Comment on tc-2022-42

Anonymous Referee #2

Referee comment on "Drone-based ground-penetrating radar (GPR) application to snow hydrology" by Eole Valence et al., The Cryosphere Discuss., https://doi.org/10.5194/tc-2022-42-RC3, 2022

"Introducing drone-based GPR in snow hydrology studies" Review

This is an exciting early experiment on UAS GPR-measured snow depth which leads me to want to give some preference to this paper for its novelty. The goals in the abstract indicate there's a fairly robust snowpack monitoring setup along with acknowledging there are some inherent challenges to using GPR--which, yes, totally agree there are challenges. The article and data itself are more along the lines of "here's what we did" instead of "here's what we found." There are interesting ideas, but not sure the analysis did the dataset justice. For a highly quantitative topic, this paper is extremely qualitative.

The authors also mention several instances there is a degree of uncertainty beyond what the data directly presents (Line 165) which doesn't strike confidence with me either. Again, despite saying LWC in the abstract was well-measured, the authors reference in the results that it was highly overestimated (Line 356), so there is a lack of agreement and consistency that doesn't support this sense of confidence.

As someone who is most interested in the drone-based elements of this study, some more robust methods in comparing the GPR-measured snow depth against the DSM-measured snow depths are warranted. Even some sort of basic spatial correlation to identify where, if any, errors are present would be fascinating. Simply summating, all errors were less than 3 cm is not a satisfactory result given that most of the shallow snowpack is in the 15-20cm range (10-25% error at 3cm).

Lastly, while the authors acknowledged that they observed different morphologies of

snow, they seemingly treated all of the snow the same, despite directly stating there are differences in density and water content from those morphologies. It's good to say you need to use different equations, but it's another to do so (Line 375). It is also a weak finding that in your results and reflections you lack confidence in those same results. Again, having some sort of GPR weighting to compensate for different snow morphologies will produce different results.

Below are numerous recommendations for edits, clarifications, and additions. Upon reflection, these cover much of the submission. I'd suggest that major analytical revisions are needed and a very different presentation of this work should result from clearer writing.

Line 10: Eliminate for instance, reverse ice and snow

Line 13: Eliminate aims to

Line 18: Replace with "weekly drone surveys", change sentence to active voice

Line 26: Awkward, rewrite; snow pack rather than snow cover? And throughout

Lines 25-30: No mention of SWE? Seems like that would be logical for hydrologic purposes

Line 30-35: Eliminate references to socioeconomic factors, focus is assessing snow-cover change, not its impacts

Line 31. hydroelectricity production is not an "economic sector", do you mean hydroelectric power? Also missing a comma

Line 36: Eliminate a in "anticipate a further"

Line 36 to 42 – cite Cho et al. Cho, E., McCrary, R.R. and Jacobs, J.M., 2021. Future Changes in Snowpack, Snowmelt, and Runoff Potential Extremes Over North

America. *Geophysical Research Letters*, *48*(22), p.e2021GL094985.

Lines 45-50: Introduce concepts earlier; statement is not a natural conclusion from the previous studies.

Line 55 – Clarify what "With a centimeter scale accuracy," means – is this vertical or horizontal; there are also numerous studies besides the one cited.

Lines 56-57: I'd disagree with that assertion, different word-choice needed

Line 57. Better citations are Harder et al. 2020 and Jacobs et al. 2021

Harder, P., Pomeroy, J.W. and Helgason, W.D., 2020. Improving sub-canopy snow depth mapping with unmanned aerial vehicles: lidar versus structure-from-motion techniques. *The Cryosphere*, *14*(6), pp.1919-1935.

Jacobs, J.M., Hunsaker, A.G., Sullivan, F.B., Palace, M., Burakowski, E.A., Herrick, C. and Cho, E., 2021. Snow depth mapping with unpiloted aerial system lidar observations: a case study in Durham, New Hampshire, United States. *The Cryosphere*, *15*(3), pp.1485-1500.

Throughout: Replace h with Snow Depth

Line 68: Define moderate precision

Line 79: If it has much attention, then where's the citation of studies? References needed to validate assertion

Line 82: Awkward, rewrite

Line 90-91: Develop this thought more. Recall why they don't work and the opportunity presented. Why the weird indent of just this sentence? What is a representative scale?

