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The Cryosphere
Discussions

Interactive comment on "Spatially continuous mapping of snow depth in high alpine catchments using digital photogrammetry" *by* Y. Bühler et al.

Anonymous Referee #2

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In this paper the authors test how well they can map alpine snow cover using an aerial photogrammetric scanning method. They use their scanner to create summer and winter digital surface models, then difference the two. In particular they test this methodology in two high catchments near Davos, Switzerland. The instrument they use to take the images (or photos, basically) is the Leica ADS80 Airborne Digital Line Sensor. The crux of the paper is that they compare snow depths derived from the scanning with depths derived from hand probing, from a GPR system, and from a terrestrial (ground-based) LiDAR scanning system. They also compare snow surface elevations derived from the photogrammetry with snow surface elevations derived from a differential GPS survey of a limited area.

As this is basically a methods paper, as such it seems like a reader of this paper would

want to know several things: 1) How well does the method work for mapping snow depth? 2) Where does it not work? and 3) How hard/expensive is it to do this work, in terms of time and money? Overall, the paper has within it the answers to questions (1) and (2), and these answers are quite positive, but those conclusions are buried away in the text in a way that makes them difficult for a reader to see or understand them. Question (3) goes unanswered. Before this paper should be accepted for publication, it should be shortened, clarified, and some attempt to answer question 3 needs to be made. The first step is to re-organize the paper. Step one is to set up the point of the paper better by rewriting the Introduction, which currently is very general. This is not the first attempt at using aerial photogrammetry to map snow. The Introduction needs to discuss previous efforts in tis area. Here are some references the authors might wish to consult:

Cline, D. (1993), Measuring alpine snow depths by digital pho-togrammetry: Part 1. conjugate point identification, paper presented at Proceedings of the Eastern Snow Conference, Quebec City, Quebec.

Cline, D. W. (1994), Digital Photogrammetric Determination Of Alpine Snowpack Distribution For Hydrologic Modeling, paper presented at Proceedings of the Western Snow Conference, Colorado State University.

Ledwith, M., and B. Lundén (2001), Digital photogrammetry for air-photo-based construction of a digital elevation model over snow-covered areasâĂŘBlamannsisen, Norway, Norsk Geografisk Tidsskrift-Norwegian Journal of Geography, 55(4), 267-273.

Lee, C., S. Jones, C. Bellman, and L. Buxton (2008), DEM creation of a snow covered surface using digital aerial photography, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 37.

McKay, G. (1968), Problems of measuring and evaluating snow cover, paper presented at Proceedings Workshop Seminar of Snow Hydrology.(Secretariat Canadian National Committee for the IHD, Ottawa).

Smith, F., C. Cooper, and E. Chapman (1967), Measuring Snow Depths by Aerial Photography, paper presented at Proc Western Snow Conf.

Vallet, J., U. Gruber, and F. Dufour (2001), Photogrammetric avalanche volume measurements at Vallée de la Sionne, Switzerland, Annals of Glaciology, 32(1), 141-146.

There are several key points that should be raised in the revised Introduction that are never really discussed clearly or comprehensively in the paper, but greatly influence what was done. The first is the problem of photo (or scan) saturation when white (snow) and black (rock) surfaces are adjacent to each other (as at the base of cliff in winter). This is an important and relevant discussion because the problem forces the authors to use an expensive and highly accurate imager/camera (the Leica ADS80) to map their areas, and it also forces them to subdivide the domain into 809 tiles rather than to work in a continuous fashion. The introduction is where this problem needs to be first addressed. Similarly, progress in point matching software has greatly enhanced the possibilities of producing snow maps, yet there is little discussion of this fact, nor a discussion of why they used the software they did for point matching.

Lastly, and it is not until the Conclusions that the authors mention this point, there is a suggestion that photogrammetry is not thought to work on snow (Section 6, Line 20). While I would dispute this statement, if the authors want to set up this negative impression of snow photogrammetry as a strawman for the paper (whereby the authors then show the statement is wrong), they need to bring the statement into the Introduction and buttress it with citations wherein it is suggested that snow photogrammetry cannot or does not work.

