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Interactive comment

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

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We would like to thank the Anonymous Referee #1 (hereafter AR1) for the review of our manuscript. AR1 qualifies our study as well carried out and documented - representing a very nice example of experimental design. We would like to thank her/him for that encouraging appreciation. We also identify in AR1's review three main and one minor concerns about our work. They are listed here below, alongside our responses.

1 – AR1 states that the geological structure investigated in our paper is "very specific" (see sentence 1 of the main text) and the innovation in our manuscript is limited to this specific setup (see sentence 5 of the main text).

We do not fully subscribe to this statement. It is correct that we do not consider several

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geological structures (for instance, models intended to represent a fault, a buried river channel or dipping blocks and so on) but only one. The structure we focus on in our synthetic modelling exercise is a tabular three-layer model designed for imaging shallow regolith (i.e. the target of our work) such as the one of the case study investigated. We believe that this structure is not "very" specific as it represents a typical regolith sequence of soil–saprock/saprolite–bedrock that mirrors the subsurface of many natural contexts (as documented in our paper). Moreover, based on this three-layered subsurface conceptual structure, we investigated several resistivity and thickness values in order to cover a wide range of regolith properties. In total, 25 conceptual models with varying resistivity and thickness contrasts were investigated. Last but not least, we also want to trigger the interest for such geological structures in hydrological process research. Indeed, as documented in our work, there is a pressing need in catchment studies for precise characterizations of the geometry and properties of regolith (for instance, factors such as the depth and composition of the soil cover and the degree of rock weathering determine water pathways, residence times in the subsurface and subsequent interactions with surface water bodies). In this sense, our paper focuses on the potential and the limitations of large scale Electrical Resistivity Tomography (ERT) surveys for this purpose and we believe that our work can be of interest for the research community targeted by HESS.

2 – AR1 expresses that the originality and the innovation inherent to our work do not seem sufficient to support the publication of our manuscript and, at best, propose to restructure our article into a technical note, likely in a different journal (see sentences 4, 6 and 7 of the main text). But, AR1 admits also that she/he may have missed some elements, which may ultimately have led to an incomplete understanding of the manuscript (see sentence 7 of the main text and minor comment 3). Consequently, AR1 asks for further clarification in this sense if possible (see sentence 8 of the main text).

We believe that our research work leads to results and findings which are of interest

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and use for the research community targeted by HESS in terms of both, originality and innovation and we will try to summarize why below. As a reminder, the objective of our work is twofold.

First, our work documents how the ill-posed inverse problem effects relate to the Electrode Spacing Increment (ESI) parameter and which is the most appropriate value for accurately characterizing the entire regolith. Of course, as said in our paper, it is well-known that inverted ERT image accuracy decreases with increasing ESI and that previous research already makes it possible to estimate the accuracy that can be expected with regard to the ESI. We agree with AR1 that our study could be considered as just as another example showing that the choice of the ESI is fundamental for obtaining accurate results. However, to the best of our knowledge, no study has documented so far in detail from which ESI threshold, why and how the effects of the ill-posed inverse problem significantly affect the inverted ERT images for such a typical regolith structure. In that sense, we believe that the new findings exposed in Section “4.1 The ill-posed inverse problem effects posed by ESI parameter related choices” (key role of resistivity and thickness contrasts, abrupt degradation of the accuracy after exceeding a threshold value corresponding to the thickness of the uppermost layer, induced bias affecting the resistivity distribution and the interface delineation for both the shallow and deeper horizons of the subsurface) can be considered sufficiently original and of interest for the hydrological sciences community that requires precise characterizations of regolith geometry and properties.

