Numerical analysis of the influence of turbulence on the exchange processes between porous-medium and free flow

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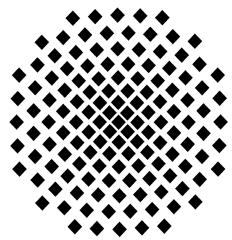
Universität Stuttgart

January 9, 2013



Outline

Motivation

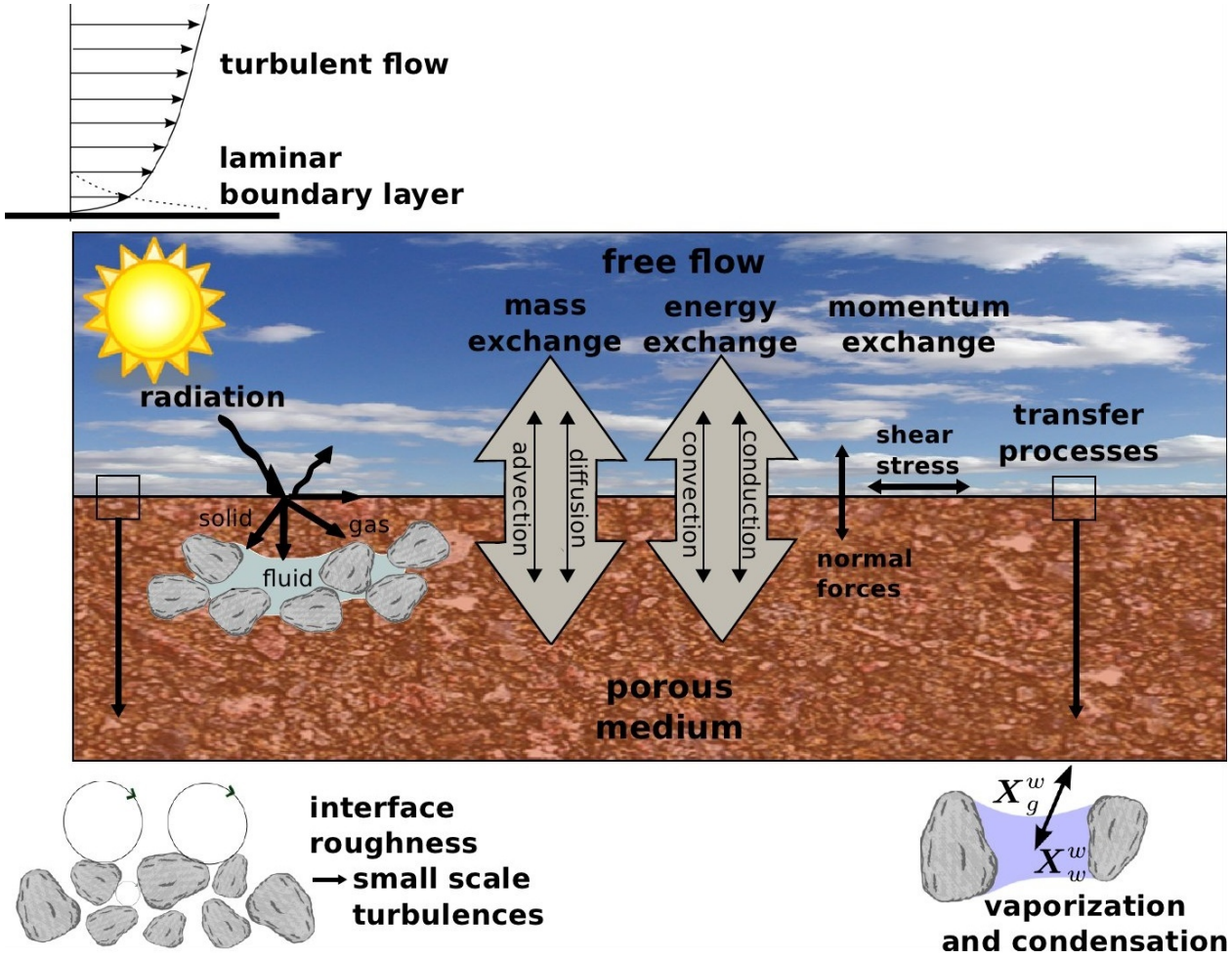
Why Turbulence?

Model Concepts

Results

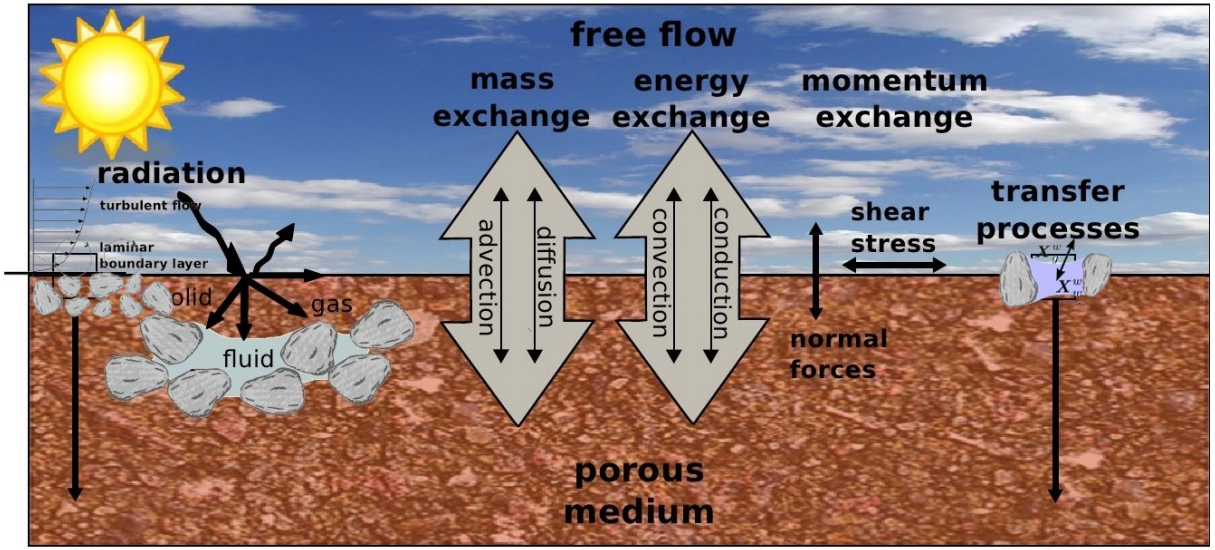
Summary and outlook

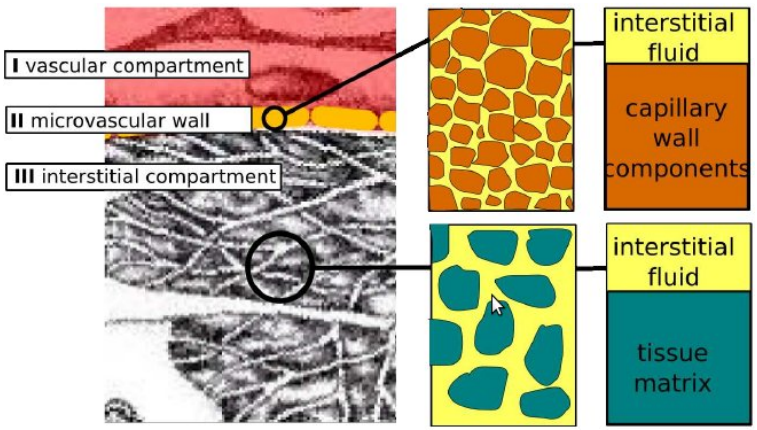
Motivation



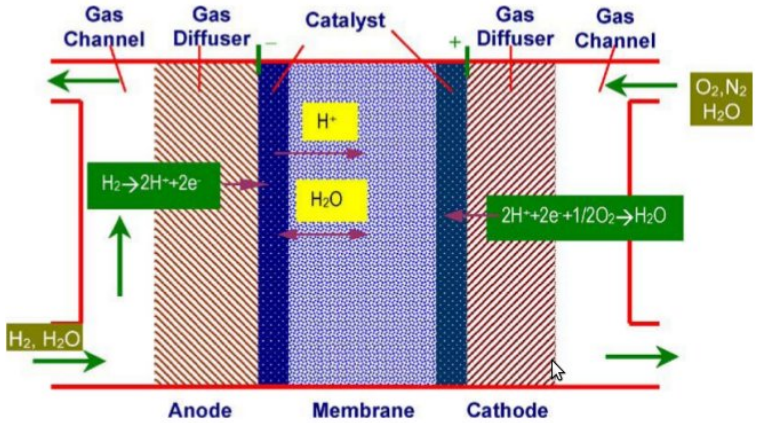
Mosthaf et al. - A coupling concept for two-phase compositional porous-medium and single-phase compositional flow

Motivation - Other applications



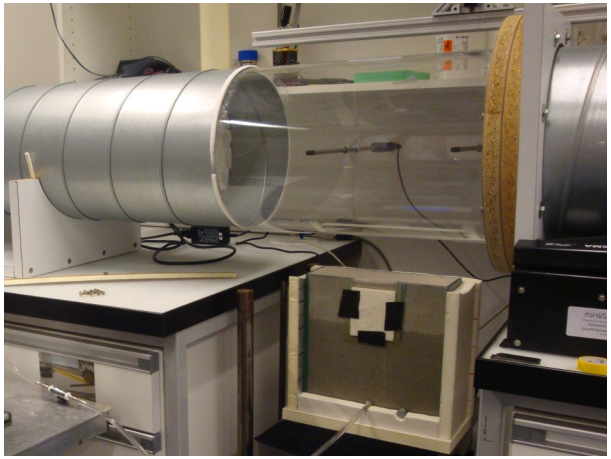


Baber - Modeling the transfer of therapeutic agents from the vascular space to the tissue compartment

