catchments as organised systems

Karlsruhe Institute of Technology

A Scalable Lagrangian Approach to Model Soil Water Dynamics in Structured Soils

a link between observables and hydrological process modelling from single macropores to the lower mesoscale

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Motivation

Example: Hoevelange, Attert, Luxembourg

Example: Weißeritz, Saxony, Germany

- Soil has organised structures (earth worms, cracks, roots, rodents...)
- Preferential flow occurs virtually anywhere and across scales

- „Heterogeneity“ is intrinsic (domain, processes, states)
- Need to look at interactions within the whole system

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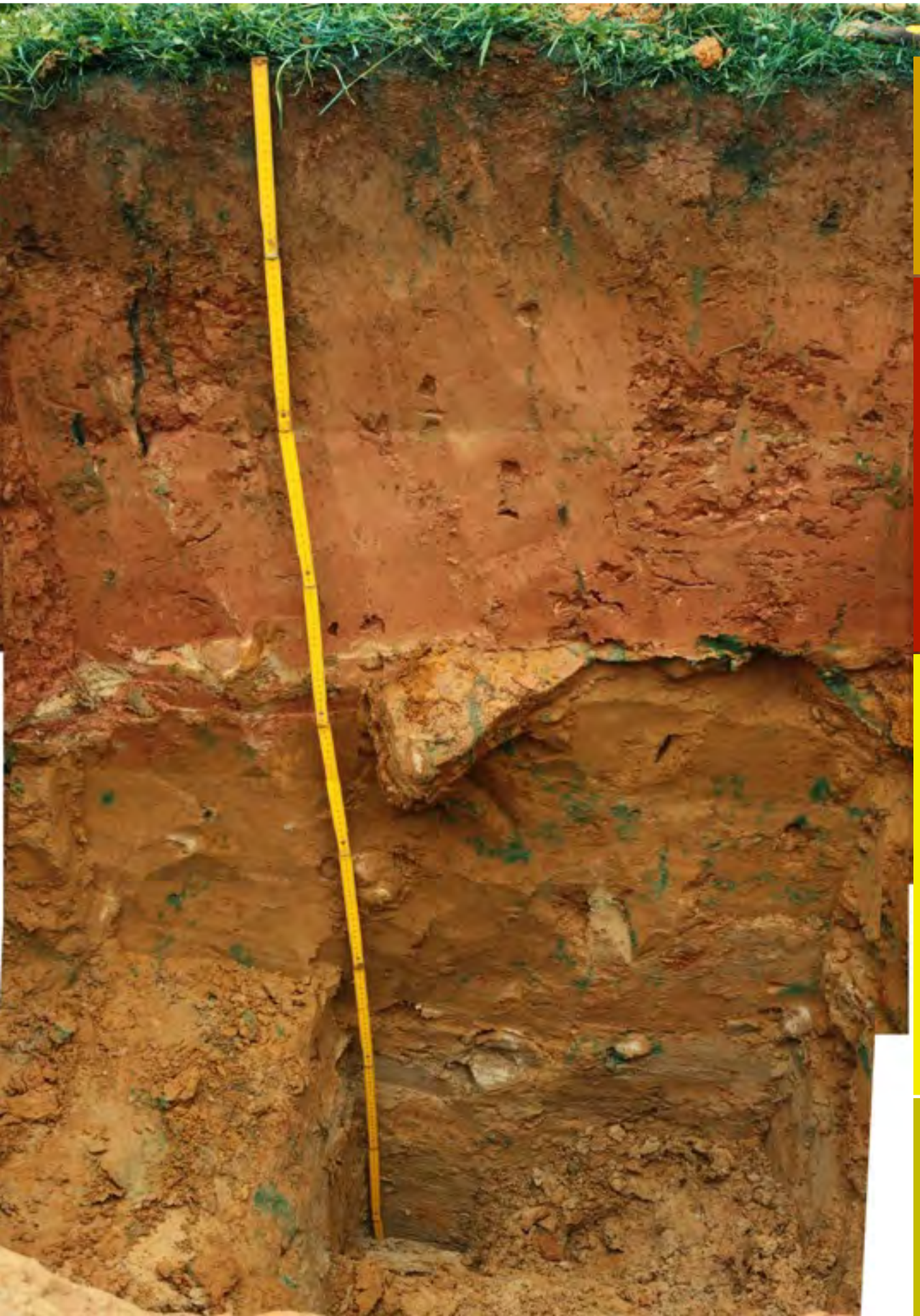

Irrigation Experiment

Hoevelange, Attert, Luxembourg
50mm, 1h, 1.2m^2
Brillant Blue + Br^-

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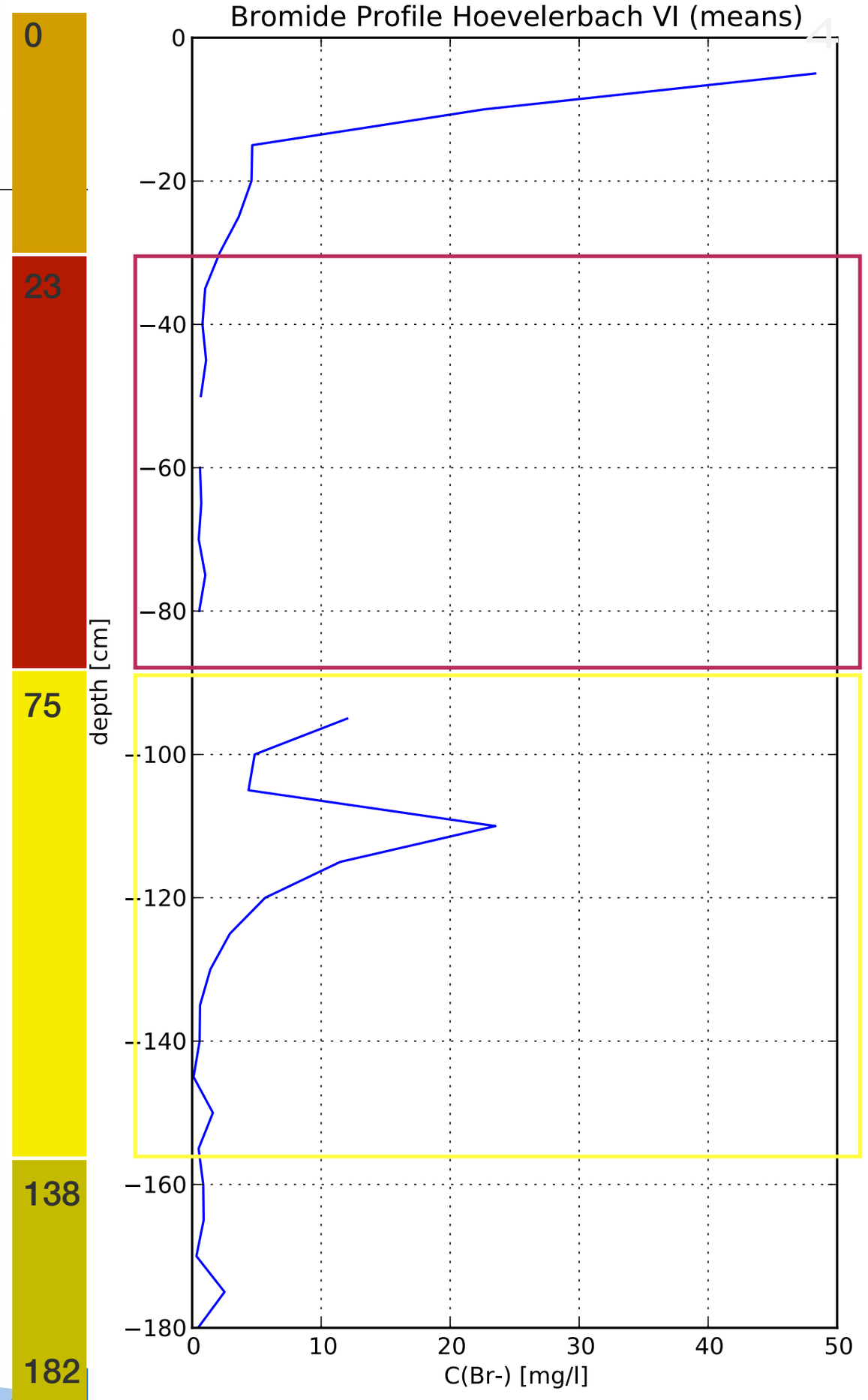
Bromide Profile Hoevelerbach VI (means)
0
23
75
138
182
depth [cm]
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
0
10
20
30
40
50
C(Br-) [mg/l]

Main Preceptions

Physical description of hydrological processes as dissipation of energy[1].
Observability of potential „parameters“
Scalability of plot to lower mesoscale

- this requires some central conceptual revisions

(1) Kleidon, A., Zehe, E., Ehret, U. and Scherer, U.: Thermodynamics, maximum power, and the dynamics of preferential river flow structures at the continental scale, Hydrol. Earth Syst. Sci., 17(1), 225–251, doi:10.5194/hess-17-225-2013, 2013.

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Outline

Present Lagrangian model concept
Results of 1D model
Pore-centred abstraction and 1.5D model
Discussion of Interfaces

(1) Kleidon, A., Zehe, E., Ehret, U. and Scherer, U.: Thermodynamics, maximum power, and the dynamics of preferential river flow structures at the continental scale, Hydrol. Earth Syst. Sci., 17(1), 225–251, doi:10.5194/hess-17-225-2013, 2013.

