Beyond classical infiltration - using Stokes flow in a diverse landscape

Dominic Demand [1], Theresa Blume [2], John Selker [3], Markus Weiler [1]

Introduction

Soil water flow during infiltration conditions cannot be discribed by matrix flow alone. However, many soil water flow models lack a physically apropriate description of fast non-capillary flow and parametrization of multi-domain models is still challenging. Alternative model concepts are mostly tested in the laboratory or in highly instrumented field sites with controlled conditions.

Hypothesis:

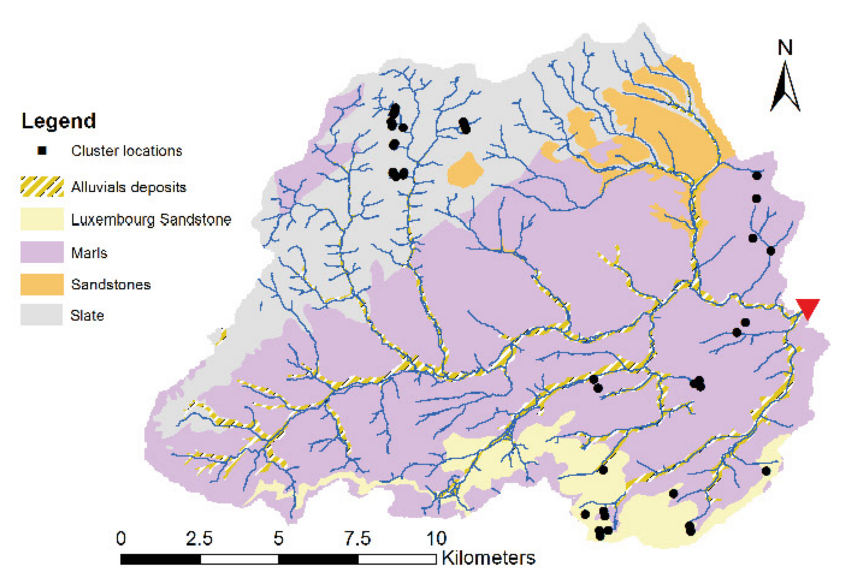
- **1D Stokes flow can be used to model soil water flow in diverse settings across the landscape**

Aims:

- **Testing 1D Stokes flow on 135 soil moisture sensor profiles**
- **Predict model parameters from easily obtainable measurements**

Study area

Attert Catchment in Luxembourg

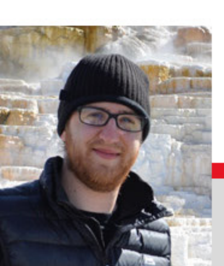


- 135 soil moisture profiles (~ 4 years of data)
- Soil moisture sensors in 3 depths: 10, 30, 50 cm
- Decagon 5TE and Truebner SMT-100 (5 min res.)
- Precipitation measurements next to the profiles

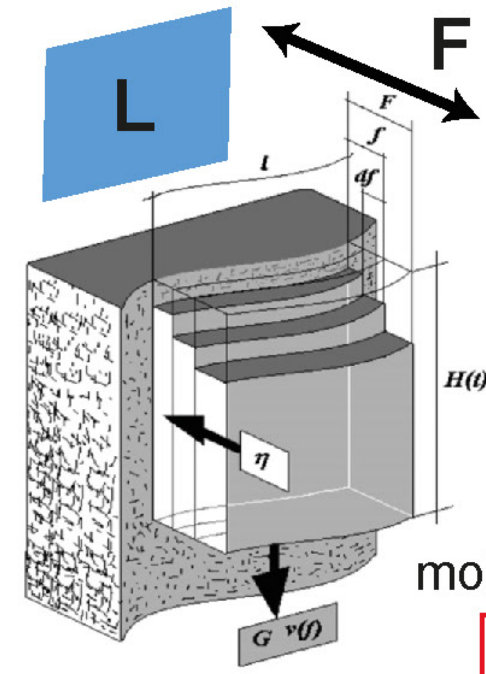
Two land-use classes: Forest & Grassland

Soil types

- Slate: Cambisol (silty loam), ~50% stone content
- Marl: Stagnosol & Luvisol (loam, clay loam)
- Lux. sandstone: Podzol & Arenosol (sandy loam)



Stokes flow as 1D single water content wave



Germann et al. (2007)