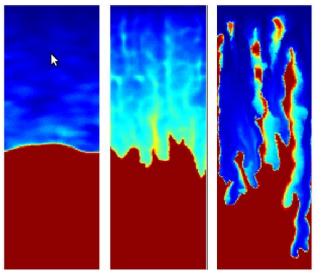


You and Liu - A two-phase flow and transport model for PEM fuel cells

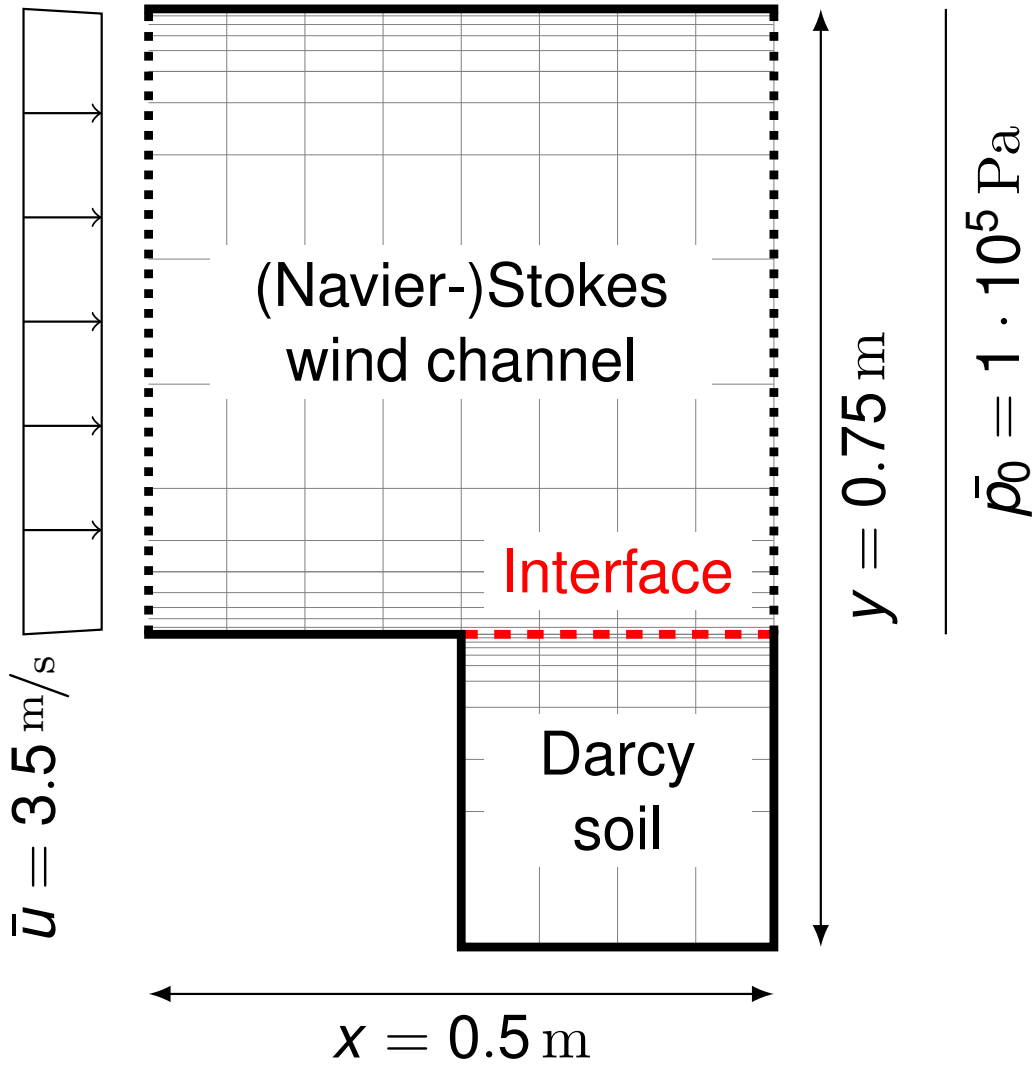
Motivation - Coupled Model



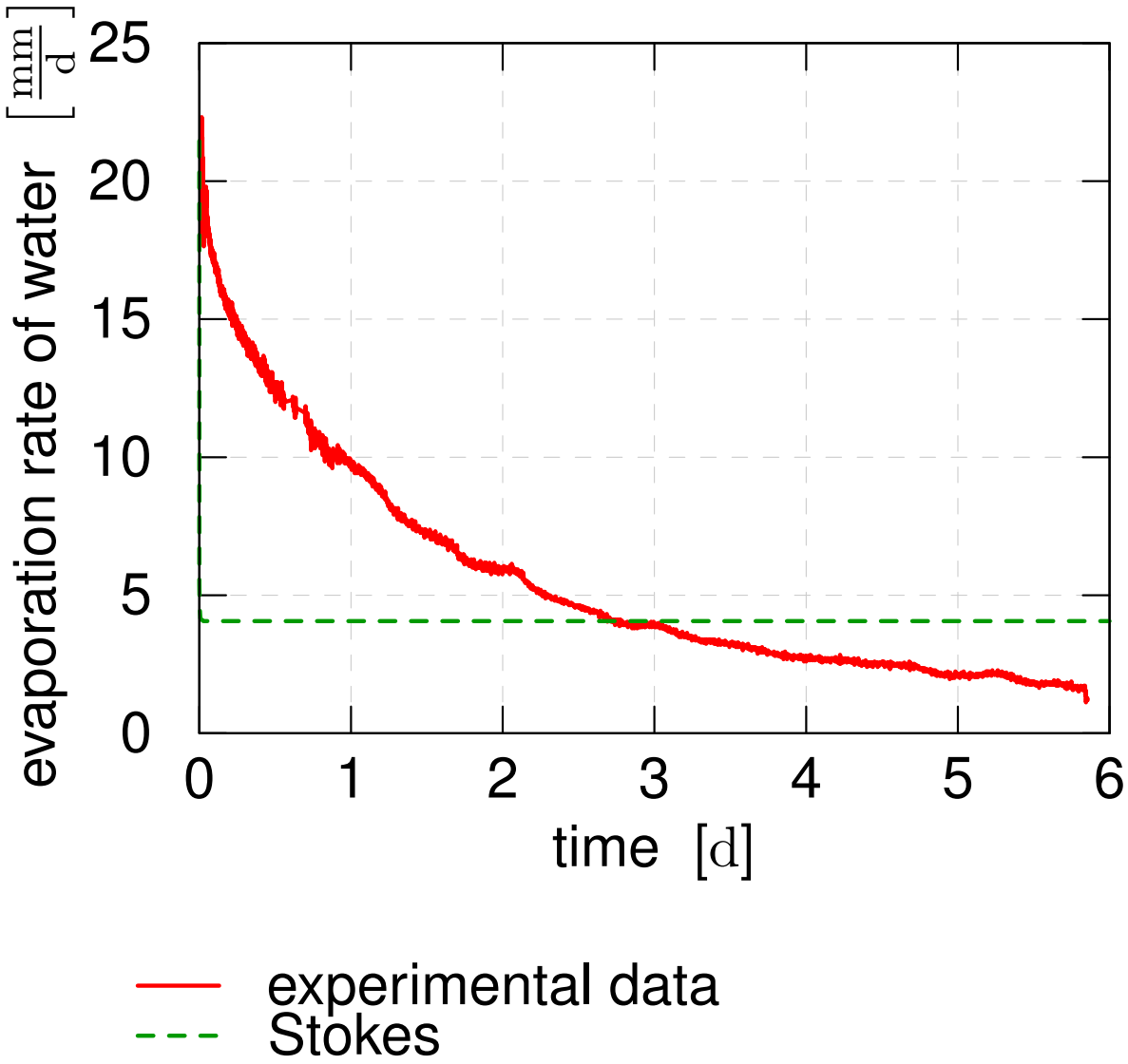
Experimental setup



Multi-Scale Interfaces in Unsaturated Soil

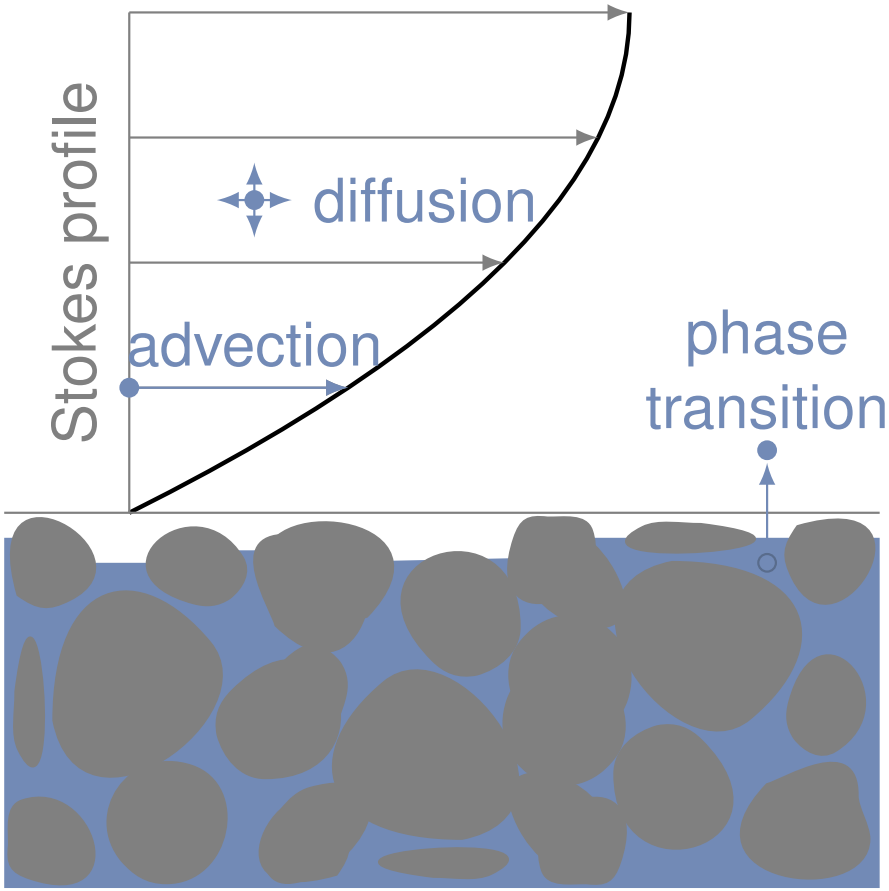


