PHOTOGRAMMETRIC SNOW DEPTH MAPPING: EVALUATION OF DIFFERENT PLATFORMS AND SENSORS

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ABSTRACT: Until today, snow depth data is mostly estimated based on point measurements, either collected manually or at automated weather stations. New photogrammetric technologies to map the snow depth distribution spatially continuous over larger areas are rapidly evolving. Especially in the field of unmanned aerial systems (UAS) new systems with better cameras and longer flight times are being developed. However, the specific strengths and weaknesses as well as the performance considering accuracy on homogeneous snow surfaces are not yet sufficiently investigated.

Therefore, we have simultaneously tested different photogrammetric platforms and sensors for snow depth mapping in the high alpine Dischma valley close to Davos (Switzerland) during winter season 2017/18. An extraordinarily snow rich winter challenged the data referencing approaches in particular. We acquired data over the whole Dischma valley with satellite and airplane based optical sensors. At two subsets in the Dischma valley, we flew with two different UAS and acquired ground-based data with a digital consumer camera. For the independent validation of the photogrammetric products we applied terrestrial laser scanning and measured snow depth by probing as well as by measurements on fixedly installed snow poles.

In this study we outline the experimental setup for a large campaign with different photogrammetric sensors and platforms. That will allow for an improved understanding of the specific advantages and disadvantages of different photogrammetric systems for operational, spatially continuous snow depth mapping in high alpine terrain over large areas.

KEYWORDS: Snow depth, snow water equivalent SWE, photogrammetry, remote sensing, alpine terrain

1. INTRODUCTION

Spatially continuous snow depth data is necessary for different applications in the alpine environment such as monitoring sensitive alpine ecosystems in a changing climate, monitoring technical snow making in the tourism industry, detecting potential snow avalanche release zones, flood forecasting and optimization of hydropower production by knowing the amount of water stored as snow (Bühler et al. (2015), Dozier et al. (2016), Bühler et al. (2016)).

Snow depth mapping with the help of laser scanning techniques is already well advanced and applied in different studies as Deems et al. (2013) underline in their review. Apart from that, first studies using photogrammetry with Pléiades satellites (Marti et al. (2016)) and manned airplanes (Nolan et al. (2015), Bühler et al. (2015)) were already performed for snow depth mapping. Photogrammetric UAS measurements for snow depth mapping were also performed recently (Van der Jagt et al. (2015), Bühler et al. (2016), de Michele et al. (2016), Harder et al. (2016)).

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Today different photogrammetric sensors with high spatial resolution are available but it is only preliminarily investigated how they perform on snow (Bühler et al. (2017)). Therefore, we performed a large measurement campaign on the 6 April and 7 April 2018 simultaneously collecting optical data from satellites, an airplane, two UAS and from the ground. For the satellites and the airplane, we defined a 125km^2 large area around the Dischma valley (Figure 1). As UAS have not been able to cover such a large area yet, we defined two smaller subsets for the UAS. The first area is situated around Schürlialp covering a surface of 4 km^2 (Figure 1 Schürlialp area) and is hardly artificially disturbed, for example by ski touring tracks. This is important to mention because snow depth mapping with UAS is working already quite well for snow surfaces with recognizable features on the surface. But smooth, undisturbed, homogeneous snow surfaces without any features are a challenge in the mapping process for snow depth distribution (Bühler et al. (2017)). In the Schürlialp area the two main expositions are northeast and southwest. The slope angle ranges from 0° to 45°, whereby the mean slope angle is around 30° to 35°. Interesting features of the Schürlialp area are the channels which wind down the slopes producing a well differentiated snow depth distribution. In the Schürlialp area we cover a large range of altitudes from 1950 m a.s.l. to 2350 m a.s.l., hence the altitude difference is 400 m.

The second area, Brämabüel, has a surface of only 0.6 km^2 and the snow cover is highly disturbed by skiers and mountain railways (Figure 1 Brämabüel area). The Brämabüel area exhibits all expositions as it is the top of a ridge. Slope angles range from 0° to 45°. The Brämabüel area covers less altitude difference and ranges from 2350 m a.s.l. to 2500 m a.s.l., hence the altitude difference is only 250 m.

To validate the results of the different photogrammetric sensors a terrestrial laserscan (TLS) was acquired for the Schürlialp area. Manual snow depth measurements for the Schürlialp area and the Brämabüel area were carried out. In addition we used fixedly installed snow poles in the Schürlialp area for more reference snow depth values.

