“Combining ground-based and airborne EM through Artificial Neural Networks for modelling hydrogeological units under saline groundwater conditions” by

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General comments:

This is an interesting paper which discusses the transformation of geophysical parameters (electrical conductivity) to geological parameters (presence of glacial till), using artificial neural networks (ANN). I think the work in this paper is suitable for this journal and presents a new contribution to the field, and therefore I recommend publication. I have two quite general scientific comments:

1) The authors explain the geology of the area in detail, and then go to great lengths to come up with a probability of glacial till. However the story just ends right there. It would be nice if they were to discuss their results (shown in voxel form in fig. 17) in terms of the geology - giving some sort of preliminary geological interpretation. Do the till distributions make sense in terms of the geology of the area? I understand this is a multidisciplinary project requiring geophysicists, geologists, hydrologists, etc, and that others will hopefully be working with your results, but it would be nice to see a small geological ending to the story here. Ok, that can be done. I agree with you that the geological impact should be outlined more explicitly, I will do that. Furthermore, the results are already used in a study that is presented in the same special issue as this article is published: **Modelling climate change effects on a Dutch coastal groundwater system using airborne Electro Magnetic measurements**
M. FanecaSànchez, J. L. Gunnink, E. S. van Baaren, G. H. P. Oude Essink, B. Siemon, E. Auken, W. Elderhorst, and P. G. B. de Louw
Hydrol. Earth Syst. Sci. Discuss., 9, 6135-6184, 2012

2) What would happen if another material (not glacial till), but having similar electrical conductivity of till, were present in the area? How will the ANN respond? Put another way, is it possible that the probability of till is overestimated due to another rock type mimicking its electrical conductivity? It is unlikely that this would occur in the study area, since the ECPTs, which cover the entire study area, did not show other rock types that the ones described. From geological expertise, it is known that the till occurs widespread over the study area, within the depth range that is covered by the airborne EM and the ECPTs. But indeed, in theory it could be possible that the probability of till is overestimated.

Specific comments:

Since you give such a complete description of airborne EM methods, I would also do the same for electrical cone penetration tests (ECPTs). Personally I am quite familiar with airborne EM but this is the first time I have heard of an ECPT. Since the ECPTs are used both as inversion constraints and for training the ANN, it would be useful for the reader to have some technical description to understand exactly what they are.

The reviewer may be familiar with AEM but most of the HESS readers are definitely not… CPTs are very common in The Netherlands and in geological environments with soft sediments. The measurements of Electrical Conductivity, together with the CPT, is often carried out for groundwater salinity studies. I will add some more explanatory text regarding ECPT On the opposite side of the coin, I think there is too much description of the airborne EM methods. The novel material in this paper is about the application of ANNs **after** a conductivity model has been found. So really, discussing how you get to the conductivity model is less important for the novelty of the paper then discussing what you do with the conductivity model afterwards. Therefore I would put more focus on the ANN section 4 and reduce the amount of airborne EM description in section 3 (but still put a few sentences in describing an ECPT). Will shorten the section on EM somewhat, but the general feeling is that the HESS reader might not be so familiar with airborne EM methods, therefore some elaboration on the method and processing is needed.

Another thought that also occurred to me concerns the non-uniqueness of the EM inversion problem and (the commonly used) pseudo-3D approach to determine a conductivity model. The probability of till is of course completely linked to the particular conductivity model, and there are many possible conductivity models given the non-uniqueness of the problem. Would it be possible to come up with a combined probability of till which took into account the various acceptable conductivity models? Of course this is probably out of the scope of the paper but might be an avenue the authors could think about in the future.
The range of possible AEM inversion models is somewhat reduced by including ECPT data, for both finding the best inversion strategy for standard LCI or SCI (without using prior constraints) and using prior constraints in the inversion.Although not presented in this paper, we tried several inversion strategies, with different a-priori constraints with respect to ECPTs and number of layers and found that the present EM models were performing the best. It would require another paper to describe this in detail, but we can spend some sentences on this subject.

