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# *Interactive comment on* "Coupled Land Surface-Subsurface Hydrogeophysical Inverse Modeling to Estimate Soil Organic Content and explore associated Hydrological and Thermal Dynamics in an Arctic Tundra" *by* Anh Phuong Tran et al.

**Anonymous Referee #1**

Received and published: 9 March 2017

Review of manuscript tc-2017-1 "Coupled Land Surface-Subsurface Hydrogeophysical Inverse Modeling to Estimate Soil Organic Content and explore associated Hydrological and Thermal Dynamics in an Arctic Tundra " by A.P. Tran et al.

General comments:
This manuscript tests a coupled hydrological/geophysical inversion scheme combining the Community Land Model (CLM) and the Boundless Electrical Resistivity Tomography (BERT) model for estimating organic carbon content as well as hydraulic and



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thermal soil parameters at an Arctic permafrost site. The inversion is conducted by combining two Markov chain Monte Carlo algorithms to infer uncertainties of the estimated model parameters. The modeling exercises are exclusively based on synthetic simulations where a set of scenarios for predicting the model parameters and the related uncertainties is investigated. The manuscript is very well written and even though it is solely based on synthetic simulations, it fits well into the scope of The Cryosphere. The applied inversion scheme is at the forefront of algorithms applied in the field of hydrogeophysical inversion so far, e.g., also considering uncertainties. While being applied in hydrological research rather frequently, to the reviewer's knowledge, it is one of the first being applied in a permafrost modeling study. The research question (estimating soil organic carbon content under freeze/thaw conditions) is challenging and justifies to test the approach based on synthetic simulations. I have one major comment that I would like to see elaborated in a revised version of the manuscript. Then I am looking forward to seeing the paper published in The Cryosphere.

Major comment:
While I am very excited by the inversion approach, I am missing a derivation of the relationship between OC and the measured state variables (apparent electrical resistivity, soil moisture, soil temperature) that should be the basis for a successful, hence, a related section should be added to the revised manuscript including the respective references. In that context I am also somewhat disappointed about the selection of scenarios chosen for testing the inverse parameter estimation as well as the related discussion because I am often missing the physical basis (= discussion of relationships between different parameters or parameters and models) – please see also specific comments below.

Specific comments:

P 1, L 2: Better use "Soil Organic Carbon Content" here.

P 1, L 17: This already relates to my major comment above but even more to the description of the physical relationships later on in the manuscript: In order to be able to estimate OC content, there must be a physical relationship between liquid water content, temperature, apparent electrical resistivity and OC which needs to be elaborated and explained clearly and which should also be the basis for defining the scenarios.

P 1, L 20: Please provide examples for land surface processes ("such as. . .")

P 1, L 24: I would prefer to use "liquid water content and ice content" here.

P 2, L 22-25: Please add references and values for all listed properties here.

P 2, L 30: Please correct "into a land surface model"

P 3, L 9: Please correct "used a single dataset"

P 3, L 14-26: There are also numerous studies from Europe and Asia that use geophysics to study PF processes which should be honored in this short review as well.

P 4, L 10: Please correct "freeze-thaw", however freeze-thaw does not necessarily require the presence of snow

P 4, L 15: Which property? Please clarify.

P 4, L 32-33: Here the authors refer to the dependence of apparent resistivity to ice/liquid water content and soil temperature. I completely agree. But where is OC?

P 5, L 25: Here the authors use theta as variable for the parameters. In the appendix the same variable is used for soil moisture. I suggest to choose another variable for the parameters as most of the readers of TC will be used to theta as variable for soil moisture.

P 6, L 26: Please number figures in the order they appear in the manuscript.

P 6, L 27: I think this should read "in the topsoil active layers".

P 7, L 8 to end of section: I suggest to move this part of the section to the results

section. I think the important message from this exercise is that porosity needs to be considered in the model as soon as OC and mineral content are distinguished. I suggest to draw this conclusion and design or select the scenarios accordingly.

P 7, L 24: Replace “the figure” by “Figure 2”

P 7, L 29: Please correct “depend”

P 7, L 30: Please correct “to a quick change”

P 8, L 6: The authors chose to use Archie’s Law here (please add reference). I am not an expert in ERT analysis but is it also applicable for soils with high OC? If yes, the relationship to OC would be in the porosity and the soil electric conduction (OC being a volume fraction of soil matrix then). How does Archie’s Law deal with ice content (reduced porosity with ice in fact being a part of the soil matrix now)? As far as I see, ice content is only considered to calculate pore water conductivity but no changes in porosity. I would like to ask the authors to elaborate on that in this section.

