The Cryosphere Discuss.,
doi:10.5194/tc-2015-220-AC1, 2016

The Cryosphere
Discussions

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

Y. Bühler et al.

buehler@slf.ch

Received and published: 16 March 2016

Dear Matt Nolan,

We thank you for your positive feedback and the constructive comments.

We do not at all intend to talk down the value of manned aircraft for snow depth mapping over large areas. We are ourselves strong supporters of this method (e.g. Bühler et al. 2015). However, to cover small areas, I am positive that UAS are more economic than airplanes in most countries around the world. The situation you have in Alaska is very special. I was really jealous to see all the nice airplanes in the gardens outside Anchorage. This is really a dream come true for every remote sensing guy. However, in Switzerland and most European countries, it is quite time-consuming and costly to get an airplane and acquire the necessary flight permissions. This is

additionally hampered by very restrictive ATC-regulations for small airplanes in Central European airspace and the use of alpine airports. Repetition flights are nearly impossible to do, we collected some quotations on that. On the other hand, the regulations to fly UAS are different for every country and sometimes even for different states and they are changing quickly. Therefore it is impossible to list all the different regulations. We confine us to give a brief description of the most important regulations for Switzerland in the paper. However, as you suggest, we amended the proposed addition"over several hectare areas"to the sentence in the conclusions to make this clearer. And you are right, compared to North America, the Swiss Alps have a very dense infrastructure (roads, railways and huts that serve spaghetti and fondue), which makes it much easier to deploy UAS, because you can reach most spots of interest quiet easily. On the other hand it is very difficult and expensive to get an airplane with flight permission on short notice.

We will include an assessment of the repeatability by analyzing the snow free road at the Tschuggen test site at all 4 flight dates. Thank you for this valuable suggestion. We add the following paragraph to chapter 4.1: "To assess the repeatability of the UAS HS mapping, we analyze the altitude deviation of the different DSM for 10550 grid cells on the snow-free road. The calculated RMSE values compared to the summer DSM (28 September) are 0.093 m (11 March), 0.052 m (24 April) and 0.045 m (12 May). This indicates that the noise of the method is smaller than 0.1 m."

Specific comments:

P1L1: The first sentence intends to give a broad picture why snow depth information is important. We therefore want to keep this sentence.

P1L2: We use the abbreviation HS for snow depth consequently through the paper, therefore we would like to already include it in the abstract.

P1L3: We change Nowadays into Currently

P1L6: We change the sentence to “even a dense measurement network like in Switzerland with more than one measurement station per 10 km2 in average “

P1L10: We add "in most countries“ to consider the situation in Alaska.

P1L15: We change otherwise inaccessible not accessible from the ground. Not all parts of the Brämabühl test site were accessible. The steep north-facing slope is very prone to avalanche danger and cannot be accessed during most days in winter.

P1L21: We added “compared to manual snow-depth measurements” to clarify this

P1L24: We change the sentence as following “This new measurement technology opens the door for efficient, flexible, repeatable and cost-effective snow depth monitoring over areas of several hectares for various applications.”

Introduction: We put the proposed discussion on UAS capabilities to the discussion section. Are you sure you are able to map avalanche danger as you write? Your impressive results in Nolan and Deslauriers (2015) show the mapping of cornices and the filling of terrain features. However I do not see that you map avalanche danger.

P2L27: We listed three different quotations of airborne LiDAR- and Photogrammetric data acquisition in Bühler et al. (2015). It is clear, if you already have a full system including airplane and pilot, that the costs are considerably reduced. However, we doubt that there are lots of users who have all this equipment available (especially in Europe).

P4L2: please see answer above

P5L20: We cite two papers demonstrating the advantage of near infrared bands. However, in this study we are not able to investigate this topic in detail. Therefore we just mention the potential by citing. We are right now working on a detailed study to quantify the benefit of near infrared bands.

P7L13: We think this is interesting information for readers who want to apply SfM and

we would like to keep it in the paper.

P7L25: We usually choose locations for our investigations that are well accessible. We would have a lot of other areas, which are not as well accessible. But the terrain characteristics of the choosen test sites are representative for a lot of areas. We change typical locations into “ that represent typical terrain characteristics in high-alpine environment ” to clarify.

P8L14: We did several tests with different overlaps. Our experience showed that 70% is a good compromise. We add “from our experience with different overlaps we conclude that”to clarify why we get to this conclusion.

P8L16: We do not use the position of the cameras recorded by the UAS GNSS as the accuracy is estimated to approximately 3 m, which is insufficient for snow depth mapping application. We only use the UAS GPS to fly the lines defined in the flight planning software. Unfortunately the producer of our UAS gives no details on the applied GNSS sensor.

P8L21: we replace selected with applied

P8L25: This is the orientation accuracy, not the accuracy of the orthoimagery. These values are calculated from the applied GCPs. We change orthorectification to “orientation”.

P9L17: See answer to P5L20. For this study we do not have simultaneously acquired NIR and RGB data but we work on a secondary study where we will have such data available.

P9L26: We mixed up the correct terms. What we use are reference points not control points. We use these points to absolutely orientate the photogrammetric products. We change GCPs to reference points RPs throughout the paper.

P11L7: We classify the are to snow and no snow. Areas not covered by snow are set to HS = 0. Negative values are not changed but due to the color bar limit, they are depicted red (HS <= 0). We change the sentence to "…. snow-covered areas have been separated from snow free patches using a simple unsupervised classification."to clarify this point.

P13L17: In our opinion the discussion is the right place to discuss this question, as we do. However, we added your suggested changes in the abstract restricting the application of UAS to several hectares areas. As you suggest we move the potential applications from the conclusion to this discussion chapter.

P15L6: In this section we discuss what could potentially improve the results. As stated before we are working on a secondary study quantifying the assumed benefits. We clearly state " However, further studies have to investigate the real benefit of NIR bands for photogrammetric HS mapping in more detail. "

P15L19: Yes this is a mistake. We change GCPs to RPs anyway (see answer P9L26). C is a combination of a and b leading to an absolutely referenced HS map with no offsets in the HS values. As we do not use the UAS GNSS measurements (they are not accurate enough), we must apply RPs, either relative or absolute. We do not understand your proposed approach of matching the HS maps to the probe measurements as we would have a large number different cells with the HS value of the probe (plus minus lets say 5 cm of error). Furthermore we would not be able to assess the achieved accuracy of the HS product if we use the probe measurements for referencing. We add the following sentences to discuss the possibility of very accurate onboard GNSS referencing: "RPs would not be necessary if a very accurate (better than 0.05 m) GNSS system would be available directly on the UAS. First UAS products with such high-accuracy GNSS sensor are already available on the market. However a first investigation by Harder et al. (2016) indicates that the achieved orientation accuracy is not sufficient for snow depth mapping without ground reference measurements."

P16L9: We add "of the HS maps"

P17L1: Here our experience is different. We are not able to reliably map the ground

around and below trees and bushes. It is possible that this effect is less distinct within data with lower GSD. Therefore we want to keep this statement. However we change impossible into "difficult"

Conclusion:

As suggested we move the list of potential applications to the discussion chapter. In our opinion it is not necessary to map entire catchments for water resource prediction or flood warning, but it may be sufficient to map representative subsections which can be done wit UAS. Therefore we want to keep this application in the list even though this can also be done with manned airplanes, as we showed in (Bühler et al. 2015). However we add "small" to alpine catchments.

Interactive comment on The Cryosphere Discuss., doi:10.5194/tc-2015-220, 2016.