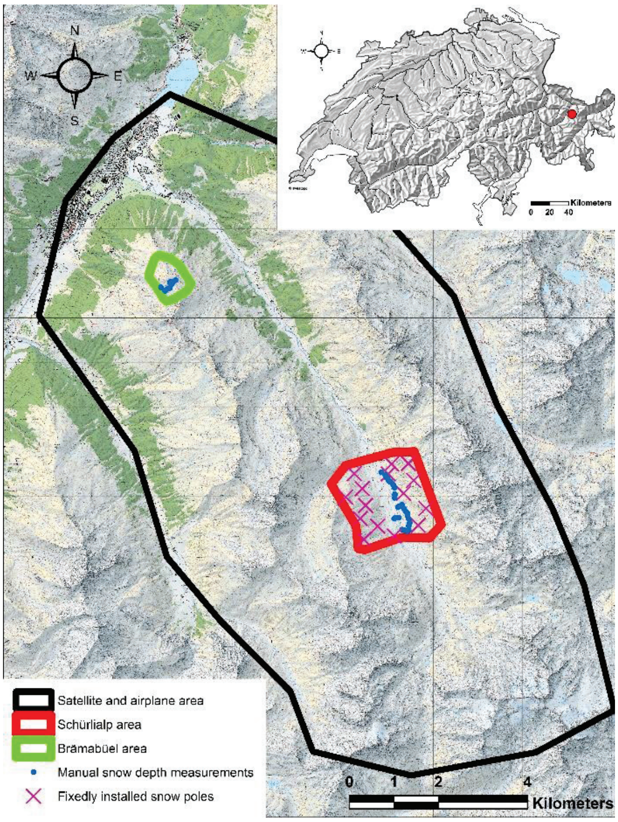

Figure 1: Satellite and airplane area; the Schürlialp area which was flown with the eBee+ UAS and the Brämabüel area which was flown with the DJI Phantom 4 Pro UAS (Pixmap© 2018 swisstopo).

2. OPTICAL SATELITTE DATA

WorldView-4 satellite data was acquired on the 6 April 2018 with a resolution of 0.33 m/pixel for the panchromatic band and a resolution of around 1.3 m/pixel for the multispectral bands. The WorldView-4 satellite has a panchromatic band (450 – 800 nm) and 4 multispectral bands: red (655 – 690 nm), green (510 – 580 nm), blue (450 – 510 nm), near-IR (780 – 920 nm). The satellite has a swath width at nadir of 13.2 km and was tasked by the company European Space Imaging.

Pléiades Tri-Stereo data was acquired on the 7 April 2018 with a resolution of 0.55m/pixel for the panchromatic band and a resolution of around 2 m/pixel for the multispectral bands. The Pléiades satellite has a panchromatic band (470 – 830 nm) and 4 multispectral bands: red (590 – 710 nm), green (500 – 620 nm), blue (430 – 550 nm), near-IR (740 – 940 nm). The satellite has a swath width at nadir of 20 km and was tasked by the company Airbus Defence & Space. Figure 2 shows an example of a pansharpened Pléiades image of the recorded perimeter. Pansharpening and digital elevation model (DEM) creation are executed with SocetGxp 4.3.0.2 for both satellites. But we will also investigate the performance of other processing programs such as Ames Stereo Pipeline developed by the NASA (Shean et al. (2016)).

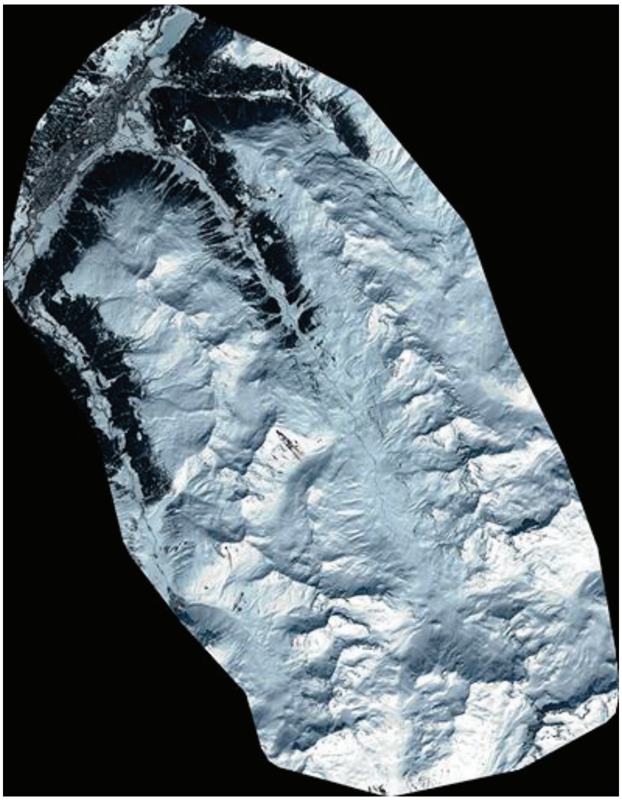

Figure 2: A pansharpened Pléiades satellite image of the 7 April 2018.

3. AIRPLANE DATA

Airplane data was acquired with an UltraCam Eagle M3 by the company Flotron. Unfortunately, the airplane flew only over the Dischma valley on the 12 April 2018, 5 days later than the other data acquisitions because of technical problems. Furthermore, the metrological conditions during the data acquisition were cloudy. But as no snow fall event occurred from the 7 April to the 12 April 2018, we can neglect the time lag in an area of higher elevation like the Dischma valley. DEM creation of the airplane data is executed as well with SocetGxp 4.3.0.2. But we will also investigate the performance of other processing programs such as Aigsoft PhotoScan.

