General comments

This paper describes the application and results of the steady-state SNMR method recently developed by the Aarhus working group on different sites in Denmark. The water content models of the inversion results (inversion with vertical smoothness constraints) are depicted and compared to transient electromagnetic data. The authors estimate water tables from the maximum gradient of the shallowest water content increase in these models. The water tables are depicted in maps and are compared to the water levels measured in boreholes.

The manuscript is well structured and easy to follow. The measurement progress of the steady-state method compared to the standard SNMR method is impressing. However, I have some concern regarding the relevance of these case studies, at least in the form in which these are presented in this initial version of the manuscript. It reads like a pure documentation of the measurement progress that the new system can make. However, it is not possible to assess the output. Thus, I suggest major revisions:

Reply: We thank the reviewer for their remarks. The authors have addressed the comments and a detailed explanation is given in the following text.

1. An uncertainty analysis of the water table results is missing. The reader is not able to assess them. Differences between estimated and measured water tables (from boreholes) remain undiscussed. In Fig. 5 discrepancies of several meters can be seen. What is the problem here? Is this an issue for future research? Can it be solved in some future?

Reply: An uncertainty analysis of the water table results is difficult to assess with the deterministic inversion scheme used. We have tested multiple regularization schemes and saw little to no variation. We are using a regularized inversion and are unable to rely on posterior covariance matrix based parameter uncertainties. This will leave only the Bayesian inversion schema which we are currently in the process of implementing. Therefore, an uncertainty analysis is not added in this manuscript. However, the differences between estimated and measured water tables are discussed. Generally, the differences are in the order of a few meters. In the inversion, we are limited by a predefined discretization as stated in the inversion section. This discretization has increasing layer thickness with depth. Therefore, deep estimates such as those found in Fig. 5, is susceptible to defining the ground water table at a layer below or above the true ground water table. For instance, at 10m depth the layer thickness is 1.6m. A finer discretization could enhance the ability to define the water table. Furthermore, the water table estimation from the gradient, is not necessarily the best way of assessing the water table depth but is an unbiased tool to assess the water table from the SNMR results.

2. The authors state that the decrease in the water content models can be attributed to clayey sediments in the subsurface without providing any evidence. They stress that regions with low resistivity (from TEM) indicate clay layers that explain the decrease of the mobile water content, but many water content models are not in agreement with this assumption. Corresponding examples are ignored in the discussion.

Reply: We thank the reviewer for this comment. For each of the campaigns, a more nuanced discussion of the discrepancies encountered is added. Especially in Fig. 5 discrepancies are seen where the SNMR profiles are projected 200m to 300m onto the TEM resistivity profiles. This is because TEM and SNMR data comparisons are not formed of spattialy overlapping data (but

nearby). This could account for some of the inconsistencies since geology could vary within the 200m from SNMR to TEM measurements, but a discussion on these is added to highlight various explanations. Borehole IDs are added to statements of geology with a reference to the online free database where all boreholes are present.

3. The sensitivity of the applied pulse sequences with depth should be presented and taken into account for the interpretation of the results. Maybe the decrease of water content mentioned above is simply due to the decreasing sensitivity with depth in many measurements.

Reply: Griffiths et al., 2022 presents sensitivities of similar pulses with similar current ranges. The short pulses, i.e., 10ms and 20ms pulses, are not very sensitive below 20m depth. However, the 40ms pulse sensitivity peaks around 25m at high currents and this pulse is used in all 3 campaigns. For this reason, we are capable of interpreting on data from the first 30m with confidence. We will add details on the depth of investigation to the revised manuscript. A more rigorous estimation of the depth of investigation is the subject of on-going parallel research.

In addition to showing at least one example sensitivity function for the SNMR measurements, I further suggest a detailed documentation of at least two data examples – maybe one of the best and one of the worst measurements. This could demonstrate the potential and also the limitation of the proposed SNMR method.

Reply: Thank you for your comment. A figure containing data from each of the campaigns has been added. The sites are picked at random and generally show the trends and noise found at the different areas of interest. These sites are representative of the majority of data within each survey. To show one of the worst measurements would not be valuable since these have been removed from the water table estimates due to high noise conditions.

P3L83: Fig. 1

Reply: Typo has been fixed in revised manuscript

P4L90-92: The style of the pulse…

- Please give a reference for the interested reader who wants to learn what the difference is and why it matters to control the polarity of the pulse.

