Initial Author Response for "Simulating snow properties and Ku-band backscatter across the forest-tundra ecotone", Woolley et al.

The authors would like to thank the editor and Reviewer 1 for the time taken to provide the detailed and thorough reviews. Our responses are in blue, modified text that we will add to the revised document in italics and reviewer comments are in black.

Answer to Reviewer 1:

The study compares simulated snow parameters using SVS2-Crocus to in situ measurements at a study area in the NWT, Canada. Two versions of the model are applied; the default model and an Arctic-specific modification. Several locations with differing vegetation and snow conditions are analyzed. Furthermore, a forward model is used to simulate microwave backscatter from SVS2-Crocus outputs, comparing these to backscatter simulations using the in situ data directly. A microwave-effective snowpack concept, which aggregates the data to three representative layers, is used. The paper is of interest to the scientific community as it has become clear that some type of fusion of modelled and remote sensing information is required for successful retrieval of SWE from spaceborne radar. This concerns, in particular, approaches using Ku-band SAR backscatter. This paper takes some steps to attempt to quantify how an advanced coupled land-surface -snow process model reproduces natural snowpacks in a challenging environment, and what are the implications on (simulated) backscatter. As such, the study is worthy to consider for publication.

We thank the reviewer for their comments and are pleased that the study is considered suitable for publication.

The study is also generally well written although some specifics in the methodology are hard to grasp and require several readings. For example, from the abstract it was not at first obvious that actual observations of backscatter are not used, only simulations. Furthermore, it is hard to discern where exactly the three layer aggregates (radar equivalent snowpack) where used: in simulations based on SVS2-Crocus, in simulations from snowpit data, or perhaps both? Terminology referring to the sites also changes occasionally, sometimes referring to the biome (tundra, forest), sometimes to the names defined in Figure 1. These are the main examples, but the complexity of the diverse model settings makes the paper somewhat hard to follow and requires particular care in describing the experimental setups.

We thank the reviewer for these constructive comments and for highlighting the need for greater clarity in the description of the methods. We will revise the manuscript accordingly to improve the clarity and consistency:

Abstract: We will revise the abstract to explicitly state that no radar backscatter observations are used in this study, and that all results are based on forward simulations using the SMRT model. The following modified text will be added to the manuscript abstract:

> *'Simulated backscatter from multi-layer (~20-layer) SVS2-Crocus snowpack simulations and simplified 3-layer 'radar-equivalent' SVS2-Crocus simulations were compared to simulated backscatter from snow pit observations (with no snow layer simplification).'*

Methods: We will clarify when the 3-layer 'radar-equivalent' snowpack configuration was applied to our simulations. The simplified configuration was only used for the SVS2-Crocus driven simulations, while the snow pit-driven simulations retained the full detailed measured stratigraphy. The following text will be added to the last paragraph of the introduction within the manuscript:

> *'The impact of an ensemble of simulated snow properties on Ku-band (13.5 GHz) backscatter using the Snow Microwave Radiative Transfer Model (SMRT; Picard et al., 2018), is then tested under three configurations:*
>
> 1. *SMRT driven by a detailed (~20-layer) SVS2-Crocus simulated snowpack.*
> 2. *SMRT driven by a simplified (3-layer) radar-equivalent SVS2-Crocus simulated snowpack, following the approach of Meloche et al., 2025.*
> 3. *SMRT driven by raw snow pit observations, representing the best available measured representation of the snowpack and serving as a reference for assessing model performance.'*

Terminology: We will revise throughout the manuscript the text to ensure consistent references to site names and vegetation types. We will refer to all sites by their individual names, as described in Figure 1. These are:

- Upper Plateau
- TVC
- Valley
- Small Shrub
- Mixed Shrub
- Shrub Tree
- Havikpak

However, in section 4.2 (Profiles of density and SSA), we perform statistical analysis on groups of sites defined by their vegetation types, as outlined in Figure 1. This grouping is also clarified on Section 3.2.1 of the manuscript. The site groups are as follows:

- Tundra (Upper Plateau and Trail Valley Creek)
- Deciduous Shrub (Valley, Small Shrub and Mixed Shrub)
- Forest (Shrub Tree and Havikpak)

Further details of how this is modified in the manuscript can be found on Line 176 of this document.