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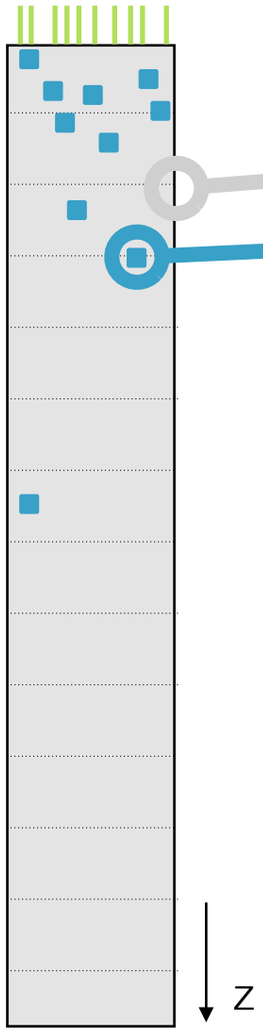
General Concept

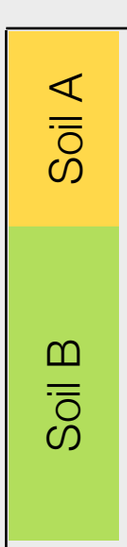
Soil Column

Eulerian grid for REV concepts (e.g. psi) of the „static“ domain

Lagrangian representation of the water (particles)

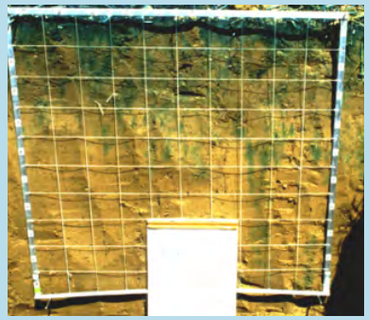


Matrix Properties >> Diffusion

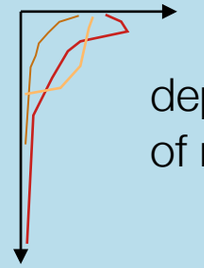


α,n,ksat,
θsat,porosity...

Macropore Properties >> Advection



pdf of advective velocity



depth distribution of macropores

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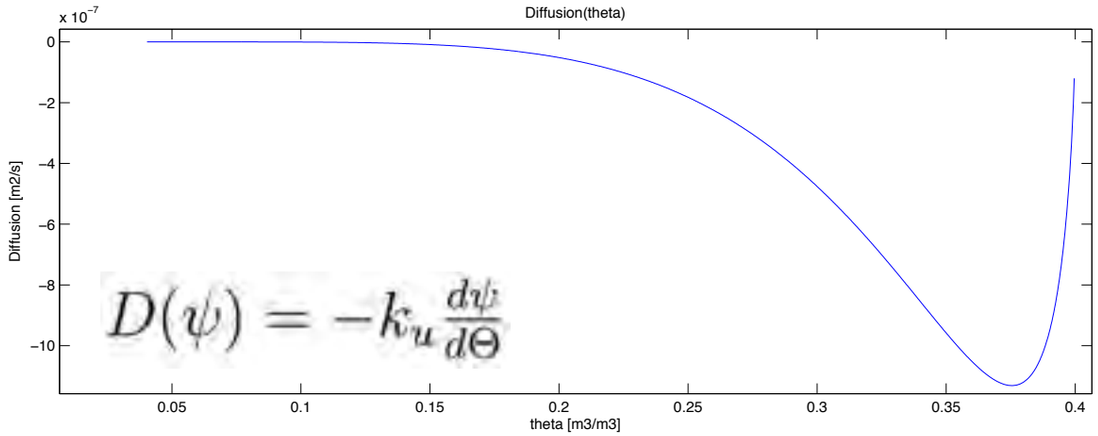
Model Core

Diffusion –› Random Walk



Random Walk Step:

$$x_i + \xi^1_{-1} * \sqrt{6 D_i dt}$$

Advection –› Deterministic Step

$$x_i + v_{adv} dt$$

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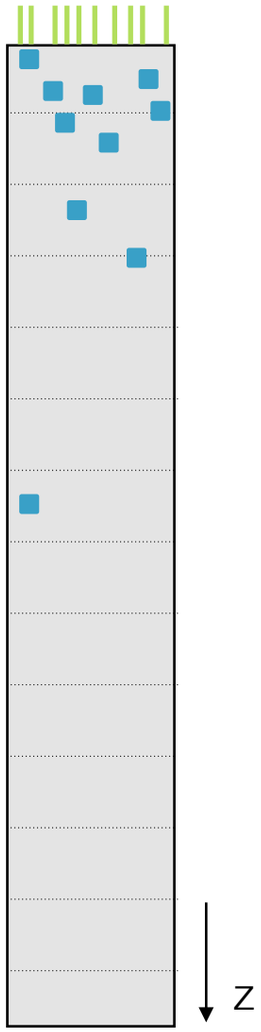
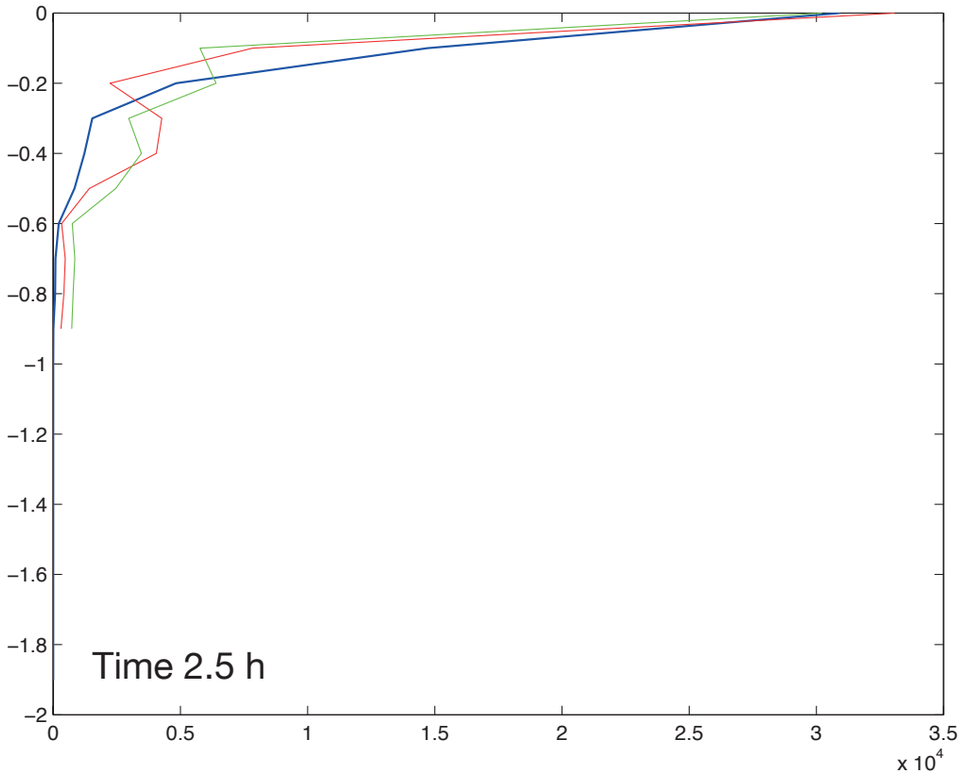
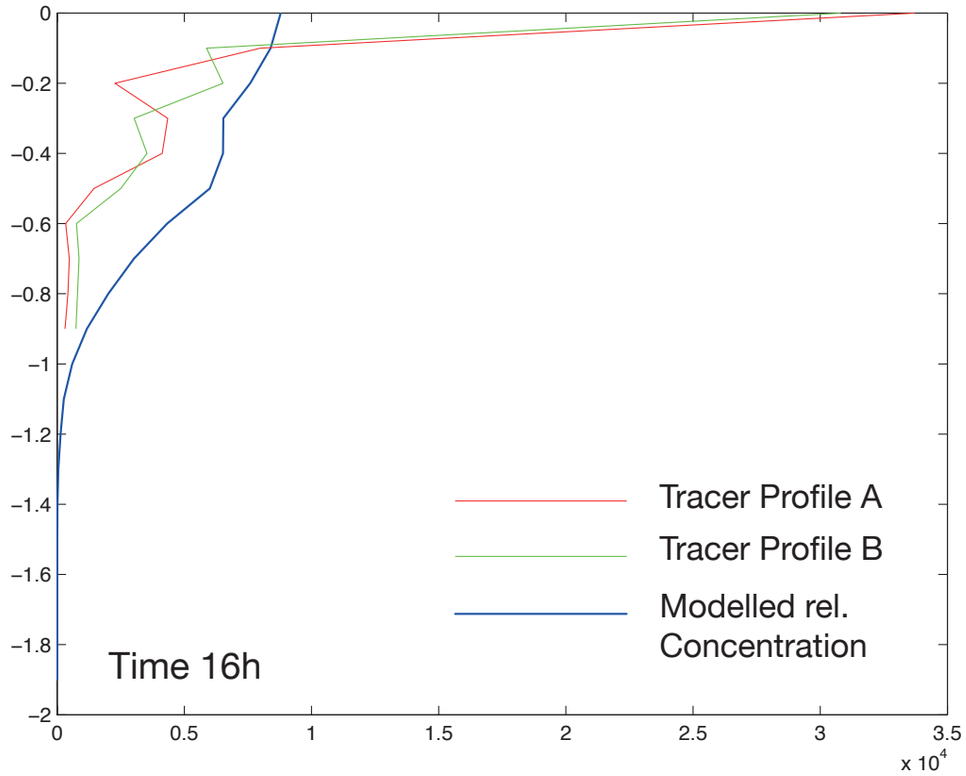
Particle Approach 1D

