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The Cryosphere Discussions

Interactive comment on "Shallow snow depth mapping with unmanned aerial systems lidar observations: A case study in Durham, New Hampshire, United States" *by* Jennifer M. Jacobs et al.

Anonymous Referee #1

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Jacobs et al. present snow depth maps measured with a lidar onboard an unmanned aerial system (UAS). The snow depth are calculated as the difference between a snow-on and a snow-off DTM. They study a shallow snowpack with snow depth inferior to 20 cm in a flat open terrain and forested terrain. The lidar snow depth are compared to in situ magnaprobe measurements. They also provide some insights on what controls the lidar precision. The article is innovative as results are obtained with a new combination of sensors and platform which is lidar and UAS. This was, to my knowledge, only suggested by Vander Jagt et al. (2015) but not yet tested. Although this article fo-

cuses on shallow snowpack, it can be inferred that this method is promising for deeper snowpacks in open terrain. I see two points which should be addressed before I would recommend this article for publication.

1. The novelty of this work is not well highlighted. L 95, the authors state: "However, to date there are few previous studies that estimate snow depth using UAS-based lidar (Vander jagt et al., 2013(5!))." In my understanding Vander Jagt et al. did not use UAS-based lidar and no other study ever did. The authors should verify the method in Vander Jagt et al. (2015) and cite the "few previous studies" that did similar work, if they exist. If this article is the first to present snow depth maps measured with UAS-based lidar, this should be clearly stated.

2. The main drawback which should be resolved is the way the "precision" and "accuracy" of the lidar snow depth maps are presented through the article. First, these two terms are not clearly defined. "Precision of the mean snow depth" is found first at L 232 and compared to "one-sided confidence interval". However, this last term is defined as equivalent to "the uncertainty of the lidar estimate of the snow depth" L181 in a confusing paragraph. Following this, it seems like we end up comparing "accuracy" and "precision" of the snow depth (L232) which I do not think was the initial goal. I rather understood that the authors intend to compare i) the accuracy calculated by comparing lidar and magnaprobe snow depth to ii) the lidar precision defined as the one-sided confidence interval. If I understood correctly, this need to be clearly stated, terms to be defined and consistently used. The definition of precision and accuracy proposed in Eberhard et al. (2020) found in Maune and Naygandhi (2018) might help. Related to this topic, the authors use within-cell standard deviation of the elevation twice: in equation (1) in what seems related to the accuracy of the lidar and L 262 to define "the within-cell variability". It seems like in the first case, the standard deviation results from error in the lidar while in the second case, the standard deviation results from the natural variability of the snow pack. As long as this is not clarified, it is hard to understand the point of the paragraph starting L260 in which the authors state that "In

addition to the lidar point cloud density, the ability to precisely capture the snow depth also depends on the within cell variability".

Minor comments are listed below. L21 : better repeat snow probe instead of "in situ"

L21 : "with" instead of "from" ?

L 34 : Make clear that the albedo is "higher" than the ground albedo not than the deeper snowpacks albedo.

L 55 : precise "point measurements"

L 55-57 : Could you clarify this sentence. Maybe split it in two. Plus, I do not understand the opposition you see between increasing spatial variability and small-scale feature. Finally, is it so sure that spatial variability "naturally increases with spatial scale"? Fig. 4. of Deems et al. (2006) seems to show that spatial variability stops increasing above a typical distance of the order of 10 m.

L 63: If you list the methods using difference of surface elevation, you may want to include spaceborne photogrammetry (e.g. Marti et al. 2016, McGrath et al. 2019, Shaw et al. 2019). Otherwise, if you prefer focusing on airborne method, you should remove references to terrestrial laser scanning.

L 76 : what is "micro scale" and "field scale" ?

L 96 : Vander Jagt 2015

L 135 : How do such angles occur since the channels are between -15/+15°? Is it because of the roll and pitch of the UAS?

L 151 : Please indicate what kind of "non-ground point" you observe in this area. Trees, artifacts.. ?

L 153 : Do you further use th and w notations ?

L 154 : "mean" without s?

L 159 :What do you mean with "Following processing"? The sentence is not clear.

L 181 : This paragraph is confusing. It seems that lines 181 and 187 are not consistent. Is the "uncertainty" from L181 the same as the one from L187? See main comment about precision and accuracy. L 181 : you state "uncertainty of the lidar estimate of the snow depth" is the "one-sided 95 % confidence interval" L 185 : you define a "pooled standard deviation" not used after. L 187 : you combine "snow depth uncertainty", "number of lidar return" and "pooled degrees of freedom" to calculate "the one-sided width of the 95 % confidence limits"

L 185 : Does this assume that the spatial variability within the cell is negligible? See main comment on precision, accuracy.

L 191 and following : Please make clear for what resolution these percentages hold.

L 198 : You state "0.95 %" of the forest cells are empty for the 1 m resolution grid. Does that correspond to the white areas in the western forest (Fig. 4) ? In case it is, this seems to be more than 1 % of the forested area. In case it is not, what are these white areas?

L 212 : In "(12.2 cm +-0.56 cm)", is 0.56 cm the standard deviation of the population of mean snow depth ? Or is it related to the standard deviation described in L 185 ?

L 215 : First time the word "tube" is used. Was it the "federal snow sampling tube" (L 172) ?.

L 232-233 : "precision" is not defined above. This sentence is thus hard to understand.

L. 260 : " In addition to the lidar point cloud density, the ability to precisely capture the snow depth also depends on the within cell variability. " Why? Is it a statement based on the way you calculate the lidar precision or an assumption which should be justified? See main comment on within-cell variability.

L. 260 : this is not mandatory but since you use standard deviation, did you check

whether the distribution is normal or not ?

L 319 “boresighting”

L 319. Could you explain what boresighting is ? Not sure The Cryosphere readers know what it is.

L. 368 : Could you provide details about the “simple penetration test” ? If this not it, do you think it would be possible to dig a snow pit at the location of the magnaprobe measurement to evaluate probe penetration ?

L. 389 : “moderately” please give values.

L 510. Missing a carriage return before “Starkloff”

Fig. 1: what’s the reason for the buffer around the forest polygon, especially why is the forest peninsula out of both zones (east of the field, west of the western forest) ?

Fig. 2.a The number of returns per cell seems to follow a relationship of type $y=kx^2$ with k the average density of the point cloud and x the cell resolution. Could you comment on that? Did you expect that?

Fig. 2.b It is not so easy to distinguish the two distributions. Maybe remove the vertical lines of the bars ?

Fig. 5, what are the gray points/area on panel a. It seems absent in panel b.

Fig. 6.a. Isn’t that surprising that the STD per cell is the same with snow on and off in the forest? Could you comment on that?

Fig 7. Label the panels a,b,c,d instead of A/B top/bottom. Zoom in the panel b. Keep a. as it is and add a square showing where b. is. It is really not clear what is shown in A,B. Are we in 2D view from top in A and from profile in B?

Reference:

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