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Interactive comment on "Large-scale ERT surveys for investigating shallow regolith properties and architecture" *by* L. Gourdol et al.

Anonymous Referee #2

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"Large-scale ERT surveys for investigating shallow regolith properties and architecture " By Laurent Gourdol, Rémi Clément, Jérôme Juilleret, Laurent Pfister, Christophe Hissler

General comments

Quite well written, with deep numerical and field application studies as well as practical consequences for geophysicists, this paper deals with CZ regolith thickness characterization with ERT, issue that is a very important problem for geophysicists because they have to "deliver" reliable geometries for hydrological modelling. It is of interest for hydrologists. The paper doesn't perfectly fit with HESS journal* because, basically, it is a good technical paper dedicated to geophysicists who want to improve the geometry knowledge of some regolith structures in one dimensional situations, with an original

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Discussion paper

approach. This objective is important for the community of Critical Zone, because regolith structure and thickness/properties are key parameters. Taking into account the above remarks, I would suggest the authors either a) to change their introduction to draw more attention to the implication of their study for hydrology and probably, in the discussion part, develop more arguments to show how their geophysical method improvement brings a definite advantage compared to large ESI survey for getting more accurate results for hydrological modeling (i.e what is the sensitivity of hydrological model to thickness determination of the regolith) b) Submit their paper to a more specialized (geophysical) journal. An alternative way would be to present the paper as a case study explaining more about the site and its hydro(geo)logy, then presenting the complete survey (all 2m ERT lines), and the difference in regolith volume with and without shallow interpolation, and the consequence in the hydrological modelling. *"fundamental and applied research that advances the understanding of hydrological systems, their role in providing water for ecosystems and society, and the role of the water cycle in the functioning of the Earth system".

Specific comments (see also pdf annotated manuscript for notes location and other comments)

Title "Large-scale ERT surveys for investigating shallow regolith properties and architecture ": I would suggest to remove the word "shallow" because the paper deals also with deep interfaces. Also, the word "large scale" is not adapted because you deal also with small scale surveys that are entire part of your methodology. At last, "properties and architecture" is not adapted: what is it exactly "properties" and "architecture"?: consider re-formulating the title.

Abstract Note 1 : The sentence :"However, ERT measurements with a high vertical resolution remain restricted to shallow depths, essentially due to the requirement of small electrode spacing increments (ESI)" should be modified: High vertical resolution is effectively restricted to shallow depths due to the intrinsic physics of the method, not to the electrode spacing. Diminish electrode spacing is a "only" way to get more dense

shallow current lines with a better lateral sampling and thus improves the capacity of the method to describe shallow electrical structures. Note 2: " . . . a thin surficial layer can influence inverted ERT results ïČŸ Please describe briefly this influence "and cause a resistivity bias, " ïČŸ idem ". . .both at the surface and at deeper horizons. To overcome this limitation, we propose adding interpolated levels of surficial apparent resistivity based on a limited number of ERT profiles with small ESI". ïČŸ This sentence is quite unclear : what "interpolated" means?

Introduction Note 3: "Conventional investigation techniques": conventional is too vague. Geophysics could also be "conventional", at least used by many CZ teams on watersheds Note 4: "The characterization of subsurface properties and the delineation of layer boundaries. . ." the word "layer" may not be appropriate: it refers to layered ground. ERT is more dedicated for 2D and 3D structure. You should consider change this word throughout the all text. Or explain why you are using ERT for 1D structure instead of "vertical" electrical soundings. Note 5: "In many cases, the subsurface structure to be characterized is shallow and should be measured with a precise vertical resolution, thus requiring a small electrode spacing increment (ESI) (Reynolds, 2011; Chambers et al., 2014)". This statement, already written in the abstract, makes me quite confusing. And as it is the main motivation of the paper it requires to be explain. âĂć All the subsurface structure should be ideally characterized, whatever the depth, not only at shallow depth. . . âĂć "precise vertical resolution": what is "precise" to you? âĂć And "vertical"? âĂć "thus": this is probably the confusing word: the link between electrode spacing and the vertical resolution at depth does not exist. Small electrode spacing allows to describe more precisely shallow structures. âĂć You should rewrite as follows, as a suggestion (?): "When shallow structure are under interest, we need to consider small electrode spacing. However, when making long (large) surveys, small electrode spacing are not considered because it is time consuming. Therefore the questions rise: are deep structures well defined (within the limits of the intrinsic limitation of the method that is a decrease of the resolution with depth) if the shallow structure is not well sampled? How can we enhance our knowledge of shallow struc-

tures when making long survey? Note 6 : here you are announcing a layered model. It is not clear why you are dealing with 1D model using a 2D-3D measurement protocol-method. Again, why don't you use only a "vertical" electrical sounding? You should explain somewhere why the 1D geometry is under study.

