This study examines the influence of aspect and slope position on snowpack parameters i.e., depth, density, and liquid water content (LWC), within a subalpine watershed in Colorado, USA. The variations of these parameters are evaluated using GPR, in situ stations, snow pits and SNOWPACK modeling. The study found that mid-winter melt events predominantly affect south-facing slopes, triggering later flow of LWC downslope and the redistribution of SWE. Additionally, ice layers develop on south-facing slopes during mid-winter periods. Flat terrain exhibits a steady increase in soil moisture throughout the winter. In contrast, as spring progresses, north-facing slopes witness the pooling of liquid water at their base.

The findings underscore the importance of considering aspect and slope position when estimating snow water resources. However, many conclusions are based on qualitative reasoning and are not always support by the collected field evidence. While the snow modeling community is undoubtedly moving towards better representation of complex snow redistribution and melting processes, this paper does not provide sufficient quantitative evidence to significantly advance our current understanding of snow dynamics. If the authors intend to maintain a qualitative and conceptual approach, the manuscript should be retitled to reflect this focus. Additionally, a dedicated section should be included to address the study limitations. For instance, the paper could discuss why factors such as wind, canopy, terrain roughness, and eventually gravitational transport were not explicitly considered in this analysis.

Thank you for the comments. We appreciate the constructive suggestions and agree that further clarification on what is being interpreted versus directly observed would better represent this work. Additionally, more details on uncertainty and limitations can be expanded on during the revisions. Below are replies to specific comments in blue as well.

Major comments.

- While I appreciate the complexity of organizing extensive snow campaigns and the integration of various tools like GPR, snow pits, and SNOWPACK, I'm uncertain about the optimal utilization of GPR in this study. While GPR can efficiently survey transects, its application here seems to be limited to average this information to a single-point observations (derived from averaged TWT and snow depth along the transect). The potential uncertainty associated with this approach is not explicitly addressed, and it appears to be significant. Additionally, GPR limitations in wet snow conditions and its inability to provide detailed snow layering information, particularly regarding ice lens formation or wind redistribution, makes the use of GPR difficult to justify in this work. Furthermore, the absence of radargrams as supplementary materials, which is an interesting data per se, hinders reproducibility and future works.

These are good points that could use further description/justifications in the manuscript. We used GPR because of the smaller research team that would not be able to dig as many snow pits as GPR transects to cover the spatial extent of this research. However, we disagree that the GPR uncertainty is significant. Given that depth is well constrained through manual depth probes (more details on depth variability additions discussed in later comments/responses), we expect bulk SWE estimates to have similar uncertainty to pit observations (Meehan et al., 2024). We can certainly expand on this discussion for clarity in the revisions. We agree that it is a limitation in that GPR is unable to obtain detailed snow layering information. We are also happy to provide the radargrams as supplementary materials as well.

Reference: Meehan, T. G., Hojatimalekshah, A., Marshall, H.-P., Deeb, E. J., O'Neel, S., McGrath, D., Webb, R. W., Bonnell, R., Raleigh, M. S., Hiemstra, C., and Elder, K.: Spatially distributed snow depth, bulk density, and snow water equivalent from ground-based and airborne sensor integration at Grand Mesa, Colorado, USA, The Cryosphere, 18, 3253–3276, https://doi.org/10.5194/tc-18-3253-2024, 2024.

- The paper introduces the canopy influence as a key factor affecting the energy balance (L66 on), yet the specific role of canopy within the study domain remains unclear. While LiDAR data is mentioned and depicted in Figure 1e, its utilization in the analysis is not explicitly detailed. The discussion on canopy effects often lacks specificity, relying on generic considerations rather than relate to the specific test site. Similarly, the approach to estimating snow density from GPR data is confusing. The introduction suggests that density is generally considered uniform and that GPR can provide spatialized accurate measurements (L74 on). However, the subsequent averaging of density along transects contradicts this assumption. It would be beneficial to see a comparison of the radargrams, also at a qualitative level, before averaging them (this may further support the conceptual model of Fig 9). Additionally, the absence of uncertainty quantification in the results section hinders the interpretation of comparisons and the reliability of conclusions. I suggest addressing these points, such that the paper can strengthen its scientific rigor and provide a more comprehensive understanding of the complex interactions between canopy, topography, and snow processes.

Good point about the clarity of some of the methods. We will certainly revise some of the methods to clarify these points. LiDAR data were only used to characterize the site and canopy height in specific locations. Further details can be provided, but there was no use of LiDAR data in our analysis. We will also revise the text to clarify the GPR methods. We believe that density within each transect should be relatively uniform, but from transect to transect it will vary. The use of averaging is due to the different footprint of measurements between the depth probe and GPR. Uncertainty quantification can certainly be added to the manuscript to strengthen the rigor and provide further understanding.

Detail comments

L14 From Sec 2.3. it is not clear how the calibration of GPR snow density is done using snowpits and SNOTEL stations.

A more detailed description will be added. In general, we estimated the density using GPR-depth methods and compared to the snowpits and snow pillow, correcting for any bias with the assumption that the snowpits and pillow are the “true” values.

L23 This assertion seems to be limited to the particular characteristics of the study area and may not generalize to other conditions.

This is true, we will revise the text to clarify that this may be site-specific and further detail the site characteristics so other researchers may draw insights towards other sites.

L75 Typically, bulk snow density is measured using a federal tube or within snow pits by summing the density derived by smaller volume tubes (or triangular prisms), as described by Kinar and Pomeroy, 2015.

Yes, we can revise the text for clarity.

