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Interactive comment on "Soil hydraulic material properties and subsurface architecture from time-lapse GPR" *by* Stefan Jaumann and Kurt Roth

Anonymous Referee #1

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Jaumann and Roth consider the problem of inferring for soil hydraulic properties for the situation when (1) hydraulic and electrical properties only vary with depth; (2) interface locations are known and they are horizontal; (3) the initial position of the water table is known. The data at hand are GPR traces acquired over time during a controlled variation of the water table. The experiments are carried out at the ASSESS test site, a large-scale facility for studying the use of GPR data in vadose zone hydrology with known layering, control of water table and supplementary data, such as, time-domain reflectometry data. The inversion methodology uses a 1-D solver to the Richards equation, a 2-D electromagnetic forward, and a rather elaborate (but also somewhat convoluted) optimization algorithm with little demonstration that it enables

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the localisation of global minima and that the ensemble members used provide a reasonable estimate about parameter uncertainty. One of the key aspects of this algorithm is the automatic detection of events (typically negative and positive peaks) in the GPR traces. The writing is overall good, but I also feel that the manuscript could be simplified and shortened.

1. The authors state in title and abstract that they estimate the subsurface architecture. Reading this, I expected the retrieval of 2-D or 3-D geometry of lithofacies. Instead, the authors assume a known layered system and "simply" infer for parameters in the Mualem model (and allow for some very small variations in interface locations). I find this terminology to be inappropriate, and it should be stated that the authors infer for hydraulic properties of multiple known layers. From what I understand, this is the main novelty of this work: using water table fluctuations to infer hydraulic material properties for more than one layer (2 in this case; much less significant than the statement on line 5 in abstract).

2. The authors need to put this work into context. How does the presented work improve understanding about vadose zone processes, how can the used method be used for actual field applications (not that easy given that it is assumed that everything is 1-D and that interfaces are known, which is seldom the case)? Many readers are likely to question why to go through all this trouble instead of doing the same inversion using a few TDR probes. The answer is related to larger-scale applications, but this is not handled here (only one GPR position). A clear motivation is needed in introduction and before the conclusions. In short, why should someone that is not working at ASSESS read this work and how can it advance hydrology or the use of GPR to characterise hydrology. This is not clear reading the present version of the manuscript.

3. It is disappointing to only see applications in 1-D. What is the reason for not modeling flow in 2-D, to use all three monitoring locations, and the full extent of the water table fluctuations? Is this something you plan to do in the future? Also, how to deal with the fact that the 1-D representation is unsuitable for significant drainage? After seeing

Figure 1 and 2, it is easy to be a bit disappointed when only seeing results that consider GPR position 3 and no significant drainage. The tank has a nice 2-D subsurface architecture, but it is here simplified to a known 1-D layered system.

4. Figure 1: Make it very clear in figure and caption that you only consider data from GPR antenna 3. It is somewhat confusing to see this spatial representation, while all the treatment relates to one GPR position. I would not use the term “radargram” to represent time-series of the GPR traces, as radargrams (e.g., page 6, line 7) are often thought of as a time-distance plot. Make it clear in the text that all the GPR results and simulations only model the trace at a given location over time and that no spatial information is treated (except depth).

5. Explain clearly what is meant by subscale physics. These are all macroscopic representations, so why call them “subscale”.

6. I recommend that some pseudo-code is added for the algorithm used in 2.3.4. Is the method practical for 2-D and 3-D applications?

7. 2.4 is called parameter estimation, but it is never written that the parameterization in terms of geology is assumed to be known +- epsilon. This is a very strong assumption and it would be much more difficult to solve the inverse problem if one would actually infer the “subsurface architecture”.

8. Equation 11. How are the standard deviations estimated in practice (see also page 15, line 11)? Are they due to observational errors (estimated how), modeling errors (estimated how) or purely ad hoc? Page 3, line 9: What is the implication of excluding data events for the global optimizer (simulated annealing) used?

