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Hydrology and Earth System Sciences Discussions

Interactive comment on "Multi-method geophysical measurements for soil science investigations in the vadose zone" *by* B. Weihnacht and F. Börner

Anonymous Referee #1

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General

The authors present the results of geophysical field experiments conducted at a test site in south-west Germany. They use petrophysical models and laboratory data measured on soil samples collected at their field site to develop and validate relations between geophysical and hydrological properties of the probed soil material. The field experiment represents an interesting approach to investigate the potential of geophysical techniques for estimating hydrological properties of soil material based

on petrophysical model basically developed at the lab scale. However, from my point of view some important issues of this approach are missing or not discussed (e.g., discussion regarding scaling issues, validity of the used petrophysical relations, error analyses). In addition, I see some major technical problems, especially, regarding geophysical data acquisition, processing and interpretation. Thus, the manuscript is not acceptable in its present form; i.e., from my point of view, very major revisions are required.
In the following, more detailed comments are given and discussed. I refer to page, line, and figure numbers in the pdf document provided by the journal. These comments should help the authors to rework and improve their database, analyses, and interpretation.

Some more detailed comments

Page 2660, lines 17-24: The general statement that geophysical techniques are minimum invasive and efficient tools to map large areas (compared to more conventional methods) is correct. However, the experimental setup including the geophysical techniques presented in this study seems to be not applicable for mapping soil properties on larger scale. This should be clarified and the authors should clearly present the goals of their study within the introduction.
Page 2661, lines 1-6: Of course, it would be desirable to have a unique set of petrophysical models linking geophysical parameters with the hydrological properties of interest. However, often we observe complex (e.g., non-unique) or weak correlations between geophysical and hydrological parameters also depending on the composition of the soil or rock material (numerous examples can be found in the literature). For example, Knoll (1995; Proc. SAGEEP, 25-35) investigated the relation between dielectric constant and hydraulic conductivity for sand-clay-mixtures and Mazac et al. (1985 and 1990) studied the relation between electrical resistivity and hydraulic conductivity.

HESSD

4, S1394–S1399, 2007

Interactive Comment

These studies are classical examples for complex geophysical-hydrological parameter relations. Furthermore, such examples illustrate the challenge in linking geophysical and hydrological parameters and I doubt that general petrophysical laws explaining such complex relations can be found. The authors should address these points. In this context, also alternative approaches to link and integrate geophysical and hydrological data should be discussed (e.g., statistical/geostatistical or stochastic approaches).
Figure 1 including the corresponding discussion in the text: Another box titled "geophysical" should be added on the left of the presented flow diagram. This box should be linked to the box "geophysical proxies" by an arrow labeled "inversion";. This modification helps to understand that the geophysical proxies are not the values we measure; rather these proxies have to be estimated via inversion routines from the measured data which are, for example, voltage (dc electrics) or travel times of radar or ultrasonic waves. In this context, the authors should discuss that geophysical inversion is usually a non-linear inversion problem characterized by a number of well-studied difficulties (e.g., non-uniqueness of the solution). Thus, the estimated proxies are subject to errors caused by errors of the measured data (estimates of these errors are given in Table 2) and uncertainties in the inversion process. Uncertainties in the inversion process include also assumptions made in the used forward model (such as the straight ray assumption made by the authors for the analysis of their travel time data sets). In this context, the authors should also examine the accuracy of positioning source and receivers (including electrodes) and the influence of positioning errors on their parameter estimates. Analyses of the reliability of all estimated parameters (geophysical and hydrological parameters) have to be included, i.e., the authors should present/estimate error bars on the estimated values in Figures 5 and 6 (see also comments regarding the presented geophysical parameter or "proxy" models).
Page 2662, line 7: Again, I doubt that "correct information about hydraulic parameters" can be provided by geophysical tools (see comments above). The optimum we can expect is a reliable estimate of the parameters of interest including their spatial variations. Honesty is the best policy.

HESSD

4, S1394–S1399, 2007

Interactive Comment

Page 2663, lines 4-5: It is not clear where the soil samples have been collected. Were they taken after geophysical experiments from the outcrop walls? This sampling procedure has to be clarified.

Page 2663, lines 10-11: Which tools are used to measure field porosity? This not clear at all and has to be clarified.

