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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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First I want to point out that the authors have conducted sound scientific experiments that are well supported and described, and I believe their work deserves to be published. UAS snow depth measurements will be an useful alternative to measure spatial snow depth distributions in the future and I encourage the authors efforts to push the boundaries of this technology towards such an important scientific subject as well. I also understand and would have had probably the same enthusiasm because of the great data presented, however, when M. Nolan summarizes that the sentence: "UASs enable fast, flexible, repeatable and detailed analysis of the spatial distribution of mountain snow cover" describes the essential findings of the work, I have a slight different opinion. UASs enable neither fast nor flexible analysis of the spatial distribution of mountain snow cover as it depends on with what method you compare it to. If you

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compare it to manual snow probing you are certainly right, but not in comparison to recent technologies such as laser scanning. UASs need a lot of pre-organizing work, if it comes to snow depth measurements many ground control DGPS measurements (to achieve such an accuracy), and significant post processing time. In comparison to laser scanning not that fast. With being flexible I have the biggest issues, in my opinion UASs are everything but flexible. For commercial purposes (and that counts also for scientific applications) the legal limitations in many countries are significant. Usually you need a proper license to fly above populated areas such as ski resorts and you need to get permission for every flight from the air space administration. For example it took us 1 month of paper work to have an UAS flying on Svalbard (same size and weight). And then you are only allowed to fly in line of sight, which means in practice an area about 500 per 500 m wide, which is exactly what you present in your data. Thinking further on about suitable flying weather and illumination conditions you have in harsh mountain climate conditions such as in maritime coastal mountain weather or arctic weather rather more down days than flying days (strong wind and/or snow-fall, very cold and high altitudes (low battery), night, very flat light, etc.)! You present data from 6 measurement days with perfect weather conditions (I assume), therefore it would be interesting what wind, air-temperature as well as air-pressure and cloudi-ness occurred while completing the measurements. I have seen many researchers UAS crashing due to unfavorable conditions in mountainous terrain! So you have to learn flying an UAS first, before starting to make useful measurements. Furthermore you need significant computing time and rather powerful computer equipment to post process the data and create the DEMs. Thinking about the costs, I have the same opinion as Matt, I do not think it is cheaper to ask a company to deliver a DEM of a snow surface 500 x 500m, using a UAS or a laser scanner. In fact I know 2 companies that charge the same, they just use the laser scanner or the UAS depending on the area they have to measure. If the incident angle is sufficient enough and no shaded ar-eas exist they always use the laser scanner. So I would reduce your statement to what you explain in a later step to something like this: "In particular within flat areas, where

terrain sections behind convex landforms such as hills or moraines cannot be covered, UAS based digital photogrammetry is a promising option for HS mapping in alpine terrain." That hits the application in reality much better in my opinion. That leads me to the applications you have in mind: "precise water resource prediction for hydropower and flood warning in alpine catchments (Jonas et al., 2009)Âż I have the same opinion as Matt, not enough coverage. Same counts for: "validation of snowpack and snow hydrology models (Bartelt and Lehning, 2002; Mote et al., 2003)" Snow pack models yes, but snow hydrology? I think you did a good job to describe it for small catchments. "Survey of snow distribution in ski resorts to improve the track management (Damm et al., 2014)Âż I do not see that at all, track management in ski resorts is made by GPS measurements in real time from snow groomers, which is quiet sufficient, the worker knows immediately how much snow is underneath him (his snow groomer), so I do not see ski resort employees additionally flying around with a UAS (above people?) needing to post process the data, etc. All other applications have also been satisfactorily completed by alternative methods in the same or better accuracy, which are more flexible than UAS, so why using now an UAS (laser scanners scan up to 5000 m nowadays in very fast operation speed, the measurement is basically done in 30 min. all in all) . For sure you can use an UAS for those applications, but there is no improvement to existing methods except for the already mentioned one. So to summarize my maybe too long statement and I just cite Matt: the paper reaches well beyond the scope of its scientific findings to make claims about the implications or justifications of this work without support for those claims. These claims need to either be removed or validated. Thus overall I think the paper would be substantially improved by changing the wrapper placed around their work and rewriting it to focus on the useful results they found and their true significance – they have shown that they can measure several hectare areas in a variety of terrain types at very high spatial resolution and very good accuracy and this will benefit many types of studies that are currently hampered by the lack of such measurements. For the methodology I have a further comment, I really do not understand why you did not validate your data against laser scanning data and

used manual probing instead, see Prokop et al. 2008 (Prokop, A., Schirmer, M., Rub, M., Lehning, M. Stocker, M. (2008): A comparison of measurement methods: terrestrial laser scanning, tachymetry and snow probing for the determination of the spatial snow-depth distribution on slopes.) Here you see laser scanning is more accurate than manual snow probing and your employer has even 2 laser scanners at least from what I know. But of course it is not mandatory, but at least you should cite this paper from your institution to have knowledge about the different accuracy standards.

Specific comments: Abstract Line 15: Delete sentence: "Such systems have the advantage that they are comparatively cost-effective and can be applied very flexibly to cover otherwise inaccessible terrain". Line 24,25: remove flexible and cost effective and investigating the worlds cryosphere Introduction: Line 24: the foot print size is not much of an issue with laser scanning anymore, about 25 per 25 cm footprint size in 1000 m distance to the scanner with very low incident angle so I would erase the sentence "TLS-accuracies suffer from acute illumination angles, resulting in unfavor25 able laser footprints, in particular within flat areas". Page 4 line 19: avalanches Test sites and data acquisition: please include here or in table 2 and 3 the following parameters, air temp., air pressure, wind speed, all at flying altitude, cloudiness, and duration of measurement/flying campaign as well as actual battery durance per flight/time, how many batteries did you use? Page 8,9. When you talk about the reference measurement using avalanche probes and GNSS please cite here Prokop et al. 2008 (Prokop, A., Schirmer, M., Rub, M., Lehning, M. Stocker, M. (2008): A comparison of measurement methods: terrestrial laser scanning, tachymetry and snow probing for the determination of the spatial snow-depth distribution on slopes) and discuss shortly the accuracy to be expected. Braemabuehl: mountain top page 12: You do here an analysis of the HS dependent on aspect. I would delete that totally as well as figure 7. It is a known fact that south facing slopes have usually lower HS if there isn't significant snow drifting involved. In my opinion this analysis has nothing to do with the actual topic of the mapping process of HS using an UAS, so I would skip that part totally. Please adapt the discussion and conclusion section to the arguments I pointed out in

the general comments section. Figure 2. Are you sure the scale bars are correct. It seems that the scale bar is the same even though the size of the images is different.