Motivation - Evaporation rate Stokes flow



Why turbulence? - Free flow transport processes

isothermal Stokes flow



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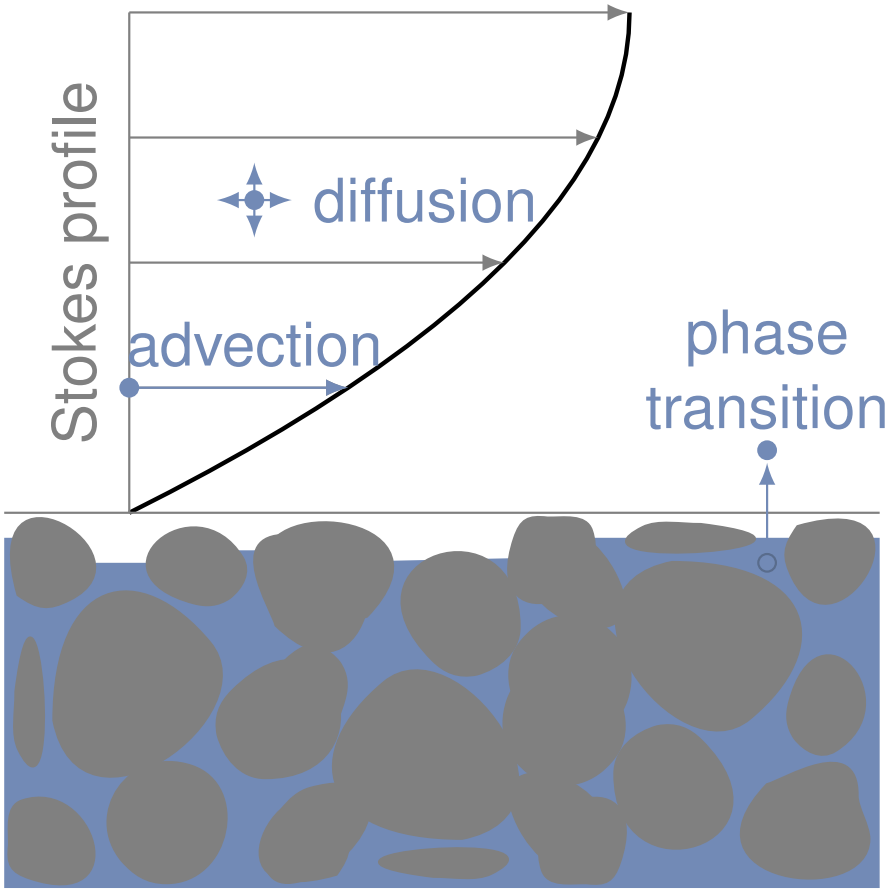
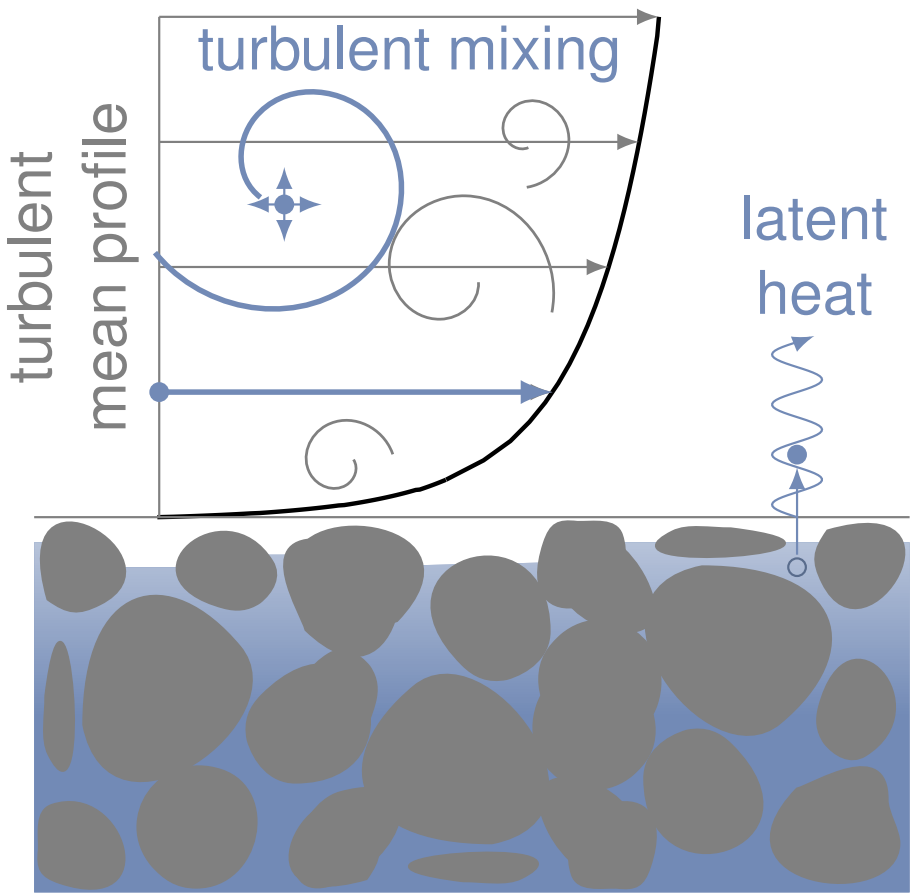
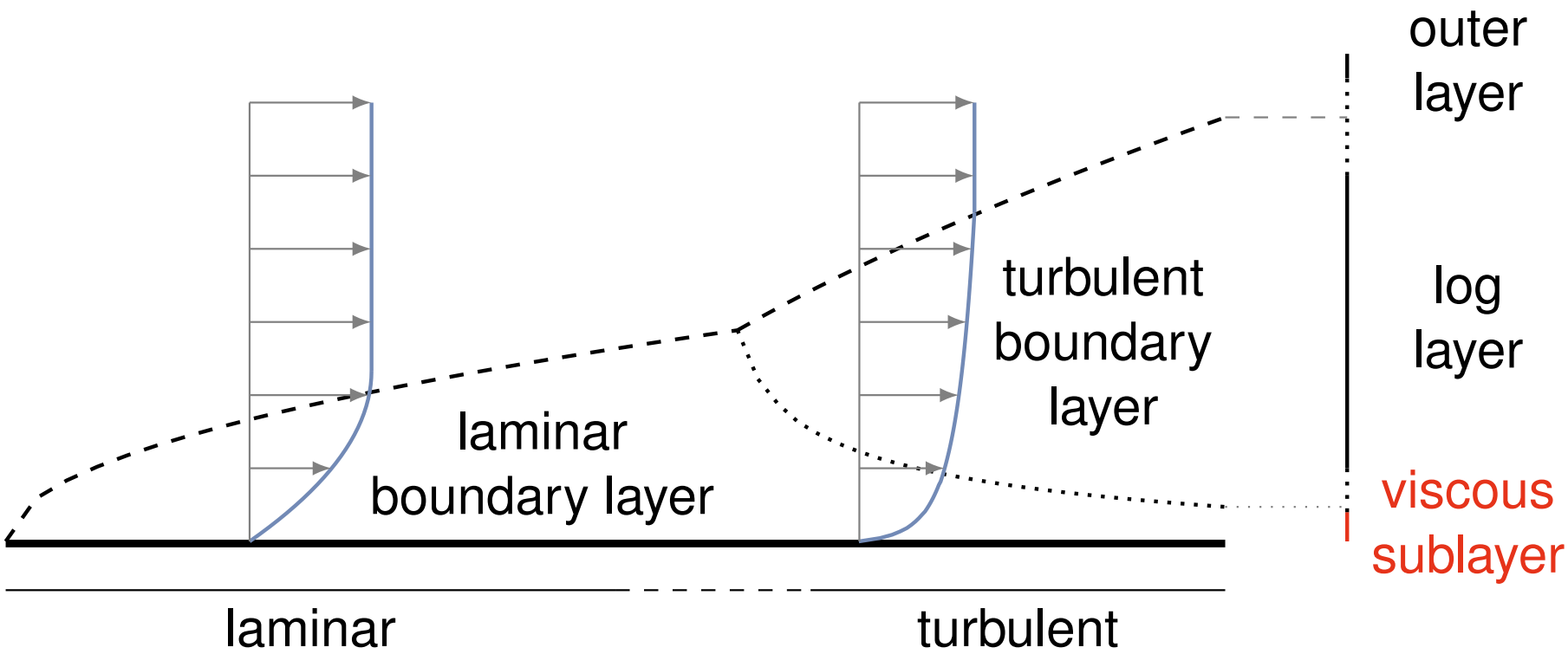