9, lines 5-6: I don’t understand this statement at all. Is this simply related to the fact that you damp the update size or is it something else?

10, page 13, line 5: Why not estimate the source wavelet as a part of the inversion (frequency and shape)?

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11. A transition is really needed when starting 3.2.1. Write explicitly that you first will consider a synthetic test case to gain knowledge about the information content in the data and the ability of the inversion to provide a reasonable model. Explain the geometry of this model, explain how noise was added to the generated data. Similarly, a transition is needed when starting 3.2.2 (e.g., After inversion, we find that the. . .)". In Figure 9, add estimated "by inversion".

12. Work a bit on the definitions of paragraphs (e.g., page 26).

13. Reconsider the use of phenomenology in favour of more common language in hydrology:

"the science of phenomena as distinct from that of the nature of being. âĂć an approach that concentrates on the study of consciousness and the objects of direct experience."

Smaller comments (suggestions):

Page 1, line 2: Should be "Ground. . ." not "ground. . ." Replace "to" with "that is suitable to" to clarify that the GPR method was not built explicitly for this application. There are many more applications of GPR.

Page 1, line 3: Remove "precisely". It is clear that a quantitative method (pretty clear) is used, so what is precisely supposed to mean? Especially given the rather low agreement with TDR estimates for the field data.

Page 1, line 8: Perhaps explain what an "association algorithm" is.

Page 1, line 20: Replace "monitors the hydraulic processes accurately" to "is sensitive to hydraulic processes". What is monitored with a TDR is essentially the dielectric constant, which indirectly is related to hydraulic processes.

Page 2, line 6: Remove "are the easiest and" with "offer". Maybe the measurement procedure is easier, but the real work is in the modeling and inversion. Not clear to me why this mode is easier than say borehole data.

Page 2, line 12: Add “indirect” before “information”.

Page 2, line 14: add “to reproduce when used” before “for”.

Page 2, line 15: Replace “in” with “for”, remove “)”. Sentence starting on line 15 is not clear. Why is this information not as important when considering precipitation or flooding events?

Page 2, line 23: Remove “quantitatively”, this statement does not add anything.

Page 2, line 23: Remove “balance” with “are faced by an inherent trade-off between”

Page 2, line 27: A fair bit of self-referencing throughout. Why not cite some of the many other works related to GPR modeling.

Page 3, line 7: Replace “may even” with “lead to better convergence and may even”

Page 3, line 16 (and many other places. It should be “sensitive to”, not “sensitive on”.

Page 3, line 19: I know that both uses are correct, but I prefer to treat data in plural form: One datum, several data.

Page 3, line 12: Add “for porous media” before “the standard”.

Page 4, line 18: Explain already here that the reason for ignoring the large drainage event is that Richards equation is solved in 1-D.

Page 6, line 8: Why only one antenna? Why not model this as a 2-D system?

Page 6, line 15: Why conductivity at dc conditions. It should be the conductivity at around 400 MHz, typically 50% or so higher than the DC value.

Page 6, line 20: Clarify that one normally has no idea about the power of the GPR source, only some basic idea about its shape. This implies that some sort of normalization of observed and simulated traces are needed.

Page 6, equation 7. Here, the dependence of temperature is included, but it is written later that this was not done and it led to errors on the scale of one standard deviation in time. Also, how are boundary conditions in the tank modeled in the EM code?

Page 6, line 31: Use Archie to explain how big this approximation is. Depends on the differences in porosity of the sands used.

Page 7, line 4: Should be “corresponding” instead of “corresponding”.

Page 7, lines 13-14: Confusing as treatment to simulated and observed data are mixed. For example, (ii) only important for real data and (iii) only needed for simulated data. Please clarify what is done for (1) simulated data and (2) observed data.

Page 7, line 18: Is this correction valid for a dipole radiation pattern.

Page 7, line 23: “i” in italics.

Page 27, line 19: Replace "favourably" with "reasonably well".

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