Reply: A reference is added to the style description for the already cited:
Grombacher, D., Griffiths, M., Liu, L., Vang, M., and Larsen, J.: Frequency Shifting Steady-State Surface NMR Signals to Avoid Problematic Narrowband-Noise Sources, Geophysical Research Letters, 49, e2021GL097 402, https://doi.org/10.1029/2021GL097402, 2022.

P4L93: The number of pulse moments…

- More explanation is necessary:

o What is the current range?

o What impact has the sampling density given by the number of pulses?

Reply: The current range is from 5-80 A and is sampled linearly. Added description of the current range at P4L92-94:

The current density could possibly be decrease by having 4 different pulses with much overlapping sensitivity, seen in Griffiths et al. (2022). It explains how we are able to decrease measurement time between campaigns ending up at 25 min of acquisition time per site.

The employed current densities decrease between the surveys due to our improving field practices, where data redundancy in collected data suites has been continually reduced. Future research will focus on minimizing the acceptable current densities that still deliver satisfactory resolution.

P4L95: with -> considering !? Why one minute, not more or less?

Reply: Changed "with" to "considering".

One minute was chosen based on field observations that it generally returns a high signal to noise ratio for Aars. One minute is simply a convenient duration in that it allows quick back of the envelope calculation of the total measurement duration at each site. For comparison between campaigns, the same stacking time were used for the other two campaigns. If noise conditions require it, the stacking time can easily be increased, but this will decrease the number of soundings per day.

P4L96: I suggest switching the last two sentences of this paragraph to refer to the tables in the order in which they actually appear.

Reply: We thank the reviewer for this comment. The order of the sentences has been switched in the revised manuscript.

P4L97: information regarding -> "general information regarding" or "an overview of…"

Reply: Sentence changed to "*In table 1 general information regarding the campaigns is shown.*"

P4L101: The spectral analysis approach is not standard in SNMR post-processing, please give a reference.

Reply: A reference is added which describes the spectral analysis approach:
Liu L, Grombacher D, Auken E, Larsen JJ. Complex envelope retrieval for surface nuclear magnetic resonance data using spectral analysis. Geophysical Journal International. 2019 May;217(2):894-905.

P5L112: What is a stabilizer function? Please give a reference.

Reply: Reference added to this line.

P5L120: It is hard to believe that these alternative regularization approaches will really give "identical" results -> maybe formulations such as "very similar" or "the same with regard to the uncertainty of the measurements" are more appropriate.

Reply: "Identical" has been changed to "very similar" in the revised manuscript.

P5L129: At what depth does the clay approximately appear? As we learn later, the SNMR results are maybe affected by it.

Reply: Specific depths and borehole IDs has been added to the manuscript to refer to the evidence of clayey sediments. The depth of the clay encountered by boreholes are 50m but the TEM results reveal that the layer is sloping and occurs at around 10m East in the area of interest.

P6L133, Table 2:

- The label of the first row “pulse” is misleading. Obviously, you apply more than just four pulses. I suggest “pulse protocol” or “scheme”.

Reply: The table’s first row will now read as “*Pulse protocol*”. The change has been applied for each campaign table.

P6L140: What are the criteria for this heuristic determination? Your statement reads very arbitrarily. It is better to exclude those datasets that do not allow the application of the described procedure.

Reply: By inspection, the relaxation parameters showed a clear transition which were used in determining the water table in an otherwise limited structure in the water content profile. The two water table estimates have been omitted from the figure.

Even with the data presented (Fig.2), I cannot understand how your procedure can lead to the marked water tables for S6 and S7. For these two, the marked lines do surely not correspond to the maximum gradient of the water content increase. In my optinion it would be better to admit that your procedure cannot be applied to all the data and that future research is necessary on this issue. For S6 and S7, I suggest setting the water tables for S6 and S7 to zero, which seems reliable given the SNMR data.

Reply: For S7 there is a small decrease in water contents followed by a slight increase which is found to have the highest positive gradient. However, we agree that the water tables could be set to zero as to where the maximum water content is encountered, and still be used in the final water table map, without exclusion of the datasets based on the previous comment. Based on feedback from the second reviewer, we are now using the elevation of the water table instead of water table depth, with the elevation of the water table set to the topography, i.e., water table depth equal to zero.

The same is true for S3 and S5 in Fig.3.

