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Interactive comment on "Characterisation of subglacial water using a constrained transdimensional Bayesian Time Domain Electromagnetic Inversion" *by* Siobhan F. Killingbeck et al.

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We thank the reviewer for their time reading our manuscript and their constructive comments and suggestions. We greatly appreciate all feedback provided. All comments are addressed as completely as possible, and we consider our manuscript much-improved as a result. The revised manuscript is attached as a pdf with all changes tracked. In our text below, the reviewers' comments are first, with our response directly beneath.

General comment: This manuscript presents a good example of TEM survey to investigate the subglacial water. The trans-D Bayesian inversion is used to extract the resistivity information from the TEM data using the structural constraints to improve the accuracy. The seismic velocity is used to jointly delineate the material lithology. However, the manuscript is more likely to be a case history than a technical paper, as the trans-D Bayesian inversions is performed using the 1D forward operator from Leroi and the 1D trans-D Bayesian inversion has been reported in several literatures. On the contrary, the manuscript presents solid results in characterizing the subglacial water jointly using the TEM, GPR and seismic data. Hence, I recommend the manuscript to be organized as a case history. Furthermore, the trans-D Bayesian inversion can be used to quantify the uncertainty of the inversion, which is its major benefit. However, the manuscript gives litter discussion about where the uncertainty comes from. Especially, the possible distribution that that the errors in the data obeys and how it is related to the chosen of the form of likelihood function. It would be good if this contains can be added.

Response: Thank you for your review and comments. We have already described the site in detail and presented a case history of Midtdalsbreen in Killingbeck et al., 2019 (referenced throughout this paper). Therefore, we did not organise this paper as a case history but rather an application of this method, MuLTI-TEM, of which the results have complimented and further improved our original case history presented in Killingbeck et al., 2019. We have added the sentence, and relevant references, in P5 L31 to address this further: "More detailed information on previous glaciological and geophysical studies on Midtdalsbreen can be found in Andersen and Sollid 1971; Etzelmüller and Hagen, 2005; Reinardy et al., 2013, 2019; Willis et al., 2012." However, we feel that our contribution carries more weight than a case-study, given that we develop existing approaches with the implementation of external depth constraints; indeed, we are grateful that the reviewer notes that our approach improves the robustness of our subsurface characterisation. We have emphasised this aspect of the work in the introduction to our paper, specifically in P2L7-11. With regards to the data uncertainty comment, we un-

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derstand we have not been clear when discussing the uncertainty variable and where it comes from. We do say "estimate of their uncertainty (σ) derived from the variance of each data point calculated from the stack recordings". However, we have provided more details about this parameter in the manuscript by adding more detailed sentences in P5L14-15 stating it is dataset specific and defined for each different dataset, P9L11 clarifying we use 5% of the signal at each timegate, a similar noise model to Blatter et al. (2018) and P13L8-9 stating "The data variance (σ) was kept at 5% of the signal at each timegate as this was a good representation of the data variance of each data point calculated from the 3 stack recordings acquired in the field."

Specific comment 1: P2L13-14: "TEM methods . . .. . .by an offset transmitting coil". The grounded-wire or coincided loop are also commonly used to transmit the source signal of a TEM survey Response: Added grounded-wire and coincided loop to this sentence.

Specific comment 2: Compared with the methods mentioned in the INTRODUTION, Equation 1 only provides a poor estimates of DOI, without considering the current/noise level. Maybe the authors want to illustrate the role of transmitter loop size in controlling DOI, but it is well known that a larger loop will achieve a deeper earth. Response: We have altered the estimation provided in the introduction to that of Spies (1989), which explicitly takes account of the noise level.

Specific comment 3: Equation 2, 3,4. . . The vector and matrix should be bold. Response: This has been corrected.

Specific comment 4: P4L24-25: "since the accuracy of GPR depth estimation is âĹij100-times smaller than the thinnest resolvable layer in TEM". Please add references for this statement. Another question: if the accuracy of the depth constraints from GPR results is higher, then what is the purpose of the variation of the dimensionality? Response: We have changed this sentence to "In our case, in which constraints are drawn from high resolution GPR data, we consider depth constraints to be exact since the accuracy of GPR depth estimation is centimetre scale (Killingbeck et al., 2019), compared to the meter scale resolution of the TEM.". We have also added the appropriate reference which presents the methodology and results for the GPR depths and their uncertainty. The depth constraints provide information on the thickness of each layer enabling us to restrict the model space, by adding resistivity boundaries, of each specific layer. The variation in dimensionality allows resistivity variation within each defined layer, without having to fix the resistivity of that specific layer to one single value.

