The Cryosphere Discuss., 8, C1729–C1737, 2014
www.the-cryosphere-discuss.net/8/C1729/2014/

The Cryosphere
Discussions
Open Access

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

Y. Bühler et al.

buehler@slf.ch

Received and published: 5 September 2014

Dear Referee

Thank you for reviewing our paper and for your comments helping to improve the paper.

We understand that the case study is not perfectly designed. But considering the difficult high alpine terrain, the available financial and personal resources and the novelty of the application, we consider the design as the best we could achieve. Definitely we would love to have more reference data covering the entire investigation area and more spatially continuous snow depth measurements from airborne laser scanning but this was not possible with the available resources. In our opinion we present a sufficient variety of different state-of-the-art reference data sets with an acceptable distribution.

We think this study is very valuable for further investigations on high spatial resolution snow depth mapping.

In your review you criticize a lack of technical photogrammetric skills. We have to contradict this statement. Our remote sensing group has long-term experience in photogrammetry and published their results in numerous renowned remote sensing and photogrammetry journals. A main aim of this paper was to make it compact and well understandable for all readers in particular from the hydrology and snow science community, as TC is not a pure remote sensing journal. Listing a lot of technical details will make the paper harder to understand and is not of interest for a big part of the readers. However we will take your input serious and add essential parameters in the revised manuscript if possible in the form of tables.

The central point of this study is to generate a snow depth map for the investigation area and to validate the accuracy of the produced map based on independent, simultaneously acquired reference datasets. We do not see why the performance of the instrument should be dependent on the elevation (at least in the elevations range we have in the Alps). It is obvious that the performance is dependent on the slope angle. However, GNSS and GPR measurements can only be performed at directly accessible locations. Considering the avalanche danger we were not able to enter steep slopes at the day of the overflight. The area covered by the TLS is in our opinion representative for the terrain in the region of Davos with a mean of 27° and values ranging from 0° up to 81°. The frequency distribution for the TLS data is given in Fig. 1. We will discuss if we want to include this frequency distribution into the revised manuscript. The TSL reference is the most important for our validation with 55'272 pixels to compare. Therefore your statement "ground observations are poorly representative of the general conditions of test sites" is not justified for the study even though it is for the other reference datasets. We removed the outliers in the reference datasets as described in the sections 3.2.1 to 3.2.4. We do not want to exclude further reference points based just on slope angle. Such points will always occur in high alpine terrain, maybe more extensive planning of the data acquisition can minimize them, but this was not possible due to the strict timing (everything had to be ready at the time of overflight) and the available resources. We think it is a fair way to describe the occurring problems in the text as we do in the paper.

Fig. 1. Frequency distribution of the slope angles within the TLS reference test site.

There are no official documents on terrain changes in this region existing. We describe significant terrain changes we identified, such as glacier volume changes and the water level change of the lake Davos, in section 5.2. No larger rockfall or landslide events were reported.

Traditionally snow depth is mapped using point measurements from observers or automated weather stations. This information is the interpolated into spatial continuous maps. Most parameters in snow science are point measurements. Therefore we thought that "spatially continuous" would stress the difference compared to traditional snow depth measurements. However we can shorten the title as you suggest. It is a mystery to us how you get to the conclusion that this should be an evidence of low experience in digital photogrammetry. Certainly you can map parameters in a way that is not spatially continuous (which is usually done in snow related work today).

We underlie our statement by publishing cost ranges from quotations of three different independent data providers offering both, digital photogrammetry and LiDAR to cover the test site of the study. The main cost reduction (40-52%) is coming from the shorter flight time necessary to cover the area. Therefore the price difference gets more distinct the larger the area to cover gets. The total prices are 25 – 37% lower for digital photogrammetry than for ALS (Table 1).

Table 1. Cost estimation ranges in 1000 CHF derived from three independent quotations from data providers offering both, LiDAR and photogrammetry. The tender was to acquire a final DSM with approx. 2 m spatial resolution and a vertical accuracy of ~30cm over the test sites Davos and Wannengrat (145 km2) once with ALS and once

with digital photogrammetry.

In our opinion the 12 bits radiometric resolution is more important the NIR band because it hinders image saturation occurring in 8 bit imagery even within the NIR band. Due to the high contrast between dark rocks and fully illuminated snow cover the 255 available values for an 8 bit band is clearly insufficient. However we will highlight the role of the NIR band and give a table on the ADS bands (Table 2) in the revised manuscript as you suggest.

We will provide more information on the number, distribution and RMS errors of GCPs and the number of tie points in the final manuscript. The source of the GCPs is a combination of ground survey and a few existing stereo images. Details will be given in the final manuscript.

We appreciate the hint to the wrong spelling of Trimble. We will replace DGPS to the correct term dGNSS and the mention the use of reference station, provided by swisstopo. However we do not think that the technical details of the used dGNSS is of major interest to the readers.

Since the "Adaptive Automatic Terrain Extraction" in the used software SocetSet is a "black box" regarding the used parameters in all iterations, no listing of the used parameters can be provided.

We will clarify this point. As already written, due to the very steep terrain, occlusions may happen and blunders occur. These blunders are the reason for different mean slope values at the same area from different points of view. The slope is calculated from the surface model used for the image matching.

Using digital photogrammetry techniques obviously only the surface can be measured, including above ground objects. In high alpine regions with sparse vegetation the surface is very similar to the terrain. From the ALS campaign only the final DTM product was available where first return signals have been filtered out. The dataset is described in (Grünewald et al., 2010). In our study the GRID data was compared.

The term digital elevation model (DEM) is used as the overall term for height information, being it surface or terrain. To avoid confusions, we will go through the paper and check the terms DEM, DSM and DTM.