Material and methods Note 7: "To cover a sufficiently wide range of subsurface structures and properties," Actually, the reader doesn't understand exactly from which situation those models are derived. When talking about "structures", it is actually only "layers". The range of resistivity has also to be explained: what could be the soil characteristics you are considering? In short: why you choose a) a 1D model, and b) such range of thicknesses and resistivity values? You should more clearly say that your model are derived from a field question. And therefore, the case you are dealing with is a specific one, and the conclusion derived will be related to your case study and similar structures Note 8: "the vertical resolution needed to properly characterize the subsurface". You need to explain what you are considering with "vertical resolution" and "properly". It is compulsory to understand what objective you are targeting. Note 9: "ERT survey design": the design is also derived from synthetic modelling or not? If yes, say it. Note 10: the processing of field data is very well described. However, this part should be reduced to shorten the paper, because there is no technical implication for the presented study: ie. the conclusion of the paper doesn't depend on this careful process, apparently. If I am wrong, ignore my remark. Note11: those effects have not yet been described, and the reader is expecting such a description much earlier to be convinced that your work is important. Note 12: "We use these subsets to fit four linear regressions between the apparent resistivity data for external electrodes separations of 1.5, 2.5, 3.5 and 4.5 m respectively, and those of the first acquisition level measured with an ESI of 2 m." The problem here is to understand, without figure, how you propose to "fill" the 2m spacing data sets with additional extrapolated data. The concept of "linear regression" in particular is not clear because apparent resistivity data values (see a 1D sounding curve, and see several curves with different contrasts) doesn't follow linear behavior with increasing electrode spacing. A figure, or a scheme

is necessary. Consider also the case with a conductive second layer: in this case, the resistivity of the second layer could have an influence on the regression : is it still linear? Moreover, this part regarding the filling of sparse data set could be explain later in the paper, once the reader has discovered the synthetic ERT results. Note 13: inversion process description. One of the main question also is the size of the triangular cells you considered. What is the influence of the meshing to the resolution of the shallow subsurface? As shallow resolution here is the main point, you should tell more about this.

Results Note 14: The presentation of the results is clear. There is very little difference between the 2 arrays presented. Therefore, I was wondering if the presentation of only one array could be considered, to shorten the paper. The difference between the two arrays could be explain with one figure comparing the results of the two arrays for some situations? Note 15: The fact that in case of low resistivity contrast the inversion artefacts are higher should be explained by the influence of noise. You may conduct a short study on this point: take a model that display the worst results, take the original synthetic apparent resistivity data, add noise to those data with an increasing noise level (say 0.5, 1 3 and 6%) and invert: do the artefacts increase? If yes, the influence of noise into the artefact production should be explained: the lower resistivity contrast and higher noise, the worse artefact? Note 16: do those overall estimation values coming from the inversion parameters? Choosing a different lambda changes those values? Note 17: In figure 5 and in the text, you use the term "external electrode separation": not so clear may be you should explain that it is the "minimum array extension" (3x0.5 = 1.5m etc) and remind to the reader the corresponding ESI Note 18: Figure 5 again: the value with 6m should be close to the values with 4.5 m (in red crosses). But it is not the case. Why? Note 19: You are assuming that, following your results of Figure 5, that the apparent resistivity at 6m is linearly proportional to the apparent resistivity at lower ESI. From the geophysical point of view, this may be not true. What is possible to say is that the apparent resistivity at low ESI can be derived from ESI 6m assuming a linear interpolation for your models. And uniquely for them? I.e we could find layered models

that will display non linear relationship especially when having a conductive second layer. So you explore if other combinations of model (resistive/conductive/resistive for example) as well as different thicknesses of the solum could change the regression logic and what could be the consequence for the study. Note 20: "Nonetheless, overall, the inaccuracy remains considerable, as shown by similar dispersion of resistivity ratio distributions, regardless of whether the ERT images were inverted from standard (Figure 10-a) or upgraded (Figure 10-b) apparent resistivity datasets using an ESI of 2 m. " This inaccuracy should have a considerable consequence for hydrological modelling? Finally, even if the enhanced 2m ESI ERT with additional interpolated data improve the solum /subsolum definition, is this improvement so important for hydrological modelling with regards to the overall inaccuracy of the ERT method that smoothes a lot the resistivity patterns?

Discussion Note 21: Âń We ideally recommend using an ESI that is close to the thickness of the top subsurface layer in ERT surveys to mirror the architecture and properties of the subsurface correctly. This choice is relevant to characterize not only the shallower layer, but also the subsurface in its entirety – even when solely aiming for the characterization of deeper layers." The first reason makes this recommendation evident = "You want to define the first layer? Go for small ESI!" The second reason is definitely the good result of the study = "You want a correctly defined deep layer interface? Go for small ESI also!" However, this conclusion is, for now, restricted to your regolith logic only. The study of the reverse case (resistive/conductive/resistive, very common also in some parts of the world) should be carried out to confirmed (or not) this recommendation. Saying this, I understand that I am asking to add more modelling work. This work can be partially undertaken in the discussion part only, by modelling only few well-chosen cases, then derived the (same?) conclusions and saying that this recommendation can be extrapolated to other regolith resistivity patterns or saying that the recommendations you give are restricted to your regolith pattern only, and proposing to the geophysicist to apply the same methodology for is own case.

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2018-519/hess-2018-519-RC2-supplement.pdf

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Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2018-519, 2018.