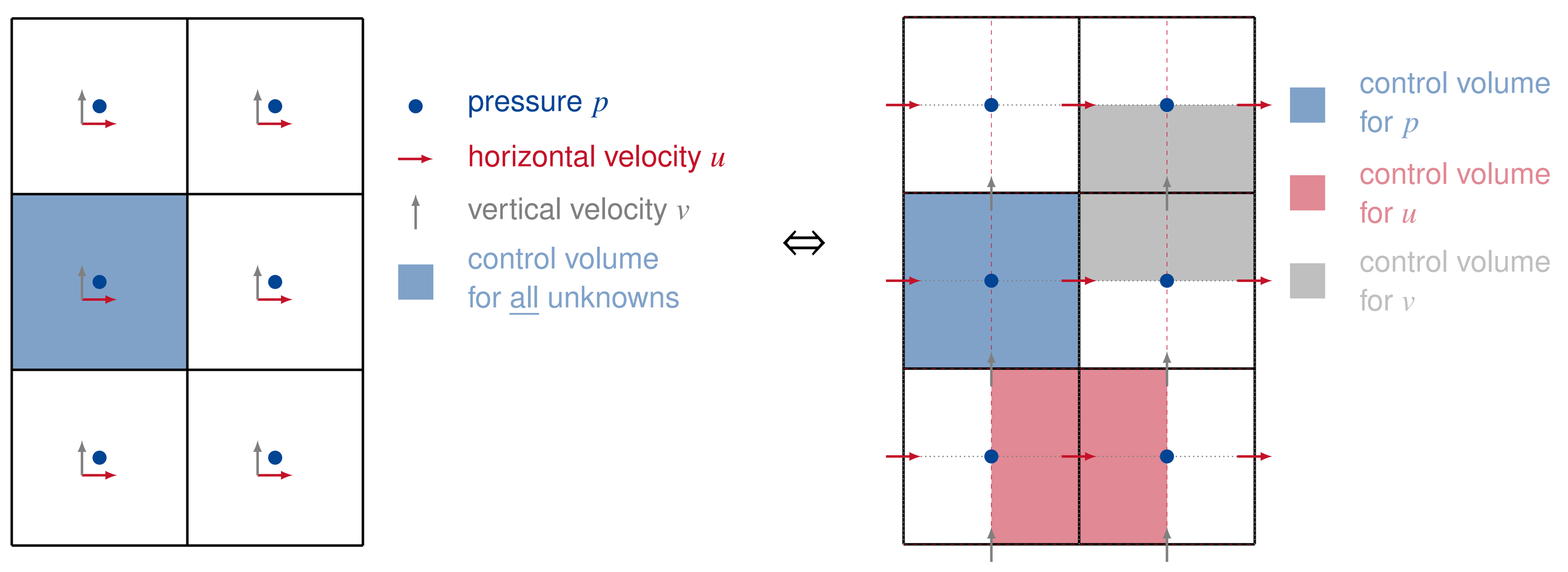

Figure 3: *Different discretization schemes for modeling free flow.*

Coupling

The coupling of the turbulent free flow and the porous-medium flow will be done in a similar manner as in [2]. This means, that mass transfer, normal forces, tangential forces, and heat transfer have to be coupled.
Interface related concept as those of Beavers and Joseph [1] or Schlünder [4] will be used and compared.

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

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This study is done in cooperation with the research unit MUSIS.

Link to this poster.

Experiment

To get a better understanding of the influence of relevant parameters, experiments will be performed at the CESEP, Colorado School of Mines.
Additionally, Lattice Boltzmann simulations for small soil samples will be performed at the TU Braunschweig.
The focus herein lies on analyzing the influence of ...

Surface Roughness

- no evaporation

1. smooth plate
2. impermeable + rough
3. permeable + rough

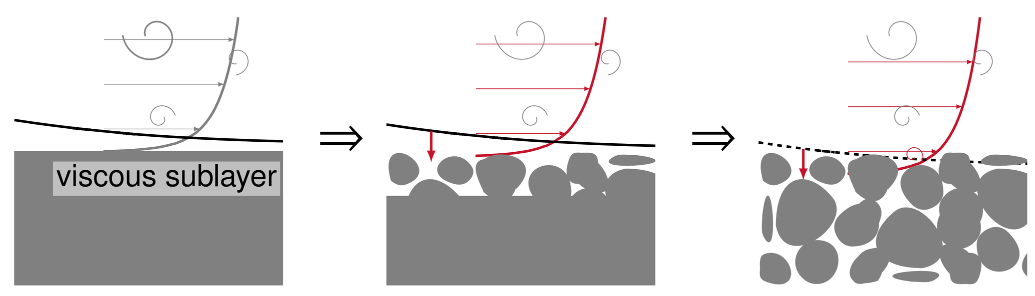

Figure 4: *Surface roughness effects on free flow velocity profile.*

Saturation

- no evaporation

1. fully saturated
2. step-wise decreasing initial saturation by $\Delta S_w = 0.1$