My main concern, however, is related to the usefulness of the backscatter simulation setup itself. The SMRT model is treated as a black box, testing which kind of numbers come out with each version of the input data. It seems that the pit data forcing is used as the "truth", with SVS2-Crocus -based simulations representing deviations ("errors") from this. No real effort is placed on which parameters actually induce these differences, beyond testing different approaches for tuning the optical grain size/SSA. Since the study is based on only simulated backscatter, one could expect a thorough sensitivity study on different parameters, or something similar. Perhaps using the 120 ensemble members in SVS2-Crocus makes this a challenge; however, you could then consider dropping the ensemble approach, and use individual, controlled simulations?

The primary objective of this study was to investigate uncertainty in snowpack modelling and its effect on snow backscatter simulations. Recognising the known uncertainties in the simulation of SSA and density by detailed snowpack models in the Arctic (Woolley et al., 2024; Royer et al., 2021; Domine et al., 2019), we chose to focus on the impact on backscatter simulations using SMRT as this is the primary objective of our study. Given the wide range of possible SMRT parameter combinations and model options (Sandells et al., 2024), we adopt the configuration constrained by Montpetit et al., 2024 at Trail Valley Creek. The configuration was considered suitable for our simulations, as it was specifically optimised for the tundra snow conditions at TVC through the calibration of microstructural (e.g. correlation length, microstructure model) and radiative (e.g. soil permittivity, roughness) parameters against field snow pit and radiometric observations and validated through Ku-band backscatter simulations using airborne SAR data. The same approach has been applied in related studies (e.g. Meloche et al., 2025; Montpetit et al., 2025).

By adopting this configuration, we were able to isolate the influence of snow model uncertainty on simulated snow backscatter. Our focus is therefore on quantifying and understanding the implications of snow model uncertainty, which can be effectively investigated using the approach established by Montpetit et al., 2024. Expanding the analysis to include SMRT parameter sensitivities at this stage would dilute the primary objective of the study.

To clarify this in the manuscript, we will add the following text to section 3.2.2, SMRT:

> *'We adopt the configuration constrained by Montpetit et al., 2024 as it was specifically optimised for the tundra snow conditions at TVC through the calibration of microstructural and radiative parameters against field snow pit and radiometric observations and validated through Ku-band backscatter simulations using airborne SAR data. By adopting this configuration, we were able to isolate the influence of snow model uncertainty on simulated snow backscatter.'*

Further, some confusion is created by first choosing to fix a scaling parameter in the forward model (the polydispersity factor *K*) at unity, only to re-introduce another scaling parameter with basically the same end result, as adjusting *K* would have had. I realized only after some time that the idea is to try to scale the SVS2-Crocus SSA to observations; however, the choice of the scaling factors tested seems arbitrary. Of some interest could be to try to derive your own optimal scaling for 1) SSA 2) density 3) possibly another parameter, such as snow depth, and with the (average) optical scaling reconduct the simulation exercise.

We thank the reviewer for this constructive suggestion. The scaling factor from Brucker et al., 2011 was originally selected because it is one of the few documented values directly applied to Crocus model output and microwave simulations. The value represents a vertically averaged adjustment intended to capture differences between wind slab and depth hoar snow types. We also adopted this value to limit the risk of overfitting our simulated output to field data.

That said, we acknowledge the uncertainties associated with applying this factor within our study. Considering the reviewers comments, we have reconsidered this approach. Rather than relying on the fixed value of 0.63, we have removed this step from our evaluation. Instead, we focus on the role of SSA and density (Fig. 8, 9e & 9f), as these snowpack properties are key contributors the backscatter simulations in SMRT, and they determine the exponential correlation length that governs scattering behaviour.

We outline in detail on Line 243 of this document how we will modify the manuscript to account for the removal of the 0.63 scaling factor.

Please see major comments below for specifics.

Major comments

Abstract: by reading only the abstract, it is not fully clear that you do not actually use observations of backscatter: "Modelled backscatter…were compared to backscatter using…" please make it more explicit from the start that this is a simulation exercise.