Soil Column

particle approaches for tracer and heat transport > so use it directly







We can mimic observed tracer profiles (advection, contaminant transport)

BUT we lack macropore-matrix interaction, the timing when advection ends and skewed lateral moisture distributions

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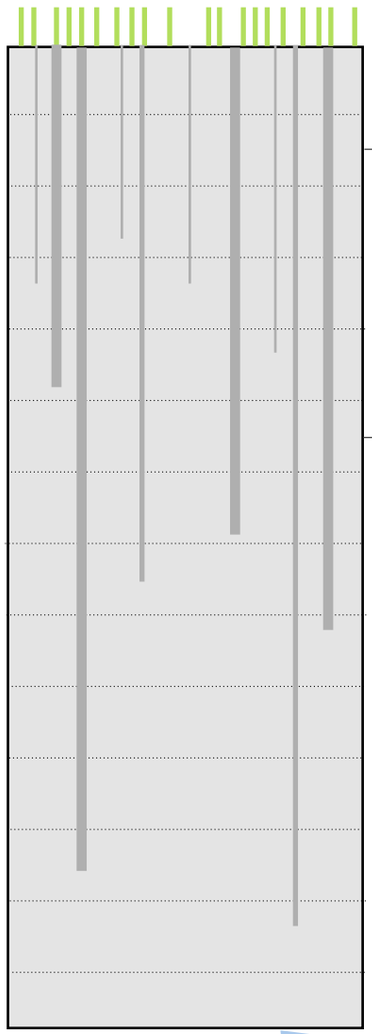
Prototype 1.5D

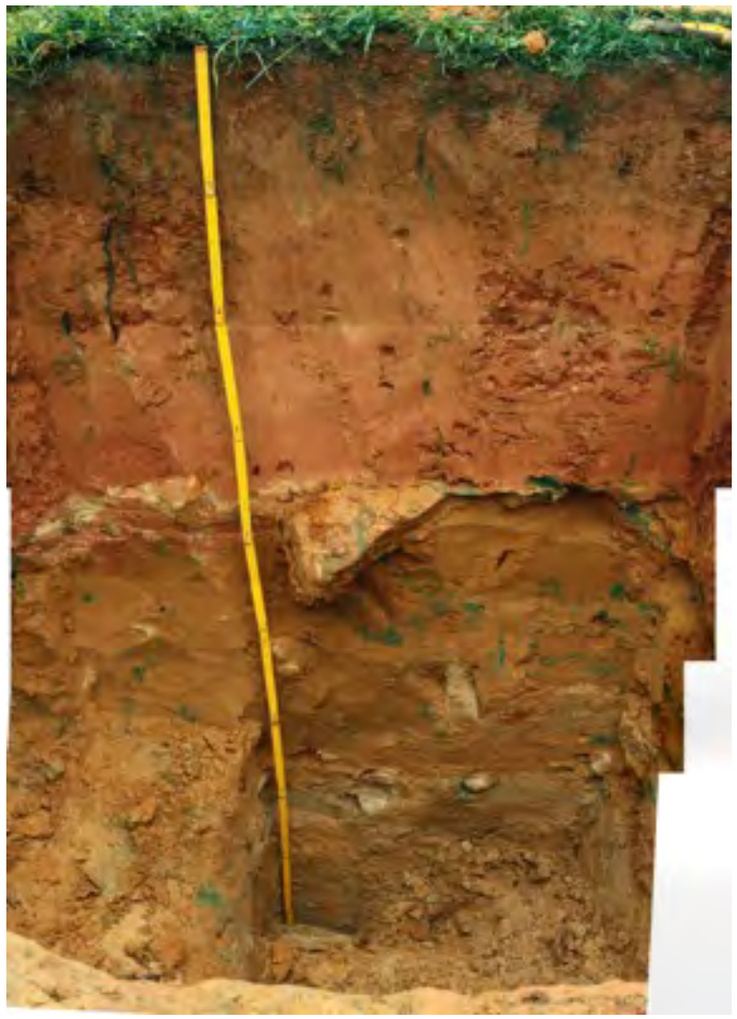
Pore-centered abstraction

from areal share of macropores
and given radius distribution with
assumed circular shape



- area/volume of macropores
- min | mean | max radius
- coating factor

- share & density of macropores
- distance distribution from macropores



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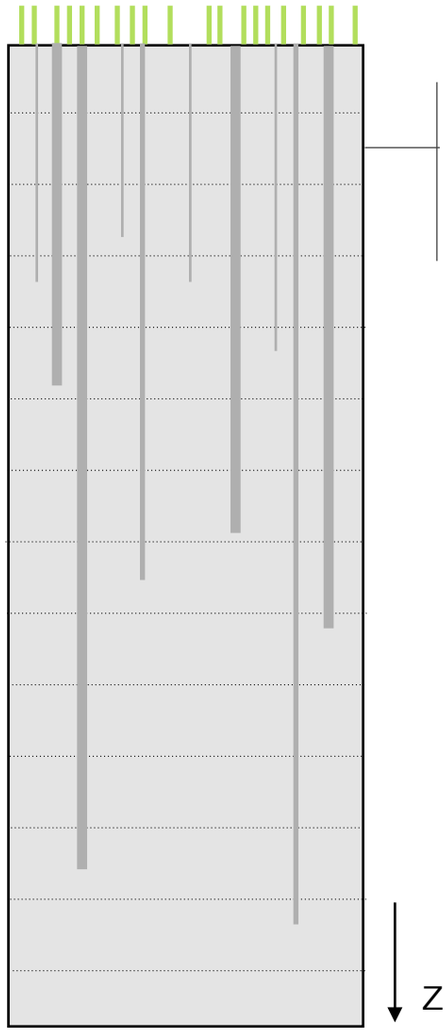
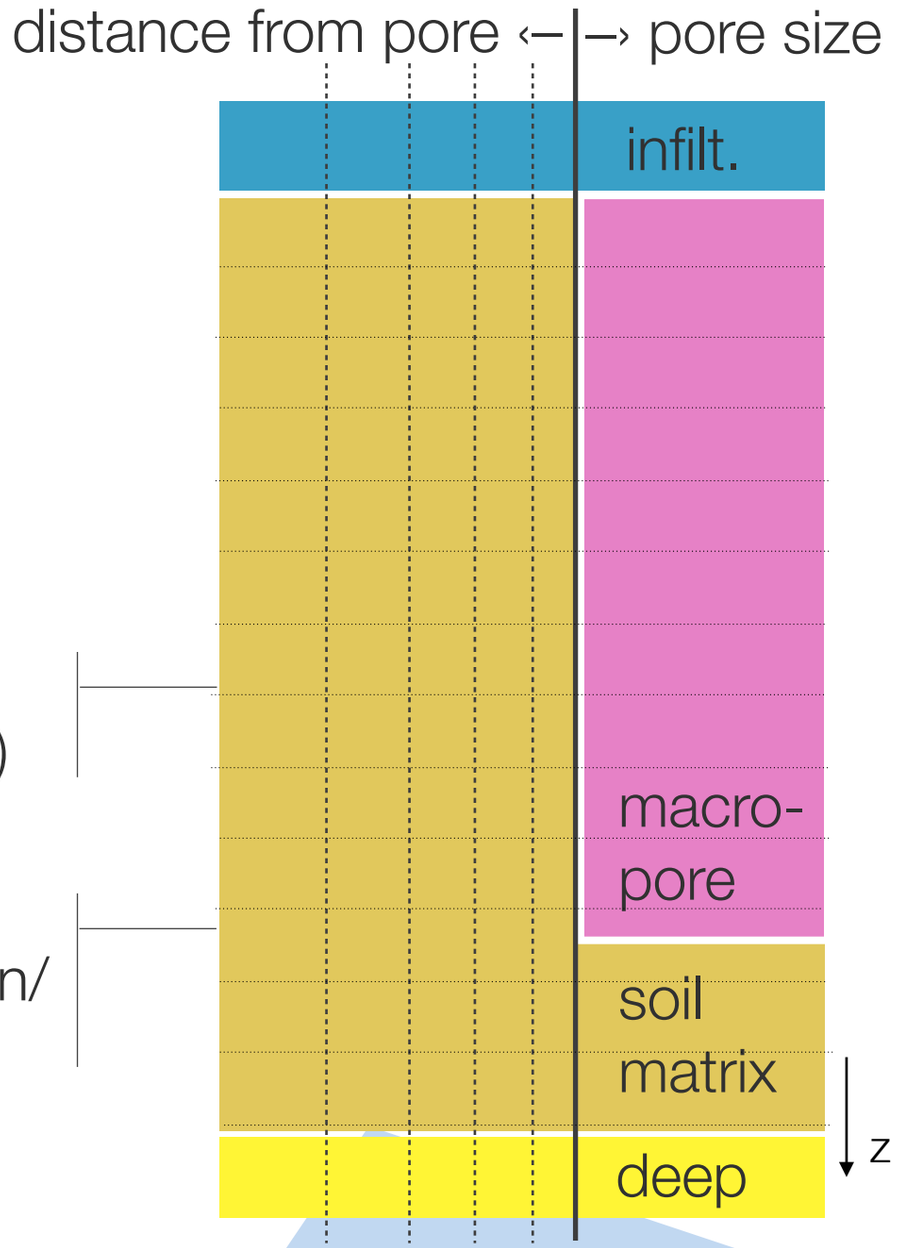


- area/volume of macropores
- min | mean | max radius
- coating factor

Eulerian (grid):
- REV properties (psi...)