The innovation of our work lies in the second aspect of our study that focuses on the issue “What can we do if we still have to use a larger ESI?” This problem is particularly important for large scale ERT surveys (such as catchment scale studies) that could be really cost and time-consuming if a too small ESI is used. To overcome this limitation, our work proposes a new approach to reduce the ill-posed inverse problem effects for carrying out large-scale ERT surveys with a large ESI. Indeed, in the event of an ERT survey carried out with a large ESI – and for which the first acquisition level (i.e. quadrupoles whose external electrodes separation is of the smallest possible extension) does not directly give information on the resistivity of the subsurface structure's top layer (in our case the solum), we propose to take advantage of the correlation between this first acquisition level and additional surficial apparent resistivity acquisition levels (i.e. quadrupoles with smaller external electrodes separations) obtained from a reduced number of ERT profiles with a smaller ESI. If the top layer has a rather constant thickness and resistivity, the correlation could then be transposed to areas where the larger ESI have been used and where data gaps prevail in the shallow subsurface. This novel approach is described in section "2.3 Upgrading apparent resistivity datasets measured with a large ESI". Note that in our manuscript we made the mistake of not highlighting the title of this section as the other titles (title in normal text instead of bold, no extra line spacing before and after the title). We apologize for this as it may mislead readers (this section could unfortunately be understood as a part of the previous section!). Indeed, a careful reading of this section is necessary for an overall comprehension of our manuscript (for instance to understand Figures 5 and Figure 9 showing, respectively for the synthetic and the field datasets, the good correlation between the first apparent resistivity acquisition level using an ESI of 2 m and the four selected surficial apparent resistivity levels acquired with an ESI of 0.5 m; see minor comment 3). Using our two synthetic and field datasets (see respectively sections "3.1.2 Application and assessment of the proposed approach to upgrade ERT datasets" and "3.2.2 Comparison of standard and upgraded ERT results obtained using an ESI of 2 m"), we demonstrate that this new protocol significantly improves the accuracy of ERT profiles based on large ESI. It is thus promising for carrying out large-scale surveys (such as catchment scale surveys) in a cost-effective and more robust way ("4.2 Potential and limitation of the upgrading procedure proposed in this study").

3 – In her/his review, AR1 asks if any noise was considered in our synthetic case (see minor comment 1). She/he stresses that maybe we are not paying attention to measurement noise (see sentence 6 of the main text) and suggests that potential noise effects should be included in the discussion (see minor comment 1).

It is correct that measurement noise (due to either field characteristics, electrode arrays, magnitude of measured potentials or electrode spacing errors) can impact the accuracy of inverted ERT images as pointed out by several authors (e.g. Labrecque et al, 1996; Zhou and Dahlin, 2003; Dahlin and Zhou, 2004; Hilbich et al, 2009). In our study, we focus on the assessment of ERT images regarding the ESI parameter and that is why we do not put the emphasis on noise effects in the discussion. That said, we nevertheless pay attention to the noise characterizing both synthetic and field datasets. We consider that the noise is not a major control on our inverted ERT images accuracy. Indeed, as mentioned in section “2.1 Synthetic resistivity dataset” of our manuscript (see 2.1.2 Forward Modelling, ERT arrays and units of electrode spacing; page 4, lines 22-24), to achieve a realistic (but of good quality) synthetic dataset reflecting the properties of a field survey, we applied a systematic Gaussian noise distribution with 3% standard deviation relative error to the apparent resistivity dataset to simulate the noise commonly recorded with the resistivity meter. Note also that we took care to check/ensure the "good quality" of apparent resistivity measurements done in our case study. Indeed, as mentioned in section “2.2 Field study” of our manuscript (see 2.2.2 ERT survey design, data collection and processing; page 6, lines 17-26), measurement precision and accuracy were characterized based on the analysis of standard deviations obtained for repeated measurements and standard errors calculated for normal-reciprocal measurements pairs. Even though the overall quality of the data was good, a cleaning procedure was also applied (rejection of obvious outliers, quadrupoles presenting a measured potential lower than 10 mV or a standard deviation of the repeated measurement higher than 3%).

4 – AR1 writes (minor comment 2): “While the manuscript is well written, I do not understand why the authors insist on using the term "mathematical criteria". Isn’t it trivial that this is math? Defining chi would be much better (not to mention using the Greek chi instead of the textual chi)”

If our paper is accepted for publication in HESS, note that we will avoid the term “mathematical” to talk about the chi^2 criteria and will use the Greek chi instead of the textual chi. As AR1 suggests, we will also define in section “2.4 Inversion procedure” why chi^2 is used to assess the adequacy between the model response and the observed apparent resistivity (while the root mean square misfit error is the normalized root mean square of the data fit and should be in the range of the relative data error, chi^2 is a measure on how good a model fits the observed data for a given data error and thus this measure scales with the error).

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