We will change the text to:

> *'Simulated backscatter from multi-layer (~20-layer) SVS2-Crocus snowpack simulations and simplified 3-layer 'radar equivalent snowpack' SVS2-Crocus simulations were compared to simulated backscatter from snow pit observations (with no snow layer simplification).'*

In Abstract, line 25: "leading to high errors…" this is misleading again, as an "error" in simulated backscatter implies you have measured the actual one. Rather, this is a root-mean-square difference between two simulations with different model forcing. I would suggest to change the terminology throughout the manuscript, also changing RMSE(rror) to RMSD(eviation)

We agree with the reviewer and will change the terminology throughout the manuscript to RMSD(ifference) to reflect that we are presenting differences.

Introduction: this section is very nicely written

We thank the reviewer for this positive comment.

…except that in the last sentence, you should already make clear which (Crocus outputs, field data, or both) are converted from multi-layer to the radar-equivalent 3-layer setup. Now this is not clear at all.

We will revise the last sentence of the introduction to provide more clarity:

> *'The impact of an ensemble of simulated snow properties on Ku-band (13.5 GHz) backscatter using the Snow Microwave Radiative Transfer Model (SMRT; Picard et al., 2018), is then tested under three configurations:*
>
> 4. *SMRT driven by a detailed (~20-layer) SVS2-Crocus simulated snowpack.*
> 5. *SMRT driven by a simplified (3-layer) radar-equivalent SVS2-Crocus simulated snowpack, following the approach of Meloche et al., 2025.*
> 6. *SMRT driven by raw snow pit observations, representing the best available measured representation of the snowpack and serving as a reference for assessing model performance.'*

Figure 1 is very good and informative. However, can you add a scale for the snow depths? I guess the average snow depth can be indicated just as easily as the relative depth?

We agree with the reviewer's suggestion and will include a scale bar in the revised figure. The updated version of the figure will be submitted at a later stage.

Throughout the paper, please choose which name you use when referring to sites. Now, sometimes "forested sites" and "tundra" are used, sometimes "Havikpak" etc. You could also use always both to be explicit e.g. "Upper plateau (tundra)"

We thank the reviewer for pointing out this inconsistency. We will refer to all sites by their individual names, as described in Figure 1. These are:

- Upper Plateau
- TVC
- Valley
- Small Shrub
- Mixed Shrub
- Shrub Tree
- Havikpak

However, in section 4.2 (Profiles of density and SSA), we perform statistical analysis on groups of sites defined by their vegetation types, as outlined in Figure 1. This grouping is also clarified in Section 3.2.1 of the manuscript. The site groups are as follows:

- Tundra (Upper Plateau and Trail Valley Creek)
- Deciduous Shrub (Valley, Small Shrub and Mixed Shrub)
- Forest (Shrub Tree and Havikpak)

We acknowledge that this distinction may not have been sufficiently clear in the original text. To address this, we will modify the first paragraph of Section 4.2 to explicitly restate the grouping and refer the reader back to Figure 1. The revised paragraph will read as follows:

> *'Figure 5 and 6 compare measured and simulated profiles of snow density and SSA for Upper Plateau, Small Shrub and Havikpak, representing three sites of contrasting vegetation type (see Fig. 1) for the 2021/22 and 2022/23 winter seasons, respectively. All remaining sites are displayed in Appendix B. We discuss the results from figures 5, 6, 7 and Appendix B in this section with reference to all measurements, within each vegetation type, as classified in Fig. 1: Tundra (Upper Plateau, Trail Valley Creek), Deciduous Shrub (Valley, Small Shrub, Mixed Shrub) and Forest (Shrub Tree and Havikpak). Measured profiles of snow density at tundra and deciduous shrub sites exhibit the typical structure of an Arctic snowpack: low-density basal layers ranging between 150 kg m^{-3} and 300 kg m^{-3} overlain by higher density surface layers ranging between 300 kg m^{-3} and 400 kg m^{-3} (Fig. 5 & 6, Appendix B). At forest sites, measured snow density shows less variability throughout the snowpack with surface and basal layers exhibiting similar densities (Fig. 5 & 6, Appendix B: WS Mean: 196 kg m^{-3} ; DHF Mean: 192 kg m^{-3}). Despite differences in snow density, the pattern of measured SSA is consistent amongst all sites with lower SSA values for basal layers (ranging between 5 m^2 kg^{-1} and 20 m^2 kg^{-1}) and higher SSA (ranging between 30 m^2 kg^{-1} and 60 m^2 kg^{-}) values for near-surface layers (Fig. 5 & 6, Appendix B). The variability between*

measured pit profiles of density and SSA decreases from tundra to forest (Fig. 5 & 6, Appendix B).'