- Based on Newton's shear flow
- Gravity is only dominant forcing
- Drives water flow against the viscous momentum dissipation

Parameters:
L: Contact length [$m^2\ m^{-3}$]
F: Film thickness [µm]

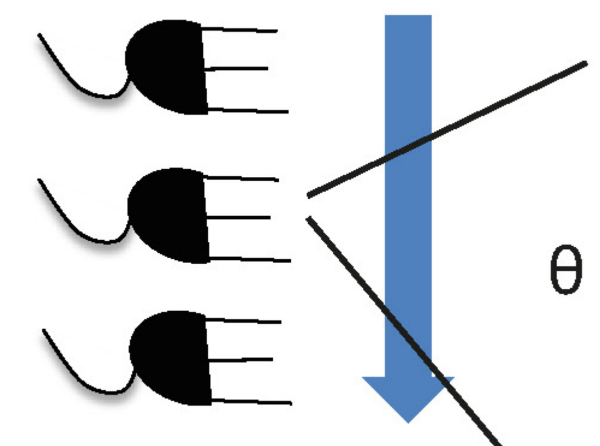
mobile water content (w):

$$w = L * F$$

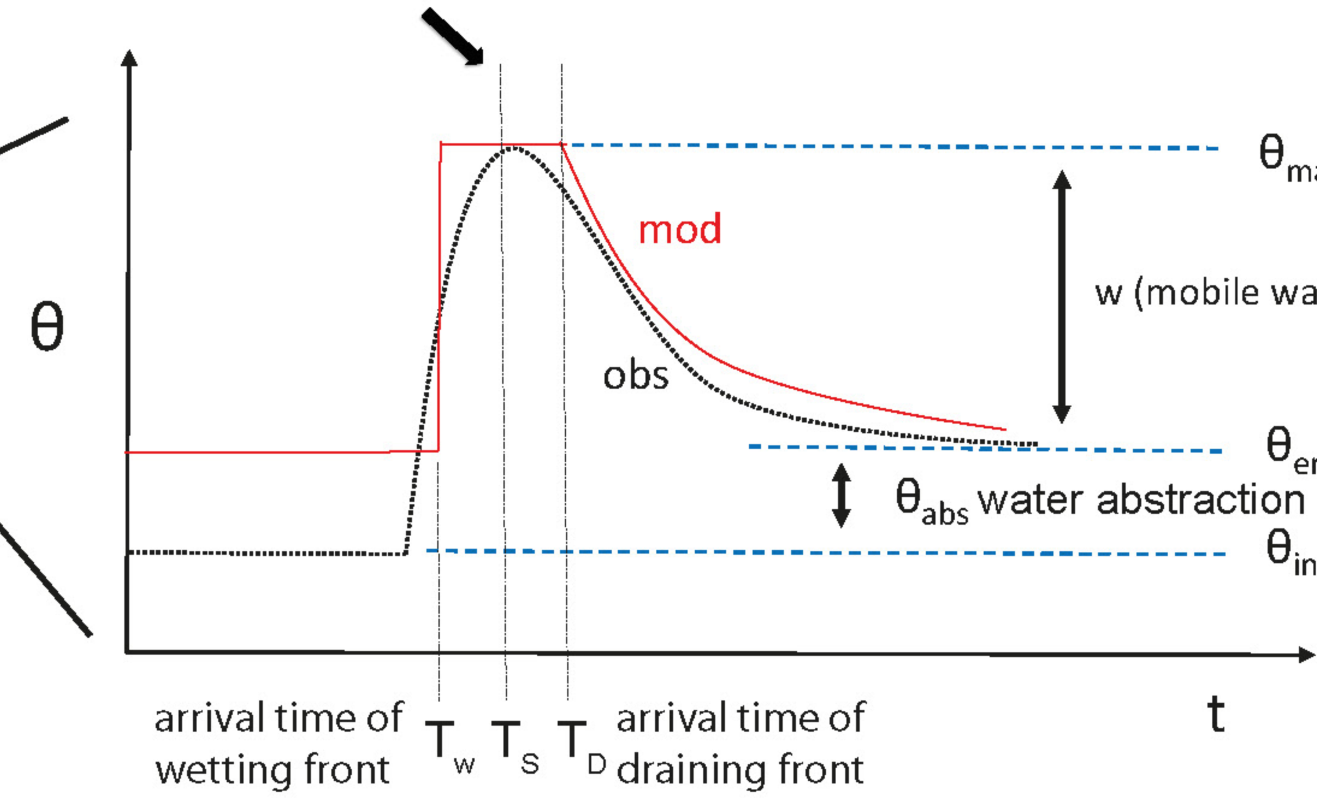
flow velocity (v):