Specific comment 5: The elements of RJ-MCMC are outlined in the manuscript. It would be good if details of some key techniques are introduced, such as the principle to judge the convergence of the chain, how the accepted samples are resampled to suppress the correlations of the sample. Response: Convergence of the chain is performed simply by increasing the number of iterations and checking that the resulting distributions are the same. We have added Figure A2 in the Appendix to illustrate this. Furthermore, we "thin" the Markov chain (within the code this is controlled by the line "thin=100") to suppress correlations within the sampling chain and to speed convergence. This uses only every 100th model to compute the distribution statistics. We have added a sentence in the manuscript at P5 L25 to address this: "We thin the Markov chain by using every 100th model when computing the distribution statistics, which suppresses any localised correlations of neighbouring models and speeds up convergence."

Specific comment 6: P11L4-5: "One million iterations were sufficient for the posterior distribution to converge (a test of 2 million iterations produced the same posterior)". Add the results of the test would be good. Response: This has been added as a new figure, A2 in the appendix, and referenced in the above sentence within the main text.

Specific comment 7: P13L9-10: "data fit with the ensemble models are shown in Fig. 7(ii)". The model ensemble contains multiple models. Whose data fit is shown here, is it the average datafit? If it is, adding the error bar would be good. Response: This is a

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comparison of the observed data and 200 randomly chosen forward models from the model ensemble. This is stated in the figure caption but not the main text, but we have added this to the main text to make it clearer.

Specific comment 8: P14 "5.2 2D Resistivity profiles". The 2D profiles is obtained by the stitching together the 1D inversion results or sampling the 2D model space as a whole. If the later one is chosen, how the 2D grids are updated? Response: The 2D profile is obtained by stitching together multiple 1D inversion results along the lines. This is already explained in the main text "…invert multiple independent 1D soundings acquired along Lines…".

Specific comment 9: Why the synthetic inversion of the 2D case is not given? Response: Because the 2D profile is obtained by stitching together multiple 1D inversion results (comment above), only synthetic inversions of the 1D case were needed.

Specific comment 10: Figure 10: As the presentation of the data is interpolated, please add the indicator of the recording station at the top of the figure so that the actual spacing of the stations can be illustrated. Response: We have added the location of the multiple 1D TEM soundings acquired along each line to Figure 10. The resistivity and seismic data were acquired in the same field season along the exact same lines, the acquisition parameters used in the field were chosen/set up so the two methods could be directly comparable with minimal interpolation needed. The active seismic acquisitions were performed with a Geometrics GEODE system and 48 10 Hz vertical-component geophones. For cross-glacier lines A, B and C, the source and geophone locations had 2 m intervals (where the CMP binning was 4 m); for the down-glacier line D, these were increased to 4 m (where the CMP binning was 8 m). These parameters are documented in Killingbeck et al., 2019. Multiple 1D soundings were recorded with the TEM system with 4 m intervals on the cross-glacier lines and 8 m interval on the down-glacier line, matching the seismic CMP binning for each line. However, the location of each 1D sounding and binned seismic CMP did not exactly match up, therefore, we interpolated and resampled both the resistivity and Vs solutions, originally sampled every 4 m (Line A, B and C) and 8 m (Line D), to every meter so there was a resistivity and Vs data point at each meter along the line. This has been made clearer in the text by the addition of the sentences: “The resistivity and Vs profiles are linearly interpolated such that they have mutually consistent sample intervals (1 m) and depth extents (40 m). The TEM and seismic were acquired in the same field season along the same lines, the acquisition parameters were chosen so the two methods could be directly comparable. However, the location of each 1D TEM sounding and seismic common midpoint gather are offset by 2 m, therefore, we linearly interpolated and resampled both the resistivity and Vs solutions, originally sampled every 4 m (Line A, B and C) and 8 m (Line D), to every meter thus making them directly comparable.”

Technical corrections: The manuscript is well written and I do not have technical corrections. Response: Thank you very much for your kind words.

Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2019-126/se-2019-126-AC1-supplement.pdf

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2019-126, 2019.