Reviewer #2: Chris Donahue

We are pleased to hear that you find the manuscript well-written and suitable for publication in *The Cryosphere*, and we greatly appreciate your suggestions for improvement. We are committed to addressing each of your comments to enhance the quality and clarity of our work.

General comments:

1 The main weakness of the study is the application of the manual density measurements in the reference dataset, the gamma and lidar fusion dataset, and in the defined uncertainty for the reference dataset. Figure 3 highlights large variation in density over the surveyed areas and simply taking the average density to represent the entire area introduces bias. Since this is the basis from which the SWE map is assessed, why were the locations of the density measurements considered? Were GPS points taken for each of the density measurements? I think a spatially interpolated density map would greatly improve the robustness of the analysis and the results for both the gamma SWE and gamma + lidar SWE. As for the uncertainty in the reference SWE, equation 4 describes the error in a single density measurement but does not represent the error propagation to SWE as a result of taking the average density over the survey area. The error in any given pixel should additionally contain the spread (e.g., 95% percentile) in density measurements over the survey area relative to the mean.

From previous work on snow density–depth relationships for prairie snow covers (shallow, windblown, and highly spatially variable) it has been demonstrated that, for snow depth < 60cm, density does not vary significantly with depth. Since the study areas are relatively small and subject to similar conditions (mainly blowing snow processes) there is little expected benefit to increasing the complexity of the density representation beyond applying a mean observed density (Shook and Gray 1994). In contrast, the uncertainty in measurement of the density of shallow snow is such that an interpolated map will add significant noise that can be avoided with an average representation. Not all density observations had GPS locations taken, largely due to fieldwork/logistical constraints under COVID protocols, so we do not have a consistent GPS positioning to employ. Regarding the uncertainty in the reference SWE, we don't quite understand the comment. The uncertainty in reference SWE (Eq3) does consider the uncertainty of the average density applied (as calculated in Equation 4).

Shook, K.R.;Gray, D.M., Determining the Snow Water Equivalent of Shallow Prairie Snowcovers., Presented at Eastern Snow Conference, (1994), 1:14

2 One of the main goals of the paper is to present a new instrument for measuring gamma rays, however the detailed description of the data collected by the instrument is not shown nor described in detail. Per the manufacturers website, the MS-1000 collects data for multiple radionuclides across spectral channels. Please include full details of the data collected and how the total counts C were calculated based on the collected data. An example of the collected data (potentially as a sub-figure in Figure 1) illustrating the collected data would be a nice addition that will help the reader understand the data collected with the instrument.

We recognize the importance of providing a comprehensive description of the data collected by the UAV-gamma spectrometer. We will include more information about the how the total counts C were calculated and add a figure to the supplement if warranted.

3 Units are missing in many locations throughout figures and tables, that I have noted below.
We acknowledge the oversight in missing units in various parts of the manuscript. We will ensure that all figures and tables have the appropriate units clearly stated in the revision.

Line-by-Line Comments

Line 18: In the abstract the "reference dataset" is mentioned without context to what it is. I recommend briefly describing it here for clarity.

We will clarify the reference dataset in the abstract.

Line 22: I think this statement is somewhat misleading. The gamma+lidar fusion approach did not improve the results "substantially" and in fact the average site wide SWE measurement was slightly worse compared to the gamma SWE measurement alone. What did improve substantially is the spatial resolution of the SWE distribution.

We will clarify that the improvement is in the greatly increased spatial representation of SWE.

Line 25: Resolution is better described in terms of fine and coarse. I recommend that fine/coarse replace high/low when describing resolution.

We will update the terminology.

Line 82: Missing the word "of"
"Approaches to correct for overwinter changes require independent estimates of soil moisture change.."

We will correct this.

Line 90: include the term "gamma" in UAV spectroscopy/spectrometry.

We will correct this.

Line 95: The terms spectroscopy and spectrometry are used interchangeably in manuscript. I recommend choosing one of these terms and use it consistently, which should probably be spectrometry because that is the term used in the title.

We will update the terminology to be consistent as suggested.

Line 115: change was to were.

We will correct this.

Line 116: "to" is not needed here.

We will correct this.

Line 124: northwest and southeast are one word.

We will correct this.

Line 128: snowpack should be singular in this context.

We will correct this.

Line 152: Per major comment 1, please provide more information on how the spectral measurement was turned into count rates.

We will update our description on this processing step. See also our response to reviewer 1 on this topic.

Equation 4: This equation describes the uncertainty for the density measurements, but it does not describe the uncertainty that is propagated to your spatial SWE reference dataset by using the average of the density measurements across the entire survey error. The uncertainty for any given pixel in the reference SWE map should be defined somehow based on the spread of the density measurements in Figure 2 if you decide to keep the analysis based on the average density.

We don't fully understand this comment as we are propagating the uncertainty of the average density and uncertainty of snow depth estimates from the UAV at each pixel prior to propagation to the overall average SWE observed for the respective study areas.

Line 202-203: How was the lidar data interpolated? DIB or interpolation? Please add here.

We will clarify this. The UAV-lidar data is at a very high density (~100 pts/m^2) and we utilised LAStools approaches to convert the irregular point cloud to a 0.25 m gridded representation via a TIN surface fitting approach. Rescaling from the 0.25 m base resolution to other resolutions used the mean value of the new/larger grids.

Section 2.3.3: I don't understand why this analysis was not done spatially instead of using the average height and the average SWE from the two data products. This seems like a much more robust analysis and would make for a much stronger sensor fusion analysis.

There is spatial variability in the fusion. The spatial variability comes from the UAV-lidar snow depth (0.25 m resolution observations). Only the density is an areal average per the approach/justification explained in the second major comment. We will clarify this further.

Table 2: Add units to table. Also please add a statistic that describes the spread of the density measurements (i.e., 95 percentile, standard deviation, etc.)

We will update as suggested.

Figure 2: Snow density needs units on the y-axis and in the caption, I am not familiar with any convention that uses (-) as a means to describe a density.

We will update as suggested.

Line 229: Consider reminding the reader here what CV stands for. It is defined much earlier in text and I had to go back to remind myself.

We will update as suggested.

Figure 3: What are the units of bias in this figure (y-axis). Could you provide some more context as to why some of these are positive and negative.

We will be updating this figure to remove the mean bias panel as per Reviewer 1's comments.

Figure 4: y-axis units missing on bias, RMSE, and n. Also is the red fall stubble line missing in the number of observations plot? If it is underlying one of the other lines please make visible by increasing the line width of the underneath line or using dashed line.

Indeed, the fall and spring stubble lines are plotting on top of each other. We will modify this presentation as suggested.

Line 256: Biases should be described as positive/negative.

We will update as suggested.

263: “negative bias” used here, good!

Thanks

Table 2: Table missing units.

We will update as suggested.

Figure 7: Consider modifying the y-axis label so that it is clear that this doesn’t refer to snow density. Also, would it make sense to add the gamma_lidar fusion distribution here?

The addition of the gamma_lidar fusion here is a great suggestion. We will update accordingly.

Line 306: P should be rho.

We will update as suggested.

Figure 8: Make clear which way the difference is done (ie., gam_lid – ref OR ref – gam_lid)

We will update as suggested.

Line 344; ““…snowpack density changes…”’

We will update as suggested.

Line 402: “be” not needed

We will update as suggested.

Your detailed and insightful review has provided us with clear directions for improvement. We are confident that these revisions will strengthen the manuscript and make a valuable contribution to the field. Once again, we appreciate your valuable feedback and look forward to submitting a revised version of our manuscript.

Sincerely, Phillip Harder, Warren Helgason and John Pomeroy