Complementary development of geophysical and hydrological observation and modelling techniques advancing understanding of soil water processes in structured soils

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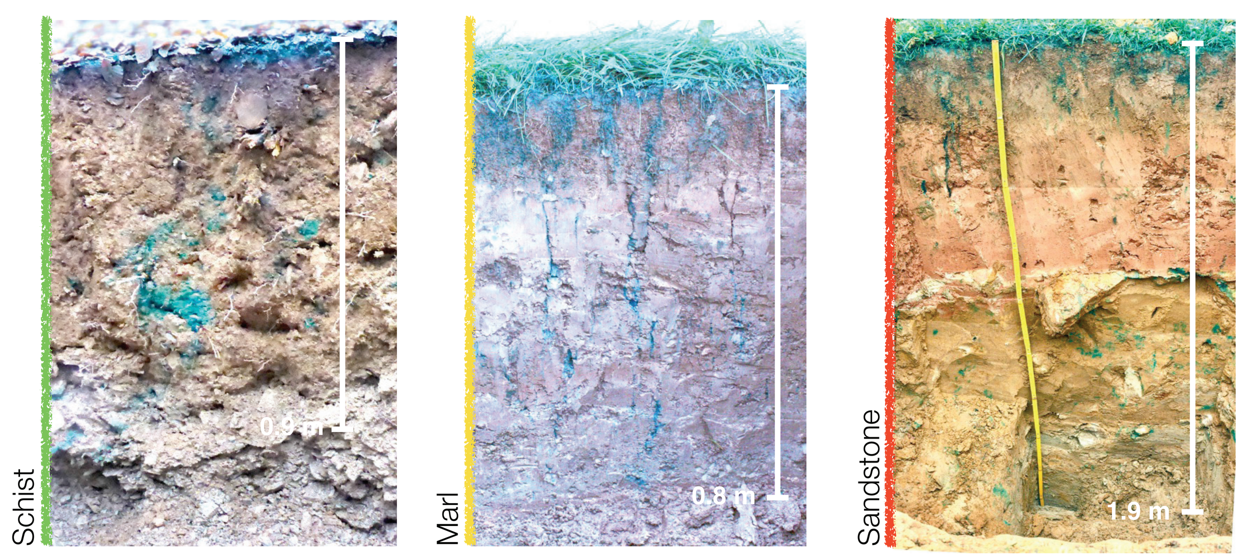
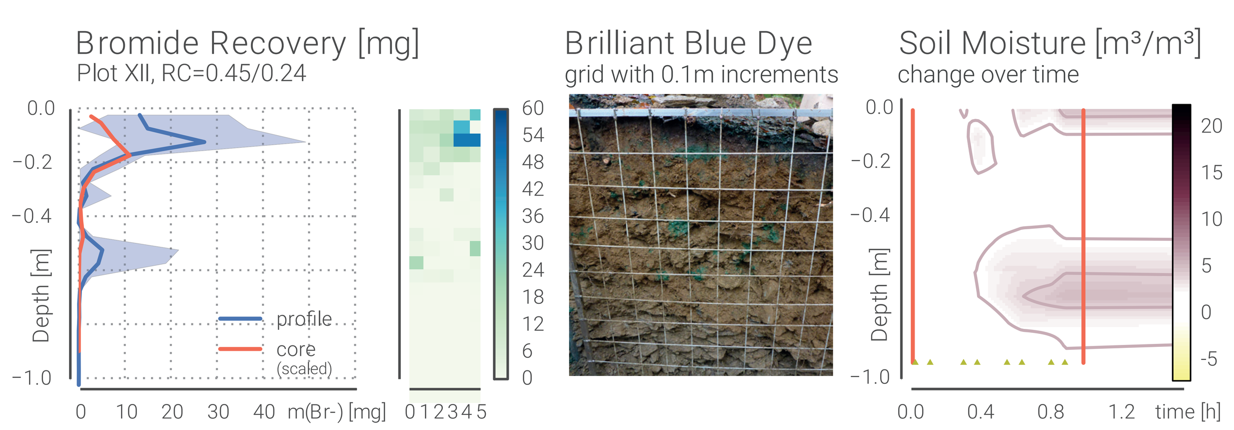
1 Non-uniform flow challenges process observation

Non-uniform flow is observed in many soils as imprint of flow structures and non-equilibrium conditions. Observations of soil moisture or tracer breakthrough dynamics require spatial aggregation much larger than individual structures. Dye tracer recovery does not resolve the dynamics and prohibits repeated investigations.





