

The Cryosphere Discuss., referee comment RC1
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Comment on tc-2022-42

Anonymous Referee #1

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-RC1>, 2022

Summary: Valence et al. present findings from a field campaign in Quebec in 2020-21 that integrates novel drone-based GPR snow property retrievals and comprehensive in situ observations from both automated instruments and snow pit observations. These methods are quite new and exciting, and I expect that this paper will be of significant interest to the research community. Below, I provide my general and specific comments.

General comments

1. Quantify findings and include these details in the abstract

- At multiple locations in the manuscript (noted in Specific Comments), changes in the snowpack characteristics (the results) are presented in a general, non-quantitative manner; e.g. "the LWC increased." The manuscript would be strengthened by replacing these statements with specific quantitative results from the analysis. The most important of these findings should be added to the abstract to replace the current focus on the TDR results, as the novel drone-based GPR results should be highlighted more prominently.

2. Refine writing

- Introduction: The introduction could be strengthened by refining the writing to provide a more detailed and direct introduction to the novel work presented in the manuscript. By doing so, there would be more space for a more thorough literature review, for

which I have provided a few examples in the Specific comments.

- Split study and condition section: The condition details are results (and even extends into interpretation/discussion) and thus seem better suited to appear at the beginning of the results section after the Method sections introduces the AWS observations.

3. Details on SfM snow depth acquisition, processing, and interpretation:

- Provide more specific details in Section 3.3, for instance % overlap of images, flight pattern, UAV height AGL, processing/filtering steps, the resolution of the gridded DSM rasters, the specifics of the ground control points, the nature of the ground surface in the snow-off DSM, etc.
- Were the ground control points used in DSM model development or used as independent checkpoints? What is the basis for the reported 3-5 cm uncertainty?
- Were the surveys done in an identical manner on all dates? Were the GCPs deployed and surveyed each time?
- On what basis were the maps considered "satisfactory" (In 273)? Were they independently evaluated by distributed snow probe observations?
- How were the drone-based snow depths and radar travel times aligned/integrated (e.g., Figure 5)?
- What was the "good agreement" between the SfM depths and those of the AWS (In 347)?

Specific comments

Title: The title should be modified to more accurately reflect the key findings of the work; previous publications have used drone-based GPR, so the use of "Introducing" is not fully justified

10 – ...dictate the quantify "and timing".... Suggested addition in parentheses

13 – what is a mild episode?

13 – This study develops... delete "aims to"

14 – replace repetitive with repeated; here and elsewhere in the manuscript

15 – define GPR at first usage

18 – “on a weekly basis” – while the four surveys occurred at a weekly interval, it would best to describe the scope more specifically by stating the total number of surveys, as this could be misinterpreted as surveys occurring weekly throughout the winter

20 – properties “were” monitored using TDR...

22 – I would encourage a revision of the abstract to focus on the main findings of this work. At present, the findings listed after “Among others...” focus on results from the TDR probes rather than the drone-based GPR work. Further, the last point “the hydrological influence...” is an interpretation based on the TDR and lysimeters, rather than a direct finding. I suggest revising to highlight the main findings from the novel GPR methods.

33 – “reported from cold regions.” I wouldn’t describe all of these locations as cold regions, so I suggest describing them in a different manner.

39 – Specify the period of time over which the Li et al., 2019 study documents an increase in ROS events.

50 – consider replacing “capture” with more precise terminology

55 - SfM derived snow depths do not have cm scale accuracy – is this statement referring to the spatial resolution? Most previous studies document RMSEs of ~10 cm.

65 – Consider adding Holbrook et al., 2016 (Estimating snow water equivalent over long mountain transects using snowmobile mounted ground-penetrating radar) in *Geophysics*, doi:10.1190/GE02015-0121.1.

80 – add Guneriussen et al. (2001; InSAR for estimation of changes in snow water equivalent of dry snow, *IEEE*, 39(10)) reference to Rott et al., 2003

88 – add Webb et al., 2021 reference to Mavrovic et al., 2020

97 – I thought Yildiz et al. (2021) was working in dry snow conditions?

105 – add Prager et al., 2021 (Snow Depth Retrieval with an autonomous UAV-mounted Software-defined radar, *IEEE*) reference to Jenssen and Jacobsen, 2020

107 – what was the approximate area of the study plots?

110 – what is BVE?

111 – List the figure references as Fig. 1a. rather than Figure 1.a

112 – replace topography with topographic

113 – what is the meaning of clearance in this context?

113 – given the prominence of the slope comparisons in the findings, I would consider adding a subplot showing surface slopes to Figure 1. What is the variability in slope within these plots?

113 – delete “main station hosts”

114 – what are the hydroclimatic variables that are measured?

118 – replace hyphens with en dashes; here and elsewhere

121-123 – given the importance of these ROS events to the findings, I suggest describing them in more detail. For instance, how did the precipitation rates vary? Duration? Cumulative amount?