p9, eqs 1 and 2 and associated text. As pointed out in the above, it is unclear from the text why the *K* parameter is fixed here, while later on you choose to scale the SSA. I realize this is due to the experimental setup of comparing "simulations vs. simulations" , and this should be clearly mentioned. You should display the scaling factor you use in eq. 2 (and maybe forget about *K*, since essentially you do not use it).

In response to the reviewer's comment, we will remove the scaling factor step (use of 0.63) from our backscatter simulations. This is explained further in our response to the reviewer's next comment. The scaling factor is therefore not required in equations 1 and 2 and will be removed from the associated text and discussion.

We will, however, retain the polydispersity parameter (*K)* as 1 in Equation 1. Although multiplying by 1 may appear redundant, we retain the *K* term because polydispersity is an evolving area of study in microwave snow modelling (Picard et al., 2022; Montpetit et al., 2024; Sandells et all., 2024). Including it explicitly allows our framework to remain consistent with emerging formulations and facilitates future model development where variable polydispersity may be incorporated. This will be clarified in the methods section of the manuscript as follows:

'The polydispersity was assumed to be 1 for all simulations. Fixing K = 1 provided a consistent configuration suitable for our analysis of simulated SVS2-Crocus backscatter versus simulated pit backscatter. This assumption isolates the influence of snow microstructure and density differences between SVS2-Crocus and pit measurements, while avoiding additional uncertainty introduced by varying polydispersity.'

I also fail to see why the scaling factor of 0.63 derived in a paper from 2011 could be relevant. I would suggest another approach: 1) derive your optimal scaling factors required to match SVS2-Crocus to field data 2) do this at least for SSA, density and snow depth 3) analyze which is the most important factor to scale (which has the largest impact) for each surface type. As an optimal case, you could test scaling all three+ parameters to match the field data, and see how much RMSD remains from variability in the ensembles.

We thank the reviewer for this constructive suggestion. As outlined above (Line 123 of this document), the scaling factor from Brucker et al., 2011 was originally selected because it is one of the few documented values directly applied to Crocus model output applied to microwave simulations and represents a vertically averaged adjustment intended to capture differences between wind slab and depth hoar snow types. We also adopted this value to limit the risk of overfitting our simulated output to field data.

That said, we acknowledge the uncertainties associated with applying this factor within our study. Considering the reviewers comments, we have reconsidered this approach. Rather than relying on the fixed value of 0.63, we have removed this step from our evaluation. Instead, we focus on the role of SSA and density (Fig. 8, 9e & 9f), as these snowpack properties are key contributors the backscatter simulations in SMRT, and they determine the exponential correlation length that governs scattering behaviour.

The manuscript will be revised in response to this comment as follows (the revised figures will be provided at a later date):

Figure 9: Panels C and D will be removed, retaining panels A, B, E and F. The figure caption will be as follows:

> *‘Comparison between pit simulated backscatter and SVS2-Crocus simulated backscatter for a multi-layer (A, ‘Original’) and 3- layer (B, ‘Original’) radar equivalent snowpack (interquartile range, median) for the 2021/22 and 2022/23 winter seasons at Ku-band frequency (13.5 GHz). C & D) comparison with a minimum SSA of 8.7 m^2 kg^{-1} (‘Minimum Value’; maximum optical diameter equivalent 0.75 mm).’*

Table 1: Rows C & D will be removed, retaining rows A, B , E and F.

