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The Cryosphere Discussions
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Interactive comment on "Mapping snow depth in alpine terrain with unmanned aerial systems (UAS): potential and limitations" *by* Y. Bühler et al.

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Dear Referee

Thank you for your very late but valuable review. In our opinion we have already answered a lot of your questions with the answers to the review of Matt Nolan and Alexander Prokop. Therefore we limit here the answers to the questions going beyond the points of the two other reviewers.

The additional point you bring up in the general comments is that we should not make statements on fixed-wing UAS as we did not use them in this study. That is true but we have quite some experience at our institute with fixed-wing UAS and did fly (and crash) them around Davos (CH) and Innsbruck (AT). We have flight experience with a SensFly eBee, a Trimble UX5 as well as self constructed devices. However, in the paper we

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will mark all broader statements on fixed-wing UAS with “from our experience”. In our opinion, the statements we make are well enough supported by our experience in alpine terrain and are valuable hints for readers, therefore we want to keep these statements.

Specific comments:

In our opinion this investigation reveals a lot on potential and limitations of UAS for snow depth mapping in alpine terrain. We also discuss this point. Therefore we want to keep it in the title, if the editor agrees.

P2L1: changed as suggested

P2L10: please see answers to M. Nolan and A. Prokop

P2L13: changed as suggested

P2L19-20: As we have three DSM acquired during different dates in winter at Tschuggen, we can monitor ablation processes. We cannot do that at Brämabühl as we only have one DSM acquired during winter.

P2L23-24: changed as suggested

P224-26: changed

P3P1: Changed to individual sentences

P3L13: Changed to “Remote sensing is useful to monitor”

P3L15-17: We thought a lot about the best position for this definition. As it is essential for the entire paper, we decided to bring it at this place, early in the paper.

P3L21-23: In our opinion this sentence makes sense here as it describes a recent TLS application where snow depth is the key variable.

P3: We think the text is better structured keeping the two paragraphs

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P4L5-6: changed to “were insufficient for most applications ”

P4L11: changed as suggested

P4L11-16: changed as suggested

P4L20: changed as suggested

P4L20-21: We update and include the recently published papers

P4L23-27: rewritten to “De Michele et al. (2016) conclude, that UAS-based HS mapping holds great potential, but that further studies are required especially with regard to multi-temporal mapping, to sensors capable of measuring in near infrared bands or to the mapping of different snow cover conditions (new snow, wet snow, ice crusts etc.).”

P5: we merge 2.1 and 2.2 as suggested

P5L10: change to “of better than 2.5 m (personal communication from Ascending Technologies)”

P5L17-19: We list the filter thresholds we have available. As we do not further use the different filters in this study, this information is sufficient in our opinion.

P6L1-20: We do not understand, where you suggest putting the section break.

P6L11: changed as suggested

P6L12: changed to “good”

P6L13-15: changed to: The radiometric and spatial resolution of the Sony NEX-7 camera enable the generation of highly accurate digital surface model (DSM).”

P6L19: changed to “due to limited carrying capacity, space and battery power.”

P6L19-22: We add “from our experience” and change not appropriate for high mountain areas into “difficult to fly in high mountain areas”

P6L23: This is not a speculation but a feedback we get from nearly all colleagues flying

fixed-wing UAS in mountains. This is clearly the point causing most trouble applying fixed-wing UAS in alpine terrain. And should therefore stay in our opinion.

P6L9-11: we do not find an inconsistent tense here

P6L13-20: We describe the data acquisition parameters in the chapters 3.1 and 3.2. We did not perform a sensitivity study of the DESM quality to the parameters yet but we are planning such a study for this winter.

P6: We add “using dense point cloud generation with the default parameters”

P6L23: changed as suggested

P7L5: changed as suggested

P7L9: changed as suggested

P7L9-11: yes from the summer DSM resampled to 1 m

P7L13-15: This overlap was chosen based on discussions with different colleagues and is based on our own experience. We are planning to investigate this question in more detail in a follow on study. To make this clear we write “From our experience”.

P7L18-20: we add: “The Tschuggen test site can now be covered with one battery.” And “To cover the Brämabühl test site we need four batteries”.

Sect 3.1 & 3.2: we already list the areas in the tables 2 & 3.

P9L17: We are currently investigating the benefit of NIR compared to RGB. This was not yet investigated for this study.

P10L3: there could be other causes why a slope is not accessible. Therefore we want to keep the e.g.

P10L5: changed as suggested

P10L6: changed as suggested

P11L4: This is the mean snow depth averaged over the entire test site. There are only a few spots with remaining snow cover (Fig. 4)

P11L18: changed to “average underestimation of HS by 0.2m”. In our opinion this formulation is more precise as bias.

P11L26-29: This are the RMSE values per class (as it is written). We change mean shift to bias as suggested and add “for all three flight dates”.

P12L28: The correlation between the reference HS measurements and the photogrammetrically measured HS is in our opinion a useful estimation of the mapping quality, as many readers will be used to correlation as a measure of quality. As the investigated test sites are typical for alpine catchments, want to keep these values. They depict that no drift of error occurs at very high or low HS values.

P13L1: In our opinion our description here is easier to understand and more precise

P13L3-4: we change mean deviation to bias. WE compare to the stddev within a reference plot as we write.

P13L20-21: We want to keep this information as we think it is important for the readers.

P13L21-23: we add “Based on our experience” to make this clear

P13L23-24: We did flights were we had air temperatures of -25 ° C, -30° can occur in the early mornings in Davos. We faced problems with cold batteries several times.

P14L6-9: we add “Our experience shows that”

P14L13: changed as suggested

P14L18: changed as suggested

P14L23: changed as suggested

P15L6-12: We are investigating the difference between NIR and RGB this and next winter. We do not have reliable quantitative results yet to publish them in this paper.

S5.3: Coregistration is an absolutely crucial point for photogrammetric HS mapping. Therefore we want to keep this part.

P17L13: changed as suggested

P17L15-16: In Switzerland you are allowed to fly at an altitude of 500 m above ground, so it is feasible. We cannot mention all the different regulations around the world here.

P18L9-26: Moved to the discussion as suggested

P19L1-3: rewritten to “We expect that UAS will get more and more important for mapping applications also high alpine terrain and that this methodology will change the frequency and quality of geodata acquisition fundamentally.”

Fig5: we add “for the HS values” to clarify.

Fig7: we add “(bars) and (line) to clarify”

Fig8: We remove this trend line as it is too close to the 1:1 line

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