Page 2664 line 5 - Page 2665 line 19: Here, the authors provide some background on the performed geophysical experiments including field setup and geometries (see also Figure 4). From my point of view, a major shortcoming of this study is the limited geometry of the experiments resulting in limited spatial coverage and (probably) in unreliable parameter estimates. For example, the authors have only used zero-offset profiling (i.e., transmitter and receiver are always at the same depth) to measure radar and ultrasonic travel times. Multi-offset measurements (as usually performed in cross-hole tomographic surveying using seismic or radar waves) allow for a more reliable reconstruction of the velocity field. Also for the resistivity experiments, an electrode setup adapted from crosshole measurements would allow for a more detailed reconstruction of true resistivity values. The authors have to discuss why they use these "simple" field geometries and should illustrate the limitations of it (e.g., using synthetic modeling studies).

Page 2664, lines 20-22: The processing of the radar data includes dewow filtering before picking first arrival times of the signal. However, a dewow filter is usually a process which can distort the early parts of the first arriving wavelet and, thus, may result in erroneous first break times. This is the reason why dewow filtering is usually avoided before first break picking. This point has to be considered and should be discussed. Within this discussion the authors should provide some more details on the applied dewow filter, i.e., filter technique including the relevant parameters (residual mean, median or frequency filter, window length or frequency band of the filter etc.). In this context, I have to mention that no geophysical data are shown within the entire manuscript. In addition, there is no discussion regarding the quality and reliability of the recorded field data. The authors should include such a discussion and should

HESSD

4, S1394–S1399, 2007

Interactive Comment

EGU

present some typical field data examples allowing the reader to evaluate the quality of the different types of field data (e.g., recorded radar traces) and the reliability of derived data (e.g., travel time picks).

Page 2664, line 25: Using equation 3, the authors assume non-magnetic and low loss media as well as straight rays to transform radar travel time into dielectric permittivity. These basic assumptions of this forward model (i.e., this equation) have to be discussed in more detail as they might introduce significant errors in the estimated parameters (see also comment regarding Figure 1). Using the resistivity values presented in Fig. 5 and the frequency content of the recorded radar data, the authors should estimate if the low loss assumption is valid for the radar experiments presented in this study. It is well known that the straight ray assumption is valid for velocity variations up to approximately 10 to 15 percent. From the permittivity curve shown in Figure 5 and the values given in Table 3, I estimate velocity variations in the order of 30 percent for adjacent layers. Thus, refraction effects could probably not be neglected in this data set, i.e., ray curvature has to be considered. This problem is even more severe for the P-velocities presented in Table 3. Here, the authors report variations in the order of 300 Page 2664, lines 10-19: I see further major technical problems in the presented resistivity survey. In such small scale field experiments the dimensions of the electrodes can be problematic as a fundamental assumption of the technique are point electrodes; i.e., the extension of the electrode is small compared to the spacing between individual electrodes. This has to be clarified and discussed in more detail. In addition, equation 5 results in an apparent resistivity, i.e., for inhomogeneous material the calculated resistivity represents not the true resistivity of the probed material. However, the authors assume that the calculated values are true resistivities (i.e., they have probed a homogeneous half-space with their electrode array). This is obviously not the case for the investigated soil column (see Figure 5 and Table 3). In addition, equation 5 is only valid for a homogeneous half-space; i.e., we have a plane boundary between two half-spaces, one representing air and one the conductive soil material. Considering the sensitivity of a Wenner array (e.g., Friedel, 2000) and the layout of the performed experiments (see sketch in Figure 3), I doubt that the half-space assumption is valid in the presented experiments. As sketched in Figure 3, electrical measurements were carried out in an approximately 20 cm wide vertical valley. Such topographic effects can significantly distort the measured values and have to be considered in the analyses. In addition, we have to consider that the opposite outcrop is found in a distance of 40 cm to the electrode array having a total length of 20 cm; i.e., in a depth of twice the maximum electrode spacing we have a major contrast in the electrical properties (from soil material to air). Also this will influence the measured apparent resitivities and has to be considered when analyzing the data.

Figure 6, including the corresponding discussion in the text: The discussed uncertainties in the geophysical parameter estimates propagate. Thus, error analyses are also required for the parameters presented in Figure 6 (for both lab and field measurements).

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 4, 2659, 2007.

HESSD

4, S1394–S1399, 2007

Interactive Comment