The text in section 4.3 Simulated Ku-band backscatter will be revised, to discuss only method 2, limiting the minimum SSA of the snow grains to a value of 8.7 m^2 kg^{-1}:

> *‘As the underestimation in basal SSA values simulated by both default and Arctic SVS2-Crocus strongly influence the simulation of snow backscatter, we addressed this bias by constraining the minimum SSA of the snow grains to a value of 8.7 m^2 kg^{-1} (Fig. 9c & d). The selected value represents the average median DHF value from all pit measurements at all sites and removes the effect of unrealistically low simulated SSA values.*
>
> *Implementing a minimum SSA value removes the influence of large snow grains on the simulation of snow backscatter and allows the simulation of a weaker backscatter that is more representative of measurements (values ranging between -10 to -12 dB). Applying a minimum SSA value also reduces the difference between default and Arctic SVS2-Crocus suggesting this method constrains a key model uncertainty that contributes towards the inaccurate simulation of snow backscatter (Fig. 9c & 9d; Table 1c). The average RMSE of all sites is reduced when applying a minimum value by 59% for default SVS2-Crocus 390 and 67% for Arctic SVS2-Crocus for 2021/22 and 2022/23. The reduction in the RMSE for Arctic SVS2-Crocus is greater than that of default SVS2-Crocus, suggesting the improved simulated density profile contributes to the improved simulation of backscatter when the large influence of low SSA values is removed.*
>
> *A radar-equivalent snowpack is able to replicate the scattering behaviour of the multi-layer snowpack, resulting in an RMSE below 1 dB (Table 1) at all sites except for Shrub Tree (RMSE: 1.32 dB) and Havikpak (RMSE: 1.30 dB) in 2022 where snowpacks are deeper and more complex than in 2023 (Fig. 4). The overestimation in simulated backscatter when compared to snow pit simulated backscatter is consistent between both multi-layer (Table 1a) and 3-layer simulations (Table 1b). Following the pattern of the multi-layer snowpack, implementing a minimum SSA values reduce the RMSE at all sites when using a radar-equivalent 400 snowpack by 54% (default SVS2-Crocus) and 65% (Arctic SVS2-Crocus) for 2021/22 and 2022/23. The computation time in SMRT simulations was reduced by 60% by simplifying the multi-layer snowpack (~20 layers) to a radar equivalent snowpack (3 layers). The radar-equivalent snowpack can therefore increase the computational efficiency for SWE retrieval algorithms without altering the scattering behaviour.’*

Any reference to the 0.63 scaling factor, reducing the scattering behaviour of the snow grains with a vertically averaged scaling factor of 0.63, will be removed from the manuscript. Paragraph 2 of section 5.2, Capacity to simulate snow backscatter, will read as follows:

'An improved simulation of snow backscatter can be achieved by implementing a minimum SSA value of 8.7 m^2 kg^{-1}, reducing scattering effects of the snowpack. Implementing a minimum SSA value removes the influence of large depth hoar snow grains and constrains a key model uncertainty when simulating backscatter. Although the polydispersity value was assumed to be 1 for all simulations, a fixed value of K provided a consistent configuration suitable for our analysis of simulated SVS2-Crocus backscatter versus simulated pit backscatter. Typical polydispersity values based upon measurements in tundra snow range from 0.6 - 0.75 for rounded grains and 1.1 - 1.9 for depth hoar (Montpetit et al., 2024; Picard et al., 2022; Sandells et al., 2024), which relate to the two-layer nature of an Arctic snowpack (Derksen et al., 2014). However, few studies have applied a polydispersity parameter to simulated outputs. In typical Arctic depth hoar (polydispersity 1.1 – 1.9), this amplifies the influence of larger snow grains (low SSA/high optical diameter), increasing the exponential correlation length and the simulated microwave scattering. Consequently, instead of accounting for polydispersity in SVS2-Crocus, this analysis focuses on accurate estimation of SSA.'

The first line of the last paragraph of the conclusion will be modified to:

'Scaling the scattering effect of snowpack microstructure by implementing a minimum SSA (8.7 m^2 kg^{-1}) improved the simulation of snow backscatter at Ku-band frequency at all sites across the forest-tundra ecotone.'

Again, it is not clear to which data the n-layer -> 3-layer conversion is applied. Apparently to SVS2-Crocus at least, but is it applied to field data as well? Or are filed data always simulated "as is"?

