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Discussions

Interactive
comment
on
"Combining
ground-based and airborne EM through Artificial
Neural Networks for modelling hydrogeological
units under saline groundwater conditions" by

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1 General Comments:

The manuscript (MS) describes a technique to map the presence of a glacial till using electrical conductivity models. The models are obtained by one-dimensional (1D) inversion of the HEM and SkyTEM data and then the Artificial Neural Networks (ANN) are used to map the probability of the till. To train the network the electrical conductivity data from adjacent Electrical Cone Penetration Tests (ECPT) are utilized. The obtained 3D models of the probability of the till agree well with the information derived from drillings available in the area.

I like the ideas presented in the MS, however I think that the structure should be modified.
The main part of the paper, concerning ANN, is left to the very end and is quite short, while there is a lot of text concerning the geology of the area and the data processing and inversion. I would suggest to shorten Sections 2 and 3, and enlarge Section 4 of the MS.
This suggestion will be considered, although the "average" reader of HESS is most probably not so familiar with airborne EM, so we will not shorten the airborne EM too much. And the section on the ANN will be expanded to put more emphasize on the novelty of this method in the setting of airborne EM.
It is unclear whether this is a general approach, that can be used in other regions, where ECPT and airborne EM data are available. The authors do not justify why 1D inversions are sufficient. Would the interpretation of the till be different if a 3D inversion was applied? It is also left out how long it takes to obtain the final 3D model of the till. Some explanations are not precise, and should be clarified. Most of the figures should also be improved.

This approach is general. It can be always applied if a lithogical unit corresponds with a somewhat changed electrical conductivity (or any other geophysical parameter).

In Siemon et al. (2009) it was stated that 3D inversion for both HEM and TEM data is still not state of the art. Particularly in groundwater surveys the lateral changes in conductivity with respects to the system footprints are generally very moderate and 3D inversion is not required. (That is totally different in mineral exploration surveys!)

Below I present my concerns and remarks that I hope can help the authors to improve
the manuscript.

2 Specific Comments:

1. p 3272: I think that most of the first paragraph of the Section “Study area” is not necessary and drives the reader away from the main idea of the MS, the ANN, as suggested by the title.
We think that the geological history and the sediments is important to understand the way the EM signal should be interpreted, although the section might be a little bit long. We will shorten the section on the geology, but will stick to the main idea that the sediments (together with the salinity of the groundwater) are the main source of variability of the EM signal.
2. p 3274, l 11 and Fig. 4: I think that Fig. 4 and the last paragraph of subsection 3.2 is not necessary for the MS and could be removed.
We think that it is important to show the reader that the till has different EC signature, compared to the other sediments. This Figure shows that the till has, in general, a lower EC than the other sediments, and therefore it can be distinguished from the other sediments by its EC signal. Figure 3 shows some examples of this distinct EC signal, while Figure 4 summarizes it in a histogram.
3. p 3275, l 7: “... 150 m in resistive and 50 m in conductive grounds ...” What are the resistivity values of resistive and conductive regions, respectively?
about 100 Ohm*m (EC=0.01S/m)

