Direct inversion for water retention parameters from MRS measurements in the saturated/unsaturated zone – a sensitivity study

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The idea of applying MRS for characterizing the vadose zone has been discussed for almost ten years. First experiments showed that it is actually possible to identify water in the unsaturated zone (e.g. Roy and Lubczynski, 2005). However, the reliability of this information is usually quite poor due to low signal-to-noise ratios (S/N). Moreover, it has become apparent that the usual MRS interpretation concept based on smooth inversion techniques is not suitable to estimate hydraulic parameters, unless time-lapse MRS is performed to monitor water fluxes in the subsurface (Roy and Lubczynski, 2005; Costabel and Yaramanci, 2011).

Costabel and Yaramanci (2011) suggested an alternative MRS inversion approach for estimating water retention (WR) parameters. It is based on the soil physical parameterization of the capillary fringe (CF), i.e. the transition between the unsaturated and the saturated zones. In doing so, a WR model (e.g. after Brooks and Corey, 1964) that describes the water content increase in the capillary fringe is included in the MRS forward operator. Consequently, the CF inversion approach directly provides the WR parameters and, following the common soil physical concept of piston flow, it becomes possible to estimate the unsaturated hydraulic conductivity as a function of the saturation degree.

We have developed and investigated the CF inversion approach further to account for different WR models and to assess its general applicability. Its forward operator generally consists of five parameters: the saturated and the residual water content, a parameter for the height of the CF, a parameter describing the gradient of the water content increase in the CF, and the water table. However, the residual water content for our examples is generally neglected. This is in common with the usual assumption that water related to the smallest pores is unvisible with MRS due to the instrumental dead time.

A sensitivity study based on both synthetic and real data analyzes the resolution properties, the uncertainties and the cross covariances of the involved parameters. The inversion is realized with the software package GIMLi using a Marquardt-Levenberg minimization scheme using logarithmic barriers to keep the parameters within reasonable ranges along with the computation of model uncertainties.

For every WR model, we found that it is not meaningful to invert for all parameters at once. At least, an estimate of the CF's height or the water table must be available as a-priori information. Otherwise the CF inversion cannot reliably be applied, even when the noise level is unrealistically low. The accuracy of the saturated water content is generally high with errors less than 1%. Depending on the actual noise level, the uncertainties of the other parameters are in the range of 10 to 100%, i.e., only for moderate noise conditions the CF inversion can provide WR parameters accurate enough to estimate the unsaturated hydraulic conductivity. However, the CF inversion is a first attempt to interpret MRS measurements with the focus on hydraulic parameters characterizing the vadose zone.

References

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