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Discussions

Interactive comment on "Quantifying Shallow Subsurface Water and Heat Dynamics using Coupled Hydrological-Thermal-Geophysical Inversion" *by* A. P. Tran et al.

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The manuscript of Tran et al. address important questions that needs to be addressed for efficient and reliable integrated terrestrial Earth monitoring and interpretations using geophysical data. They couple a state-of-the-art two-phase (gas and liquid) and three-component (air, water, heat) simulator and its associated inverse capabilities with an electrical resistivity tomography (ERT) forward solver. By inferring the values of the petrophysical parameters they can use the ERT data together with point-measurements of state variables to infer various properties of the subsurface. A synthetic test example shows that ignoring the influence of temperature on the resulting electrical conductivity leads to biased estimates of hydrodynamic properties. They also

present an application to the Rifle site, Colorado, and show that the method is capable of parameterizing a subsurface model such that it can make quantitative predictions of various state variables. What I like with this paper is that it highlights both the need and the challenges of fully-coupled hydrogeophysical inversion. Clearly, multi-phase and several components must be included. This leads to many unknowns to estimate and the estimation is quite difficult to achieve due to non-linearity and the limited information content in the available data. Also, I do appreciate the attempts of using a global sensitivity analysis to enable the parameter estimation to focus on the most important parameters. I judge that this would be a very nice contribution to HESS after moderate revisions.

Comments: 1. It is a bit surprising that variations in solute concentrations are not considered. One would expect that the rainwater is much more resistive than older formation water. I realize that this is challenging, but mentioning this in the discussion as an outlook might be appropriate. Also, there is no information (at least I did not see it) about what salinity/electrical conductivity of the pore water that was assumed. I assume that a constant value was chosen. Was it based on actual water samples or was it a fitting parameter to get the right amplitudes in the resistivity model? This needs to be clarified.

2. The hydrological model contains simply two geological layers with uniform properties. Clearly, the ERT response must consider the deeper (aquitard) Wasatch formation. I assume that the authors do this, but again, this is not stated in the manuscript. In short, the model domain is different for the electrical problem and this must be clarified. Perhaps the authors embed the simulated resistivities in the fill and alluvial layer into the model shown in Figure 3a?

3. The only lateral heterogeneity in the model is due to a spatially varying interface between the alluvial fill and the alluvial layer. Clearly, any ERT delineation of this interface will be highly uncertain (especially as the water table divides the gravelly sand into a saturated and an unsaturated part. I assume that the interface was guided by an

observed interface in well TT02? This should be explained and the sensitivity to errors in this interface should be discussed in the paper.

Minor comments: Page 1, Lines 18-19: Are the measured data relatively accurate and the simulated data reproduce them (what is written) or is it the predictions that are relatively good (what I assume the authors want to write). Please correct. Also, try to be quantitative and replace "relatively" with quantitative measures.

Page 2, line 4: Perhaps "play an important role in controlling" instead of "control". Other factors control this partitioning as well.

Page 2, line 5: Is ecosystem moisture an accepted term?

Page 2, line 10: Perhaps "spatio-temporal". Reconsider the term "native". Generally speaking, this sentence would be easier to follow by clarifying what are the differences in scales between the so-called native processes and ecosystem functioning.

Page 2, line 12: I suggest to remove "direct measurements". Soil moisture is typically inferred from dielectric properties. This is not a direct measurement. Indeed, one can discuss if direct measurements exists altogether.

Page 2, lines 21-24: Data and models are not the same! Hubbard et al. (2001) integrate geophysical models/tomograms with point measurements. On line 24, add "pumping tests" as these are needed to get the average hydraulic conductivity, while the flowmeter gives relative variations.

Page 3, line 2: I think it should be "hillslope".

Page 3, lines 3-4: Unfortunately, few hydrogeophysical inversion approaches are developed to "improve quantification of subsurface processes". They are in most case only used for parameter estimation, which is something very different and much more restrictive.

Page 3, line 6: You need a qualifier before inversion, something like "hydrological".

Page 3, line 13: I don't think that "its" is used correctly here. Please rephrase.