At the top of page 3279 you say that you include the ECPT data as a-priori information to increase resolution. From what I understand, this means you are including this data into the starting model of the inversion. If so, I would argue that such a procedure does not actually improve resolution but rather helps in keeping the inversion from running away into a local minimum by giving a decent starting model. If you are actually using the ECPT data as a regularization for the inversion, the story is a bit different. A few extra comments to clarify what you exactly mean would be helpful here.
The ECPT data are used to define a a-priori model within a certain radius of each ECPT point. The a-priori model has constraints, i.e not only the starting model is altered but also the starting model parameters have a-priori standard deviation. The standard deviation is dependent on the distance form the ECPT. This means that we use the ECPT in the regularization. The text has been clarified so this is better explained.

I think the title of the paper could be slightly changed: You are using EM and ANNs specifically to look for the distribution of glacial till (not to quantify hydrogeological units in general – of which there are many). So I think till should be mentioned somehow in the title. Like: “Combining ground-based and airborne EM through Artificial Neural Networks for modeling glacial till under saline groundwater conditions”

Abstract (pg. 3270, lines 8-10) “The saline groundwater in the area was obscuring
the EC signal from the till but by using ANN we were able to extract subtle and often non-linear, relations in EC that were representative for the presence of the till”. This is stated in the introduction but I see nothing in the body of the paper that convinces me that the ANN overcomes the problem of saline groundwater obscuring the till signal. You are right here, it is not mentioned explicitly in the text, but it is nonetheless the case. In Fig. 3, the distinction between Holocene (clay) and Post-Saalian (sandy) sediments is not clear from the EC profile (there is a steady increase in EC), while one would expect a step in EC from clay to sand. I will put more emphasize on this issue in the body of the text

Pg 3273, line 12-14. Can you explain more about how cone sleeve and tip friction tell you information about geology? Especially since you go into so much detail about the two EM systems you might as well give a brief explanation of the CPT (and ECPT). Sure, will do that in the section that will give more detailed information on the ECPT method.

Pg 3275, line 7. As the depth of investigation presumably comes from a skin depth argument here, can you give your precise value for a “resistive” and “conductive” ground? About 100 an 10 Ohm*m
Pg 3276, line 6. A half space model is truly that: A half space with no layers. I would say “:::inverted to layered models with five layers:::.” Ok!

Pg 3278, line 2. What was the moment of the source? You don’t say anything about current here. Only the number of windings and area of the loop.
Technical corrections:
Pg. 3270, line 10. Remove comma after non-linear. Replace “for” with “of”. Will be corrected
Pg. 3272, line 6. Write out NAP in full before using the acronym. Will be corrected

Pg. 3278, line 24. Change “access” to “assess” I think? Will be corrected
Pg. 3278, line 29. Change “minimal” to “to be a minimum”. Change “layer” to “layered”. Will be corrected
Change “accurate” to “accurately”. Will be corrected

Pg. 3279, line 2. “A-priory” should be “A-priori”.Will be corrected
Pg. 3279, line 15. Change “satisfactorily” to “satisfactory” Will be corrected
Pg 3279, line 28. Change to “::. the inversion. Vertical, lateral and spatial constraints are also used.” Will be corrected

Pg 3286, line 24. Change to “::. map the till layer in as detailed a manner as possible:::”
Pg 3292, Fig 2. Labels should be larger. Furthermore, write out full names of geological units definitions in figure caption, directly on the figure or in a table together with the figure. Will be corrected
Pg 3294, Fig 4. Need y-axis label. What are the units of the y-axis of this histogram? Not counts it seems. %

Pg 3298, 3299, Fig 8a, 8b. Title of graphs is too much. Can this be said in the figure caption somehow? Sure, will be corrected

Pg 3301. Fig 10. What is the black line on the conductivity section? Likewise for Fig. 11. Say something about this in the figure caption. The black line indicates the centroid depth values (z*) derived from the data of the lowest frequency as a measure for the depth of investigation.

Pg 3307. Fig 15. “EM models and drillings” (make plural) Will be corrected

Cheers,

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