

## ***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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Received and published: 6 April 2016

Dear Alexander Prokop

Thank you for your fast and constructive review. In our opinion we have already answered a lot of your questions with the answers to the review of Matt Nolan. Therefore we limit here the answers to the questions going beyond the points of Matt Nolan.

You bring up a very important point, the one of legal regulations. It is true that UAS are a hot topic in the press right now and every country, or even every state and community, brings up its own regulations. And it is true, if the regulations are strict, UAS are not flexible anymore, as it seems to be the case for Svalbard. However, to make this point more clear we add the following section at the end of the introduction and move up the part from chapter 2.2:

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“The regulations for flying UAS vary a lot from country to country or even between different states or communities. If it is necessary to get a flight certification / permission a long time before data acquisition, this limits the applicability and flexibility of this technology considerably. The regulations in Switzerland are quite user-friendly and are easy to fulfill as long as the UAS is within line of sight, no special permissions are necessary except you want to fly over crowds (more than 24 people within short distance) or close to airports (Swiss regulations: <http://www.bazl.admin.ch>). However before applying UAS, the local regulations have to be checked carefully.” We do not understand why UAS should need more pre-organizing work than laser scanning. Also with laser scanning you need reference points and reference measurements. And, if you want to scan areas with different expositions (this is usually interesting for snow depth investigations) you need more than one scanning position, rising the effort in time and costs considerably. Additionally, the entire TLS equipment, plus the power unit required for self-sufficient operation of a TLS in the field, are typically much more bulky and heavy than the UAS-equipment. If we reference the winter DSM onto the summer DSM, as we do at the test site Braemabühl, we do not need reference points at all and are very fast in data acquisition (flight time for Tschuggen ca. 5 minutes, Braemabühl ca. 15 minutes). We will add this information and information on the weather conditions as you suggest. In our opinion UAS is not “better” than laser scanning but it is a valuable alternative / complementary technique, as we state at several locations in the paper. From our experience, UAS is definitely cheaper than laser scanning to cover smaller areas with different expositions where you would need more than one scanning position to cover the entire area. Such cases occur very often in alpine terrain if you want to cover more than one mountain flank. So we get more and more requests from our institute to cover areas that have previously been covered by laser scanning. An important problem with long-range laser scanners such as the Riegel VZ 6000 is that they are not eye safe and you have to be sure, that nobody can look directly into the scanner also not with binoculars. This is very hard to ensure at least in the Swiss Alps. Also, the UAS device itself is about a quarter the price compared to the costs

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of a laser scanner. We were able to acquire TLS data simultaneously to the UAS data for this study at our Austrian test site – a publication of the results is in progress. Additionally, we plan more such simultaneous data acquisition campaigns for this and next winter. The application in ski resorts is no problem from the regulations point of view in Switzerland. The limitation of existing dGNSS systems on snow groomers is that they only know the snow depth where they drove through but they do not know what is next to them in particular next to the ski tracks. We have already requests from ski resort to test UAS for this purpose. However, following the suggestions of you and Matt Nolan, we limit our statements (costs, flexibility, data acquisition speed etc.) to “small areas”.

In our opinion we focus in this paper on the UAS results we found within this study. The outlook on potential applications, causing critics from the reviewers, is now moved to the discussion part and clearly marked as “potential applications”. However, we are convinced that such an outlook is very interesting for the readers and does not reach “beyond the scope of the study”. We discussed this point with different colleagues and they all have the opinion that such an outlook belongs into the paper. Big parts of this outlook are based on discussions and requests from SLF colleagues and we think they are valuable for the readers. P1L15: We add “compared to manual measurements” P1L24/25: we remove “investigation the worlds cryosphere” as suggested but we want to keep “flexible and cost-effective” but add “for small areas”. P2L24: this is still a big problem for a big part of our applications, as the SLF laser scanning experts report. Therefore we want to keep this sentence. We add the requested information on flight time, batteries used and weather conditions within the description of the test sites and data acquisition. We add the suggested citation Prokop et al. 2008. Braemabühl: In our opinion such an analysis of snow depth distribution along different expositions is of value for the readers as it is a straightforward application of the UAS datasets. We perform this analysis at the exposed mountain top test-site as we expect a large influence of wind drift. Therefore we want to keep this analysis. Figure 2: The scale bars are correct. We covered slightly less area within the first data acquisition that is

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why the ortho image of March 11 looks a bit different.

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

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