Reply: The water tables of S3 and S5 in Fig. 3 has been changed to topography level.

P10L190: This is an effect…

- Please reformulate this statement. Of course, there will be shallower water tables when the terrain slopes.

Reply: The sentence has been deleted. Since topography is included in the maps, this formulation is no longer necessary.

P10L200: “Evident” is too strong in this context unless you present ground truth. Again, please provide at least an estimate of the depth at which clay layers were found on your test sites.

Reply: A less loaded word has been added with a description of where the clay is located by the TEM and a description of where the clay layers are intercepted is now given.

“By the SNMR results alone, the decrease could mean a less saturated unit or a unit containing more bound water but comparing with tTEM results, which highlights a conductive unit beneath the resistive meltwater sand, at about 15 m to 20 m, it seems that this is a more clay rich unit.”

P10L204: shows

Reply: Fixed

P10L206: Please discuss the decrease of the mobile water content of S3 (Fig.5b) in detail. Here, there are no indications of a conductive layer in the subsurface.

Reply: Thank you for making us aware of this. Unfortunately, the wrong water content profile was set at this location (from a more northern sounding, where the conductive unit is visible) and for S6 in the same profile. We apologize for the inconvenience, and we have fixed the issue while checking all other soundings, which were right. The decrease is not as profound yet is still present and will be discussed in the text. We have also added a description on how different sensitivities for the methods yield these differences.

P10L207: Also in Fig.5c, there are undiscussed discrepancies. Regarding the TEM results, the models of S1 to S4 should be very similar. Please discuss why this is not the case.

Reply: Differences between TEM and SNMR results are discussed in the revised manuscript. One possible explanation is that we are projecting the SNMR measurements on to the TEM resistivities 200m away. Further, a change in water content can occur without a severe affect on the resistivity measured by the TEM method. The outlier of these is S3 where a decrease in water contents is not visible after the peak. Further it seems that at S3 a higher maximum water content is found here. This could indicate a higher porosity, or a coarser material. The effect on TEM results, would be very limited, since the sand is quite resistive in profile.

P10L209: That statement is not true. Please reformulate or erase this sentence. By having all these water table estimates it is possible to track nothing more than the water tables in the region.

Reply: The statement has been reformulated to a clearer statement that it is possible to track the water table in the region.

P11L217: I totally agree. Do you plan to implement such constraints in the future?

Reply: Yes, it is in the pipeline to implement LCI and possibly SCI for the SNMR inversions. Preliminary results show great promise for constraining relaxation parameters using LCI and future work will be focused on this topic.

P11-12, Figure 4 and 5: I do not see the point why you focus the analysis on three different profiles in this area, when all these profiles show in principle the same water levels without significant changes. As a matter of fact, there is some variation that could be interesting to focus on, e.g. the two yellow points with water tables at about 15 m. However, these are excluded from the profile analysis. Even if these estimates are not plausible it is much more interesting to discuss them and to learn about the limitations of the method.

Reply: The three profiles were based on close TEM measurements, since acquisition of this data was limited to gravel roads between the trees. Further, after reviewing comments from the second reviewer, the water table depths figures were changed to indicate water table elevation, which diminished the outliers greatly. Therefore, the authors have decided not to change the profiles in the plots.

Anyway, if you prefer to show different profiles, please label all the different involved measurement points clearly, e.g., from S1 to S20 for the current analysis, and include these labels in the map to guide the reader through these two figures.

Reply: Each sounding has been numbered from S1 to S18 since two of the soundings occur twice in the profiles. Additionally, topography has been added to the profiles while all axes are now elevations instead of depth below surface.

P13L247: I cannot accept this conclusion, at least not as direct conclusion of your analysis. Of course, we expect that the content of mobile water descreases with increasing clay content. However, this relationship is not doubtlessly evident by the depicted datasets. For many of the depicted water content models, the decrease actually starts at depths shallower than the corresponding decrease in resistivity, see for instance S1, S2, and S4 in Fig.3 and S6 in Fig.5a. And there are even models where the mobile water content decreases without any indications of having a clay layer in the subsurface, see e.g., S3 in Fig.5b.

Reply: The conclusion will be changed to a more varied conclusion mentioning the different sensitivities of the two methods and how they can add knowledge in regard to resistivities and water contents, respectively. A description of the differences between TEM and SNMR results have been added in the results and discussed further.