Throughout: Unless the abbreviation is referencing first letters, replace with the actual name of variable

Line 92 Rework this paragraph through the rest of the introduction; GPR needs to be introduced earlier then the relationship between GPR and snow density. In order to motivate the study. Also forests are mentioned in several places but it isn't clear if the study seeks to capture forest snowpacks.

Line 93. permittivity is not mentioned previously or defined, there is no literature cited describing GPR and snow

Line 95: State why LWC can be neglected

Line 96: Why is snow density abbreviated, but relative permittivity not? Only one assumption is mentioned, why either?

Line 99: Showing potential how?

Lines 100-105: Major undercutting of research efforts, perhaps eliminate or decrease severe language

Line 111: MASL or define acronym

Line 112: Topographic?

Line 113 clearance?

Lines 115-120: Rewrite thermometer methods. Use positive depths for clarity.

Line 116: Eliminate thanks to

Line 118 How was snowpack temperature measured?

Line 124: Replace that with the

Line 125: Is this study only about the ablation period? Aren't they all of interest? Rewrite

Line 127: Snowpack is snow...which is by nature, cold. What does that mean? Define cold or cold content as well as initial conditions of the snowpack when the study began.

Line 129: What was it before? Language is too colloquial

Line 130: Eliminate Interestingly

Throughout: More precise language is needed. Seems colloquially written with many arbitrary adjectives

Throughout: Instead of writing about the weather, perhaps a time series of snowpack temperature?

Line 139: Decreased from 30% from what to what?

Line 140: Note date of last survey, not "last survey"

Line 142: Remained negative in F or C? Replace with "remained below ##F/C"

Line 145-149: What is this referring to? What does quasi-impermeable mean in context? Rewrite or eliminate

Throughout: Refocus study site section to reflect the study site, not the specific climate patterns which quickly blend amongst one another. Perhaps is best replaced with a figure of temperature

Line 154. Single points can't be used to quantify accuracy

Line 156: Something more formal than "spots"

Line 157 Where were the probes located? Height above ground?

Line 191: Shouldn't DJI go at the beginning? Rewrite for clarity

Lines 190-195: Why were these packages installed? What necessitated that? If they were used instead, why mention the DJI manufacturer specifications

Line 195: Is it necessary to mention Pix4D twice?

Line 201 Is this the h error or the DSM error? How was this error determined? If this is h, then this is a very low error; were there in situ observations to confirm? See the standards from previous SfM papers. What is the grid size of the DSM?

Line 214 What is "the algorithm"?

Line 255 Describe the kernel algorithm rather than referencing the GIS software.

Line 266: Draw out what that purpose was. Being explicit likely helps frame the significance of the result

Lines 270-275: Visually accurate is not appropriate. If there are no in situ snow depth measurements then there is no means to estimate the snow depth accuracy using SfM. Use consistent, non-subjective adjectives to describe snow depth. My idea of extra might be different than your own, for example

Throughout: Specific language needed. A greater reliance on numerically-sourced explanation would improve the clarity of the paper. Too often the authors resort to arbitrary language to describe the results. Provided this is a GPR paper, there had to have been intense quantitative methods, otherwise, this paper is just a description of snowpack GPR imagery.

Figure 1.a: Could you perhaps use a more hi-res map? Color would be useful

Figure 1.b: What do the numbers mean? What are the bounding boxes displaying? Legend and scale are needed. Is there imagery that isn't as dark as this?

Figure 1.c: there needs to be a way to link this figure to 1b. Maybe add instruments to this figure? Match the sensor names in table 1 with this figure; what is at the top of figure 1b? a building? A vehicle? Remove these from the figures. Flight lines are needed in this figure.

Figure 2 – correct spelling; what is relative density?

Figure 3: Use a different color scale. This signifies elevation to me, not snow depth. Red-Blue is better; indicate what red lines are

Figure 4 which line is which? Need to define alpha, beta, etc. in the figure legend

Figure 5 How were these measured? What is the origin? These lines should be on Figure 1

Figure 6: Use a graduated color scale, WAY too many choropleth options to make sense of the differences

Table 1: Replace h with Snow Depth