Lagrangian (free):
- water particle diffusion/ advection



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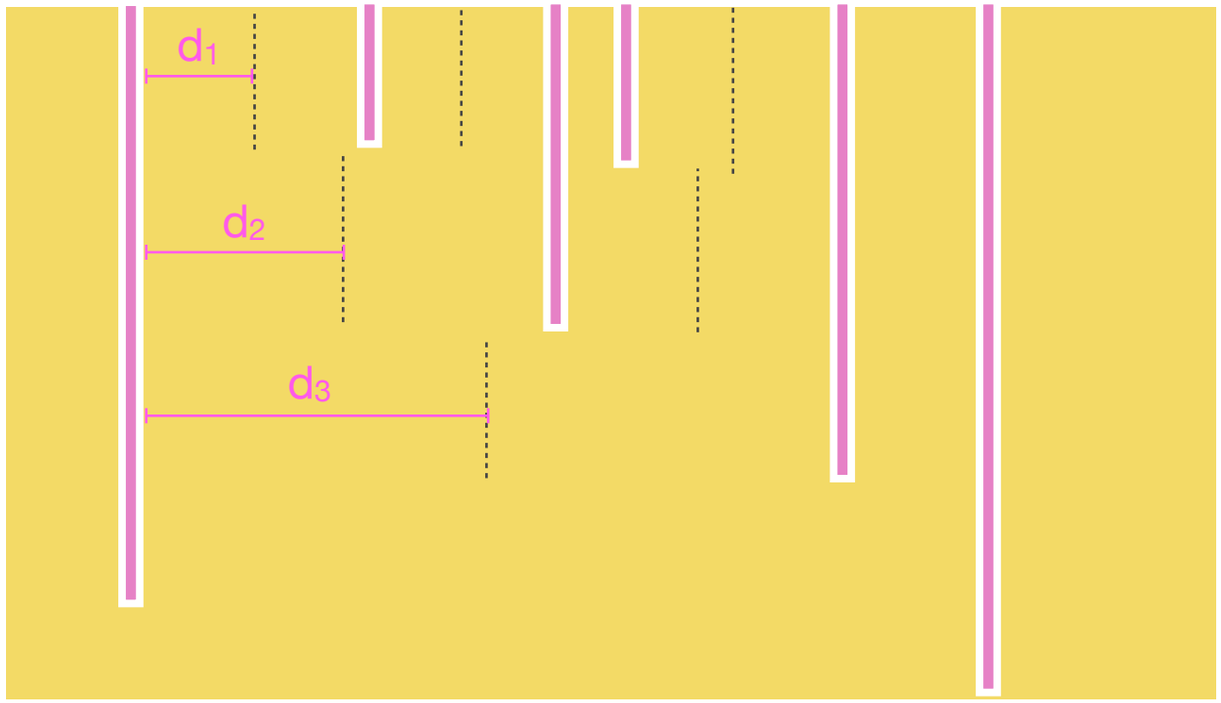
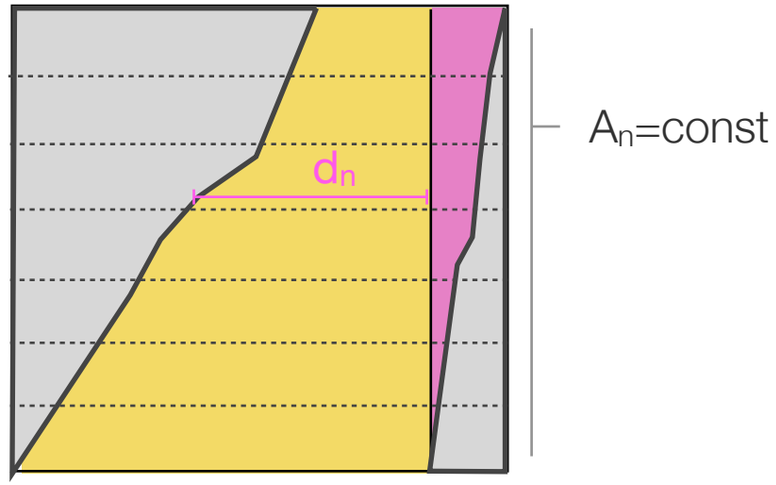
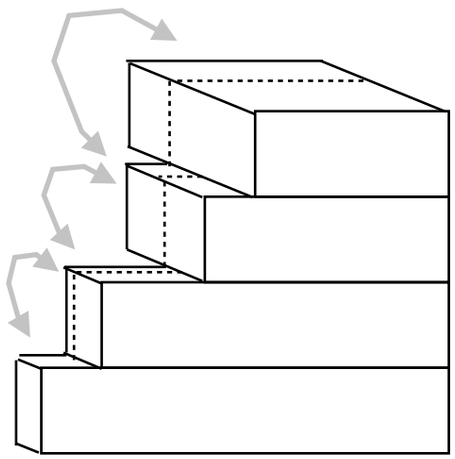
Prototype 1.5D Virtual 3rd Dimension

abstraction with many macropores



virtual 3rd dimension





random distribution to tails

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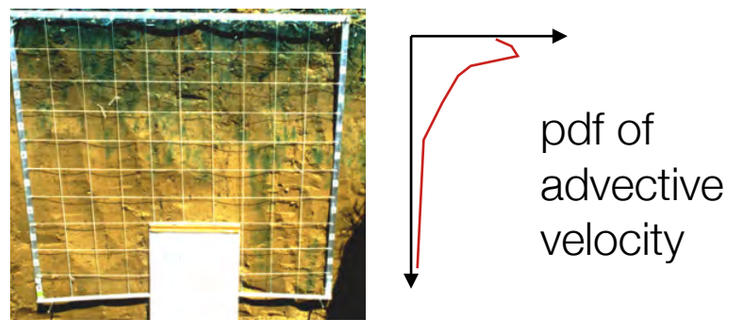
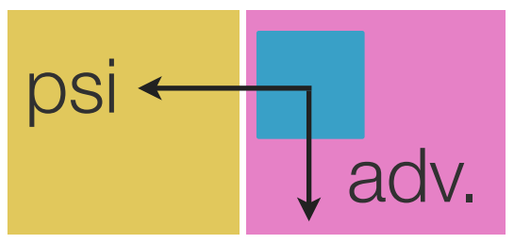
Prototype 1.5D Macropore-Matrix Interaction

Macropores allow advection

- once a particle enters the domain, its adv. velocity is drawn from pdf (tracer experiment)
- retardation of advection through:

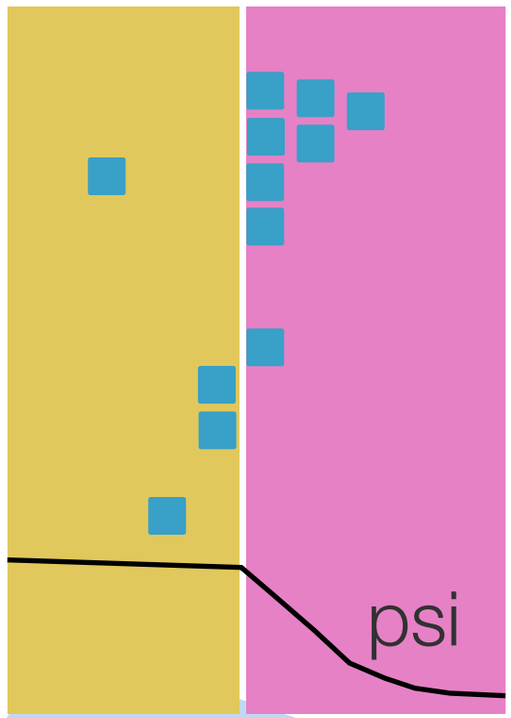
$$r = \frac{E_{binding}}{E_{kin}} = \frac{\psi_{exp} * g}{\frac{m}{2} * v_{adv}^2}$$





Particles „stick“ to pore wall

- distance from pore wall is a function of local filling
- infilt./exfilt. possible and governed through diffusion + coating factor