The n-layer to 3-layer conversion is only applied to the SVS2-Crocus simulated data. The field data is simulated as is, using the n-layers. This gave us one set of simulated backscatter coefficients from observed snow properties that was used as a reference against which we compared simulated backscatter coefficients derived from snowpack properties simulated by SVS2-Crocus. The 3-layer simplification of the SVS2-Crocus simulated data mimics the necessary approach for operational deployment with airborne or satellite data. This is now clarified within our study aims and objectives, that have been revised at the end of the introduction section of the manuscript:

'The impact of an ensemble of simulated snow properties on Ku-band (13.5 GHz) backscatter using the Snow Microwave Radiative Transfer Model (SMRT; Picard et al., 2018), is then tested under three configurations:

a) SMRT driven by a detailed (~20-layer) SVS2-Crocus simulated snowpack.
b) SMRT driven by a simplified (3-layer) radar-equivalent SVS2-Crocus simulated snowpack, following the approach of Meloche et al., 2025.
c) SMRT driven by raw snow pit observations, representing the best available measured representation of the snowpack and serving as a reference for assessing model performance.'

Whole section 4.0 on results. It is quite tedious to read endless RMSE values in the text, and the point is quickly lost. This really gets out of hand e.g. on p. 16. Please tabulate the results, refer in the text to the tables, highlighting only the most important results.

We appreciate the reviewer's suggestion. We will summarise the key findings from Section 4 in a table and revise the corresponding text to enhance readability. A version of the table will be provided at a later stage.

Figure 4: you could comment in the text that the variability of Arctic SVS2-Crocus snow depth is much reduced compared to the Default run for most sites. Why is this?

The reduced variability in snow depth is primarily due to the densification of the snowpack by Arctic SVS2-Crocus, where incorporating wind-induced compaction processes increase snowpack density and reduce snow depths to values more consistent with observations. In contrast, default SVS2-Crocus uses parameterisations designed for alpine snow types, which are not optimised for Arctic snowpacks and therefore produce higher variability in terms of snow density and associated snow depth. By considering the processes relevant to Arctic conditions, SVS2-Crocus produces less variable snow depth simulations. We will add a sentence to section 4.1 of the revised manuscript to comment about the reduced variability in snow depth with Arctic SVS2-Crocus:

> *'The reduced variability in snow depth simulated by Arctic SVS2-Crocus is primarily due to the inclusion of wind-induced compaction, which increases snowpack density and produces snow depths more consistent with observations compared to the default configuration.'*

It is also not clear against which SD data the RMSEs are calculated against. Magnaprobe, pit, or both?

The RMSD values (updated in response to a previous review comment) are calculated using both magnaprobe and snow pit data. Snow depth was measured along the 1 km transect and in spirals around each pit at all non-forested sites, resulting in approximately 800 measurements per site. These measurements were combined with the pit data to calculate the RMSD. A sentence will be added to section 3.2.1 of the manuscript:

> *'RMSD values were calculated using combined Magnaprobe transect and snow pit measurements, with Magnaprobe data serving as the primary reference.'*

Same question as above for SWE. are the RMSEs against Pit or SWE Tube values?

The RMSD values (updated in response to a previous review comment) are calculated using the aggregation of both SWE tube and snow pit measurements. At each of the three pits, we collected one SWE profile in 2021/22 and two SWE profiles in 2022/2023, which were combined with ESC-30 measurements made at approximate intervals of 50 m along each 1 km transect of snow depths.

For density, can you not calculate a reference value from SWE tubes? Do you have the snow depth from the SWE core site recorded?

We thank the reviewer for this suggestion and agree it is possible to estimate snow density values from our SWE tube measurements. However, we only have a limited number (~20) of ESC-30 measurements available for the 2022/23 winter season, and none for the 2021/22 winter season. As a result, the temporal coverage is insufficient for robust interannual comparison. Our goal is to provide an overall view across both winters, and including the SWE-derived densities from a single season would bias the analysis towards

2022/23. Therefore, we have chosen to rely on snow pit measurements to ensure consistent and representative assessment of snow density across both years.

Figure 8. The text refers to SSA, but optical grain diameter is shown. Please use one or the other.