non-isothermal turbulent flow



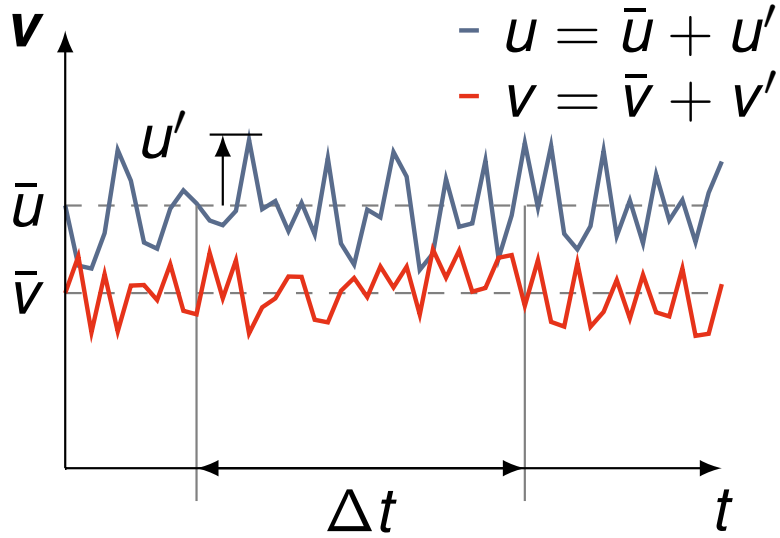
Why turbulence? - Boundary layer theory



Model concepts - Reynolds decomposition

Reynolds decomposition

- $u = \bar{u} + u'$



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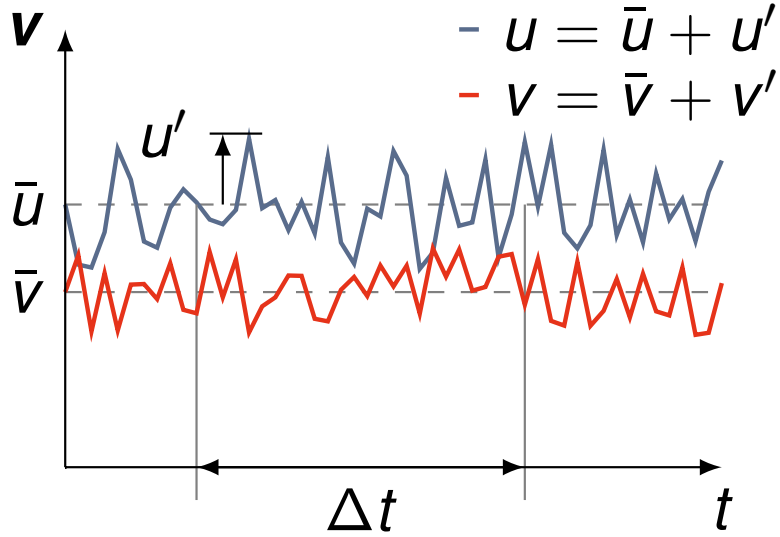
Reynolds decomposition

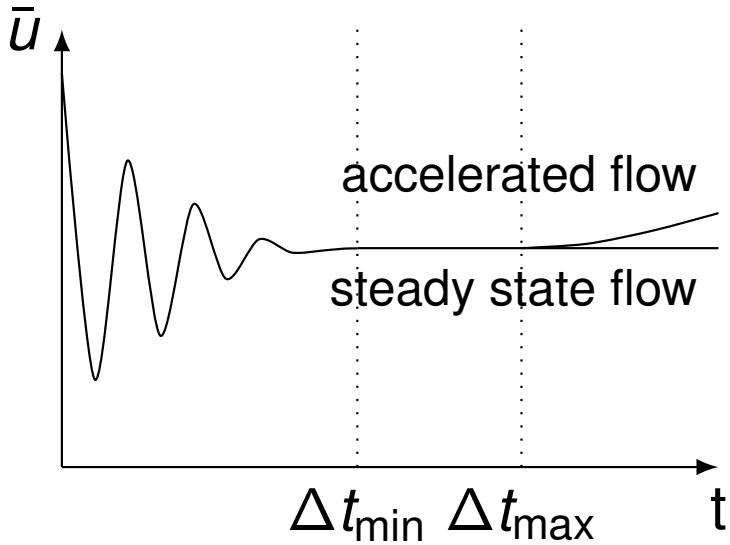
- $u = \bar{u} + u'$

Time averaging

- $\overline{u} = \bar{u}$
- $\overline{u\,v} = \underbrace{\bar{u}\,\bar{v}}_{\text{advection}} + \underbrace{\overline{u'v'}}_{\text{turbulent diffusion}}$

$\Rightarrow$ closure problem





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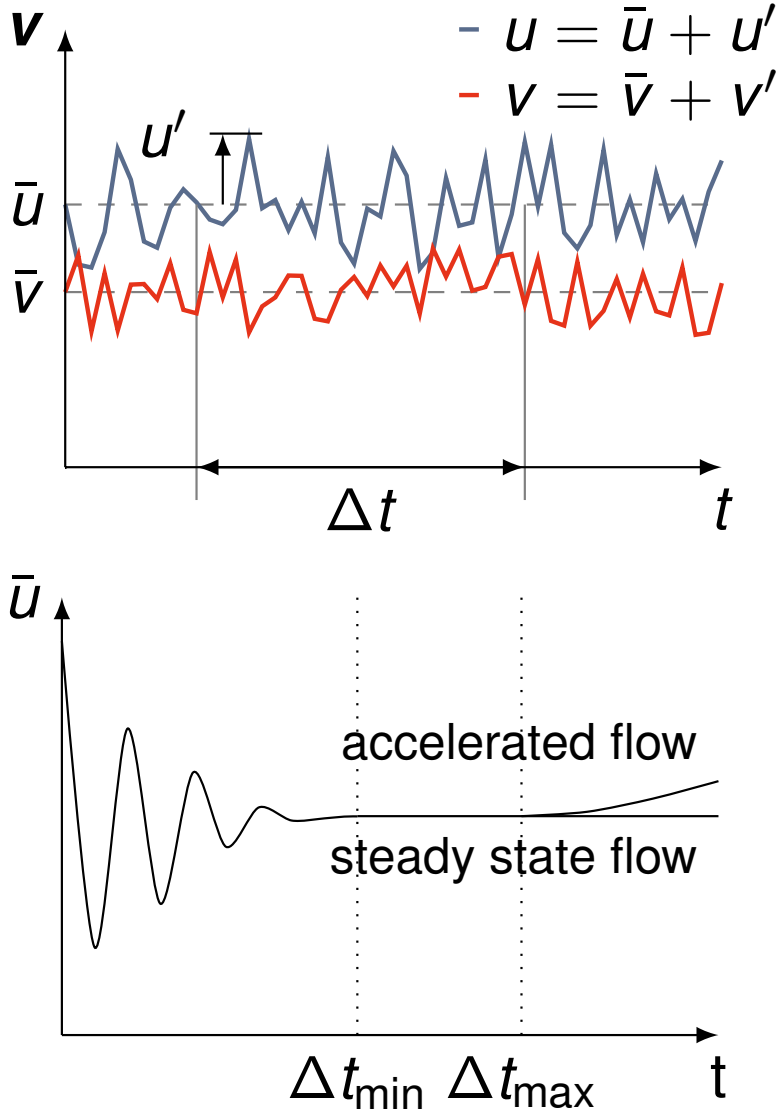
$\Rightarrow$ closure problem