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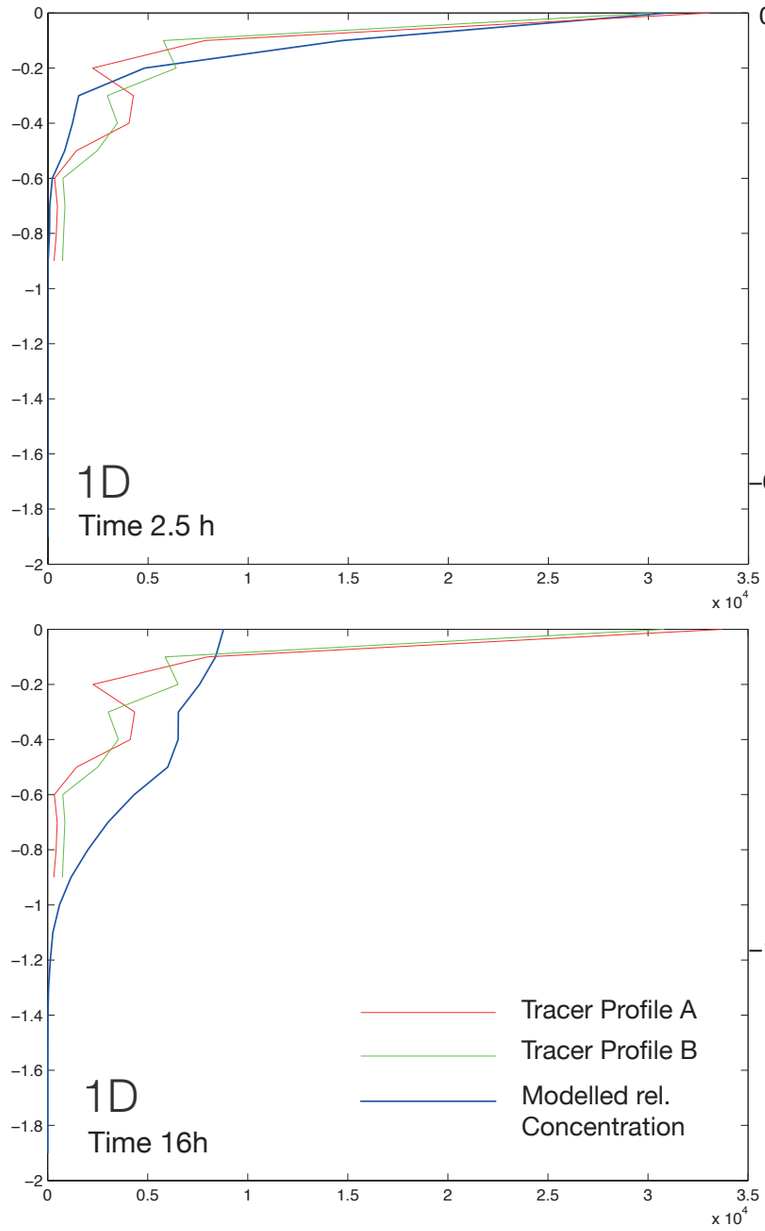
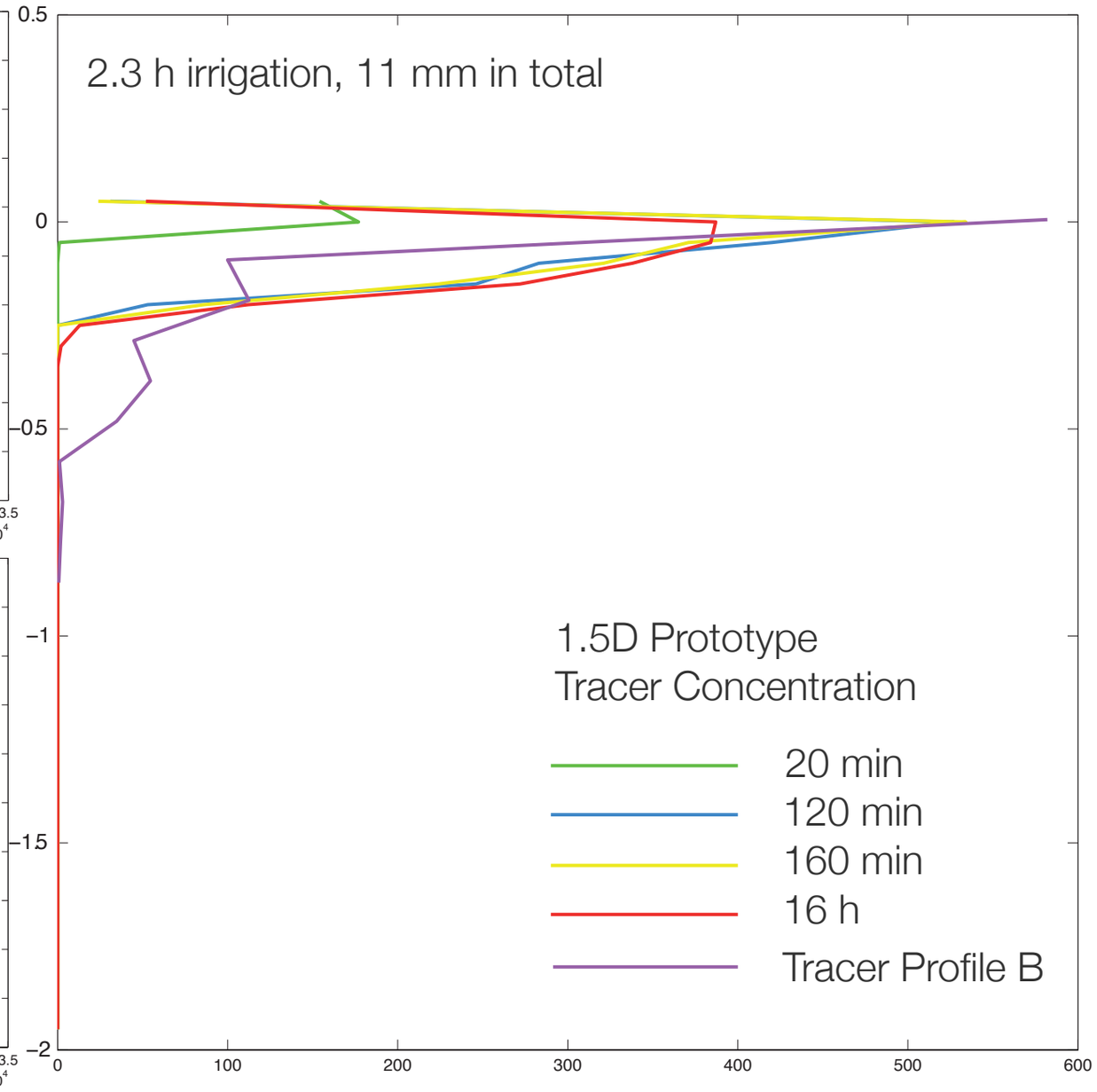
Results





Advection stops at reasonable time.

However, too low fast advection.

But far more properties.

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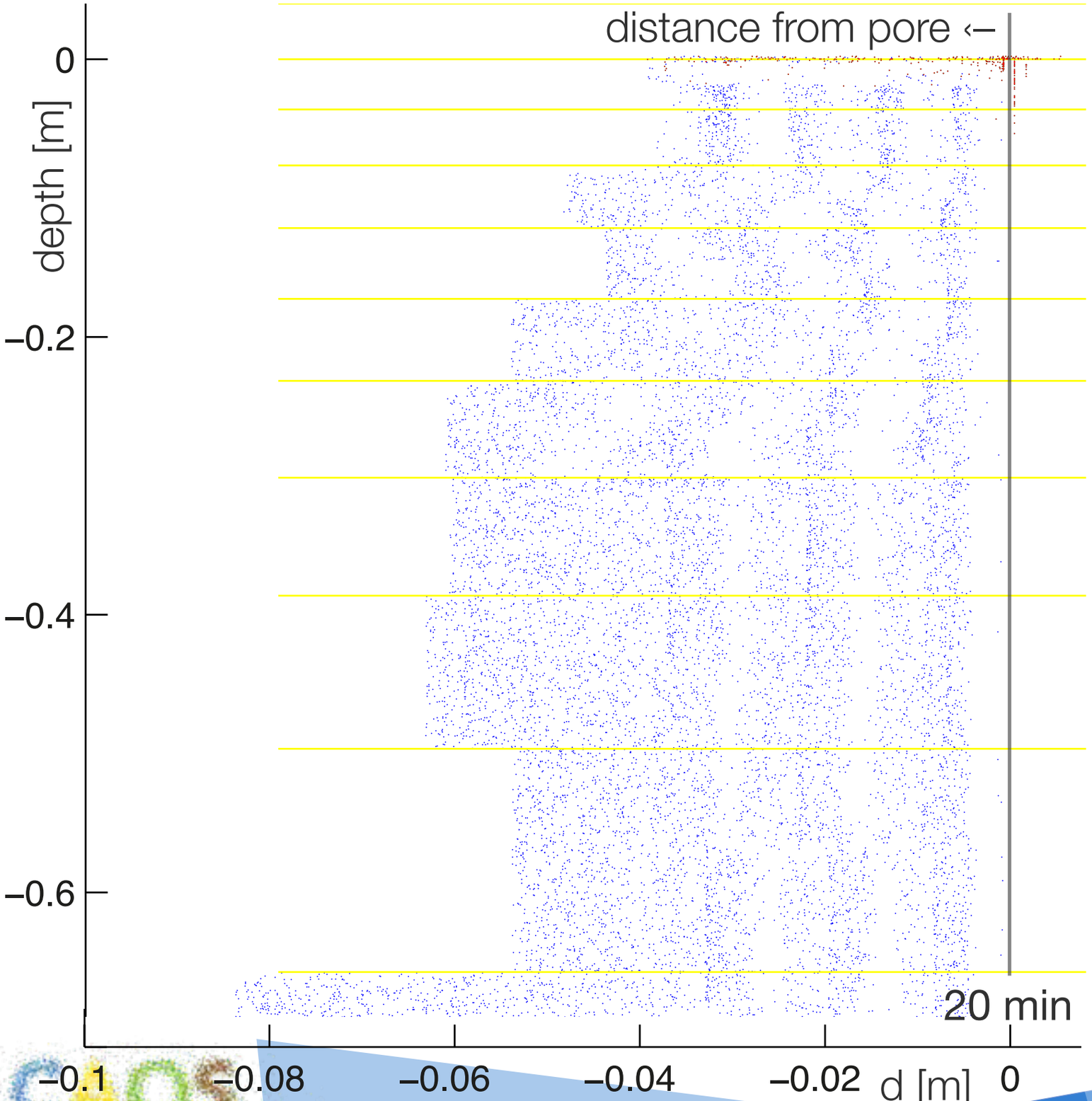
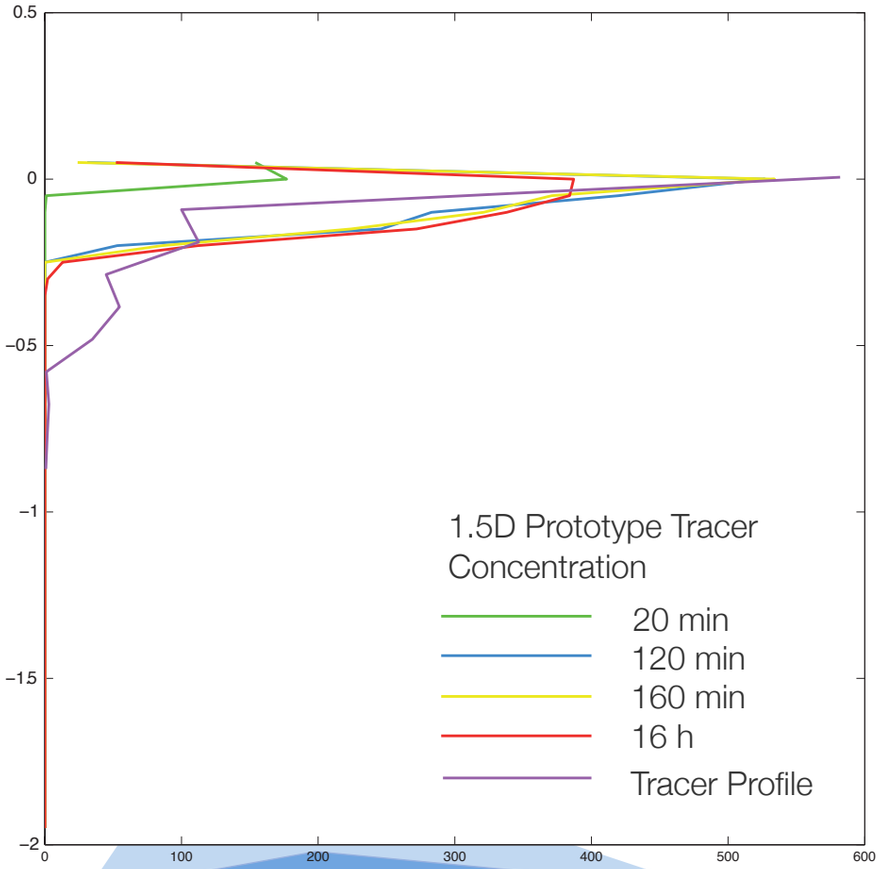
Results