P 8, L 27: Does this formula also apply to organic rich soils? Pleas add a reference.

P 9, L 12-16: Long sentence and difficult to understand. Can you split it into two?

P 13, L 3-6: This information is not essential for the manuscript and can be removed. (L5: Please correct "used“.)

P 13, L 16: This is not so relevant for the synthetic study but probably for real-world cases to be carried out in future: As we are dealing with soil layers here, is it really reasonable to interpolate the measurements? Often we observe distinct soil horizons and also very distinct "jumps" in soil properties at layer boundaries and more constant properties along the different soil layers. Another aspect: how would ERT measurements have to be inverted considering gradients in layer properties? Please rethink whether interpolation is reasonable here.

P 13-14: Scenarios: As already stated in the general comments I am a little wondering





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about the chosen scenarios. It would be helpful if to each set of scenarios a short explanation would be added why exactly these scenarios were chosen. In that context, I have the following questions which I would like to ask the authors to elaborate in the revised manuscript: Where is the relationship between OC and apparent resistivity in scenarios 1 and 2? Maybe this requires further explanation but as far as I see, in Archie's Law (eq. 4) OC primarily contributes to sigma via porosity and the soil's electrical conduction (which is fixed in this case however). So you basically vary a parameter in Archie's Law (or the BERT part of the scheme) whereas the "true" OC is modeled in CLM. How does that work? Is it reasonable to use electrical resistivity only as target variable? P 16, L 5-7: "This indicates that the apparent resistivity data is insensitive to OC content at z=0.6 m. This is reasonable, because this depth is within the permafrost (see Figure 12), where temperature insignificantly changes over time." > so apparent electrical resistivity depends on temperature but not on OC?

P 14, L 26-31: It would be nice to have the time series plots (cf Figure 12) already here including the apparent electrical resistivity data. Why didn't the authors decide to use the same time span for temperature and liquid water content? The changes in moisture and temperature (expept for layer 1) are rather low which I presume to be the main reason for the large uncertainties discussed later on. Hence the set of measurements is not really ideal for testing the inversion scheme. In order to obtain good parameter fits, the ranges in state variables where the model is fitted to should be large. Unfortunately this applies then to all tested scenarios.

P 14, L 26: I guess, this should be figure 11?

P 15, L 8: please correct: "uniformly"

P 15, L 15: Please correct "...8 and 9 is larger..."

P 15, L 20: Please correct: "influence of measurement error"

P 15, L 21: delete "of"

P 16, L 21: Please correct: “jointly”

P 16, L 23-25: "These synthetic experiments suggest that given this depth is located within the permafrost (see Figure 12), the apparent resistivity, liquid content and temperature data are in-sensitive to OC content.“ Why? Please explain. I presume the uncertainties are so large because there are almost no changes in state varibles the model is fitted to.

P17, L 9-17: I do not understand Figure 9. Why is ist reasonable to test correlations between all estimated parameters? What determines when a paramter is reliably estimated?

P17, L 29: remove "are“

P 17, L 31: So do "thermal parameters“ mean ice content here?

P 18, L 18: Please correct "confidence interval“

P 18, L 26 to end of paragraph: Figure 12 is missing in manuscript.

P 19, L 30: Please correct "in a 1-D soil column“

P 20, L 5-7: Again: Here the authors relate the large uncertainty to the missing range in tempera-ture and moisture. However, again: Which are the properties that are related to OC? It’s neither directly temperature nor moisture.

P 9, L 9-10: This sentence needs a more detailed explanation. Which property influences which state variable in which way?

P 20, L 13-15: Also here a more detailed conclusion would be helpful: In which way does the joint inversion help to constrain the model? How to the various measurements and models contribute here?

P 20, L 17-19: ... and the small range in "measured“ soil moisture states.

P 21, L 1-2: This information is not relevant for the study and should be removed.

P 21, L 4-11: Also not relevant here – please remove.

References: Please check references for typos, also check that the European "Umlaute" are in-cluded in names (e.g. Etzelmüller)

P 22, L 13: only cite papers which are at least accepted

Appendix A: Definitions for most oft he parameters are missing.

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