

Interactive comment on “Combining ground-based and airborne EM through Artificial Neural Networks for modelling hydrogeological units under saline groundwater conditions” by J. L. Gunnink et al.

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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)

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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. 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.

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.
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.
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?

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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?
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?
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?
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 vary from one cell to another.
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.
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.

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10. p 3279, l 20 - : The explanations about Fig. 8 (a,b) are not clear. The authors should explain what they do more precisely.
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.
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.
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 $\in [0,1]$. I think the authors should say few words about this.
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?
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.
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.
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

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for Fig. 11.

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.
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.

3 Technical corrections:

1. p 3272, l 4: "HEM and SkyTEM" These abbreviations were not introduced earlier in the MS.
2. p 3272, l 19: "... a marine transgression **causes** ..." → "... a marine transgression **caused** ..."
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.
4. p 3275, l 21: "... includes six-frequency electromagnetic, magnetics and radio-metrics. ..." This sentence should be rewritten.
5. p 3278, l 24: "... to accurately **access** to what depth ..." → "... to accurately **assess** to what depth ..."
6. p 3281: "... an output layer **an** one or more intermediate layers ..." → "... an output layer **and** one or more intermediate layers ..."
7. p 3281, l 7: $i = 0, 1, \dots, n \rightarrow i = 1, \dots, n$

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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".
9. p 3283, l 6: "... the ECPT, see Fig. 11c. ..." There is no Fig. 11c.
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."
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 were used 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"?
 - (b) What if there are more than one ECPT that are closer than 250 m to the model?
 - (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.
 - (d) Not clear what reference to Fig. 9 stands for.
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.
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.
14. p 3285, l 8: I am not sure what "within 1 m" stands for.

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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.
16. Fig. 12b: Is it intentionally both F and f are used?
17. Figures 1-3, 6-8, 13-17: Text, axes and tick labels are too small. Please increase the font sizes.

With best regards,

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