With a clear discussion of the current state of snow photogrammetry completed in the Introduction, the authors can then tackle whether they method works, and how well. Most of what is required to do this is already in the paper, but two issues plague the writing and organization. First, the authors seem reluctant to identify which set of measurements they want to call "truth." We all understand that any set of snow

depths measured (probing, ground LiDAR, GPR) will have inherent spatial location and vertical errors, as will the photogrammetry. Nonetheless, a reader of this paper ultimately wants to know about how well the aerial snow depth performed. Pick one of the non-photogrammetric methods and declare it the best possible "truth" and get on with the comparison. I suggest the terrestrial LiDAR might work best in this regards. Use the hand-probe measurements to ensure the terrestrial LiDAR is sound. One can find throughout the body of the text various statements relating one metric or another to the photogrammetry, but no summary or synthesis is provided. I came away with the idea that over much of the test domain the RMSE was about 35 to 43 cm (hand probe and GPR respectively) which is pretty darn good. Perhaps the most comprehensive comparison can be found in Figure 9C, but this is not thoroughly discussed.

A second problem with the text is all the caveats. Of course the photogrammetric differential mapping will fail where there is a lake that changes height due to water withdrawal. Similarly, we would not expect it to work where there are melting glaciers or buildings. These problem areas do need to be mentioned parenthetically, but not to the extent of masking the fine performance that was achieved over 90%+ of the test domain. Similarly, it is hard to make measurements in steep, avalanche-prone areas, but don't winze about. . ..just show us the measurements that did get made. This more positive approach will strengthen the paper and dispel the notion I kept getting that the method didn't work well.

Finally, for myself, when I read a methods paper like this, I ask "Do I know enough now to use the method?" I found my answer was "Not quite." I found myself wondering about flight elevation, time needed to cover the domain, issues with summer image accuracy, and so on. The authors should be trying to make the methodology as accessible as possible, and on this score the paper could be shorter, more concise, and clearer. But also along those lines, if Leica were not donating the use of their instrument, how pricey a procedure is it to produce the maps? How long did the flights take? How much human time was wrapped up in the processing?

In summary, the authors describe a promising method in a paper that is worth publishing. They are using new equipment and software, against which they conducted reasonably rigorous tests. All of this is the basis of a decent method paper, but they need tighten and focus the paper on answering the sort of questions a reader interested in the method is likely to have. My recommendation is for Major Revisions, though certainly this should ultimately be published.

Other Comments

Figures: Poor and inefficient use of figures. Figure 2 is from a Leica sales brochure and should be deleted. Figures 3, 4, 5 and 7 could readily (are far more usefully) be combined in some way. It should be possible to "see" the Wannegrat area from the same perspective in each of these figures (or some composite version), and each with the TLS outline shown for reference.

Also, it seems like there are some better ways to compare snow depths from various methods besides tables and maps. For example why not show the depth pdf of the TLS vs. the photogrammetry? Or to show how spatially consistent the data are, show a profile of GPR vs. the same profile from aerial imagery pixels? These would help readers understand how the various data compare.

Lastly, a TLS vs. photogrammetric difference map (9c) needs more discussion. The three red areas are trivial….they occupy a fraction of the domain. More critically, it appears that there is a lot of blue and yellow areas in the difference map….suggesting both -1 and +1 m order errors. Is this true and if so, what does it mean? It would help if a color scale for this map was chosen where zero is neutral but obvious.

English: The grammar and writing were generally fine….but there were quite a few minor errors that an English editor would have easily caught. Please have such an editor go through any subsequent version of the paper. Reviewers should not need to do this.

Acronyms: This paper has way too many acronyms. Try to reduce the number as they became hard to remember. Perhaps add an acronym glossary if they are all necessary.

Map Product Resolution: This got confusing and there was no clear discussion of the issue. With 0.25 m native resolution, but a 8 by 8 averaging scheme, the resolution in the maps should have been 4 m….but then a 3 by 3 rolling filter was used. Does that mean the results are 12 by 12 m. Why? Why not work at the native resolution? Try to sort this out and make a simple table (perhaps) that lays out the various resolutions.
Abstract and Conclusions: If this method works, the abstract and conclusions should be very direct about saying so…..and some synthesis number for accuracy presented: "We believe that in the complex and steep topography of the alps, the method can be used to map snow at sub-meter resolution with a vertical depth accuracy of $\pm$40 cm (????). On average this snow is 200 cm deep, which means these maps have an accuracy that is better than 20%. Compared to alternative methods of spatial mapping (interpolation between widely spaced point measurements) this method allows for. . . ."

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