

AUTHORS' RESPONSE TO THE REVIEW COMMENT
ANONYMOUS REFEREE #3

Manuscript **hess-2016-93** entitled

“Repeated electromagnetic induction measurements for mapping soil moisture at the field scale: validation with data from a wireless soil moisture monitoring network”

by Edoardo Martini, Ulrike Werban, Steffen Zacharias, Marco Pohle, Peter Dietrich, and Ute Wollschläger

We would like to thank the anonymous referee #3 for his/her comments. In the following, we addressed all the comments.

Reviewer's comment

“The authors have acquired a valuable dataset of EMI repeat surveys taken over a period of more than one year and have expended some effort with calibration and drift issues. The authors conclude, as many others recently have before them, that the EMI data do not simply indicate soil moisture, as traditionally held. Instead, apparent conductivity is, as one would expect, a complicated function of many soil and hydrologic parameters.”

Authors' response

We do agree about the fact that other studies have concluded that ECa data do not simply indicate soil moisture but are rather the result of a complex interplay of many properties and states. Nevertheless, the EMI method remains commonly used also for mapping soil water content. A clear picture of this fact is provided in the recent publication by Calamita et al., 2015 (table 1), as we discussed in the manuscript (introduction section, Page 3, Line 32 to Page 4, Line 6). As in response to other reviewers' comments, we would like to remark that, although the comparison between EMI-measured ECa and point measurements of soil water content was done by several other studies, in most of those studies no time series data and no depth-dependent temperature measurements for ECa correction were available. Hence, we believe that our study provides an extensive dataset which allows more solid investigation of the relationship between ECa and θ .

From our point of view, the complexity of EMI data is too often ignored and the numerous issues related to the use of EMI for mapping of soil moisture are not always illustrated clearly. This may generate confusion due to the fact that proximal soil sensing techniques are used for a variety of scope and there is a risk to interpret ECa beyond the limits of its applicability, resulting in misinterpretation. We believe that this situation demands proper attention, and we tried to

contribute to a more clear illustration of the EMI method using experimental data to show its evident potentials as well as its clear limitations.

Reference:

Calamita, G., Perrone, A., Brocca, L., Onoratic, B., and Manfreda, S.: Field test of a multi-frequency electromagnetic induction sensor for soil moisture monitoring in southern Italy test sites. *J. of Hydrology*. <http://dx.doi.org/10.1016/j.jhydrol.2015.07.023>, 2015.

Reviewer's comment

"The authors claim that they would like to interpret the EMI data in terms of vadose zone dynamics. There is a crude attempt to do this, by separating the time series into different epochs, i.e. wet and dry, and different parcels of land, the slopes and the valley bottom. There is an elementary use of Spearman's rank correlation to compare soil water content, in various guises, with EMI apparent conductivity."

Authors' response

We agree with the reviewer that the interpretation of vadose zone dynamics is rather crude and could have been done better if this would have been the primary scope of the paper. In our case the primary scope was to compare a time series of EMI measured ECa with the data from the soil moisture monitoring network (see title *"Repeated electromagnetic induction measurements for mapping soil moisture at the field scale: validation with data from a wireless soil moisture monitoring network"*). Hence, initially, we did not aim at a complete interpretation of soil water dynamics using EMI data as the reviewer suggests. However, the analysis of the data helped us to find indications for the different dynamics observed in the ECa and soil moisture measurements which are based on hydrological process understanding. The Spearman rank correlation coefficient is a very simple statistical coefficient, widely used in temporal stability studies (see Vanderlinden et al., 2012). Although it is a simple one, it was very useful for our scope, i.e., investigating the temporal persistence of the spatial patterns of ECa and soil moisture.

Reference:

Vanderlinden, K., H. Vereecken, H. Hardelauf, M. Herbst, G. Martínez, M.H. Cosh, and Y.A. Pachepsky: Temporal stability of soil water contents: A review of data and analyses. *Vadose Zone J.* 11(4). doi:10.2136/vzj2011.0178, 2012.

Reviewer's comment

"In general, however, I don't think in the end much was learned about the capability of EMI data to resolve vadose zone dynamics. Moreover, I am not actually sure what is the take-home message of this paper and, for that, I give the work a rating of "fair." I am not totally convinced there is a publishable result here, which is very surprising given the high quality of the dataset and the painstaking analysis that has already been done. Authors need to extract more compelling insights and convincing lessons from their dataset before this work could possibly be recommended for publication."

Authors' response

Unfortunately, the reviewer's criticism is very general and gives little guidance that could help us to locate main critical points.

We believe that the study presented in this manuscript contains important results and derived insights. Part of the results is related to the factors controlling ECa for the Schäfertal hillslope site. It is widely accepted that results of EMI surveys are site-specific; hence those findings are relevant only for future experimental and numerical studies to be conducted at the site and at similar landscapes. These results will be a valuable contribution for the many scientists involved in the hydrological observatory of which the Schäfertal is part.

But the main message that we would like to deliver with this paper is of more and broader interest for the scientific community.

First of all, with respect to the majority of the published papers on the use of EMI, in our opinion we provided a more complete overview of the possible issues related to the application of this technique. As stated in our manuscript (Page 14, Lines 6-14), there are no doubts that the method can be an invaluable support for environmental studies, as it offers the possibility to map soil heterogeneity at various scales, potentially with high spatial resolution. Nevertheless, evident limitations exist, and we believe that the scientific community may benefit from this discussion, which aims to a more consistent use of this very useful measurement technique.

In our opinion, a very important lesson learned from this study is that proper interpretation of EMI data (whatever the research goal is) requires necessarily repeated measurements (in the manuscript at Page 14, Lines 9-14). Results show clearly that the effect of θ on ECa could be easily misinterpreted if only a limited number of hydrologic conditions were represented within the EMI measurement dates. In other studies, not always EMI measurements were repeated in time and not always the analysis was supported by adequate soil moisture data (see, e.g., Calamita et al., 2015, Table 1 for an overview).

Furthermore, we showed that a solid process-based interpretation of the data is beneficial, but requires broad expertise in hydrology and geophysics and the combination of various measurement techniques. Our study presents a valuable dataset of repeated ECa measurements and high-resolution soil moisture monitoring for a site where soil properties and soil moisture dynamics were known in detail from preceding studies, and a process-based interpretation of the spatial and temporal changes of ECa. We believe that the discussion contained in the manuscript (which will be further improved by the reviewers' comments) will contribute to enhance the awareness on the potentials but also on the limitations of the EMI method.

We will improve the discussion and conclusion sections of the manuscript accordingly in order to make these points more clear.

We would also like to offer our dataset to all interested researchers who wish to conduct different analyses of the data.

Reference:

Calamita, G., Perrone, A., Brocca, L., Onoratic, B., and Manfreda, S.: Field test of a multi-frequency electromagnetic induction sensor for soil moisture monitoring in southern Italy test sites. *J. of Hydrology*. <http://dx.doi.org/10.1016/j.jhydrol.2015.07.023>, 2015.