Author Response to Reviewer #2 (Author responses are highlighted in orange)

General comments:

This work continues the author's previous research on the liquid water over Greenland. A radiative transfer model is implemented to generate a Lookup table to retrieve liquid water content during the melt season, and the retrieved results are compared with modeling results. The retrieved LWA shows a good agreement with the modeled results. This paper is of good quality, but I would like to ask a few questions before publication.

The authors would like to thank the anonymous reviewer for the detailed review and insightful comments.

Specific comments:

1. SMAP data sets. The authors chose the high-resolution SMAP data. What is the benefit of this data set in this research? In the discussion section, could the authors also elaborate more on the sentence" … overlapping observations to produce the 3.125 km gridded data but still has an effective spatial resolution of ~30 km"? How would this affect the results?

   The benefit of this data is that it improves the overall effective resolution. The effective resolution of the conventionally gridded TB images is approximately 46 km, and the effective resolution of the enhanced-resolution TB images is approximately 30 km resulting an improvement of about 30 % (Long et al., 2023). The 3.125 km is the posting grid where each grid cell is reconstructed using a set of T_B observations that overlap within the 3.125 km grid box (i.e., they are not independent), enabling added spatial pattern fidelity compared to coarser grid postings, also discussed in Long et al. (2023) and Zeiger et al. (2024).

   The results are analyzed assuming the 30-km resolution; otherwise, it does not affect the meltwater amount retrieval results.

   We will make this description clearer in the data section of the revised manuscript.

2. Permittivity of the wet firn. The author mentioned equation (3), and it seems the authors are using this equation to calculate penetration depth and absorption coefficients in the radiative transfer equation. Could the author discuss the equation used for calculating the effective permittivity?

   The dielectric constant of the dry snow was calculated using Mätzler (2006), and wet snow following Ulaby and Long (2014). Ulaby and Long (2014) model of wet snow dielectric constant is an empirical model, called the 'modified Debye-like model,' which is an extension of Hallikainen et al. (1986). We did not include the equations in the manuscript as we used the exact formulation from Mätzler (2006) and Ulaby and Long (2014) without any modifications. We briefly mentioned about the dielectric models in lines 244-245, but we will expand it to clarify more in the revised version of the manuscript. Nevertheless, readers are referred to these references for more details.

3. Penetration depth of the wet firn. What would be a typical number and range of the penetration depth?

   It depends on the average volume fraction of melt (liquid water content) and the dry snow/firn density. For a typical snow density (measured for dry snow) in the percolation zone, it can be more than 4 m for an average LWC of less than 1% with the Ulaby and Long (2014) model's wet snow dielectric constant, decreasing exponentially with the LWC. Thus, for an average LWC of 3% and higher, it is around 1 m and less (see the Figure R1 below). The average LWC in the percolation zone is typically not higher than 4%, except for extraordinary melt years (like 2012, not included in the study). The water percolation is also generally within upper 4 m.

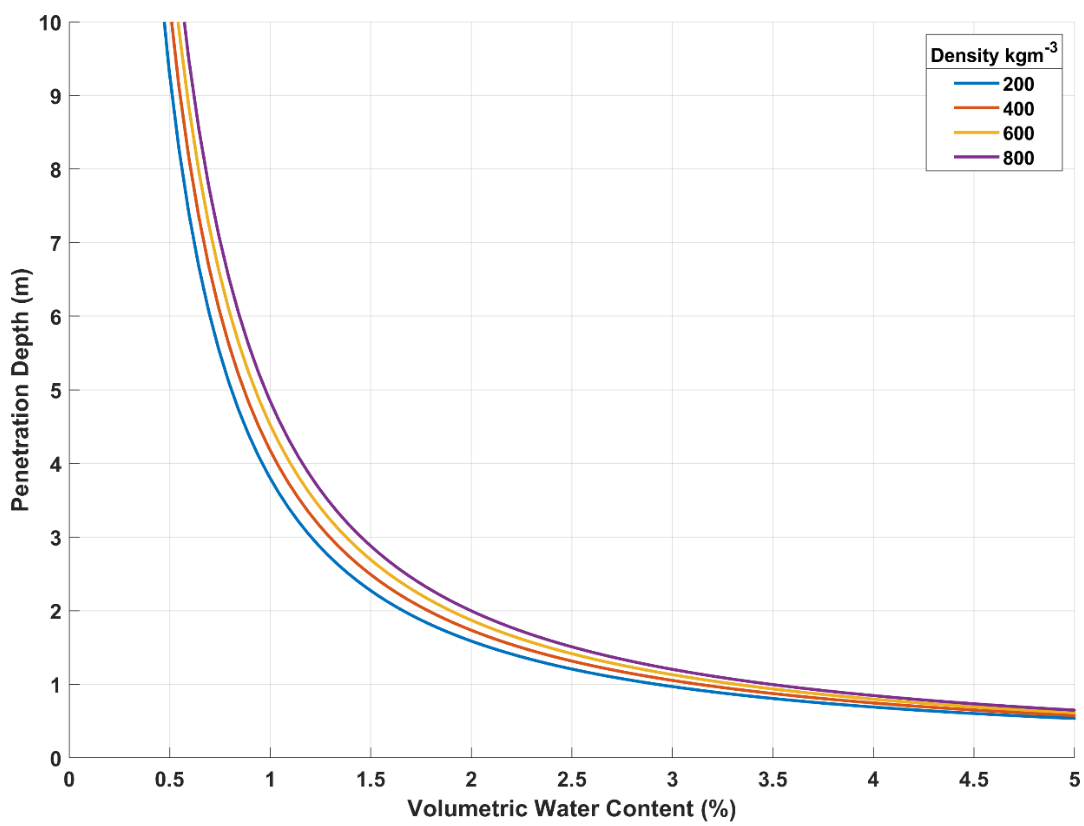

Figure R1. Penetration depth of L-band (1.41 GHz) signals as a function of liquid water content for different snow densities.