Page 3, line 24: "at high resolution (add references)".

Page 4, line 1: This is true for near-surface applications (please clarify). Seismological stations are probably used much more for geophysics in general. I would call ERT a method, not an approach.

Page 4, line 12: Replace "and" with "which". Line 17, remove "the", line 18 change to "images". Line 26, replace "into a" with "within".

Page 5, line 7: I would remove references to Archie here. Archie defined the formation factor and the effect of saturation. However, referring to Archie implies that surface conductivity is ignored, which is not done here.

Page 6, line 8: Change symbol for porosity to be consistent with the rest of the paper.

Page 6 and elsewhere: Equations are part of the sentences, so use "," and "." as appropriate after the equations. Ensure that variables are in italics. At the moment, they are sometimes, but not always (e.g., line 19).

Page 7, line 18: Perhaps extend this aspect in the discussion? Is this a big issue?

Page 8, line 11: Why not use subscript "b", as sigma_a or rho_a suggest apparent properties and not bulk properties.

Page 8, lines 17-18: It is ok to fix the cementation index, but I am not sure if I see the argument here. The surface contribution is a constant over time while the saturation contribution is time-variable, so identifiability should not be an issue if enough variations in the states are probed.

Page 9, lines 24-29: How did you balance the different types of data? Ideally, one should have a WRMSE of 1 for each data type after inversion and using actual data errors. In practice, this is essentially never done. The ERT data are given errors of 5% to somehow accommodate modeling/petrophysical errors, but they are presented as observational errors while the actual observational errors are probably less than 1%. I assume similar common “tricks” are used for the other data types. I don’t criticize this, but some discussion about how the data were weighted and reporting the final data misfits for the individual data types should be part of the paper.

Page 12, line 3: “at the within”. Please revise.

Page 13, line 13: It should be Günther. Also Rücker when his name is used.

Pager 13, lines 15-18. This is a bit of a circular argument (a similar construct is also found later in the paper). Why not write something like: As expected, the clay-rich fill and Wasatch layers show up as less resistive layers in the ERT . . .”.

Page 13, line 18: Why not across the full ERT line?

Page 13, lines 21-22. Give references that support these values.

Page 13, line 23: This is ok for the hydrological model, but clearly insufficient for the ERT modeling. Express how you extend the ERT model and account for the Wasatch layer.

Page 14, line 2: “the meteorological”.

Page 14, line 13: Write “apparent resistivity”.

Page 14, line 14: State what this implies in terms of assumptions. Using data from a well that is not located in the modeled study area.

Everywhere: Please consider to replace “heat conductivity” with the more common term: “thermal conductivity”.

Page 18, line 14: Replace “ignorable” with “negligible”.

Page 19, line 5: It should be “reproduce”.

Page 19, line 27: Write “high apparent resistivity values”, same for line 28. Also, on line 28: replace “located deeper” with “more sensitive to deeper locations”.

Page 20, lines 1-5: This problem would not appear in a log-log plot and it would be more consistent with the error model.

Page 20, line 21: It seems impossible that the downward flux is 24 mm/s. Please clarify what this value refers to? I interpret this in the same way as a Darcy flux and this seems unrealistically high.

Page 20, line 25: Replace “to the upward flow up to” with “upward flow starting at”.

Page 21, line 5: Add “estimated” before “subsurface”.

Page 21, line 15: State how much noise was added.

Page 22, lines 22-24: This is a worthy contribution, but it seems as if not accounting for the variations of salinity is a bit limiting. The precipitation will clearly be much more resistive than the groundwater. Perhaps something to comment on?

Page 24, lines 1-4: Perhaps comment on the potential of filtering approaches/data assimilation in the context of this type of problems?

Figure 1: What are the East-West trending yellow dots. What are the green dots. Explain or remove.

Figure 2: The depth is positive with depth, so please remove “-“ signs”. Also give units and properties shown (log10 of resistivity). Add “inferred” before “fill-alluvium”. Also, explain how this was done somewhere in the paper.

Best wishes,

Niklas Linde

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