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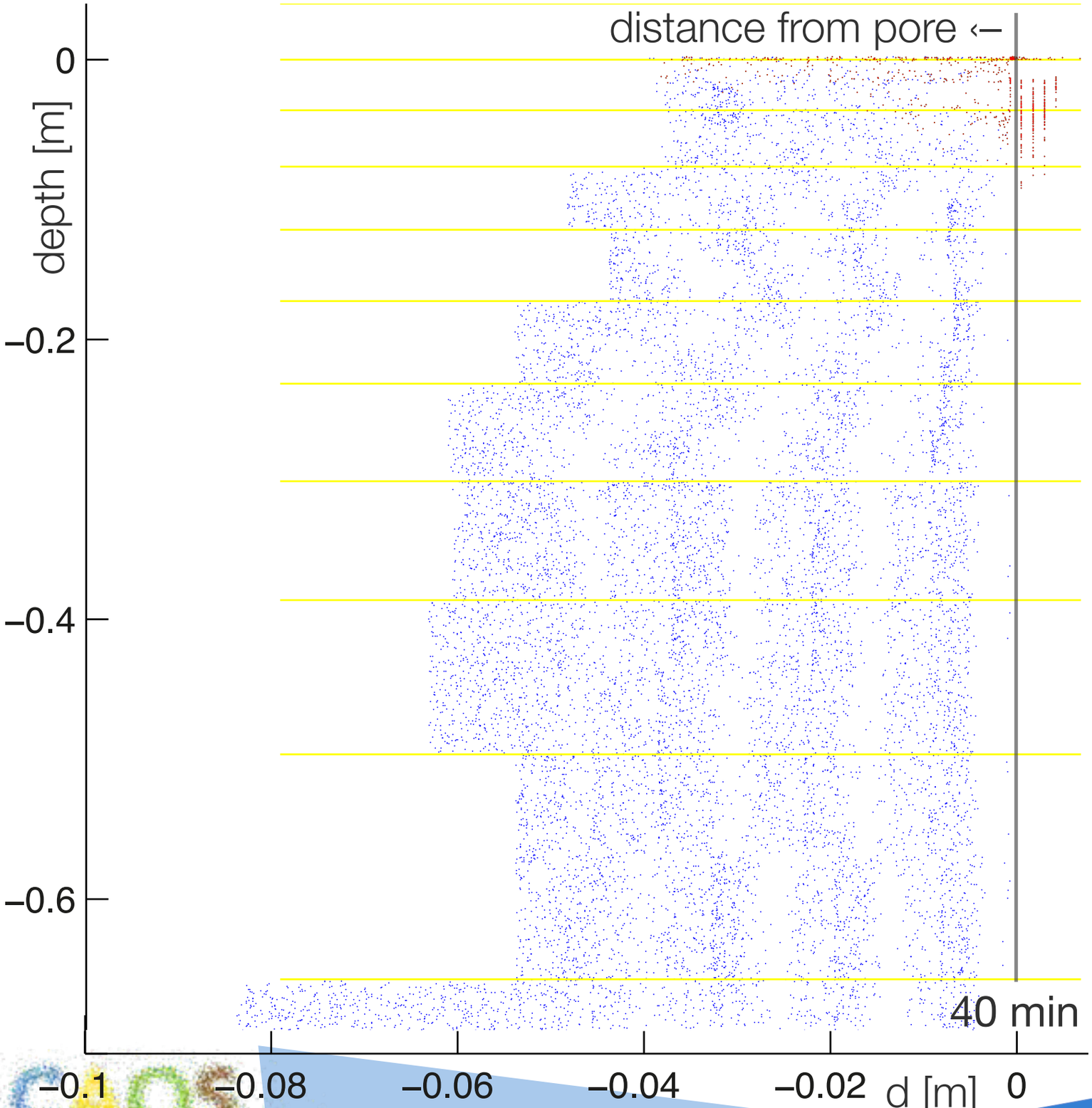