Non-uniform flow challenges hydrological models

How are advective and diffusive flow plus their interaction represented?
How does event-water redistribute if structures cannot be resolved?
What information is required to define a structured soil domain?
How can we account for dynamic properties of cracks, coatings, etc.?
How do processes scale in space and time? [...]

Overcome limitations by linking observation and models under a system perspective

Eco-hydrological systems are structured. However, most techniques (observational and modelling) consider such situations as "special case". We are investigating 4D GPR as non-invasive, spatio-temporally explicit means of observation and the Lagrangian EchoRD model as tool to advance interpretation techniques of the retrieved data.

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CAOS catchments as organised systems
DFG Deutsche Forschungsgemeinschaft

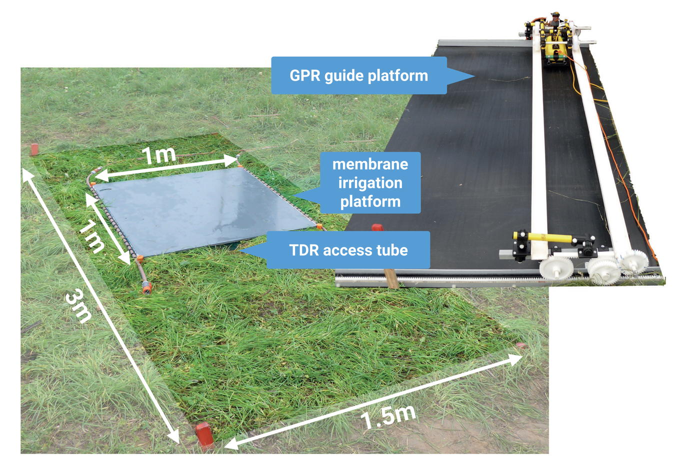
2 Irrigation experiment setup

Previous studies have shown that the teporal resolution of the GPR data acquisition is crucial for the interpretability. Thus fast measurements during irrigation are required.

» Membrane drip irrigation platform

Accurate, repeatable positioning of antennas, identical contact to the subsurface and absence of interfering reflectors

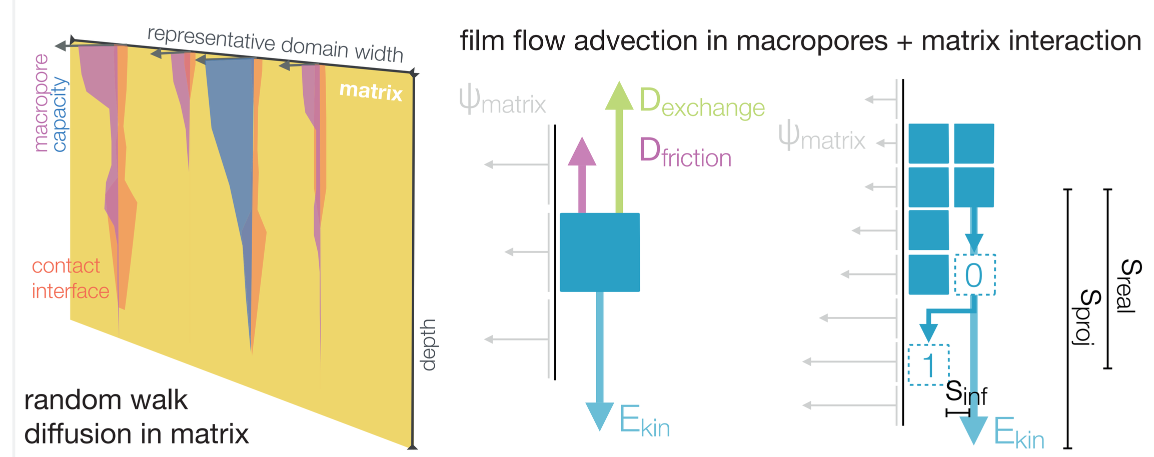
» GPR guide platform + self-tracking total station



1m² of a fallow loess site was irrigated for 2 h with 40 mm.

Model-extension of the experiment

EchoRD model as Lagrangian approach of non-uniform water flow in a representative domain (Jackisch and Zehe 2017).