$$v = F^2 * \frac{g}{3\mu}$$

← gravitational acceleration
← kinematic viscosity



Sequential reaction



$$T_w = 3\,T_D - 3\,T_s$$

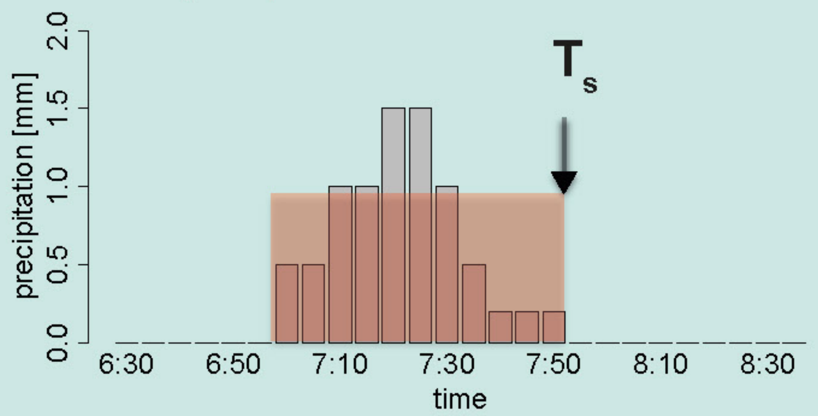
fitting!

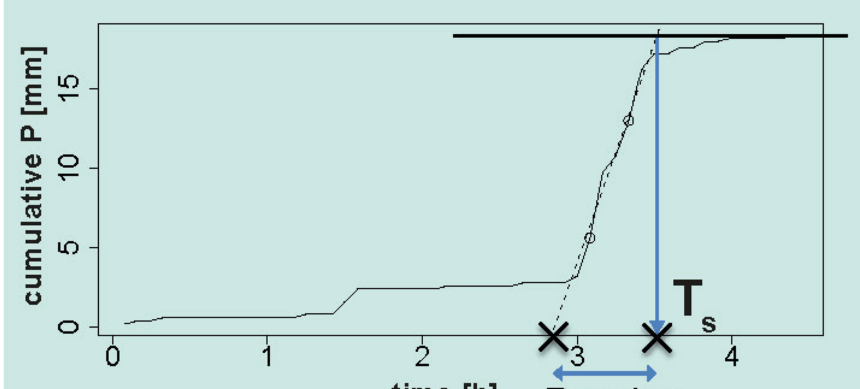
$$w(z,t) = w\left(\frac{T_D(z) - T_s}{t - T_s}\right)^{1/2}$$

$$T_D = \frac{z}{3v} + T_s$$

Modelling

Model is based on one rectangular rain input pulse:





Linear model was fitted using the 25 and 75% quantile from the bimodal distibution of cumulative P

Inverse parameter estimation

Precipitation pulses ≤ 3 h
Soil moisture increase ≥ 1% VWC

inversely fitted for T_D

DEoptim algorithm in R
(Differential Evolution global optimazation)
Objective function: RMSE

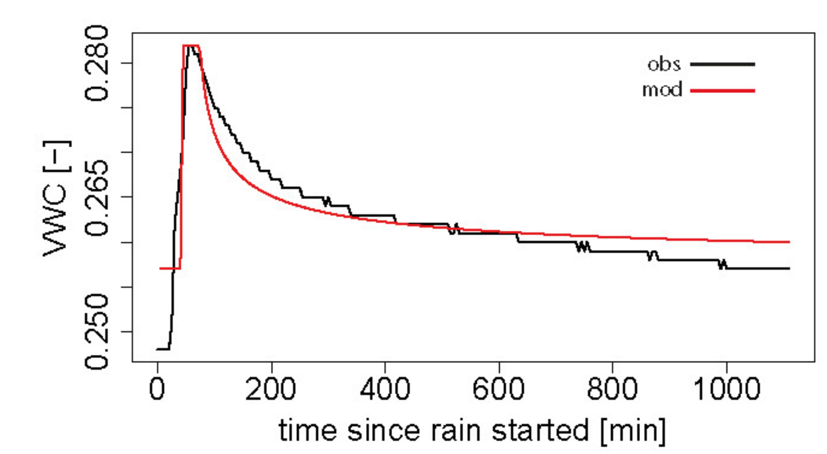
<u>events excluded:</u>
constant θ amplitude
T_w > +/- 2h begin meas. amplitude
$T_D \approx T_S$
RMSE > 0.03

