"In-situ estimation of soil hydraulic and hydrodispersive properties by inversion of Electromagnetic Induction measurements and soil hydrological modeling" - authors' responses to suggestions and comments made in Public Discussion and Editor requests.

Dear Editor and Reviewers,

Following your comments/requests we have substantially rewritten the manuscript. Therefore, it became difficult to provide a marked-up version of our revised manuscript. In order to facilitate your revision process, we have re-aggregated in 9 main items the many questions raised in the revision process. These answers should be combined with the answers we have already given in the public discussion.

Sincerely,

Mohamad Farzamian

on behalf of all authors

1) Plot scale vs field scale vs large scale

We gave detailed answers in the first round of the revision process. We recognized that we mixed the concepts of plot vs field vs large scale of application, generating confusion in the Reviewers. Accordingly, we have thoroughly revised the manuscript making clear that our methodological proposal applies at plot scale. The scaling-up from plot scale to field scale is promising, due to the potentiality of the EMI technique, but it is beyond the scope of this paper and we only addressed this potential in the last paragraph of the conclusion.

2) Coupled vs uncoupled approach

We gave detailed answers in the first round of the revision process. A synthesis of the discussion on this issue was added to the new version of the manuscript in the subsection 5.1.

3) Experimental setting

Throughout the manuscript we have inserted all the information/corrections as requested by the Reviewers and Editor concerning the dripper line, the amount of water deployed, the EC of the soil water, the lateral flow, the uniformity of the infiltration over the plot area, the scheme of Figure 2, and the laboratory analyses.

4) Synthetic experiment

We have already answered in the first round of the revision process. Here we would better explain why we decided to not carry out a preliminary synthetic modelling experiment, which was specifically asked by Reviewer 1 in order to: 1) drive the EMI inversion and 2) drive the parameter estimation in the hydrological inversion. Actually, Reviewer#1 stated: "*A synthetic modelling experiment would help to support the presented results. It would not only help to confirm that the uncoupled inversion approach is able to provide realistic parameter estimates, but it would also help to address other concerns addressed in the specific comments below, such as the information content of the measurements to reliably estimate 8 hydraulic parameters of two different layers from the limited number of available measurements, as well as the separation of the solute and the infiltration front*".

Firstly, as for driving the EMI inversion, we want to stress that with the proposed methodology, we aim to obtain the soil hydraulic properties <u>by only using EMI</u>. This main objective was not sufficiently clear in the old version of the manuscript, leading to some confusions. In order to drive the EMI inversion by a synthetic experiment, it would be necessary to know in advance the hydraulic properties of the soil layers in the profile under investigation. This is somewhat contradictory, since the aim is to use EMI for this purpose.

The second point of the question is not completely clear to us. We miss the relationship between the preliminary synthetic experiment and the number of parameters to be estimated in our uncoupled approach. Because we have not used a coupled approach in which the ECa data are involved directly in the approach; EMI models were converted to water content which were then used in the simulations. The preliminary synthetic experiment in such uncoupled approach that we applied may address the uncertainty of the hydraulic parameter's estimations from water contents data: whether this number of (only) water content data is sufficient to estimate the vGM parameters and what is the uncertainty associated to this estimation. This is beyond the scope of this paper and has been widely addressed in literatures.

The objective of the paper is to propose a methodology using EMI for obtaining the hydraulic properties of the soil profile at plot scale. In order to evaluate the reliability of the parameters obtained from the procedure using only EMI, we compared these estimations to the parameters obtained by monitoring the same process by using TDR and tensiometers at different depths. The latter are, to us, the reference properties, which were obtained by inversion using 11 water contents and 11 pressure heads for each layer and representative of the whole infiltration experiments. To make this clearer, we added in the text a graph comparing measured and simulated pressure heads to the graph of water contents already present in the first version. It is difficult for us believing that a synthetic experiment could add more information to these considerable, at least for a field experiment, number of real TDR and tensiometer measurements.

5) **EMI inversion procedures and issues**

Throughout the manuscript we have inserted all the information and clarification as requested by the Reviewer#1 concerning 1) the ECa calibration in response to general comment 3; 2) the spatial and temporal constraints, initial model and choice of regularization parameters in section 3.4; 3) the misfit information observed in Figures 3 and 9; and 4) background information from EMI data in the first experiment (Figures 3, 4, 9 and 10). We also included the reference of van't Veen et al. (2022) as suggested by Reviewer #2 in the subsection 5.3 "EMI-related sources of uncertainty" as we believe such approaches can be useful to optimize the EMI configurations.