1. Reynolds stress tensor

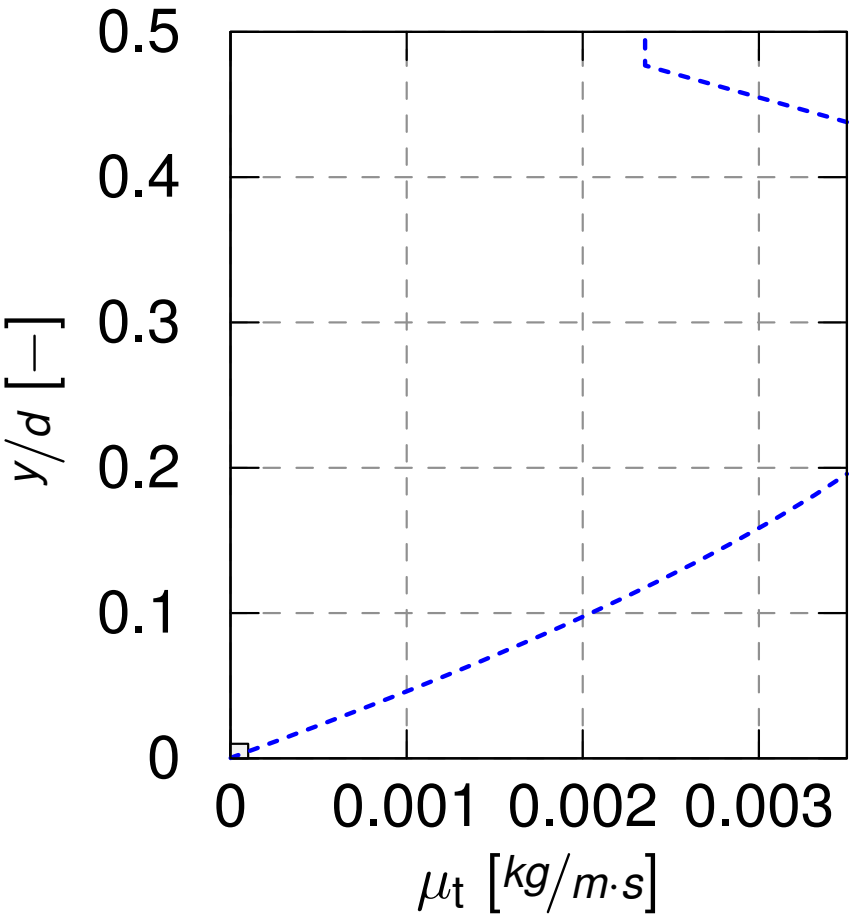
$$\overline{\varrho \boldsymbol{v}'\boldsymbol{v}'} = \tilde{\boldsymbol{\tau}}_{\mathrm{t}}$$

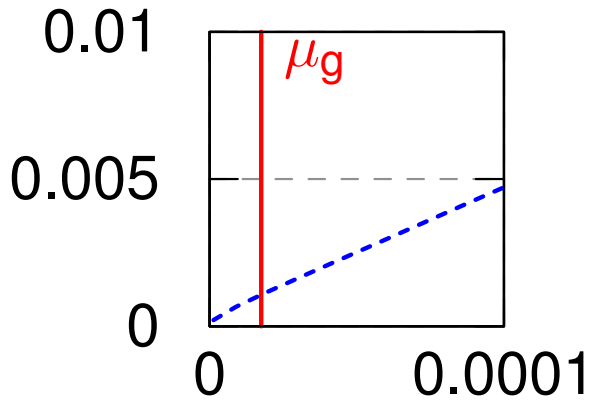
2. Eddy viscosity

$$\overline{\varrho \boldsymbol{v}'\boldsymbol{v}'} = \mu_{\mathrm{t}} \nabla \bar{\boldsymbol{v}}$$



Models concepts - Algebraic eddy viscosity models



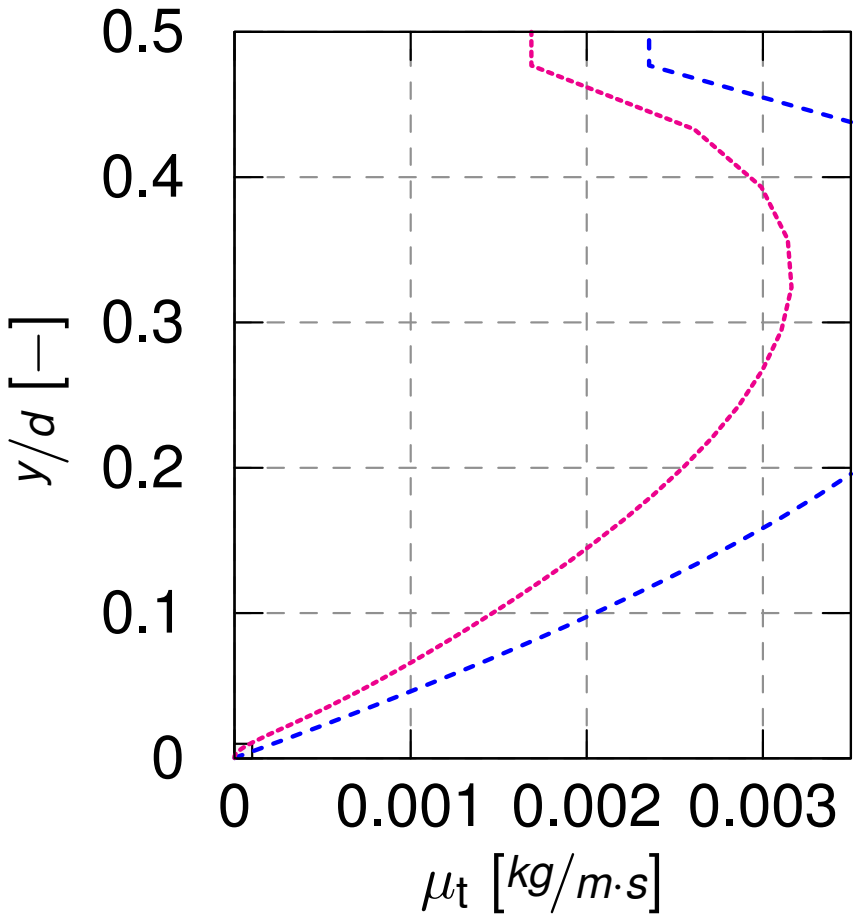


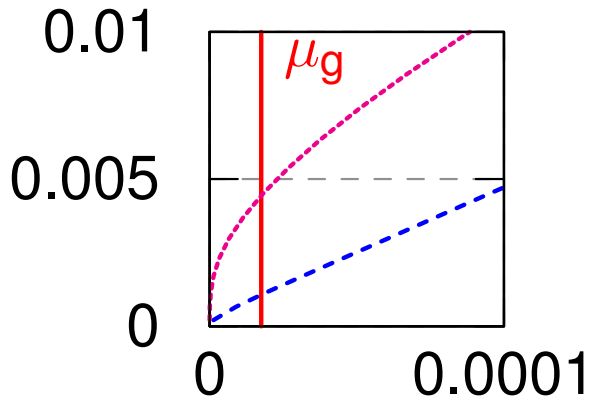
- Prandtl's mixing length

$$\mu_t = \varrho \kappa^2 y^2 \frac{\partial u}{\partial y}$$

Prandtl

Models concepts - Algebraic eddy viscosity models





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Prandtl
Hanna et al.

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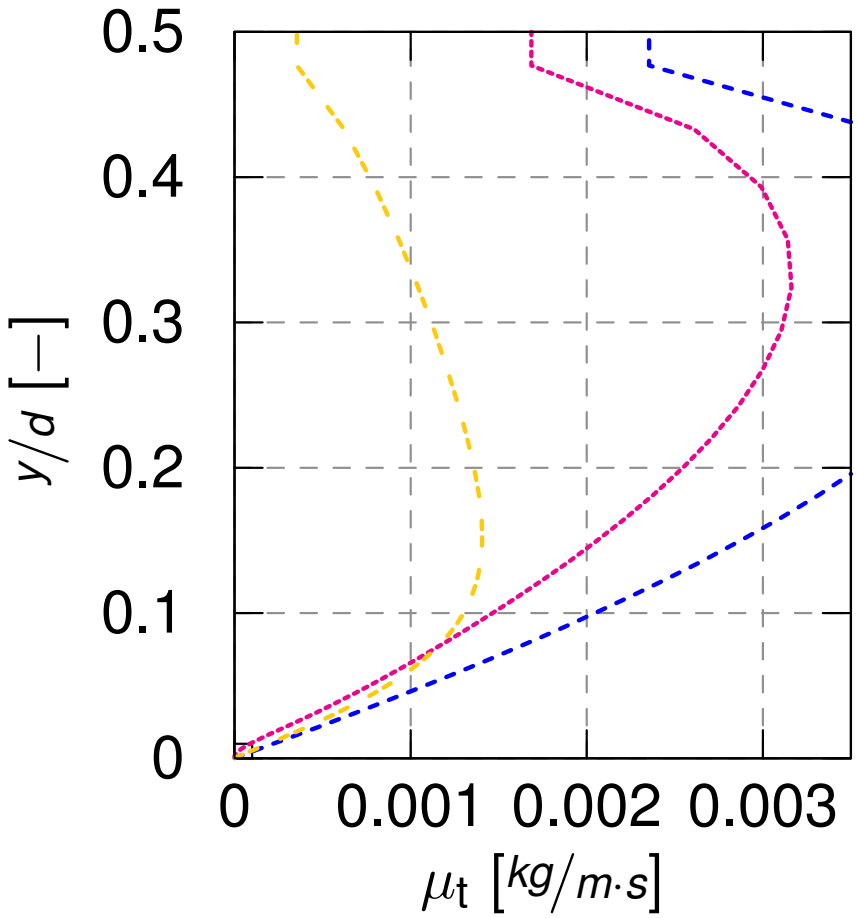

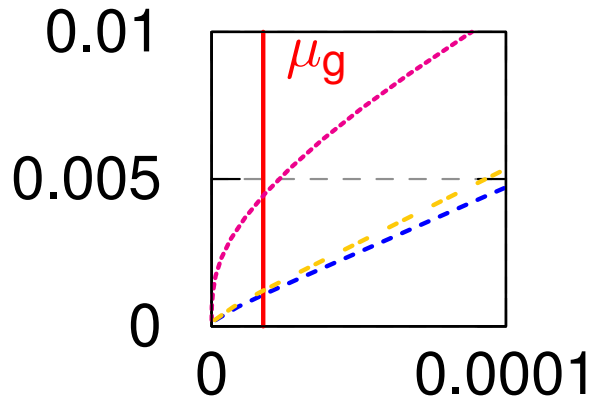

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Prandtl
Hanna et al.
Michel et al.

