The Cryosphere Discuss., 8, C1407–C1413, 2014
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The Cryosphere Discussions
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Interactive comment on "Spatially continuous mapping of snow depth in high alpine catchments using digital photogrammetry" *by* Y. Bühler et al.

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Received and published: 28 July 2014

This is a well written paper with an extensive analysis of photogrammetrical measurements of snow depth in mountainous terrain. The authors test the accuracy of their results with comparative measurements of several different types and provide a good evaluation of the advantages and drawbacks of this method. Statements about the economic advantages of the photogrammetric measurements are too strong. I recommend that the paper is published with minor changes. I have a few comments which the authors can consider as they see fit and several suggestions for corrections of typos and minor rewordings that are all rather insignificant as the paper is generally well formulated and needs little editorial corrections.

Comments:

The conclusion that the photogrammetrical measurements are more economical than aerial lidar measurements does not seem well supported by the information presented in the paper. The authors should reconsider this aspect of the paper. The authors mention on p. 3314 (l. 23-25) that more accurately measured reference points and signalizing reference points are recommended in future photogrammetric projects of this kind to improve the quality of the orientation of the imagery. In commercial or professional projects (or projects that are not university studies or pilot studies by research institutes) where man-power in field support efforts needs to be charged at full price, the cost of on-ground field support can be a substantial part of the total cost of a project, particularly in remote mountainous areas. Aerial lidar measurements with good on-board IMU systems do not need such field operations except for validation measurements. Furthermore, photogrammetric measurements may need much more processing and manual evaluation of the quality of the results compared with lidar measurements that typically result in data of relatively uniform quality (or no data at all for example in case of problems with clouds). The uniform (and very high) quality of ALS measurements may translate into substantial savings compared with photogrammetric measurements when all costs are counted in a commercial or professional project. An aspect of project cost that deserves to be mentioned in the paper, is that total project cost rises slowly with survey area for ALS measurements because of the economy of scale (better use of flying time, fully automated processing becomes more cost-effective as the area becomes larger). If aerial photogrammetry requires field measurements of reference points with a fixed density of such points per kmˆ2 and substantial manual input in the processing chain (again perhaps proportional to the project area), the ALS measurements may be expected to be relatively more cost-effective for large areas than small. The statement in the abstract that laser scanning (presumably including ALS?) "can only cover limited areas and is expensive" is much to strong and partly misleading in my opinion.

The authors mention the possibilities offered by UAVs to measure snow depth, again stressing low cost as a major advantage (snow depth measurements by this method is

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said to "much more economical" on p. 3314). This may well be true and UAVs obviously hold much promise for future developments. However, as the authors also mention, there are several problems with UAVs in this context so compared to a fully developed, time-tested method such as ALS, the statement in the paper is too strong in my opinion. In addition to the problems mentioned by the authors, there are problems with permissions to fly UAVs from aviation authorities in many countries, some (perhaps most) UAVs encounter problems in high relief areas typical of mountainous terrain, there are in some cases problems related to long ranges or terrain obstructions between the UAV and remote control devices, and photogrammetrical measurements by UAVs suffer from the same problems regarding processing and time-consuming manual checking of results as photogrammetrical measurements from aircraft discussed above.

Finally, in their comparison with aerial lidar, the authors should mention the advantage of the lidar, compared with any photogrammetric method that the multiple reflections of the lidar signal can with suitable processing be used to map partly forested/vegetated terrain where the vegetation is to some extent penetrated by the lidar, which is a capability that no other remote sensing method can offer. In this context, the authors might mention the effect of vegetation on the quality of their results. The vegetation on the ground in summer in some of the test areas (particularly the bottom of the Dischma valley) is likely to be higher in summer than the surface that is most naturally considered the bottom of the snow cover in winter (and which is sensed by the GPR validation measurements). The authors should report the bias of their snow depth measurements more clearly (in addition to the RMSE and NMAD values, e.g. in table 4) so that it is possible to see whether this effect is likely to be significant. Inspection of Figure 10 (particularly 10a) indicates that there is a tendency for the ADS snow depth to be lower than the GPR snow depth by perhaps a decimetre or two which could be due to this effect of vegetation on the bottom of the Dischma valley.