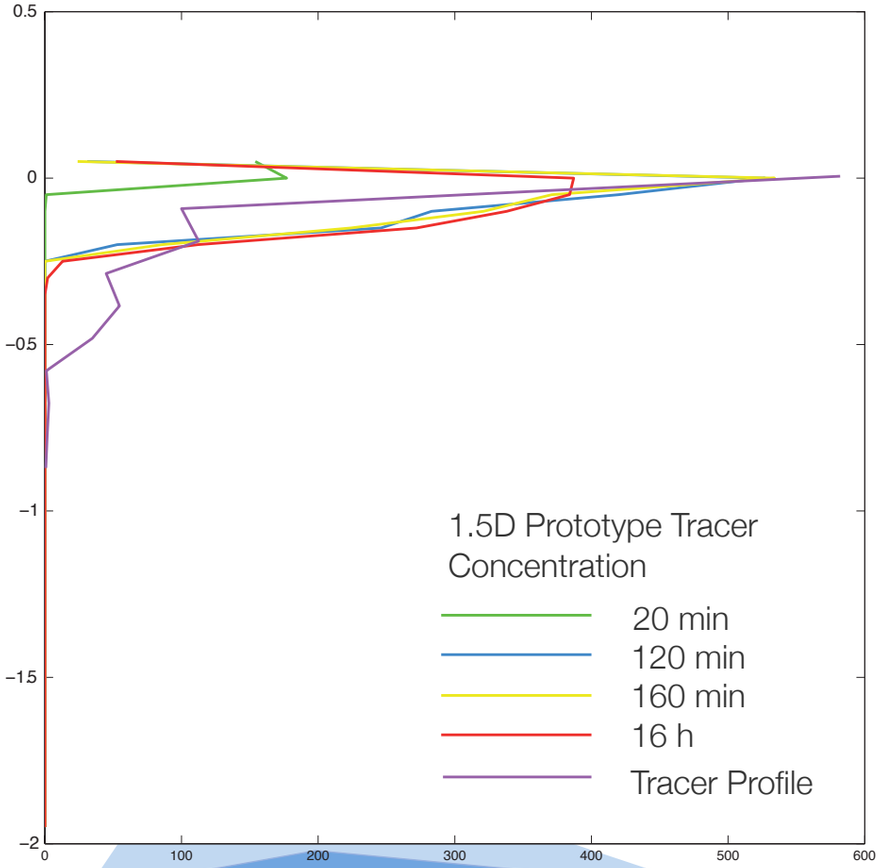

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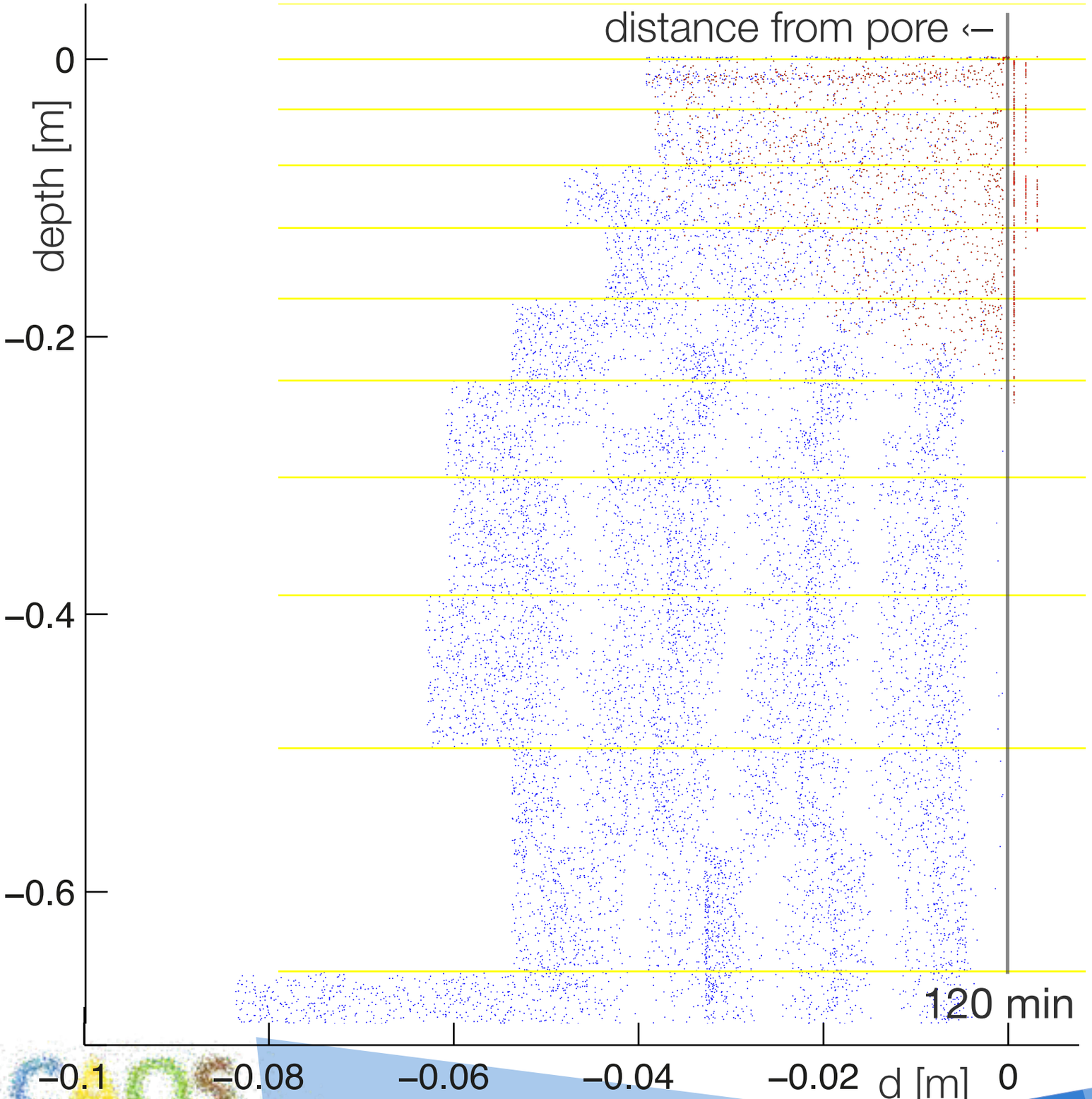
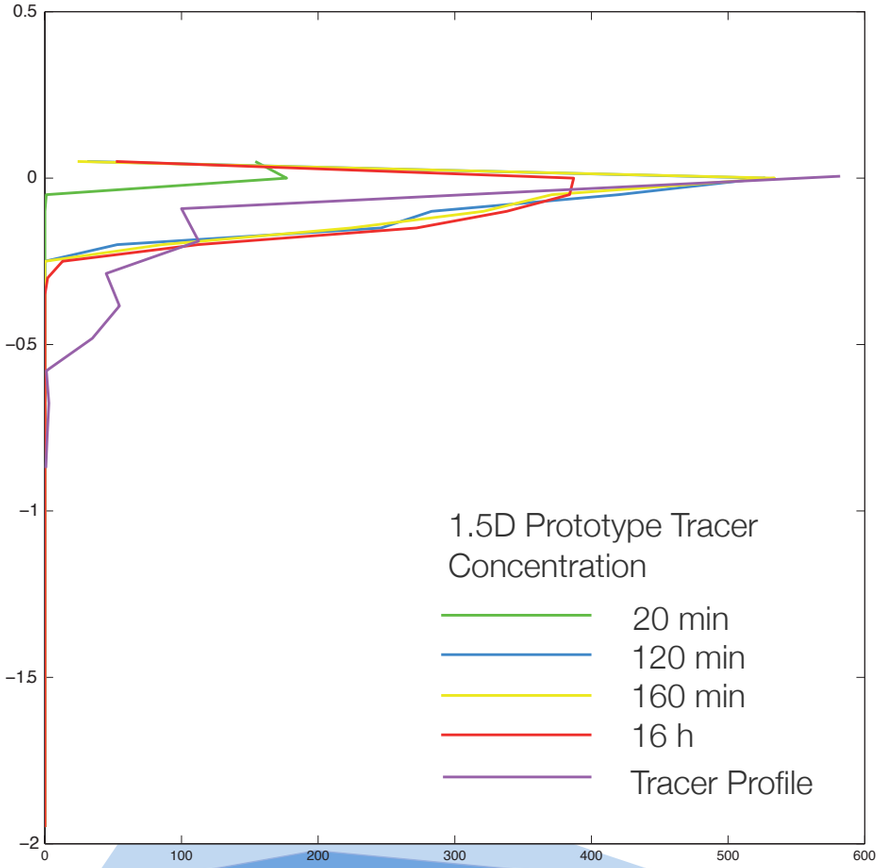
Results





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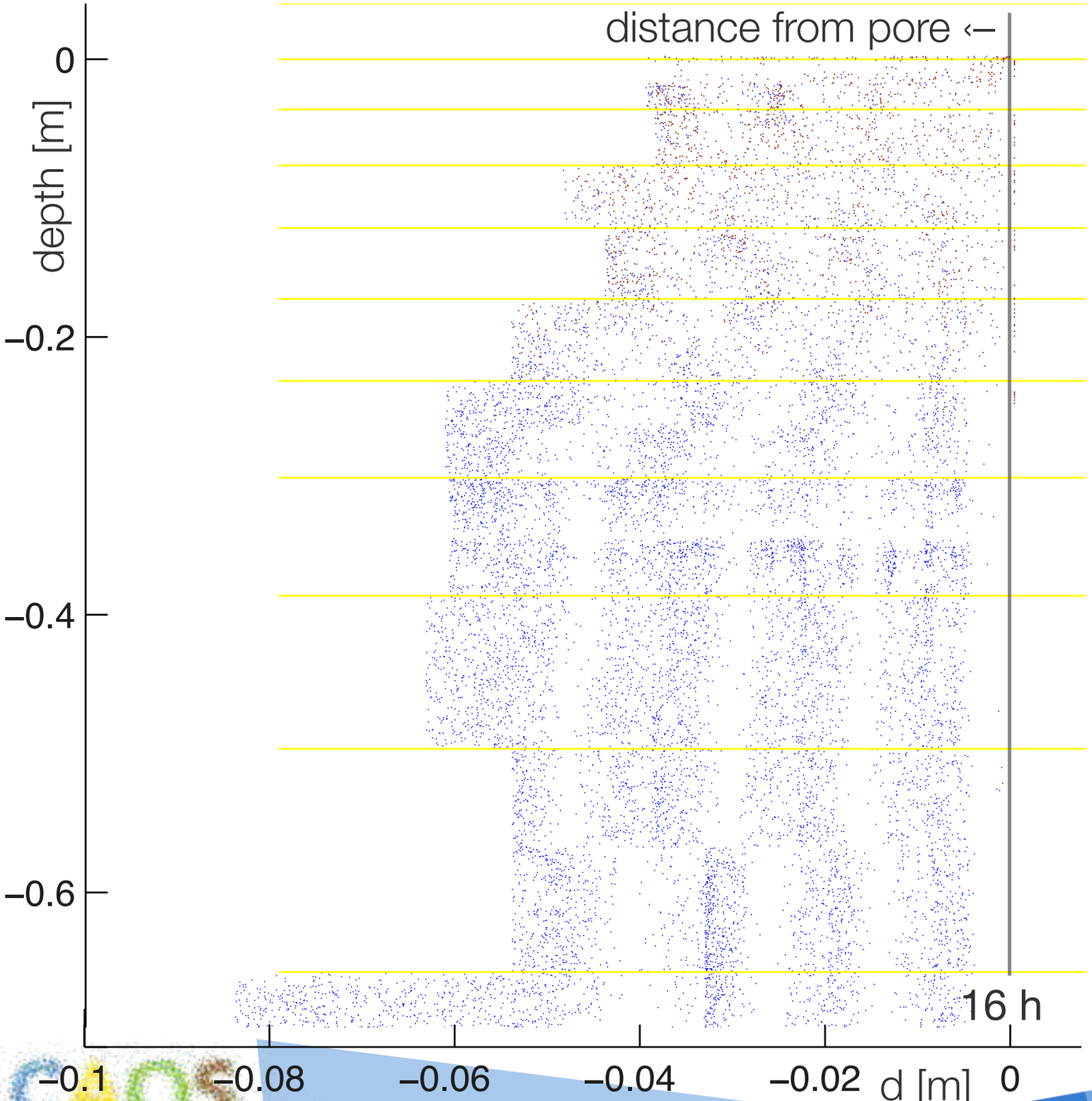