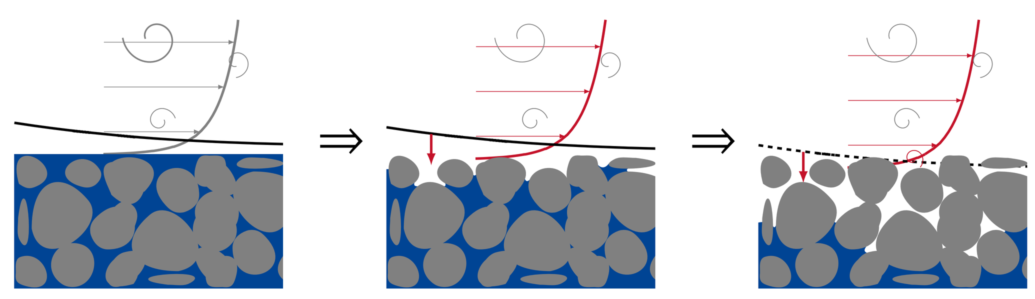

Figure 5: *Influence of saturation changes.*

Boundary Layers

- with evaporation

1. effects on velocity boundary layer
2. connection between different boundary layers

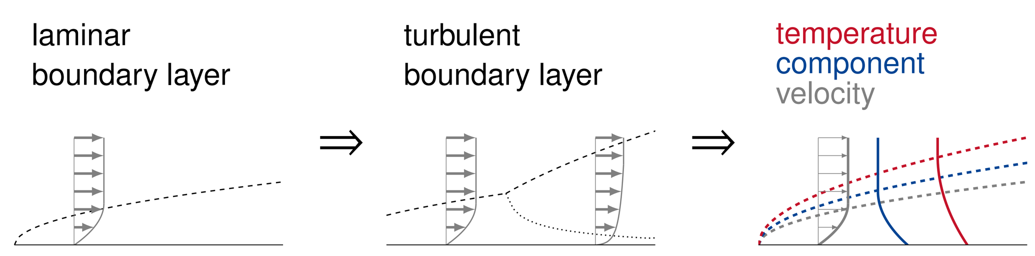

Figure 6: *Boundary layers for different flow conditions and transported quantities.*

Topography

- with evaporation

1. soil structure
2. curved surfaces

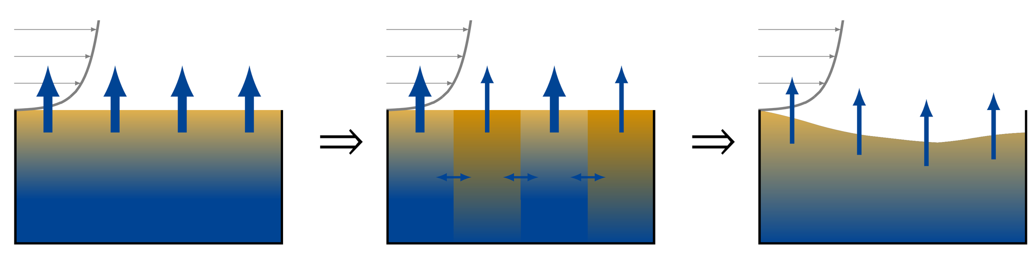

Figure 7: *Changes in soil structure and topography.*

... and integrating the results as boundary conditions for the k-ε model (so called **wall functions**) and to use them for **validation** purposes.

Outlook

short-term

- include transient term of RANS equation
- validate k-ε turbulence model
- implement coupling concept

long-term

- literature study on wall function concepts
- check simulation results for slightly curved surfaces
- mortar elements at the interface
- reduction of model complexity

Literature

[1] Beavers, G. S. and Joseph, D. D. (1967). Boundary conditions at a naturally permeable wall. *Journal of Fluid Mechanics*, 30(1):197–207.

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[4] Schlünder, E.-U. (1988). Über den Mechanismus des ersten Trocknungsabschnittes und seine mögliche Bedeutung für diffusionskontrollierte katalytische Gasphasen-Reaktionen. *Chemie Ingenieur Technik*, 60:117–120.

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