Accuracies of each stereo block will be provided. The stereo blocks of each year was orientated separately. The proportion of common GCPs will be provided. And this topic will be discussed more intensively.

In the image matching procedure the measured points were achieved by image correlation, so we will stick to the term “correlated”.

The accuracy in the unit ‘GSD’ is quite common in digital photogrammetry with aerial images or satellite images. We will separate the overall accuracy into horizontal and vertical accuracy as you suggest and will use GSD and cm.

To discuss the comparison to the GPR data we split the reference data in different segments (according to the way they were acquired). Over all points the range of snow depth is between 0.76 to 2.70m. However certain segments such as segment 1 (Fig. 10c) range only between 1 and 1.6m. We discuss this in section 5.3.4.

We will discuss the resolution issue in more detail. The input imagery used for point matching has a resolution of 0.25 m. From the points generated out of this imagery we extract a raster of 2 x 2 m. We smooth the imagery using a mean 3 x 3 pixel mean filter but we do not change the resolution there, it stays 2 x 2 m as we apply filtering and not resampling. We could go down to 1 m spatial resolution of the final product (max. 4 times the input GSD = 1 m (Zhang and Miller, 1997)) The Reason why we do so is that we intend to generate a final product for other users of snow depth maps and compare this final product to the reference data. There are different pre-products (point clouds etc.) we could compare to the reference data but our intention is to use the final, easy to handle product (2 x 2 m snow depth map). In our opinion this is the product most

readers are interested in and describing and comparing more pre-products would be of low interest for most readers.

Details to the ALS acquisition will be provided. Again we want to compare the final photogrammetric DSM product therefore we do not apply 3D least square adjustments between the two datasets.

Thank you for these helpful comments. We will delete the sentences “Resulting values higher than 15 m and lower -0.5m are considered outliers and are masked out. Values between 0 and -0.5 are set to 0 because negative snow depths cannot occur and there is a high probability that there is no or only very few snow at these spots.” We will set all snow depth values below 0 to now data because negative snow depth cannot occur. We will reproduce the snow depth maps accordingly. The reviewer is right in saying there is no scientific reason for setting value between -0.5 and 0 m to 0. We will clarify the other points mentioned in the revised paper.

The main reason for the selection of the test site was accessibility. Because a lot of areas were inaccessible due to avalanche danger and the GPR has to be operated by people. However in our opinion reference data always suffer from some limitations. We just transparently declare them. In our opinion this has nothing to do with a bad design of the survey.

References:

Grünewald, T., Schirmer, M., Mott, R. and Lehning, M., 2010. Spatial and temporal variability of snow depth and ablation rates in a small mountain catchment. The Cryosphere, 4(2): 215-225.

Zhang, B. and Miller, S., 1997. Adaptive automatic terrain extraction, Proceedings of SPIE - The International Society for Optical Engineering, pp. 27-36.

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

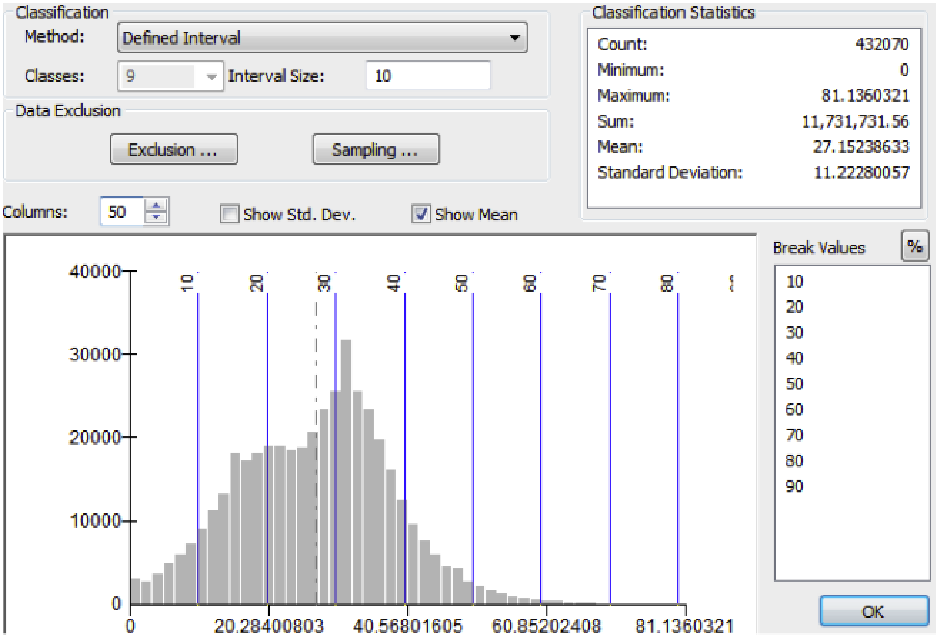

Fig. 1.

	Data acquisition	Relative difference	Data processing	Relative difference	Total	Relative difference
ALS	25 – 40	40 - 52%	18 – 40	10 – 44%	43 – 80	25 – 37%
Photogrammetry	12 – 24		10 – 36		27 – 60	

Fig. 2.

Table 2. A table of the features of the sensor will be provided, including the wavelength of the available bands:

Sensor	**ADS80-SH52**
Sensor type	CCD-line digital aerial camera
Ground sample distance	~0.25 m
Acquisition date	12.8.2010; 3.9.2013; 20.3.2012
Spectral range (used band combination in bold)	Pan: 465 - 676 nm
	Blue: 420 - 492
	Green: 533 - 587 nm
	Red: 604 - 664 nm
	Near infrared: 833 - 920 nm

Fig. 3.