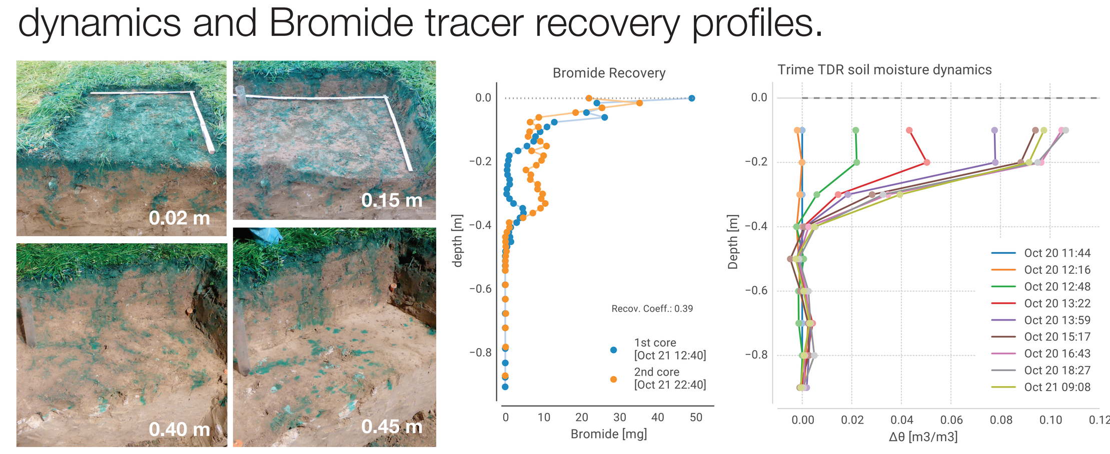
The model is setup with measured soil matrix retention properties and the distribution of macropores. We generated a stochastic field of different but equally probable soil definitions.

Forward simulation of GPR data

Using gprMax (Warren et al., 2016) the electromagnetic wave propagation in changing soil water conditions is simulated based on intermediate model states.

Experimental results

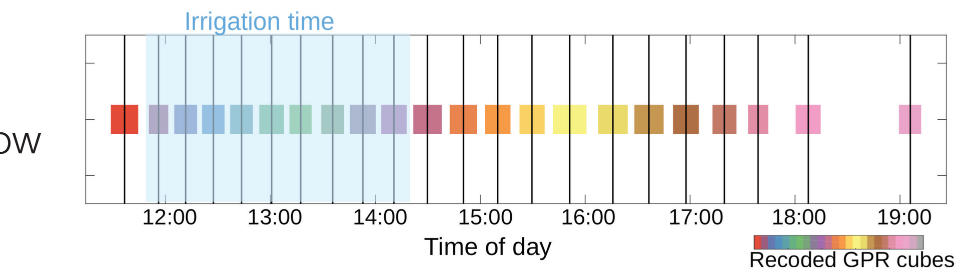
Non-uniform flow recovered as dye traces, soil moisture dynamics and Bromide tracer recovery profiles.