L91 Snow depth can vary significantly, even over short distances, due to the rugged and heterogeneous nature of alpine terrain. This variability, combined with the small area sampled by a probe, highlights the importance of quantifying uncertainties in snow density estimates. Generally an average of N measurements should be done.

Yes, we averaged a minimum of 8, but generally at least 10 probed depths, at 2 meter spacing. We will add the Lopez-Moreno et al. (2011) citation as well as conduct uncertainty analysis based on this. We will also provide more details on the measured depths in supplementary material that includes standard deviations of each transect. To summarize the observed variability of the 32 transects measured, the standard deviation of depth observations ranged from 4 cm to 25 cm with an average of 10.6 cm and a median of 9 cm.

Reference: López-Moreno, J. I., Fassnacht, S. R., Beguería, S., and Latron, J. B. P.: Variability of snow depth at the plot scale: implications for mean depth estimation and sampling strategies, The Cryosphere, 5, 617–629, https://doi.org/10.5194/tc-5-617-2011, 2011.

L92 If the primary focus of the research is to investigate the impact of aspect and slope position on snowpack dynamics, a thorough justification is required to explain why factors such as wind, canopy, terrain roughness, and gravitational transport were not explicitly considered in the study, especially given their potential influence on snow distribution and melt.

A thorough justification for this will be given in the revisions, as well as discussion towards these limitations for the study.

Fig 1a please rotate it consistently with the other figure (i.e., North up)

The other reviewer mentioned this as well. We will revise in this manner.

L162 Please explicitly state that, as reported in Webb & Mooney 2024c, TWT is calculated as an average value.

Will revise to be more explicit.

L170 the equations must be numbered.

Thank you for pointing this out. We will revise this.

L175 Please provide a method for calculating the uncertainty associated with the TWT measurements. Given the potential for significant error propagation due to small denominator values, a rigorous uncertainty analysis is essential.

An uncertainty analysis will be conducted and presented in revisions. We agree that it has the potential to be quite significant, especially under shallow snow conditions.

Section 2.4 how the SNOWPACK free parameter has been calibrated?

I am not sure what is meant by the free parameter, but in line with another reviewer's comments more details on the modeling methods will be given. The input files will also be made available in the supplementary material for reproduction of the work. There was minimal calibration of SNOWPACK, though, as the focus was to determine if and when surface melt events were occurring to support some of the interpretation of observations we made in the field.

Figure 5 is difficult to interpret. A simpler, more traditional visualization would improve the comparison of differences between the data.

Will revise to a more traditional plot organization.

Figure 6 please report the uncertainty for all the measurements.

Will report in revisions.

L287 “unusual results” respect what?

Will revise for clarity.

L305 “model weakness”? Can you better elaborate the sentence?

Will elaborate in revisions.

L308 Can you better justify this sentence showing the evidence of this mechanism?

Yes, these mechanisms will be further discussed and linked to the evidence that was observed. We will also be more clear that some of these are interpretations and not directly observed.

L 333 Why “unrealistic”? Can you better elaborate it?

Yes, the derived density was greater than 1000 kg/m^3 (the density of water). We will elaborate further in the revisions for clarity as well as explain why this happens in GPR data.

L 354 The answer to the main research question of the paper is answer considering only the melting. So, the melting was the focus of the research?

The focus did become melting. We can further clarify and revise the question and title to reflect this.

Figure 9. This conceptual figure is interesting, but it is not based on field evidence. This should be clearly stated in the text.

We can add further details and link the interpretation to observations. But, you are correct that this is an interpretation that may be better presented and stated as a hypothesis with alternative hypotheses as possibilities. We will revise in this manner.

L 367 I suspect that Dingman simplified his modeling to a homogeneous snowpack. While the four-phase model remains valid for individual homogeneous layers, additional complexity is necessary to accurately represent real-world snowpacks (which however is made up of different homogeneous layer, possibly at different phase).

This refers to the 4 phases: accumulation, warming, ripening, output. Revisions will clarify this.

L371 Given the significant spatial variability in snow depth, particularly in complex terrain, it is challenging to believe that traditional probing methods can accurately capture these variations without averaging N measurements and without a rigorous uncertainty analysis.

As mentioned above, an uncertainty analysis will be conducted. However, the survey was designed based on the Lopez-Moreno reference also given above. More data would have likely been better (as it always is), but the actual variability of the depth could not be known until after the data were collected.

L374 and conclusion: So this is only a study on the energy balance and not on snow redistribution processes?

The redistribution refers to the interpretation of SWE moving down the hillslope through lateral flow paths. This will be clarified in revisions and other terminology considered to avoid confusion.

As a final note, while there are no explicit publisher guidelines against self-citation, it is generally advisable to minimize excessive self-referencing. For instance, the accurate prediction of LWC by SNOWPACK could be supported by citing previous studies (as done in the current self-cited works) that provide also detailed information about the model details, which is not developed by the authors.

Thank you for pointing this out. It is easiest to cite one's own studies because sometimes they come to mind first. But, this is good advise that I agree with. Some of these will be replaced during revisions to avoid over self-citing.

The References section is difficult to read due to the lack of spacing between entries. Additionally, some references appear to be formatted incorrectly e.g., L87 Clark et al. should be Clark et al., 2015.

Formatting will be double-checked during revisions throughout the text, but the journal manuscript template was used with respect to the references section spacing. We can confirm the formatting of this section and revise if mistaken.

Kinar, N. J. and Pomeroy, J. W.: Measurement of the physical properties of the snowpack, Rev. Geophys., 53, 481–544, https://doi.org/10.1002/2015RG000481, 2015.

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