4. p 3276, l 3-11: As far as I understand the authors use one-dimensional (1D) inversion and then create 3D images from 1D results. If this is correct, I think this should be more transparent in the MS. Do the authors think that 3D inversion is not necessary? How would the results change if 3D inversion code is employed?
The approach as you describe it is correct, and we will make this more transparent in the text. 3D conversion: see comment above
5. p 3276, l 6: "...
were first inverted to half-space models with five layers ... . A comparison with ECPT data showed that the use of smooth fifteen-layer models provided better results. ..." It is not clear for me. Did the resulting models consisted of five or 15 layers. Could the authors clarify this confusion?
Yes, fifteen-layer results were used:
"A comparison with ECPT data showed that smooth fifteen-layer models provided better results (Mitreiter and Siemon, 2011). Therefore, the smooth-layer approach was used to include a priori ECPT data to constrain the HEM inversion." (last sentence deleted).
6. p 3276, l 11,12: It is not clear how the paragraphs ending "... were used to constrain the inversion of the HEM data." and starting "The Laterally Constrained Inversion (LCI, Auken et al., 2005) approach ..." are connected. Did the authors use the results of 1D inversions as a starting point for LCI?
No new paragraph necessary. Starting with: "For this, the Laterally..."
7. p 3276, The paragraph on the LCI: The paragraph is not clear. How exactly the constraints (prior, vertical and horizontal) are implemented in the inversion? The implementation of prior constraints is the most confusing and should be explained more clearly or left out. What the numbers 2.0, 1.1 for vertical and 1.1, 1.01 for horizontal constraints mean, in terms of how much model is allowed to very from one cell to another.
Replace text:
"All the already existing starting models close to an ECPT site (i.e. within the search radius) are replaced by the corresponding ECPT model, but only downto the maximum depth of an ECPT plus 10%. Besides these prior constraints lateral and vertical constraints are used by the LCI to find a reasonable balance between the importance of HEM and ECPT data. The most promising results could be achieved for a smooth inversion with fifteen layers using a search radius of 250–500m and depth dependent vertical and lateral constraints on the resistivities, i.e. the resistivities were constrained to 100% (vertical) and 10% (horizontal) change at shallowest depth and to 10% (vertical) and 1% (horizontal) change at the greatest depth. In this case we used 5× decimated data set resulting in a sounding distance of about 20 m."
8. p 3278, l 6: "An average sounding was produced for each 25 -30 m with close to no lateral average of the data." Not quite sure, what the authors mean.
It means that the data were not averaged more than the distance between the raw data soundings. The text will be changed so it is more clear.

9. p 3279, l 17: "... To make a comparison between all ECPTs and the closest EM model ..." Do the authors mean, that they take some exemplary 1D model from all the 1D inversion results and then for all ECPTs in 50 m radius around this model they compute average Ln(EC) for depth intervals corresponding to layers in this model. Should be written clearer.
For every ECPT the closest AEM model was selected (max. distance 50m). The AEM model has a vertical discretization that differs from the ECPT:

the thickness of the layers in the AEM model varies while the thickness of the layers in the ECPT is aggregated to 0.1m. To compare the EC of the AEM model with the EC from the ECPT, the EC from the ECPT were averaged over the same thickness as the EC from the AEM.In this way it was possible to compare EC from ECPT and AEM covering the same thickness. In the text this will be explained more clearly.

10. p 3279, l 20 -: The explanations about Fig. 8 (a,b) are not clear. The authors should explain what they do more precisely.
We will give a more thorough explanation of the figures and the way they are calculated. This relates to the previous comment.

11. p 3280, l 4 and Fig. 9: It is not clear how HEM and SkyTEM inversion results are combined, since HEM and SkyTEM areas overlap. Resistivities at certain depths were calculated individually from HEM and SkyTEM data, but gridded jointly.

12. p 3281, l 16: “The propagation of information in MLP starts at the input layer, ... which is then weighted and passed to neurons in the next layer.” I think that this was already said and can be removed. Not mentioned before in this words, so I will keep it here

13. p 3283, l 4: “one output node: probability of finding till.” From Fig. 12b the output, as derived from transfer function f, can be negative, while probability .
[0,1]. I think the authors should say few words about this. Ok, the probability smaller than 0 and larger than 1 are set to 0 and 1 respectively

14. p 3284, l 11-and Fig. 15: Do the models used for the ANN and also presented in Fig. 15 have anything to do with the inversion results presented earlier in the MS (in Section 3). Not clear. It seems from the text that the authors performed 1D HEM and SkyTEM inversions again, instead of using results described in Section 3. Why? The resulting EC with depth, derived from the inversion of the HEM and skyTEM, as described in section 3, were used as input in the ANN procedure. The ANN uses depth and EC. The EC, resulting from the EM models is used and the midpoint of the layers in the EM model was used as the representative depth for that layer.