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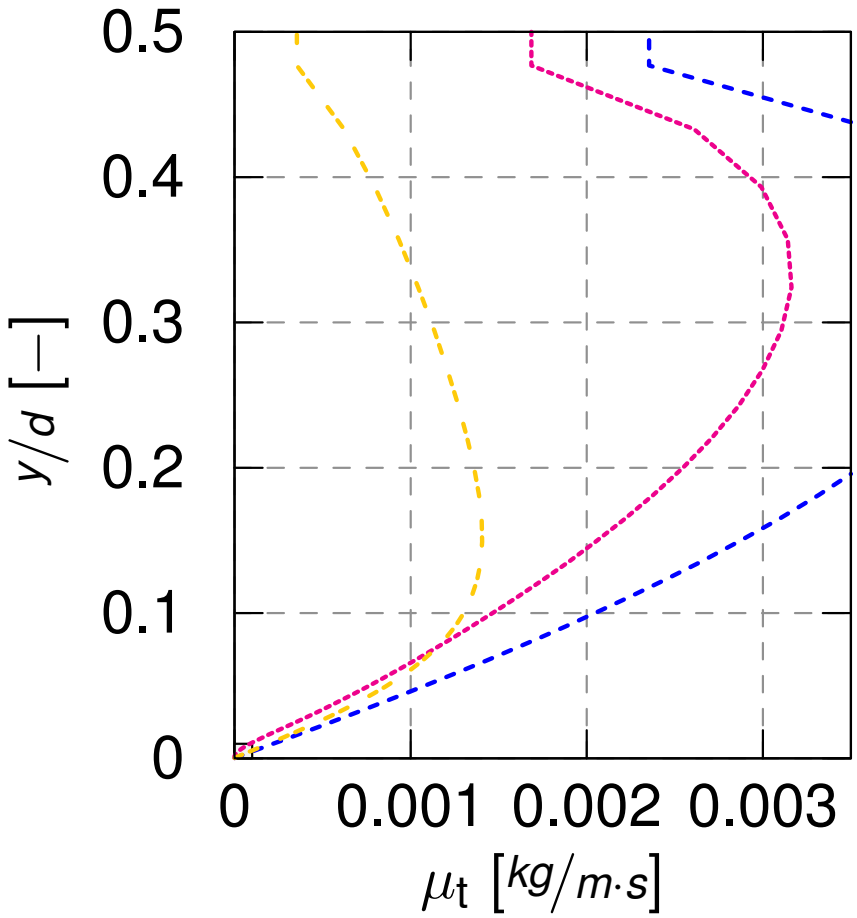

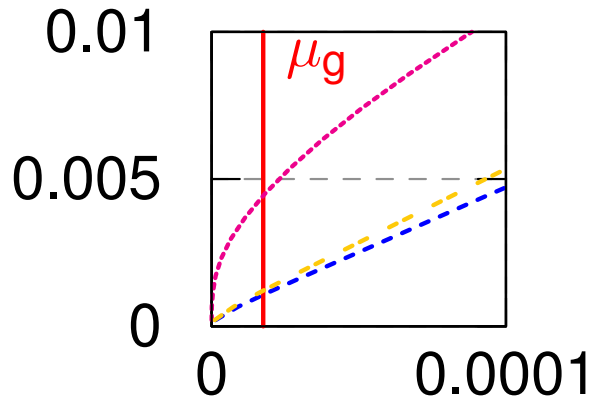

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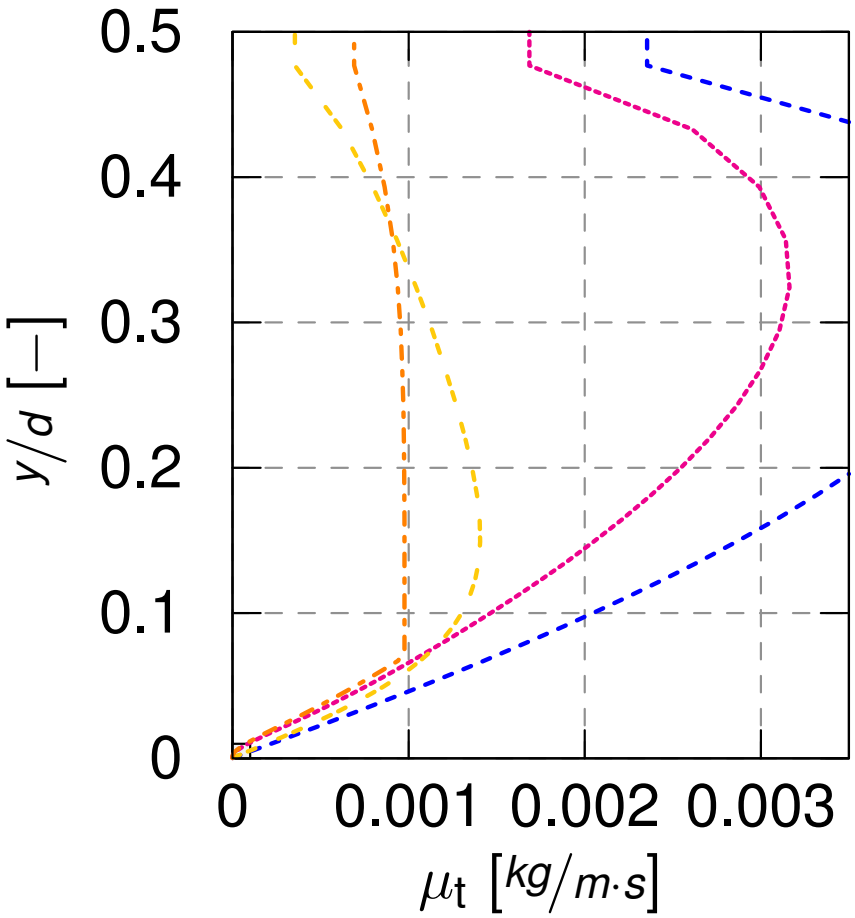
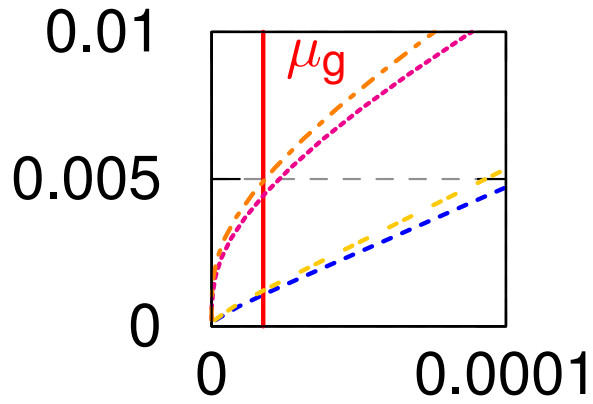
Prandtl
Hanna et al.
Michel et al.

Models concepts - Algebraic eddy viscosity models





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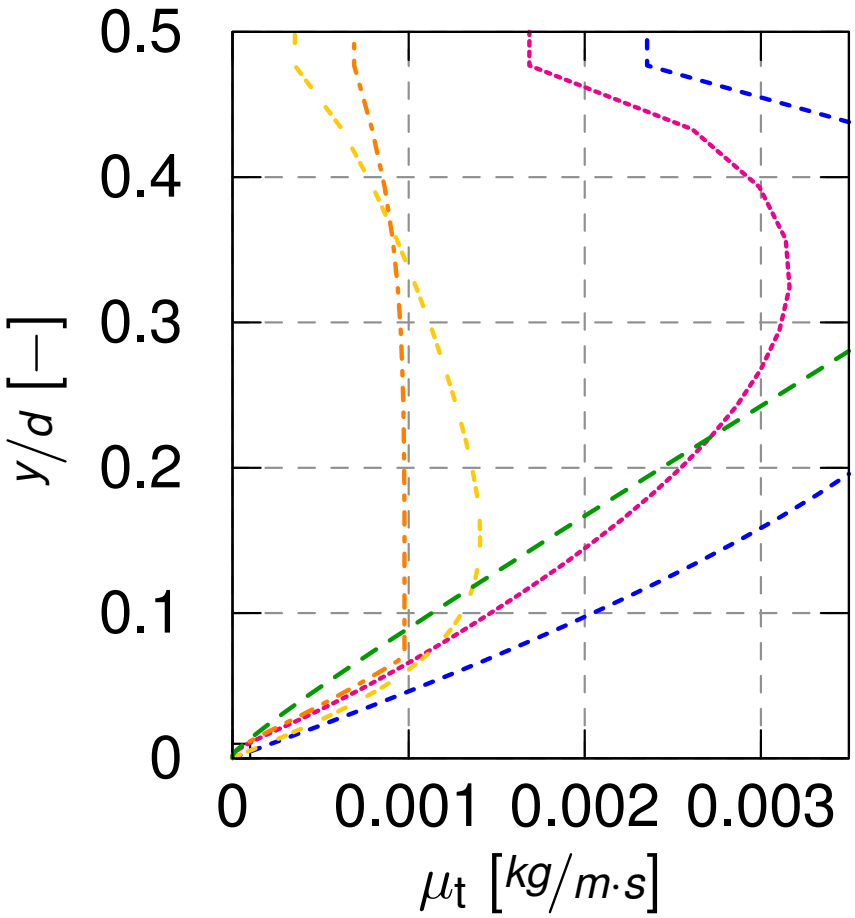
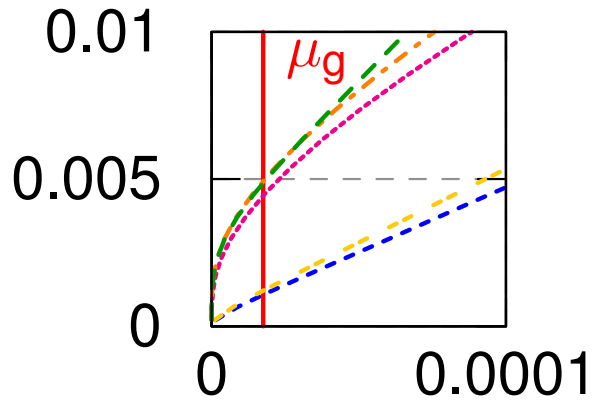
$$\mu_t = \varrho \kappa^2 y^2 \frac{\partial u}{\partial y}$$