Number of events per depth (10/30/50 cm)

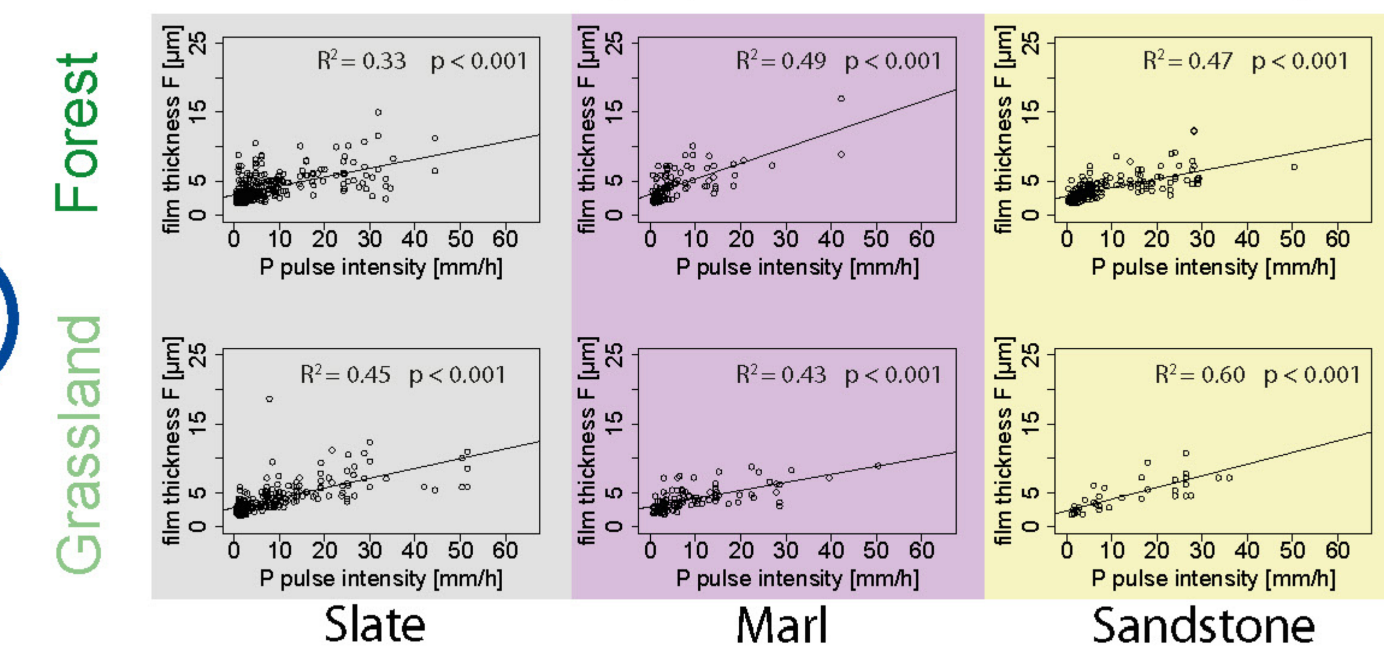
	Forest	Grassland
Slate	265 / 49 / 16	206 / 33 / 12
Marl	92 / 17 / 3	105 / 10 / 1
Sandstone	198 / 17 / 10	36 / 8 / 0