15. p 3286, l 6: “... is correctly estimated” Word “correctly” is not appropriate here, since these are field data sets and the true 3D model of the till is unknown. It is better to say that the model agree well with the known information from the drillings. Agree

16. Fig. 2: The font for the abbreviations of the geological formations is too small. The reader has to search what these abbreviations mean in the text of the MS. It is not convenient. I suggest to create a box in the figure describing what these abbreviations stand for. Agree

17. Fig. 11: The profiles in Fig.1 are marked with letters (AA’, BB’ and CC’). It would be easier for the reader if the authors explicitly mention these letters in the caption for Fig. 11. Agree

18. Fig. 12a: From the figure one concludes that the number of inputs = number of outputs = n, but the number of inputs and outputs do not have to be the same. Agree, the number of outputs will get another subscript

19. Fig. 13: Subplots (a) and (b) are very small and I think these subplots are not necessary, since the procedure is clearly explained in the text of the MS. Maybe the whole Fig. 13 is unnecessary. Since data pre-processing is so important in obtaining a good quality training dataset, I would prefer to keep the figure, though enlarged.

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Technical corrections:

1. p 3272, l 4: “HEM and SkyTEM” These abbreviations were not introduced earlier in the MS. Will be corrected
2. p 3272, l 19: “... a marine transgression causes ...” .
“... a marine transgression caused ...” Will be corrected
3. p 3273, l 1: “For the location of the profile, see Fig.1.”
I suggest to write “the geological cross-section”, instead of “the profile”, since there are other profiles in Fig. 1. Will be corrected
4. p 3275, l 21: “ ... includes six-frequency electromagnetic, magnetics and radiometrics. ...” This sentence should be rewritten. "The BGR helicopter-borne geophysical system (Fig. 5) simultaneously records six-frequency electromagnetic,magnetic and radiometric data."
5. p 3278, l 24: “...
to accurately access to what depth ...” .
“... to accurately assess to what depth ...” I would recommend to use: "... to estimate to what depth ..."because the DOI is depending on the inversion models (which could be wrong or at least inaccurate).
6. p 3281: “... an output layer an one or more intermediate layers ...” .
“... an output layer and one or more intermediate layers ...” Will be corrected
7. p3281,l7: i =0,1, :::, :n.
i =1, :::, :n Will be corrected

8. p 3282, l 1: “... corresponding Ln(EC), to learn the ANN algorithm to detect the till. ...” I think it is better to say “train” instead of “learn”. Will be corrected
9. p 3283, l 6: “... the ECPT, see Fig. 11c. ...” There is no Fig. 11c. Will be correctedto 13c
10. p 3283, l 16: “... it was decided to make the number of ECPTs to be used in the training of the ANN depending on the distance. ...” I suggest to say “depending on the distance to the EM model.” Will be corrected
11. p 3283, l 18: “If the distance between EM models and ECPT was less than 250 m, only that single ECPT was used ... If the distance between the EM models and its surrounding ECPTs is between 250 m and 1000 m, two closest ECPTs wereused in the training, while with distances greater than 1000m the three closest ECPTs were used, see Fig. 9.” Not clear:
(a) Did the authors want to say “EM model”, instead of “EM models”? Indeed, what we mean is “EM model”
(b) What if there are more than one ECPT that are closer than 250 m to the model? In the case of more than one ECPT within 250m, the algorithm uses the closest ECPT
(c) “the EM models and its surrounding ECPTs is between 250 m and 1000 m” Did the authors mean that there are two ECPTs around the EM model, which are in the distance range [250, 1000] m from that EM model. Indeed, if the closest ECPT is more than 250m away, the algorithm searches for two ECPTs within [250,1000] meter. If this condition is not met, it looks for the closest 3 ECPTs, regardless of the distance between EM model and ECPTs.
(d) Not clear what reference to Fig. 9 stands for. Should be Fig. 14
12. p 3283, l 23: “The even distribution in space of the ECPT helped considerably to obtain good trained networks for the entire area.” The ECPTs rather cover well the study area, than evenly distributed in space. I agree
13. p 3284, l 26: “... rank order correlation.” The authors should mention the this number is shown in the right lower corner of each panel in Fig. 16. Will be corrected
14. p 3285, l 8: I am not sure what “within 1 m” stands for. The depth of the top of the till

15. p 3286, l 5: “... the cross-section of Fig. 10” Fig. 10 presents HEM inversion results only, so probably the authors meant Fig. 11.Oops, I meant Fig. 1
16. Fig. 12b: Is it intentionally both F and f are used? No, will be corrected
17. Figures 1-3, 6-8, 13-17: Text, axes and tick labels are too small. Pleaseincrease the font sizes. Ok

With best regards,
Anna Avdeeva

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 3269, 2012.