Typos and suggestions for rewordings:

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p. 3298, l. 25: "Snow is an important resource in alpine regions ..., and natural hazard prevention, such as flood forecast in spring and early summer for the valleys downstream" –> "Snow is an important resource in alpine regions ... . Snow is also important in the context of natural hazards, such as snow avalanches in winter and river floods in spring and early summer for the valleys downstream" (it is somewhat awkward to state that snow is an important resource ... for natural hazard prevention, the snow is the cause of the natural hazard, not a resource for its prevention)

p. 3299, l. 7: "at already very small scales" –> "at very small scales"

p. 3300, l. 8: "since such data was available" –> "since such data became available"

p. 3300, l. 13: "with finer spatial resolution"? (strange wording, the beginning of the sentence indicates that this is an example of a study on a global scale)

p. 3300, l. 20: "limited for dry snow ..." –> "limited to dry snow ..."

p. 3300, l. 23: "we propose digital photogrammetry ..." –> "we apply digital photogrammetry ..."

p. 3301, l. 11: "in the north of Davos" –> "to the north of Davos"

p. 3301, l. 18: "works as test site" –> "is used as a test site"

p. 3301, l. 22: "at the day of " –> "on the day of" (also l. 3 on the next page)

p. 3301, l. 26: "where different hydrological studies are performed" –> "where several different hydrological studies have been performed"

p. 3302, l. 1: "is covering" –> "covers"

p. 3302, l. 9: "state-of-the-art technologies available" –> "state-of-the-art technologies"

p. 3302, l. 11: "Several teams have been in the field" –> "Several teams were deployed in the field"

p. 3303, l. 3: "gets available" –> "becomes available"

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p. 3303, l. 4: "than the ADS sensor" –> "as the ADS sensor"

p. 3303, l. 11: "2 m in between" –> "2 m between points"

p. 3303, l. 20: "close to the possible maximum" –> "close to the possible maximum that can be obtained with the number of workers participating in the experiment"

p. 3304, l. 1: "measured real-time" –> "measured with real-time correction"

p. 3304, l. 10: "In this study we ..." –> "In this study, we ..." (commas are sometimes in the manner I suggest here in the paper, see p. 3306, l. 6, and sometimes not such as here, this might be made consistent, I don't mention other similar cases)

p. 3304, l. 11: "This device proofed to accurately measure" –> "This device has been proofen to accurately measure"

p. 3304, l. 21: "Fix installed" –> "Fixed installed"

p. 3305, l. 7: "Trimbel" –> "Trimble"

p. 3305, l. 12: "data ranged in snow depth" –> "snow depth ranged"

p. 3305, l. 18: "is based on an area-based" –> "implements an area-based"

p. 3305, l. 25: "Snow" –> "snow"

p. 3305, l. 25: "which snows" –> "which results in"

p. 3306, l. 12: "than settlements" –> "as settlements"

p. 3306, l. 16: "show a maximum" –> "shows a maximum"

p. 3306, l. 17: "little distance" –> "short distances"

p. 3306, l. 21: "issue" –> "difficulty"

p. 3306, l. 21: "a not optimal" –> "sub-optimal" (also in l. 27)

p. 3307, l. 1: "Orientation of ADS80 ..." –> "The orientation of the ADS80 ..."

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p. 3309, l. 13: "Its spatial resolution is 2m equivalent to the input DSMs" –> "The spatial resolution is 2m as for the input DSMs"

p. 3309, l. 16: "few snow at these spots" –> "little snow at these spots"

p. 3309, l. 17: "identifying if a certain areas is snow free or not" –> "identifying whether a certain areas is snow-free or not"

p. 3309, l. 21: "Figs. 7. and 8." –> "Figs. 7 and 8" (check other places with period after figure numbers)

p. 3309, l. 23: "from past avalanche events get clearly visible" –> "from avalanche are clearly visible"

p. 3309, l. 25: "which are reported by Grünewald et al., 2010" –> "which were reported by Grünewald et al. (2010)"

p. 3309, l. 27: "High snow depth values" –> "High snow depths"

p. 3310, l. 1: "during one winter but are not where ..." –> "each winter but not where ..."

p. 3310, l. 8: "are glaciers of ..." –> "are the glaciers of ..."

p. 3310, l. 10: "and lowered their surface elevation" –> "and their surface elevations were lowered"

p. 3310, l. 14: "because less snow is usually accumulated" –> "because little snow usually accumulates in these areas" (less than what?)

p. 3311, l. 18: "measurements" –> "measurements,"

p. 3312, l. 4: "The RMSE is 0.35m for the mean snow depth and 0.13m for the standard deviation" –> "The RMSE is 0.35m for the mean snow depth and the standard deviation is 0.13m"

p. 3313, l. 7: "sapling" –> "sampling"

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p. 3313, l. 8: "data data" –> "data"

p. 3313, l. 19: "This antiquates the assumption that photogrammetry is not working on snow" –> "This shows that photogrammetry of this type works for snow-covered surfaces"

p. 3314, l. 10: "Software" –> "software"

p. 3314, l. 14: "less dominant" –> "less"

p. 3314, l. 17: "is not working" –> "does not work"

p. 3314, l. 18: "accuracies" –> "accuracy"

p. 3314, l. 19: "depends" –> "depend"

p. 3314, l. 29: "given points" –> "given points,"

p. 3320: "outlier removal" –> "outliner removal, mu*, RMSEˆa"

p. 3332: "the correlation between" –> "a scatter plot of"

p. 3333: "Correlation of" –> "Scatter plots of"

Interactive comment on The Cryosphere Discuss., 8, 3297, 2014.