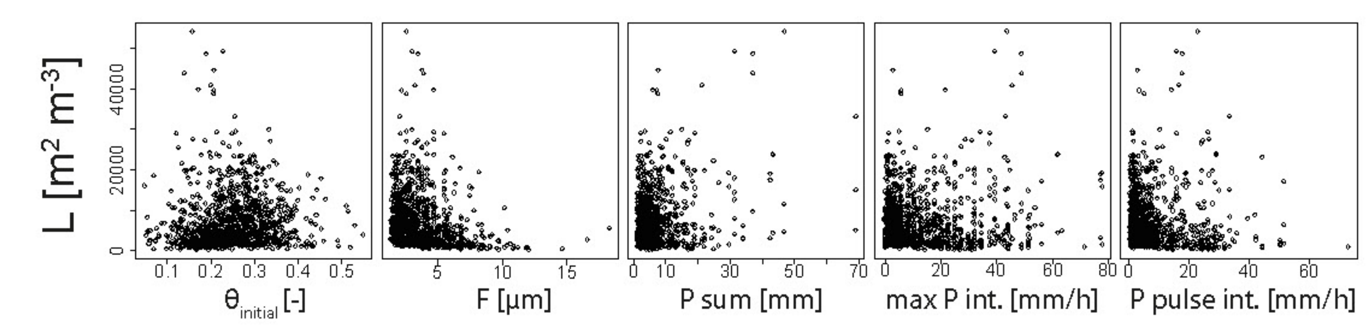
Estimated Parameters

One example of a model fit

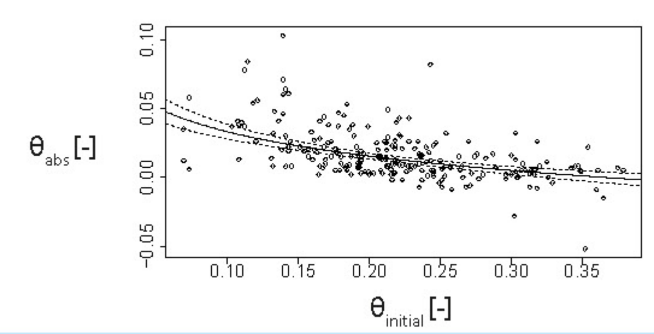


Film thickness F is proportional to the rain intensity





No relationship with the **contact length L**



$\theta_{abs} = \log(\theta_{initial})$ + max P Intensity

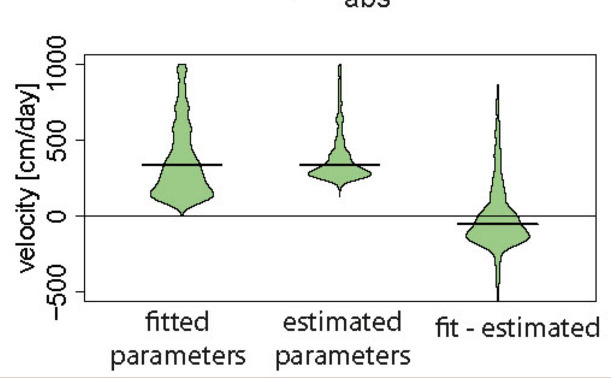
Water abstraction increases with decreasing initial VWC

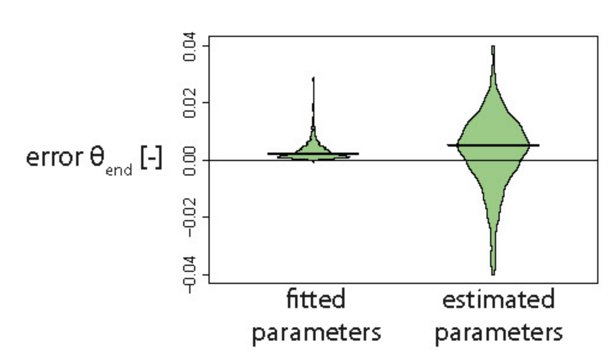
R^2 of the θ_{abs} functions

	Forest	Grassland
Slate	0.08	0.09
Marl	0.10	0.33
Sandstone	0.40	0.43

Validation of the parameters

Functions of F, θ_{abs} and monthly median L were tested





109 of 1048 events produced $T_D < T_s$ (calculation not possible)

Conclusion & Outlook

- Stokes flow can appropriately be fitted to water content waves in different environments
- The film thickness F can be predicted using the rain pulse intensity and thereby soil water flow velocity can be calculated
- Estimation of L and θ_{abs} is more difficult. This results in larger variations in final water content. Improved matrix abstraction model will be implemented

Acknowledgement

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Germann, P., Helbing, A., Vadilonga, T. (2007): Rivulet Approach to Rates of Preferential Infiltration. Vadose Zone Journal 6(2), p. 207-220.