More clarifications about the first two points:

1. Correction of EMI inversion for expected shifts and offsets: We have detailed our answer in our first round of the review process and added information and justification in the new version of the manuscript in subsection 5.1.
2. The number of layers (i.e., 7) and thickness of initial models' layers were selected based on the number of ECa measurements (i.e., 6) and investigation depth of the sensor. To test the inversion algorithm and finetune the regularization parameters, we performed several syntenic scenarios based on our expectations from spatiotemporal variability of σ_b. Note that no hydrological synthetic simulation has been performed in this regard as we clarified it in the previous point. This cannot provide quantitative information about the uncertainty connected to the inversion process, but provides a better insight into the reliability of inversion process and overall uncertainty in resolving the evolution of conductive zone (i.e. due to water and solute infiltration) over a very resistive soil with shallow bedrock. We thoroughly revised the section 3.4 and included the requested information and provided brief information about how these synthetic scenarios were selected. We also dedicated the

new inserted subsection of 5.3 “EMI-related sources of uncertainty” to the sources of uncertainty related to the inversion process.

6) **Inversion procedure for hydraulic parameters estimation**

The issue about how the inversion procedure was applied (e.g., initial conditions) and which results came out was posed in several points by the Reviewers. Due to its significant role in the manuscript, in the following we gave more details on this point:

The parameters were determined separately for each horizon of the profile. This is the main advantage of the uncoupled model allowing to characterize each layer separately.

Concerning the bedrock properties, they were known from previous characterizations. Thus, the bedrock hydraulic parameters were not estimated by the inverse procedure but were fixed to the known values.

As for the initial condition in the inversion procedure, we set it in terms of pressure heads measured by the tensiometers. The pressure head in the bedrock layer was assumed to be in equilibrium with that measured at 40 cm.

We have provided more details on the initial conditions in the text adding the Figure 7 with the pressure heads as measured by the tensiometers. In the same Figure we have also reported the pressure heads simulated in the inversion procedure.

All of this information and clarifications were added to the revised version of manuscripts.

Furthermore, there was a comment by the Reviewer: “Line 432: *I wonder whether this can be interpreted as a separation of the infiltration front and the solute front.*”

The suggestion by the Reviewer may actually be physically plausible, even if it can be only supposed from the information we have available. Firstly, the differences in the background conductivity between figure 9 (figure 10 in the revised version) and figure 4 comes mostly from the different scales used in the two graphs. Furthermore, in order to see a separation of the water and solute fronts one should use many more sensors (for example TDR probes, able to "see" both water and solute fronts) at many depths, which is not our case.

Finally, there was a request of clarification on the number of layers used for the inversion (Line 391). We decide to use the data of only two depths in order to produce the best fittings of the EMI-based water contents at the same depths as explored by TDR sensors.

7) Table 1 revision

We realized that the Bw label used in the Table 1 may have been misleading. Actually, with A and Bw we are indicating the horizon including the 20 and 40 cm depth, respectively. So, in the table the Ap and Bw soil layers should be seen as 20 and 40 cm depth. For these two depths, the dispersivity values are different.

The bedrock parameters were not shown in the original version of the Table 1. For the sake of completeness, we have reported them in the new Table 1 of the revised version of the paper. However, we have clearly reported in the table that the parameters of the Ap and Bw horizon were those estimated by the inversion procedure (the objective of the paper), while those of the bedrock were taken from the literature, according to a hydrological characterization performed on the same bedrock. Labels in the table were changed to make them consistent with the text.

Finally, concerning the values of the bedrock parameters reported in the Table 1, we recall that it is a fractured calcareous rock, which is relatively highly conductive at or close to saturated conditions, because of the activation of fractures.

8) New figures and new information

The water content values at the start of the experiment were reported in the new version of the manuscript.

A figure (new Figure 7), showing the pressure head values measured during the infiltration experiment, was added to the text. From this new figure we answer to the following requests of the Reviewers: 1) the initial condition, as measured by tensiometers, applied for the inversion procedure performed by HYDRUS 1D; 2) the simulated pressure heads obtained by the HYDRUS 1D inversion procedure.

The error bars for both the σ_b as measured by the four TDR sensors and the pressure head as measured by the tensiometers were reported in Figure 5 and Figure 7, respectively. Furthermore, in the new figures we have added the value at t=0.

9) Better writing, explanation, sentence positioning and references

Several requests concerned sentences that were not clear. Many were reformulated in the new version of the manuscript. Specifically, those of line 17, 21, 70, 105, 159, 210, 218, 287, 379, 380, Figure 7, as requested by the Reviewers in the first round of the revision process.