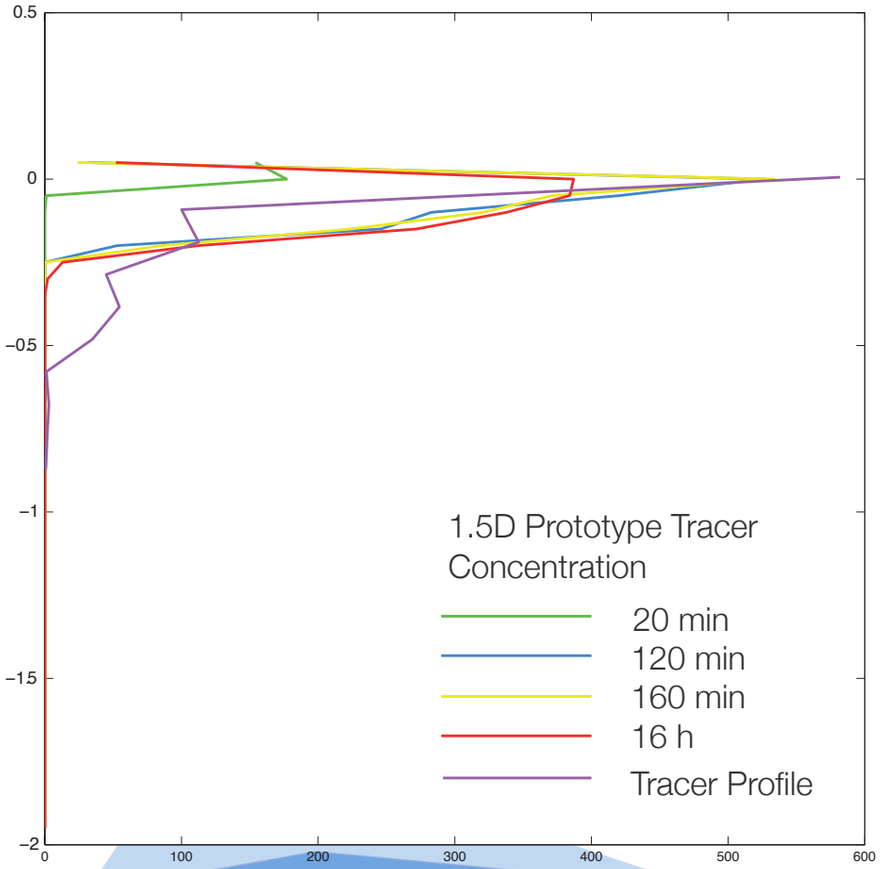

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Discussion

Not limited to earth worms/cracks! A pdf of the preferential flow domain and advective velocities suffices. -› Scalable to lower Mesoscale

The domain is not static over time! Its parameters can be updated based on more experimental findings. -› Link to ecology, seasonal activity...

Intrinsic definition of occurrence of advection through macropore matrix interaction.

BUT
Now, interfaces matter - coating, diffusion needs new definition, ...
Original idea of capturing fingering problematic due to abstraction

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Conclusion

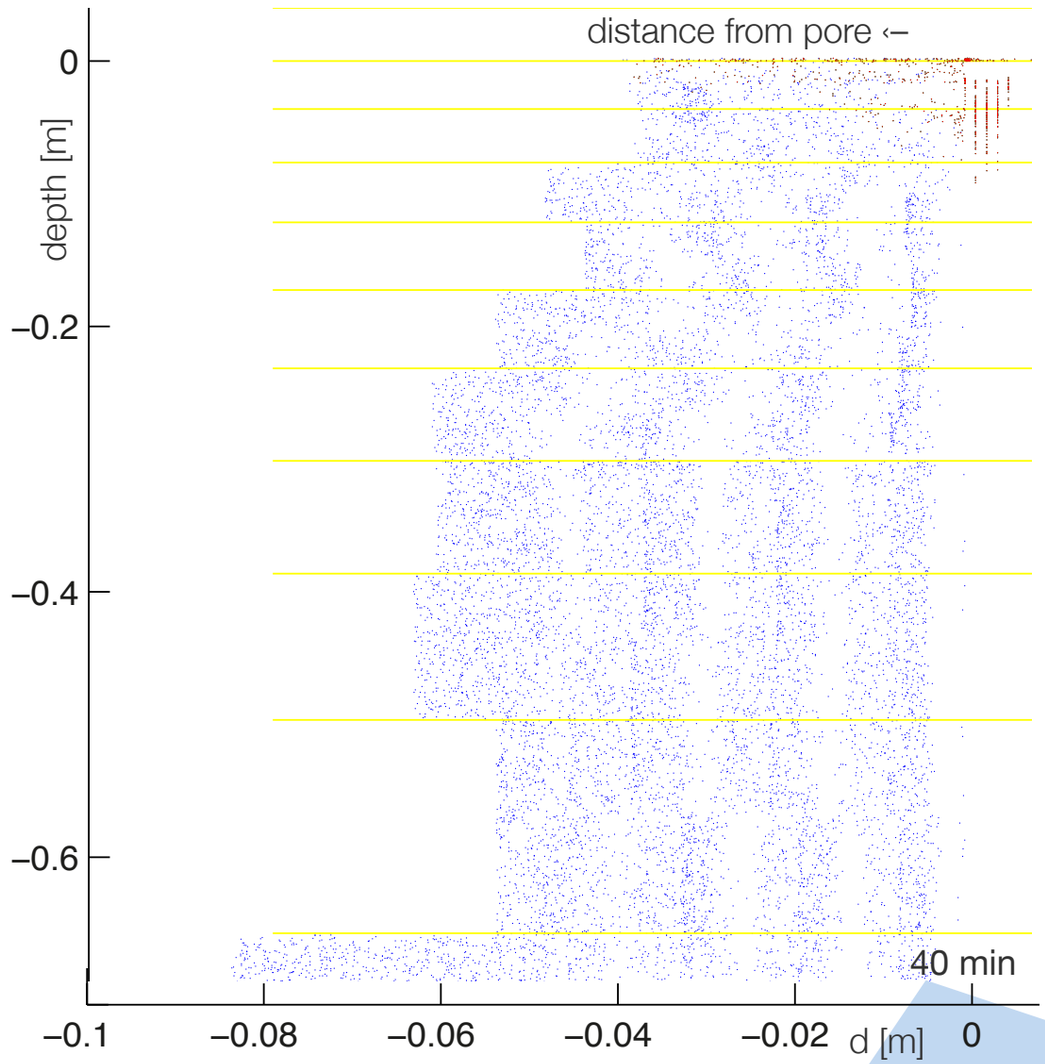
- Particle Model opens up exciting possibilities
- 1D is not enough
- the interfaces matter

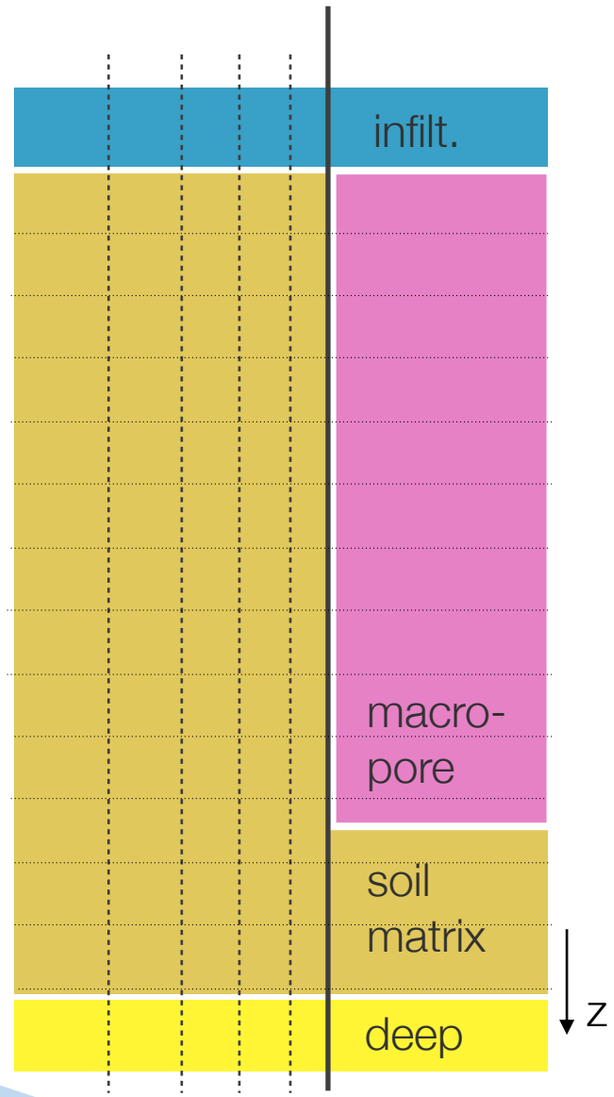
„work in progress“

we are really interested in alternative definitions of soil water diffusion and your comments

Thanks to CAOS group.

Thank you.





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