Prandtl
Hanna et al.
Michel et al.
Baldwin and Lomax

Models concepts - Algebraic eddy viscosity models





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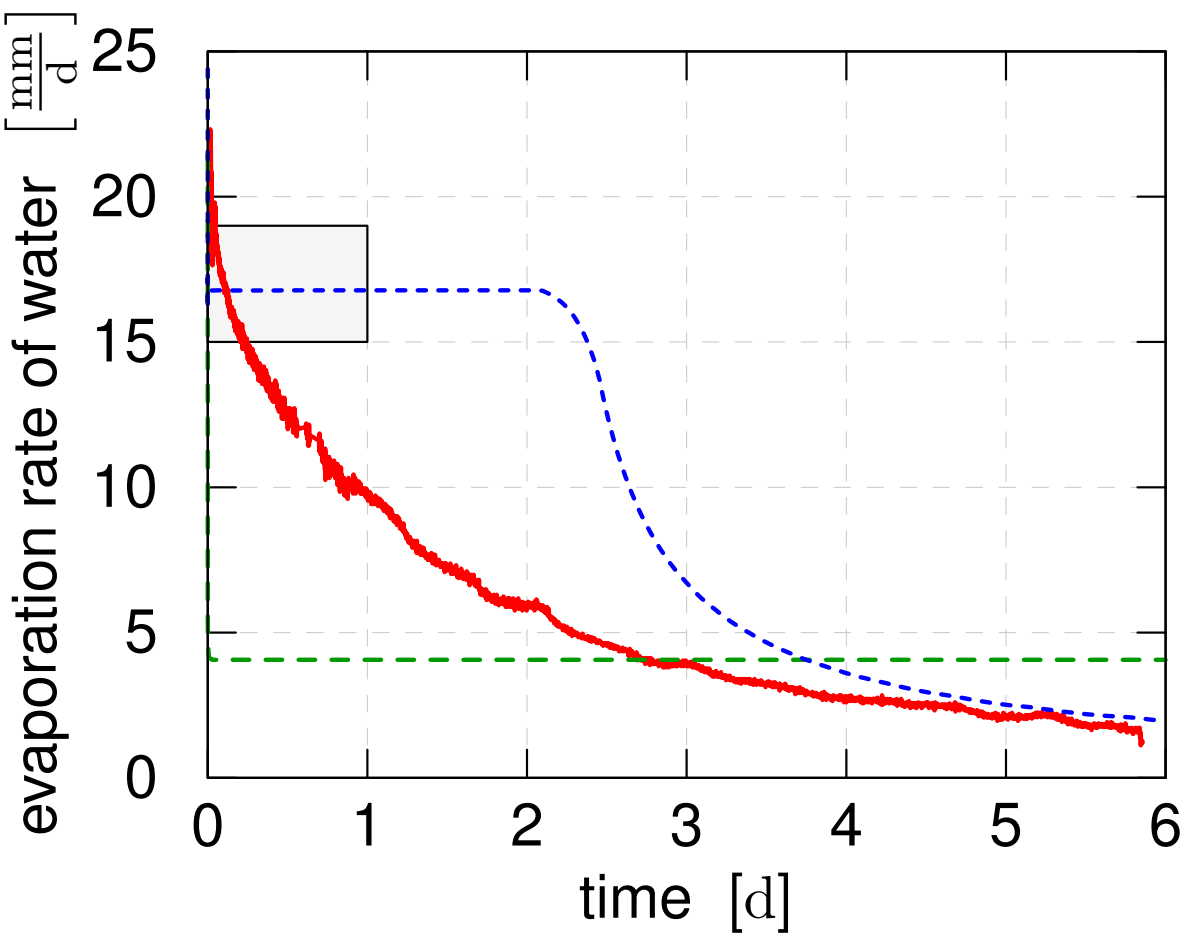
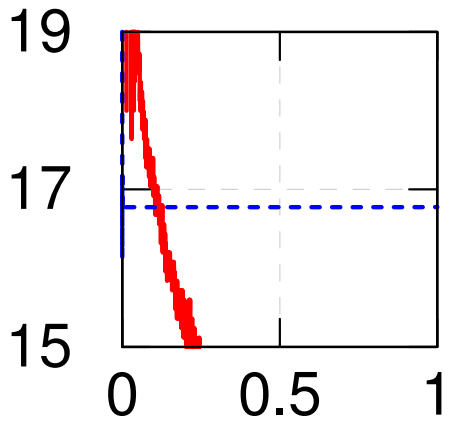
Prandtl
Hanna et al.
Michel et al.
Baldwin and Lomax
Deissler

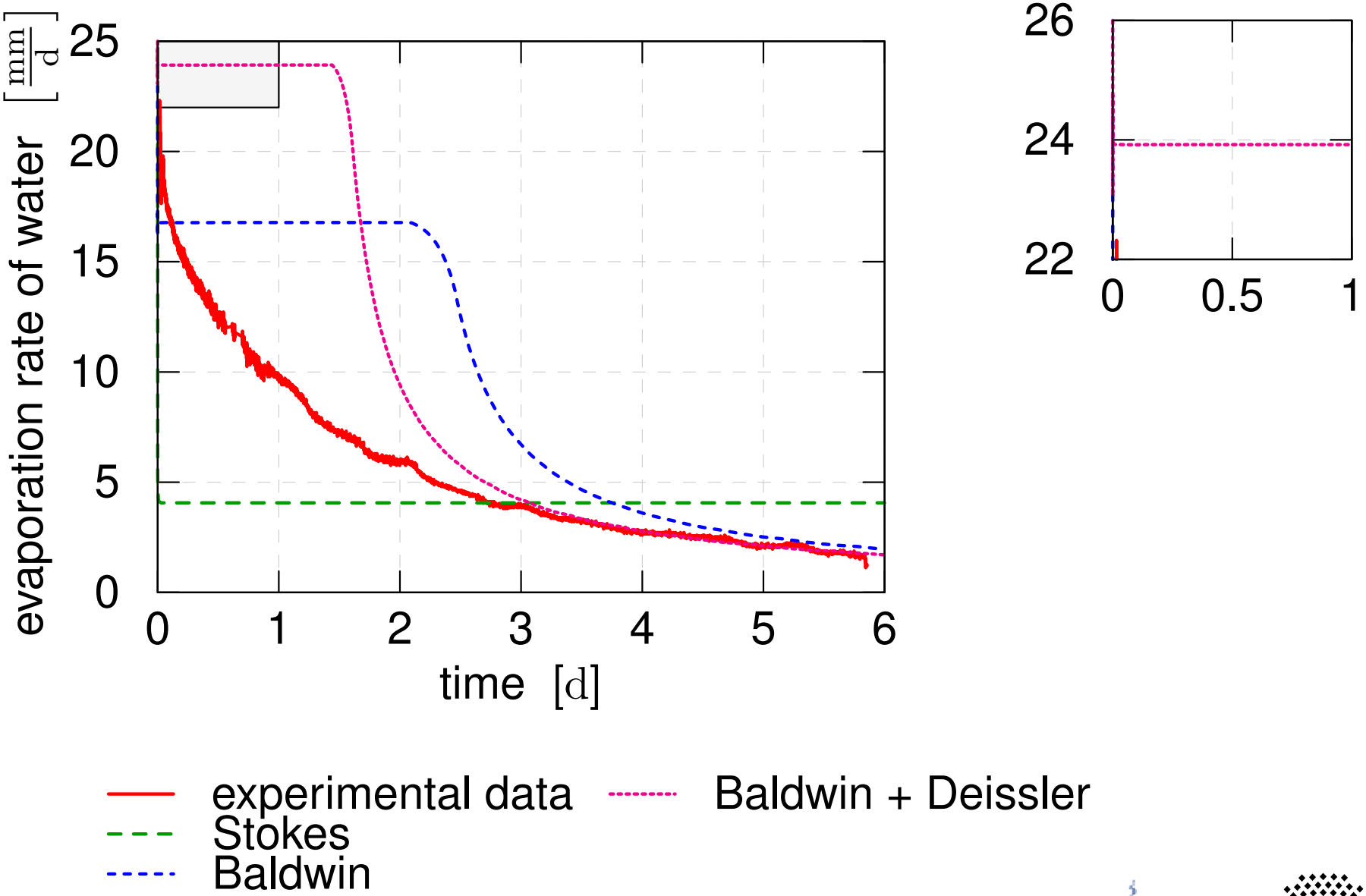
Results - Evaporation rate eddy viscosity