Thank you for pointing out this inconsistency. We will revise figure 8 to include both SSA and the optical grain diameter. Specifically, we will present a new 2 x 2 figure showing SSA (upper left), optical diameter (upper right), density (lower left) and correlation length (lower right).

In the caption, we will reference the equation used to convert SSA into optical diameter and explain that SSA is measured in the field, while optical diameter is a direct output of Crocus (it does not compute SSA directly), hence the need to present both variables.

Figure 9: the figure sort of captures why applying just a random scaling factor does not tell us much. Please consider, as suggested, making equivalent scatter plots by optimally scaling different variables. This will tell you at least which parameters carry the most weight, possibly informing where future modelling efforts should focus on.

In response to this review comment, and a major comment by Reviewer #1, we have reconsidered our approach and will remove the scaling factor step from our evaluation. Figure 9 will therefore retain panels A, B, E and D. Panels E and D will be renamed to C and D, to account for the removal of the scaling factor. The figure caption will be as follows:

> *'Comparison between pit simulated backscatter and SVS2-Crocus simulated backscatter for a multi-layer (A, 'Original') and 3- layer (B, 'Original') radar equivalent snowpack (interquartile range, median) for the 2021/22 and 2022/23 winter seasons at Ku-band frequency (13.5 GHz). C & D) comparison with a minimum SSA of 8.7 m^2 kg^{-1} ('Minimum Value'; maximum optical diameter equivalent 0.75 mm).'*

p19, lines 377-380. The two methods are already described in the Methods section, not necessary to repeat here. As indicted before, I do disagree with the usefulness of the methods.

We will remove these two lines from the text.

p19 line 385 "simulation of weaker backscatter that is more representative of measurements" Which measurements? This again seems to refer to measurements of backscatter.

We understand the confusion. We will change the text as follows:

> *'simulation of weaker backscatter that is more representative of pit simulated backscatter.'*

p19 line 394. "A radar equivalent snowpack…" reading between the lines, I realized from this sentence that the pit data were used "as is" and the radar-equivalent approach was not applied to them. However, taken out of the context of the rest of the paper, this sentence again seems to imply that you had some backscatter measurements to compare with ("…replicate the scattering behaviour of the multi-layered snowpack"). It should be made clear throughout that you are comparing simulations with other simulations.

We will change the sentence to say, 'A simulated radar-equivalent snowpack' and ensure this is made clear throughout the entire manuscript.

p19 line 398 "vertically averaged scaling factor" What is this?

The vertically averaged scaling factor is 0.63 taken from Brucker et al. (2011) and represents a vertically averaged adjustment intended to capture the differences between wind slab and depth hoar snow types. However, in response to the suggestions made by the reviewer, this approach and corresponding text will be removed from the manuscript. Please see Line 243 of this document for a detailed description of how the manuscript will be modified.

Minor comments

P8, line 194. Please clarify how exactly the division into WS and DHS was made (values).

We will add the following text to the manuscript:

'The DHF of each measured profile was determined by identifying transitions in the density and/or SSA. The transition between the SSA for different layers is often more distinct than density (Rutter et al., 2019), providing a sharper transition between wind slab (WS) and depth hoar that can be visibly identified. Where the transition between the snow types occurs, the density and/or SSA value is noted, cross referenced with those presented in Fig. 9 of Rutter et al. (2019) and the grain type reported during snow pit measurements.'

Figure 7: please switch the order of Arctic and Default in the panels. Logically, since default is the starting point, it should be displayed on the right (also to match Figure 4). explain acronyms WS and DHS also in the figure caption.

We will switch the order and explain the acronyms as Wind Slab (WS) and Depth Hoar (DHF).

p20 line 406-407 "to assess the reliability of Ku-band backscatter SWE retrievals". This statement may be the underlying reason of the study, but you do not really go into retrieval so it is also misleading. Please reword, e.g. "assess the reliability of forward model simulations driven by SVS2-Crocus, a crucial factor considering inversion of SWE from backscatter observations" or something similar.

We will reword the sentence to:

'Consequently, to assess the reliability of forward model simulations driven by SVS2-Crocus, which are a requirement to inform the inversion of SWE from backscatter measurements, an evaluation of simulated density and SSA by SVS2-Crocus was first conducted across the forest-tundra ecotone to quantify the uncertainties in the representation of physical snow properties.'

p23 line 505 large grains result in increasing exponential correlation length, not the opposite.

