

Response for RC1

General comments:

This paper reports snow physical properties obtained mainly from snow pit surveys conducted at four locations in the taiga region of Sodankylä, northern Finland, from March to May 2023. The observed snow parameters include snow height, density, layer stratigraphy, temperature, and wetness. The discussion focuses on vertical profiles, temporal and spatial variations, and differences in these snow properties between forested and open (non-canopy) conditions. In conclusion section, the general characteristics of the snowpack during the snowmelt season are summarized. The results are not particularly novel and the scientific impact is poor.

We thank the reviewer for the careful summary and assessment. We acknowledge that the manuscript is primarily observational and does not aim to introduce new theoretical concepts. Instead, the main objective is to document and analyse a unique, multi-site dataset of snowpack properties collected during the melt season in the taiga region. To address the reviewer's concern, we have clarified the study objective in the revised manuscript and emphasized the value of the dataset in boreal environment, where detailed snow pit observations during melt are relatively scarce. In addition, we have strengthened the manuscript by incorporating meteorological data and radiation balance analysis.

The only noteworthy finding is that the difference in observed snow water equivalent (SWE) between the two measurement techniques (snow water equivalent tube and snow density cutter) exceeded the differences among the observation locations. It is, however, unclear whether this result reflects low SWE variability among the sites, which were located close to each other, or large uncertainties inherent in both measurement techniques. This issue is also related to the insufficient assessment of measurement errors associated with the tools used to measure snow density in this study.

We agree that the observed differences between the SWE measurement methods likely reflect a combination of spatial variability and measurement uncertainty. To address this, we have expanded the discussion on SWE and density measurement errors. We also highlight that measurement uncertainties reported in previous studies are based on dry-snow conditions and may not be directly transferable to wet snowpacks.

Although the research background is described, the research objective is not explicitly stated. If the objective of the study is assumed to be “to clarify the temporal and spatial variability of physical snow properties,” the paper lacks sufficient quantitative analysis and discussion to achieve this goal. In particular, the analysis of meteorological data obtained from the weather station and the theoretical discussion are insufficient.

We appreciate this comment and have revised the manuscript accordingly. The research objective is now explicitly stated in the introduction as documenting and demonstrating an observational dataset of snow properties capturing spatial and temporal variability during the melt season. Furthermore, we have significantly expanded quantitative analysis by incorporating time-series meteorological data and an assessment of the radiation balance and energy available for snowmelt.

Based on the above evaluation, this manuscript requires substantial revision. I recommend that the authors rewrite the manuscript with a clear objective and corresponding presentation of the results, incorporating the following improvements, including quantitative analyses and theoretical discussions.

The manuscript has been thoroughly revised in response to all comments, including clarification of the study objective, addition of meteorological data and energy balance analysis, and expansion of the discussion.

Improvement suggestions:

- Assess the measurement errors of SWE associated with snow density observations.

Measurement errors related to SWE estimation have been discussed in previous studies (e.g., Kaasik et al., 2023; Lopez-Moreno et al., 2020), which are referenced and discussed in the manuscript. We note that these studies were conducted under dry-snow conditions in Sodankylä, whereas our observations were made during the melt season. Therefore, we emphasize that uncertainties may differ under wet snow conditions, and this limitation is now clearly acknowledged in the revised text.

- Utilize automatic weather station data at the observation sites to analyze the surface energy (heat) budget. If possible, calculate snow layer structures using a numerical model, such as the SNOWPACK model (Lehning et al., 1999) and Crocus snowpack model (the latest version: Lafaysse et al., 2025), and compare the results with the observations.

We thank the reviewer for this valuable suggestion. We have now incorporated time-series meteorological data from the automatic weather station, including air temperature, wind speed and direction, precipitation, and radiation components. In addition, we calculated the surface energy balance and estimated the energy available for snowmelt at the Sounding Station, where the full set of required observations exists. For the Lichen Fence site, snow surface temperature was derived from longwave radiation measurements to complement the analysis. Regarding snowpack modeling, we agree that models such as SNOWPACK could provide useful additional insight. However, the necessary site-specific forcing data are not available for all locations, which would limit the consistency of the comparison. Furthermore, preliminary tests indicated challenges in accurately reproducing certain observed features such as ice layers. For these reasons, we have chosen not to include model results.

- Quantitatively demonstrate the influence of canopy and ground characteristics on the snow physical properties examined in this study, including snow density profiles and the timing of snowmelt.

The manuscript has been expanded to better quantify the influence of canopy and ground characteristics on snowpack evolution. Specifically, we added analysis of snow surface temperature at both an open site (Sounding Station) and a forested site (Lichen Fence), demonstrating the influence of canopy cover on surface energy exchange. In addition, we expanded the discussion on the role of ground vegetation.

Specific comments:

L20-21: "Initial wetness was observed mid-snowpack, suggesting that refreezing from cold nights operates top down, not affecting the full depth." Is this only due to the gravitational settling of meltwater? Further theoretical discussion is needed regarding the presence of capillary barriers (Hirashima et al., 2017) related to the snow layer stratigraphy obtained from snow pit observations.