128 – what defines a “mild weather episode”? Please describe more specifically.

130 – here is one example where additional specifics could be included – how much did SWE and density increase by?

131 – , suggesting the presence of a preferential flow path.... This is an interpretation of the results and is better suited for the discussion

134 – I find the discussion of the weekly field observations and the “seven-day-long cold period” (which isn’t aligned with the weekly field observations) to be slightly confusing. I would consider adding semi-transparent shading to define the various warm/cold intervals in Figure 2 to help guide the reader.

140 – Please define magnitude of “substantial liquid precipitations.”

148 – is the statement “at least part of the ground remained frozen” based on the frost depths shown in Figure 2? Clarify this and include the appropriate figure reference.

160-165 – what was the sequence of these observations? How was the pit oriented?

165 – What is meant by “Punctual”?

165 – what was the vertical spacing between observations in the two vertical profiles?

169 – replace length with thickness.

191 – it is fairly non-traditional (in my experience) to list the manufacturer in parentheses after a specific product name. I suggest “A DJI Mavic 2 Pro UAV...”; here and elsewhere.

204 – Provide additional details on GPR integration and flight control software, as “supplied by SPH Engineering” doesn’t provide the reader with the necessary detail.

215 – replace electronic with electromagnetic

221– check equation – should this be $(c/v)^2$?

230 – replace representing with represents

254 and 256: provide units for equations 9 and 10

265 – see general comment #3 – were the control points used in the DSM model generation or were they completely different? What are you defining “significant differences” as?

268 – replace devices with solutions

269 – is this sentence necessary or could it be combined with the subsequent statement?

276, 279 – how much did the snow depth change by?

282 – given the elapsed interval, would it be better to report the magnitude of the change rather than the rate?

285 – replace fast with rapid; how is this defined? Provide specifics.

286 – Consider different phrasing than “Timewise”

287 – Quantify the tiny increase.

289 – what was the spatial offset of the lysimeter and the TDR probe?

298 – Quantify the increase in LWC

304 – the statement “This suggests the slope was more responsive....” is better suited for the discussion.

307 – ablation rather than ablations

311 – quantify the variability in the bulk permittivity; how is “quite stable” defined”

317 – how was the bulk permittivity variability calculated?

328 – revise the sentence to include the results rather than just stating that the results are found in Figure 6

333 – quantify the general increase in LWC

335 – quantify the “highly variable” LWC for both sections.

356 – how much do the drone-based results overestimate the WISe values?

358 – how are the drone based estimates calculated? Mean of all observations? Median? Proximal to the pit?

387 – “except for the density, LWC, and SWE...” – I would consider rephrasing to state where there was agreement (depth, permittivity) and where there wasn’t agreement.

400 – replace southward orientation with southerly aspect

414 – replace disposition with distribution

Figure 1b) add scale to figure? Is this a single image or could an orthomosaic be included instead?

Figure 1c) is this the snow-off or snow-on DSM? What do the red contours correspond to?

Figure 2 – add a, b, c and d labels to subplots. Does the RHS y-axis need to be divided by 15 in 2a and 2b?

Figure 2b – is the LHS y-axis depth below surface?

Figure 2d – typo in snow height in legend, how was relative density calculated? Units?

Figure 3 – replace commas with periods

Figure 3 – Switch DD/MM date format to YYYY-MM-DD to match figures 2 and 4.

Figure 4 – add a, b, c and d labels to subplots. Is it standard for these to be normalized by the first reading? How should the reader interpret the permittivity increments (i.e., comparable to relative permittivity)?

Figure 4 – I’m surprised that the permittivity values don’t capture the seasonal densification of the snowpack. Any ideas for why this might be the case?

Figure 5 – add subplot labels; y-axis “height” has a typo in all subplots

Figure 5 – swap date format to match other figures

Figure 5 – x-axis in multiple subplots has repeating numbers (6 7 7 8 and 7 8 8 9). Why is this?

Figure 5 – at what spatial resolution are the bulk relative permittivities calculated? Add this to the Methods section.

Figure 6 – Provide details on how the LWC results were kriged/interpolated? Consider overlaying the flight transects so the reader can better understand the data distribution.

Figure 7 – This figure has a lot of dead/white space, resulting in the actual results being relatively small. Please consider removing the y-axis tick labels for subplots b-d (i.e., after the first column) for each row and condensing each subplot to remove the white space to either side of the boxplots. The x-tick labels (flat, slope) could also likely be removed from all subplots other than the bottom row.

Figure 7 – swap date format to match other figures and add subplot labels

Figure 7 – Was the A2 WISe sensor used for LWC observations? If so, I would expect the dots to be colored black for snow pits. If not, what is the source for the LWC observations?

Additional figure: given the importance of the UAV radar, I strongly suggest adding in a two panel figure showing a radargram and the matching picked radargram.