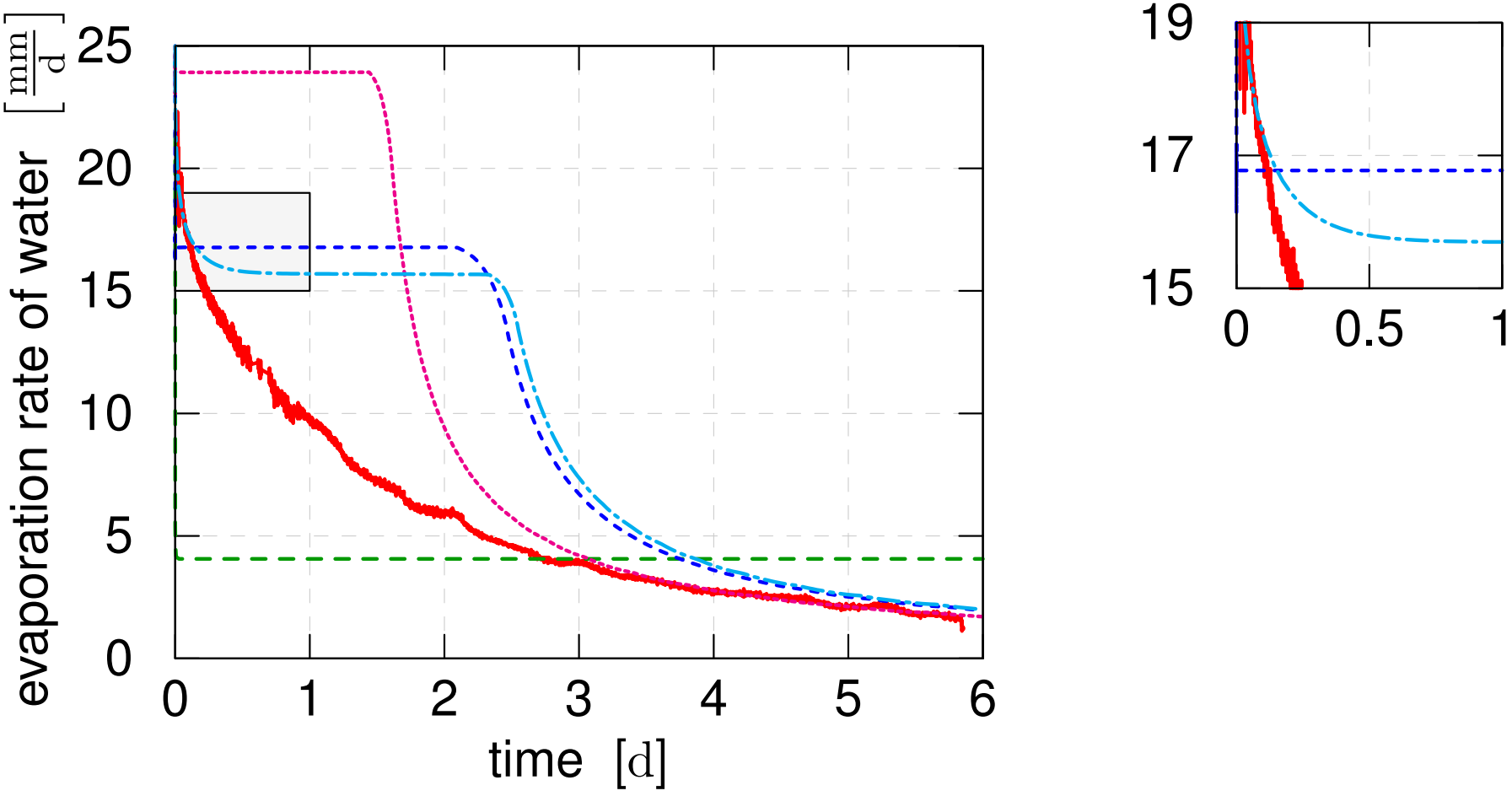


experimental data
Stokes
Baldwin

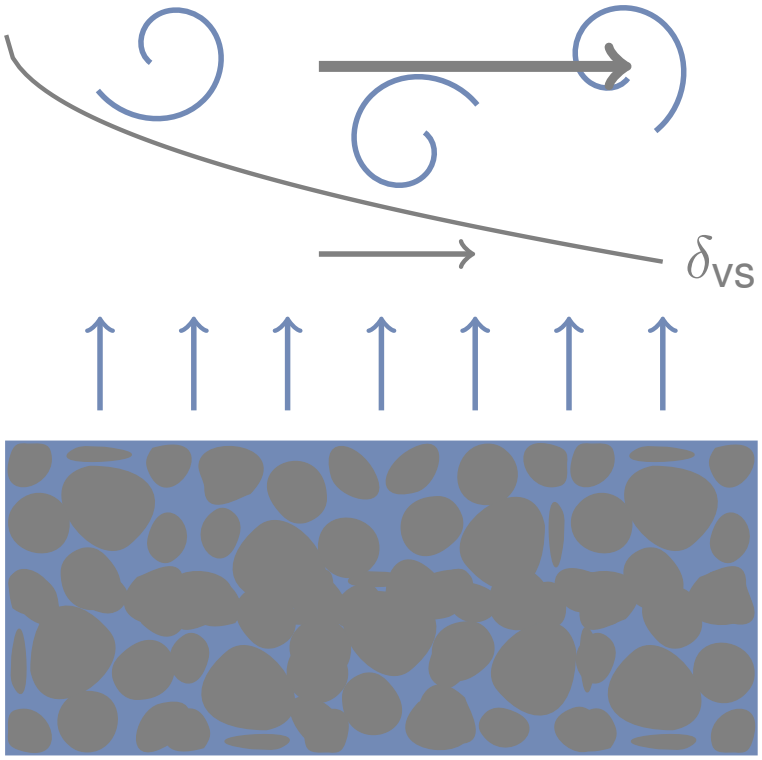
Results - Evaporation rate eddy diffusivity

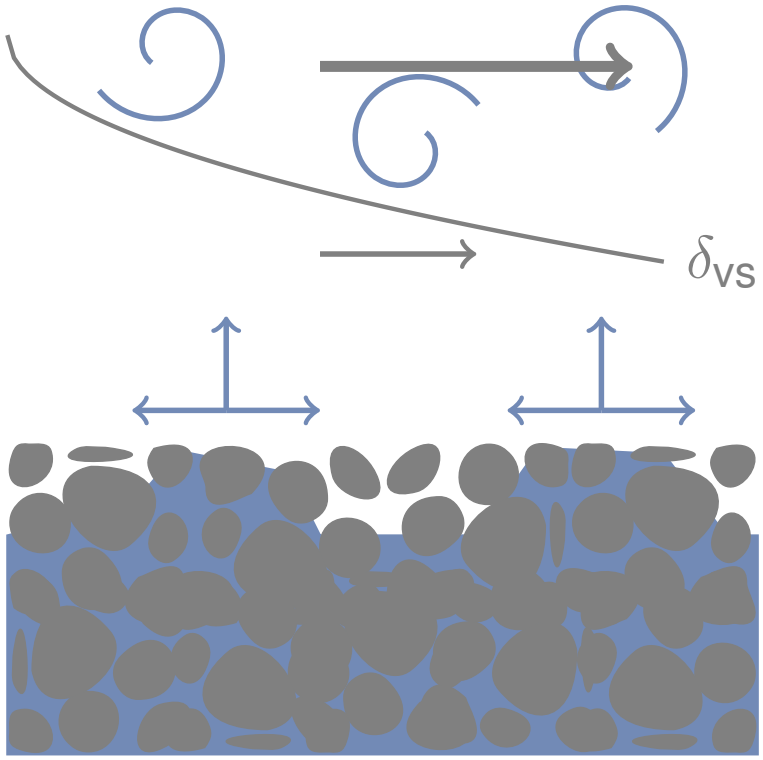


Results - Evaporation rate non-isothermal



Results - Interpretation





Summary and outlook - Summary

Transport behavior

- vertical transport in viscous sublayer is diffusion-limited
- advection near interface influences evaporation rate

Comparison with experiment

- good agreement in beginning and end
- decreasing rate not captured

Other results

- small effects of the surface roughness
- no grid convergence
- oscillating pressure

Summary and outlook - Outlook

Presented model

- numerical problems
- more complex turbulence model
- REV description for the surface moisture pattern

Field scale

- surface roughness
- heterogeneities
- gravity and buoyancy effects

Beyond the evaporation

- application to other problems (fuel cells, etc.)

PhD

- k-ω, staggered grid, DNS

Thank you for your attention.