4. Layering model for the wet firn. Usually, the density profile in the percolation zone increases much faster than in the accumulation zone; the density can be close to the ice after a few meters, say 10m. I'm wondering how the authors deal with the varying density profile in the radiative transfer modeling, given that the penetration depth of 1% wet snow can be 10 meters based on the code provided in Microwave radar and radiometric remote sensing (by Ulaby and Long)?

   The density profile is highly variable in the percolation zone and while the ice can start at relatively shallow depths at some lower altitude locations, the refreezing of seasonal melt forming discrete ice layers and ice pipes that cause significant scattering of frozen season microwave emission down to tens of meters is more typical (e.g., Rennermalm et al., 2022). Fig. 1 illustrates the effects of this variability in the percolation zone with low brightness temperature, while the areas with solid ice (ablation zone) are characterized with high brightness temperatures.

   As discussed in Sec 2.3, to account for the combined reflective effects by the complex stratigraphy due to numerous ice layers common in the percolation zone of the GrIS, as well as the effects of volume scattering in the snow/firn layer, we consider layer 2 (underneath the dry/wet snow layer) as a highly reflective layer by explicitly specifying its dielectric constant (with high real part that varies spatially). We match simulated TB under frozen condition with the mean frozen season observed TB to adjust the value for the dielectric constant of this layer, as well as the dry snow/firn density and physical temperature of the top layer. These background conditions are then used to determine the liquid water amount by a second inversion with the observed TB in the melt season. We will revise Sec. 2.3 it to make clearer.

5. Melt onset. The paper compares the melt onset with the modeling results. Could the auto weather stations provide any information (such as temperature) that can provide some ground truth evidence on the melt onset?

   The PROMICE/GC-Net automatic weather stations (AWS) provide 2m-air temperature. However, there have been several studies (e.g. Zhang et al., 2023; Leduc-Leballeur et al., 2020; Van Den Broeke et al., 2010) that showed that air temperature is not sufficient to validate the onset or presence of melt – there can be melt even when the air temperature is below the freezing point (0℃). Additionally, since the liquid water amount is presented on daily basis, there is an additional sampling issue of potential negative average air temperature on days when melt may occur during a short period, while the air temperature-based method records zero melt. Therefore, a sub-freezing point temperature is often recommended (Zhang et al., 2023; Leduc-Leballeur et al., 2020; Van Den Broeke et al., 2010). However, there is no consensus about the threshold. Hence, we preferred to compare the melt onset detection to the surface energy balance (SEB) based method (the model) that considers the net energy balance at the surface coupled with the vertical heat transfer and water percolation in addition to the air temperature. The SEB based method is considered superior to the conventional air temperature based method (Ohmura, 2001).

6. Better correlation between SMAP and EBM. In Table 1, the comparison between SMAP and EBM seems to be in agreement. Why is this so? Is this because EBM is using AWS data for calibration? If so, can GEMB somehow be calibrated by the AWS?

   Yes, we believe the overall better agreement between SMAP and EBM estimated LWA than SMAP and GEMB partly come from the surface forcing – AWS in situ measurements are better than ERA5 reanalysis. However, two model have different parametrizations of key physical processes such as snow densification, meltwater infiltration, thermal and hydraulic conductivity, permeability, grain growth, albedo etc. schemes. So, these processes need to be considered too to account for the differences which, as we discussed in Sec. 4, are out of the scope this article (some of these issues were partially covered by Vandecrux et al. (2020)). However, we are considering running both the model with the same input set (AWS data). Currently, GEMB setting is tied to ERA5 for large scale simulation. We are working to run it with point (AWS) measurements, and we anticipate we will be able to include it in the revised manuscript.

7. Possible overestimation of LWA by models. Figure 9 shows the comparison of measured and modeled temperature profiles. The modeled results seem to overestimate the temperatures and, thus, possibly the LWA. Any ideas on resolving this issue and validating the solution?

   Yes, in some cases, the models seem to retain the subsurface meltwater with a persistent wetting front (0°C isotherm) for an extended period in late summer seasons. This overestimates the total LWA (or vice versa). As we discussed in lines 466-479: "Speculating extra melt production due to possible error in the AWS surface forcing, and other surface processes in the EBM, we examined modelled subsurface temperature profile by reducing surface melt with different factors (<1). We also performed similar analysis with irreducible water content, thermal conductivity. In either case (not shown), we could not match the subsurface profiles with measured profiles within reasonable agreements." Heat transfer and firn deification are common problems in firn models (Vandecrux et al., 2020). But there are other processes in the model (such as mentioned in 6) that may contribute to this. The AWS measurements used to run the model also add some inherent uncertainties. Therefore, these problems are multifaceted, and additional works are required to understand the basis for these discrepancies.

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