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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

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GENERAL

The authors would like to thank the anonymous referee and editor for his constructive comments that certainly help to improve the paper. We will submit a revised version.

The goal of this paper is to show the capability of multimethod geophysical measurements as well as the development of petrophysical models to transfer geophysical proxies into geohydraulic parameters correctly with a minimum effort of calibrations. Another topic was the evaluation of different methods regarding sensitivity in terms of soil parameters. We are certainly aware of the complexity of the transfer model that would use a unique set of petrophysical models and regard this rather as a further goal. But, nevertheless, from our point of view, it is not desirable to have to calibrate the models for each type of soil or even sample with other "‘random"‘ fitting parameters. They should relate to the soil type and the soil characteristics. But if it were possible to obtain parameters used for an estimation by hydrologists (medium grain diameter e.g.) using geophysical methods, the resulting value would be at least as correct as the one from the laboratory because it was obtained under field conditions. Nevertheless, the calibrating effort should be reduced to a minimum.

We preferred working on a small scale for the beginning but surely see a high potential in mapping soil on a larger scale either with surface geophysics or borehole geophysics. It is also possible to use aerogeophysical methods that could be calibrated at certain points (Lambot, 2006).

The air at 40 cm distance should not have a remarkable effect on the geoelectric measurements since the maximum current electrode distance is 15 cm and the estimation of the penetration depth (AB/2) would be 7.5 cm .

The specific comments will be answered individually.

ANONYMOUS REFEREE

Page 2660, lines 17-24: see above

Page 2661, Lines 1-6: Hydraulic conductivity is a very complex parameter that is not part of our investigations so far. For its determination, one geophysical parameter is probably not enough but needs to be combined with other geophysical parameters. Alternative approaches (e.g. geostatistical approaches) are not an issue in this paper. We prefer petrophysically founded empirical models, where parameters relate to the structure of the investigated material. We added the box "‘geophysical values"‘ in Fig. 1 to explain the study further. As now explained in the introduction, we explicitely avoided inversion but used a laboratory-like setup. Inversion is certainly necessary for most surface geophysical methods. But it is also clear that sizable errors in geophysical proxies for a discretized soil volume are caused by inversion. This is the reason why we chose a setup where no inversion is necessary. For our setup, we investigated only the topmost layer, the first pseudosection layer of a geophysical survey. If the electrode distance is close enough so that the vertical borders are still detectable, which applies to our study, the resistivities obtained don't have to be inverted but can be regarded as true resistivities. They are frequently addressed as surface resistivities. (Telford et al., 1995) Errors of the positioning are added. Overall errors are estimated in Tab. 2.

Page 2662, line 7: Hydraulic parameters should not only be estimated but calculated from geophysical data. This is already done in oil exploration and the related petrophysical investigations. We certainly agree that e.g. the reliable prediction of the hydraulic conductivity is rather a further goal but nevertheless should be followed up and the dependency of the permeability from e.g. S_{por} and CEC investigated(Goode and Sen, 1988)

Page 2663, lines 4-5: The answer has been added to the paper.

Page 2663, lines 10-11: The answer has been added to the paper.

Page 2664, line 5 - Page 2665, line 19: As a first step, one vertical profile was investigated. This profile is certainly spatially limited. But, as pointed out in the general section above, geophysical data have the potential also to be conducted on large scales. The petrophysical parameters found are only valid for our profile and similar types of soil. As pointed out in the discussion of the paper, further materials are planned to be investigated to test our set of parameters. Multi-offset measurements would be useful for non-parallel layers. This is not the case on the testsite. Multi-offset measurements would also require inversion which should be avoided.

Page 2664, lines 20-22: For most investigations it is necessary to remove low frequency noise from the signal, especially when measuring in urban areas (50 Hz - noise). This is the reason why we applied a dewow-filter. The signals were calibrated afterwards with air measurements to correct any offset caused by the filtering.

Page 2664, line 25: We agree that for our setup the layer borders might not be sharply detectable. Nevertheless, there are no sharp borders depending e. g. on the sedimentation conditions, and the setup is chosen in a way that there is at least one data point in every layer of every geophysical method. The low loss assumption is valid for most radar data collected from "‘ordinary"‘ soils (Schmalholz, 2007). It is not possible to compare low frequency data (electric measurements) to high frequency data (radar measurements) for our kind of material since the complex dielectric permittivity is frequency dependent for water-containing materials. Laboratory measurements with the material from the test site between 1 MHz and 3 GHz showed low imaginary parts of the dielectric constant 1 GHz for most probes (delta approx. 1/9).

Page 2664, line 10-19: The electrodes had a diameter of 5 mm and can be regarded as point electrodes. Eq. 5 results in a apparent resistivity in general. Again, in this case, for our setup it equals the true resistivity. The sensitivity of a Wenner-array lies mainly between the two potential electrodes (Gruhne, 1999).

EDITOR

Regarding general goal: see above

Regarding "‘petrophysical parameters from geophysical measurements becoming more popular"‘: Has been changed in the paper.

Regarding soil moisture data: If samples are dried in the lab, capillary water and free water are not differentiated, which leads to errors for materials with a high share of capillary water (e. g. clay). Radar is a good tool to provide these differences since free water (dielectric constant 81) and capillary water (electric constant approximately 8-10 - close to the matrix dielectric constant) have different radar-influencing properties. It is clear to us that different soils have different parts of capillary water, which is influenced e. g. by the parameter S_{por}. We cannot consider the non-stationarity and the biota with our setup because we conducted measurements only at a certain time. In the future it would be necessary not only to obtain the geophysical parameters but also to investigate their dependency on time. For this, stationary setups that measure at certain time intervals would be needed.

Application on large areas: see above

Regarding parameters bn: Pore space structure means mainly consolidated or unconsolidated. The comment is added to the paper.

Scatter plots are added. Too little data was available to split it for training and proving of the established correlation.

Drying temperature had to be 70°C to preserve the internal structure of the material (added to the paper).

There are unfortunately no independent data for the porosity measurements. But it is clear, if there is an error the material would be denser in the field than in the lab measurements due to the build-in procedure.

The variables in Eq. 5 and 6 have been changed.

Eq. 8 and 9 and total density: We did not use the lab data for the determination of the porosity from geophysical measurements, just the compressional wave velocity. Eq. 9 was used to determine the porosity from the lab measurement and Eq. 10 for the determination of the total density from the geophysical measurements while using the estimated true matrix density of 2.65 g/cm^3.

Regarding the drop in the epsilon profile: The lab data show lower porosities and higher densities in this area but very little change (a slight decrease) in the water content. The geophysical measurements show no changes in the porosity and the density but a significant decrease in the water content. Since the results are so different, additional research would be needed to clarify this question.

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Regarding the gravel layer and the underestimation of the water content: It was hardly possible to take a representative sample in this area due to the inhomogeneity. This might be due to the differences between geophysical and lab data.

Wollschläger et al. did not work on the same profile as we did and only measured the soil water content. Since our investigations were conducted at a later date, the values cannot be compared.

Gruhne, M.: Controlling of contaminations in the underground with complex electrical measurements (in German); Proceedings of DGFZ 16, Dresden, 1999

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Schmalholz, J.: Georadar for small-scale high-resolution dielectric property and water content determination of soils; Technical University of Berlin, 2007

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