Thank you for noticing this error. We will change the text as follows:

‘However, few studies have applied a polydispersity parameter to simulated outputs. In typical Arctic depth hoar (polydispersity 1.1 – 1.9), this amplifies the influence of larger snow grains (low SSA/high optical diameter), increasing the exponential correlation length and the simulated microwave scattering.’

References

Brucker, L., Royer, A., Picard, G., Langlois, A., and Fily, M.: Hourly simulations of the microwave brightness temperature of seasonal snow in Quebec, Canada, using a coupled snow evolution–emission model, Remote Sensing of Environment, 115, 720 1966-1977, 10.1016/j.rse.2011.03.019, 2011.

Domine, F., Picard, G., Morin, S., Barrere, M., Madore, J.-B., and Langlois, A.: Major Issues in Simulating Some Arctic Snowpack Properties Using Current Detailed Snow Physics Models: Consequences for the Thermal Regime and Water Budget of Permafrost, Journal of Advances in Modeling Earth Systems, 11, 34-44, 10.1029/2018ms001445, 2019.

Meloche, J., Leroux, N. R., Montpetit, B., Vionnet, V., and Derksen, C.: Radar-equivalent snowpack: reducing the number of snow layers while retaining their microwave properties and bulk snow mass, The Cryosphere, 19, 2949–2962, https://doi.org/10.5194/tc-19-2949-2025, 2025.

Montpetit, B., King, J., Meloche, J., Derksen, C., Siqueira, P., Adam, J. M., Toose, P., Brady, M., Wendleder, A., Vionnet, V., and Leroux, N. R.: Retrieval of snow and soil properties for forward radiative transfer modeling of airborne Ku-band SAR to 855 estimate snow water equivalent: the Trail Valley Creek 2018/19 snow experiment, The Cryosphere, 18, 3857-3874, 10.5194/tc-18-3857-2024, 2024.

Picard, G., Löwe, H., Domine, F., Arnaud, L., Larue, F., Favier, V., Le Meur, E., Lefebvre, E., Savarino, J., and Royer, A.: The Microwave Snow Grain Size: A New Concept to Predict Satellite Observations Over Snow-Covered Regions, AGU Advances, 3, 10.1029/2021av000630, 2022.

Picard, G., Sandells, M., and Löwe, H.: SMRT: an active–passive microwave radiative transfer model for snow with multiple microstructure and scattering formulations (v1.0), Geoscientific Model Development, 11, 2763-2788, 10.5194/gmd-11-2763- 875 2018, 2018.

Royer, A., Picard, G., Vargel, C., Langlois, A., Gouttevin, I., and Dumont, M.: Improved Simulation of Arctic Circumpolar Land Area Snow Properties and Soil Temperatures, Frontiers in Earth Science, 9, 2296-6463, 10.3389/feart.2021.685140, 2021b.

Rutter, N., Sandells, M. J., Derksen, C., King, J., Toose, P., Wake, L., Watts, T., Essery, R., Roy, A., Royer, A., Marsh, P., 900 Larsen, C., and Sturm, M.: Effect of snow microstructure variability on Ku-band radar snow water equivalent retrievals, The Cryosphere, 13, 3045-3059, 10.5194/tc-13-3045-2019, 2019.

Sandells, M., Rutter, N., Wivell, K., Essery, R., Fox, S., Harlow, C., Picard, G., Roy, A., Royer, A., and Toose, P.: Simulation of Arctic snow microwave emission in surface-sensitive atmosphere channels, The Cryosphere, 18, 3971-3990, 10.5194/tc-18-3971-2024, 2024.

Woolley, G. J., Rutter, N., Wake, L., Vionnet, V., Derksen, C., Essery, R., Marsh, P., Tutton, R., Walker, B., Lafaysse, M., and Pritchard, D.: Multi-physics ensemble modelling of Arctic tundra snowpack properties, The Cryosphere, 2024, 5685-5711, 940 https://doi.org/10.5194/tc-18-5685-2024, 2024.