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Hydrology and Earth System Sciences Discussions

Interactive comment on "Multi-offset ground-penetrating radar imaging of a lab-scale infiltration test" *by* A. R. Mangel et al.

Anonymous Referee #1

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This manuscript presents a controlled laboratory study which examines the applicability of multi-offset ground-penetrating radar (GPR) measurements to monitor water infiltration into unsaturated soils. Using a completely automated measurement setup, the movement of an infiltration front during an irrigation experiment as well as the following redistribution phase are monitored from a time series of WARR measurements conducted on a tank which was filled with sand. Average water contents as well as the propagation of the infiltration front and the depth to a reflecting interface are estimated from NMO analyses of the GPR measurements. The estimated water contents and depth of the infiltration front are compared to independent in situ measurements and numerical simulations using HYDRUS-1D and analyses of GPR simulations using the code by Irving and Knight (2006). The results show that the average volumetric water

content in the tank as well as the depth of an interface can be determined from multi-offset measurements with high accuracy during most times of the experiment while the tracking of the infiltration front turned out to be more difficult due to interference with other wavelets. Larger errors in the estimated depth of the interface occur when the infiltration front reaches this layer boundary.

Time series of GPR measurements have a strong potential for quantitatively monitoring field to small catchment scale vadose zone water content. Such data are of interest for many environmental applications and consequently of high scientific relevance. This paper clearly shows the value of multi-offset GPR measurements for monitoring water content dynamics in the vadose zone. These measurements are already but may in future be even more facilitated by the availability of modern multi-channel GPR devices. The paper is very well written, experiment and data evaluation are clearly described and the results are critically discussed highlighting the potential but also some challenges in evaluating multi-offset, multi-temporal GPR data. I have only one major comment which I would like to have worked out in a revised manuscript. Then, I am looking forward to reading the paper in HESS.

Major comment:

I have one observation which might be some work but I think it is necessary to make the different sources of measured and modelled data more comparable: The estimated depths to the wetting front shown in Fig. 3 for the WC measurements and the HYDRUS-1D simulations show very large differences. For example, at 16 min the wetting front detected by the water content sensors is at 25 cm depth while the wetting front estimated from the model already reaches a depth of 45 cm. Has the model been calibrated to the measured data? If not, this should be improved. Here, a figure like Fig. 2 comparing the measured and modelled water content dynamics at each sensor depth would be helpful for assessing the performance of the hydraulic model. This is also important as the modelled water content profiles are the starting conditions for the subsequent GPR simulations.

General comments:

The infiltration flux of 0.44 cm min^{-1} applied in the lab experiment to reach the observed high saturation of the sand is extremely high. Field studies conducted under natural atmospheric boundary conditions will have to cope with much smaller infiltration events (usually less than 10 mm per day) and consequently much smaller changes in average water content. Nevertheless, in order to test the method in such kind of lab experiment it is definitely reasonable to cover a large range in water contents.

The discussion could be extended by also discussing the uncertainty in the average water contents calculated from the hydraulic model (see comment above) as well as the interpolated water contents from the sensors since interpolation is not trivial especially with a sharp infiltration front within the profile. In contrast, the GPR measurements have the advantage of really averaging over the complete profile.

Specific comments:

P 10097, L 12-16: Please add a few references for this statement.

P 10100, L 3-13, Fig. 1: Please add the existence of drains at the lower boundary (Fig. 1) and explain how they are operated during the experiment.

P 10102, L 12, 13 and further occurences: I suggest to use "dielectric number“ instead of "dielectric constant“ as the value depends on temperature etc.

P 10103, L 9-10, Tab. 1: How were the hydraulic parameters for the HYDRUS-1D simulations chosen? Please explain.

P 10104, L 12-18, Fig. 3: Figure 3 is rather complicated for the observations described at this place. What about adding a Fig. 2b showing only the WC data right next to

the curves presented in Fig. 2 and moving Fig. 3 between Figs. 6 and 7? Please also check the WC data point of the 45 cm sensor in Fig. 3. In Fig. 2 the arrival of the wetting front at 45 cm is $>$ 20 min which indicates a lower velocity also at greater depth.

P 10104, L. 13, L. 22 and further occurences: Water content units are inconsistent with y-axis of Fig. 2. I suggest to use [-] or [vol vol^{-1}] throughout the paper.

P 10107, L. 29: replace "that“ by "than“

Fig. 2: It is rather difficult to distinguish the lines of the different sensors. Better show a color plot here.

Fig. 4: Caption: Please add what (measurement and model) is indicated in the left and right panels of a), b), c).

Fig. 4, 5, 6, caption and various occurences in the text: I would prefer "bottom of sand reflection“ instead of "bottom of tank reflection“. A bottom of tank reflection could be expected as well but just does not occur in this experiment.

Fig. 5: Caption: Please add what is indicated by D.

Reference:

Irving, J. and Knight, R.: Numerical modeling of ground-penetrating radar in 2-D using MATLAB, Comput. Geosci., 32, 1274–1258, 2006.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 8, 10095, 2011.