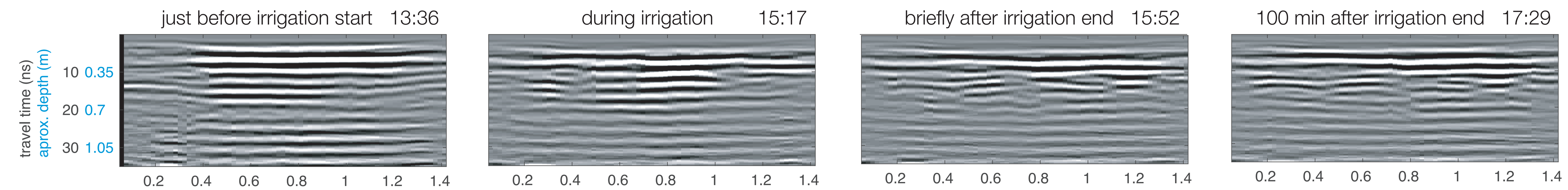


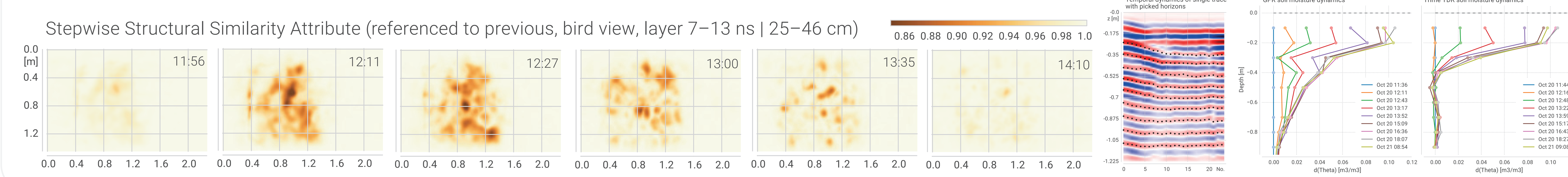
3 GPR measurements in the field

24 3D GPR data cubes recorded.
Processing through similarity attribute (Allroggen et al. 2016) and 4D gridding (Allroggen et al. 2017).

Exemplary radargrams extracted from 4D GPR volume show changes in reflection properties. However, interpretation towards processes and structures remains challenging.