We thank the reviewer for this valuable suggestion. The text has been revised to better distinguish between gravitational percolation and stratigraphy-controlled processes. In particular, we now discuss the role of capillary barriers associated with contrasts in grain size and density, following Hirashima et al. (2017), as a mechanism that can lead to liquid water accumulation in mid-snowpack layers. The revised text also explicitly links these processes to the snow stratigraphy observed in the snow pit profiles. In addition, based on the newly included meteorological data—especially precipitation—we

expanded the discussion to consider the potential contribution of liquid precipitation to the observed wetness distribution.

L21-22: "Moist and wet layers became more prevalent in the upper snowpack, while the wettest layers accumulated at the base rather than being evenly distributed." Is the former due to solar heating? More quantitative and theoretical discussion is needed. Regarding the latter, please refer to the previous comment.

The text has been revised to clarify that increased wetness in the upper snowpack is likely driven by surface energy input, particularly shortwave radiation, which promotes daytime melting. Furthermore, we have expanded the discussion to include both gravitational percolation and stratigraphy-controlled retention (e.g., capillary barriers) to explain the non-uniform vertical distribution of liquid water and the accumulation of the wettest layers in middle.

p.5, Figure 1a: Please add a scale to indicate the distance.

Thank you for noting this. Figure 1 has been updated to include a scale bar indicating distance.

L134-135: "Qualitatively, the spatial variability of the manually measured snow heights seems to be even lower than the spatial variability of the automatically determined snow heights." Is it reasonable to discuss spatial variation based on differences in manually measured snow depth at only two locations, and then compare this to automated measurements?

We agree with the reviewer that the comparison was not sufficiently supported. This statement has been removed from the manuscript.

L139 "3.2 Density section" It is necessary to explain the differences between the two snow density measurement methods and their possible reasons. Whether it is meaningful to discuss the differences between spatial variation and methodology will depend on the validity of those reasons.

Additional details have been added to describe the two density measurement methods, including their principles and potential sources of uncertainty. We also clarified the reasons for differences between the methods. We maintain that discussing difference between spatial variability and measurement methods is valuable to indicate scale of variability and measurement uncertainty.

L154-155 'Fig. 6' Typo of Fig. 5.

Thank you for identifying this error. The typo has been corrected.

L164: "This layer is observable at all locations, sometimes more pronounced, sometimes weaker." It is difficult to identify the ice layers at the airport in Figure 5.

We acknowledge that the ice layers are difficult to distinguish in the figure. The manuscript has been revised to clarify that at the Airport site these layers are very thin (approximately 0.5 cm). Additional description has been added to guide the reader in identifying these layers in the figure.

L179-182: "Across all locations, the temperature profiles ..." The temperature profile figure is not shown. Additionally, it would be helpful to include a figure showing the temporal variation of snow surface temperature, which can be calculated from the upward longwave radiation observed by the automatic weather station.

A figure showing snow temperature profiles has now been added. In addition, we included a new figure presenting the temporal evolution of snow surface temperature derived from longwave radiation measurements at the Sounding Station and Lichen Fence sites.

L222: "Similar observations were made by Hannula et al. (2016)." What is the similar observations? Please indicate the physical parameter or phenomenon.

The text has been revised to explicitly state that the comparison with Hannula et al. (2016) refers to observed snow depth evolution.

L232-233: "On the other hand, using the density cutter can systematically overestimate the density, as some areas can be sampled several times, especially in the case of layers with high densities, where accurate sampling is harder." While measuring the snow density of an ice layer is certainly difficult, I don't understand why some areas were sampled several times.

We agree that the original wording was unclear. The text has been revised to clarify that potential overestimation may arise from compression of lower layers during sampling, particularly in dense or hard layers. We also clarified that the sampling strategy aimed to minimize disturbance by avoiding repeated sampling directly above the same location.

L244-245: "Overall, a systematic error of 13% using the density cutter and 9% for the tube density measurement is considered, following the results from Kaasik et al. (2023) and Proksch et al. (2016)." This description contradicts the earlier descriptions (L238-242). Isn't the density cutter more accurate, then?

The text has been revised to clarify that previously reported measurement uncertainties are largely based on dry-snow conditions. In contrast, our observations were conducted during the melt season, when wet snow conditions can influence measurement accuracy. While earlier studies suggest smaller systematic errors for the SWE tube, its performance may be reduced in wet conditions, which could partly explain the observed discrepancies between methods.

L248: "The temperature profiles of the snow pits showed the expected patterns, particularly" The explanation appears to be based on the assumption that a temperature profile figure is shown.

The referenced temperature profile figure has now been added to the manuscript.

L2668-269: "Another source of error results from the lowest layers, which are often interspersed with vegetation, such as lichens." If this paper contains any new findings, they would likely concern the influence of ground vegetation, the effects of forests blocking snowfall and solar radiation, or the downward longwave radiation emitted from forests during the snowmelt season. Unfortunately, however, no quantitative discussion of these points is provided.

The manuscript has been expanded to include a more quantitative discussion and analysis of radiation balance and melt energy, snow surface temperature, and the potential effects of vegetation (e.g., ground vegetation and forest cover) on snow accumulation and melt.

References

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