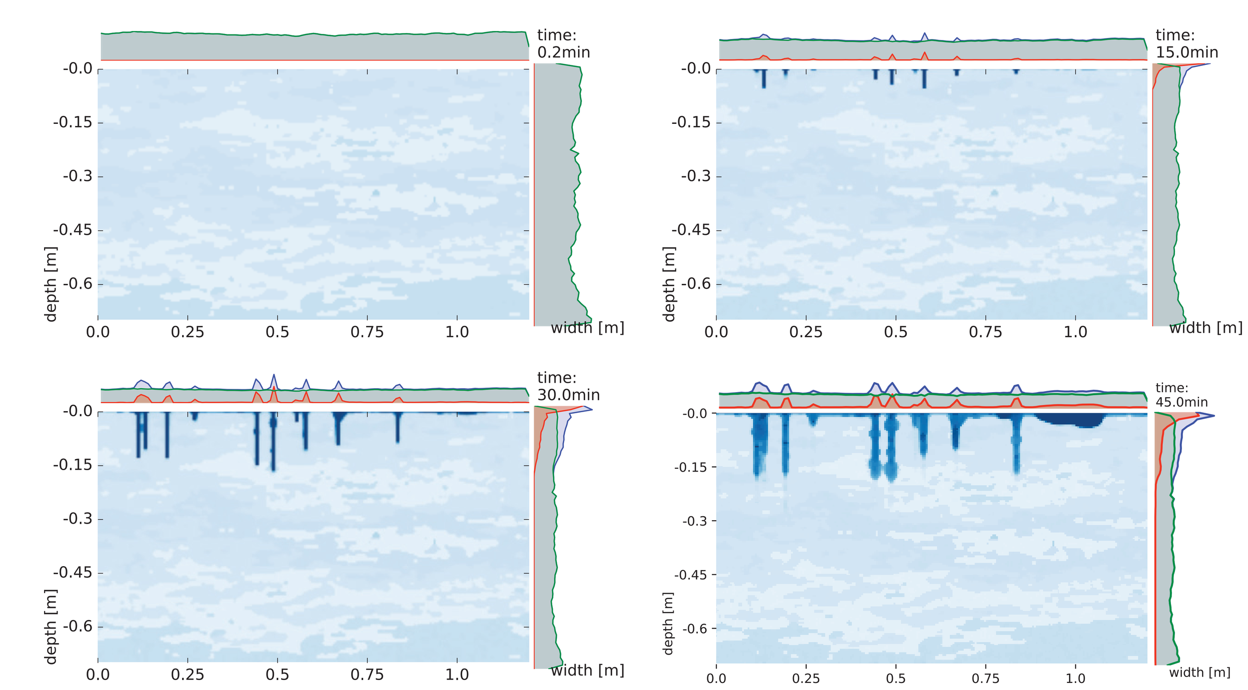


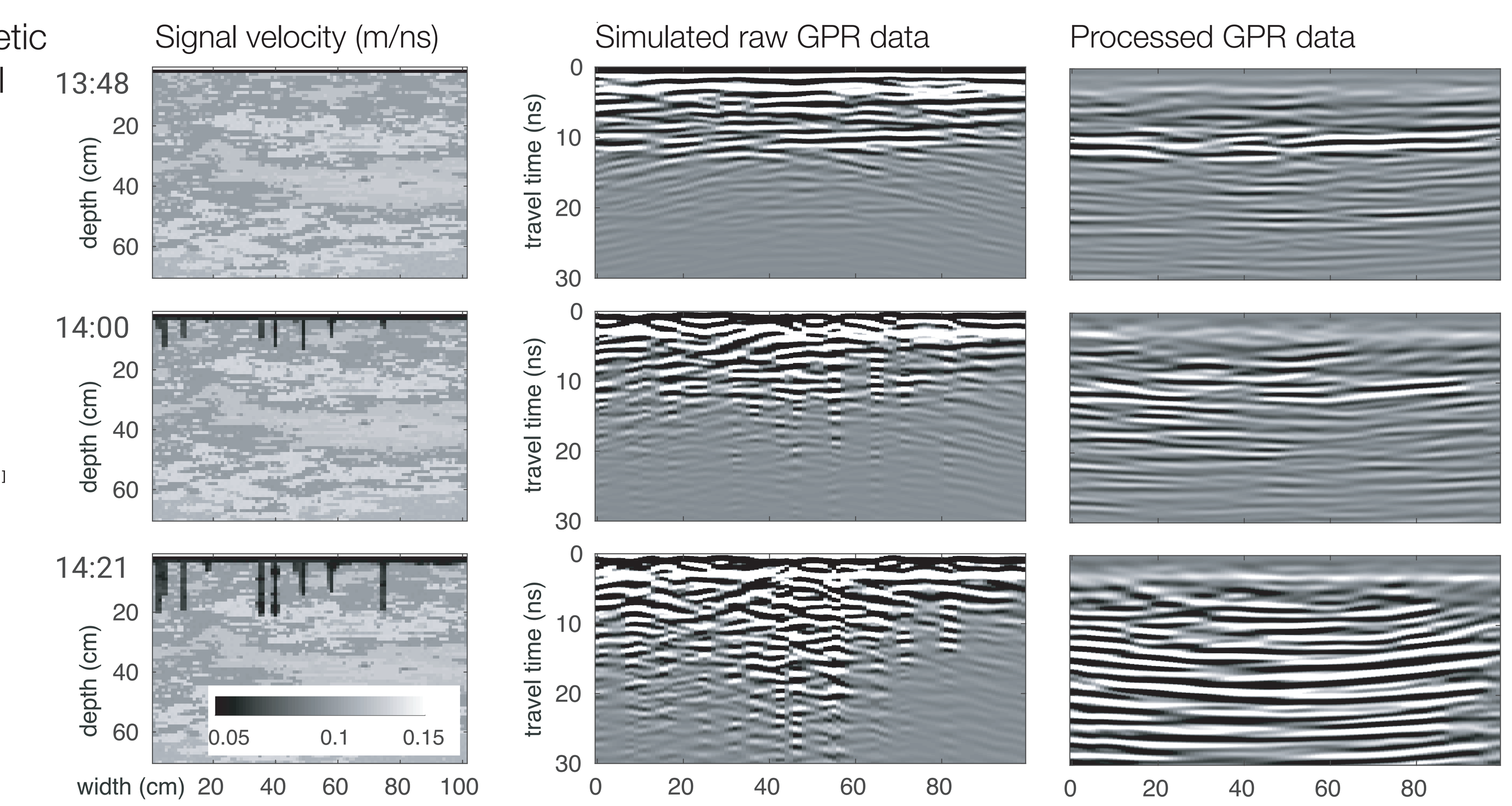




4 Synthetic data

Simulated non-uniform flow field appears realistic. However, the synthetic GPR data deviate substantially from the measured references. Top-soil features result in changes in apparently deep structures.





5 Technical limitations

› bandwidth, signal attenuation and data resolution
› extent of apperature and geometric limits
› reduction of complexity of real-world structures not feasible for forward GPR simulations

Application challenges

› temporal resolution and continuous measurement
› high-resolution antenna array systems
› interpretation of detected changes in radar data
› improve repeatability of GPR measurements

Process understanding

› relatively quick recovery of diffusive/LTE state
› for the first time, repeated experiments are possible
› large parts of the soil are only secondarily affected by infiltrating water

Outlook

› instead of moisture distribution GPR can be applied to system state detection in general
› experiments under different conditions and forcing over long periods
› improve model with necessary complexity of subsurface

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