4. UAS DATA

UAS data of the Schürlialp area was collected on the 7 April 2018 with a eBee+ of SenseFly and the SODA camera featuring a 1-inch CMOS sensor with 20 megapixel. We flew at mean flight height of 182 m with a ground resolution of 3.94 cm/pixel and a side overlap of 70% and a forward overlap of 60%. In this configuration we obtained 1550 images. 6 ground control points were distributed mainly at the valley bottom of the Schürlialp area to control the performance of the differential GNSS of the eBee+. The ground control points were measured with a differential GNSS.

UAS data of the Brämabüel area was collected on the 6 April 2018 with a DJI Phantom 4 Pro with an on board camera featuring a 1-inch CMOS Sensor with 20 megapixel. The data was acquired at a mean flight height of 86.4 m with a ground resolution of 2.33 cm/pixel. We flew with a side overlap of 60% and a forward overlap of 80% and aquired 809 images. As the DJI Phantom 4 Pro only has a normal GNSS with an accuracy of 2-3 m on board, we distributed 10 ground control points all over the Brämabüel area for aligning the images in Agisoft PhotoScan. The UAS data of both UASs is processed with the software Agisoft PhotoScan 1.4.3.

5. GROUND-BASED DATA

The Ground-based images were recorded with a Canon 750D and its kit objectiv 18-55 mm at a fixed focal length of 43 mm for the Schürlialp area. A tripod was used for taking the picutres. As it was not suitable to distribute ground control points over such a large area in the short recording time we had, the camera positions were measured with a differential GNSS. Different features sticking out of the snow served as ground control points and were measured in summer 2018. 5 camera positions with 329 images in total were recorded on the 7 April 2018. The ground-based data covers mainly the north part of the Schürlialp area. The ground-based images are also processed with Agisoft PhotoScan 1.4.3.

6. VALIDATION MEASUREMENTS

6.1 Laserscan

TLS was performed with a Riegl VZ-6000 at a laser pulse repetition rate (PRR) of 150 kHz with a vertical incremental angle of 0.007° and a horizontal incremental angle of 0.050° on the 6 April 2018. Hence the acquired scan has a mean vertical scan resolution of 0.05 m and a mean horizontal scan resolution of 0.35 m. The laser scan was performed as a 360° scan in the north part of the Schürlialp area. To have an optimal comparison a summer laser scan from summer 2017 and summer 2018 is used. The laser scan data is processed with RiSCAN Pro (2.6.2).

6.2 Manual Measurements

Manual snow depth measurements with a normal snow probe were performed for the Schürlialp and the Brämabüel area. In a 1 m by 1 m square the snow depth was measured at each corner and in the middle of the areas. The middle position served as control location and was measured with a differential GNSS. For both locations, the five snow depth measurements were averaged to one mean snow depth. Figure 3 shows the measurement scheme. We conducted 28 manual snow measurements in the Schürlialp area and 11 manual snow measurements in the Brämabüel area.

As manual snow probe measurements are only possible in avalanche save terrain, 15 snow poles were fixedly installed all over the Schürlialp area. The snow depths were read off the poles from marking at each half meter with the help of binoculars or photos.

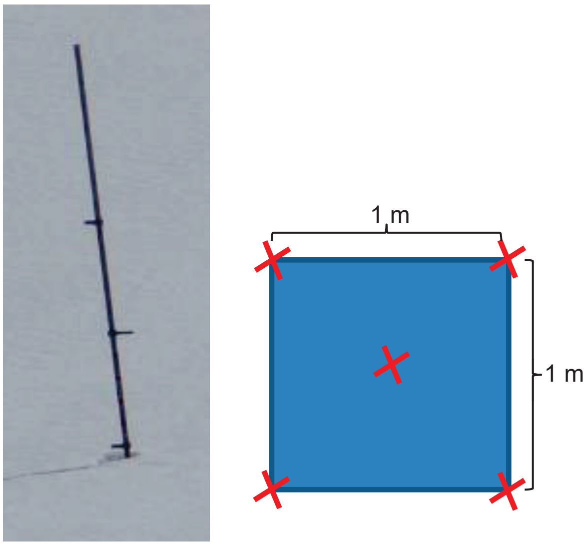

Figure 3: Installed snow pole and measurement scheme for the manual snow depth measurements.

7. PRELIMINARY RESULTS AND DISCUSSION

The preliminary results show that it is difficult to achieve good point matching results with the satellite datasets. On the hillshade (Figure 5) of the calculated Pléiades satellite DEM we see the patchy results of the DEM creation algorithm. Also, when you use the airplane data, it is difficult to obtain good DEMs, especially because of the extensive cloud cover we had to deal with. However, previous studies demonstrated that we can expect good results from airplane data under good data acquisition conditions (Bühler et al. (2015), Nolan et al. (2015)). UAS data worked out well (Figure 4, Figure 6). There is not much noise on the hillshade of the DEM of the eBee+ UAS (Figure 6) and first comparisons with the manual snow depth measurements show a mean difference between the snow depth that was calculed with the eBee+ UAS data and the manual measurements of around 4cm.

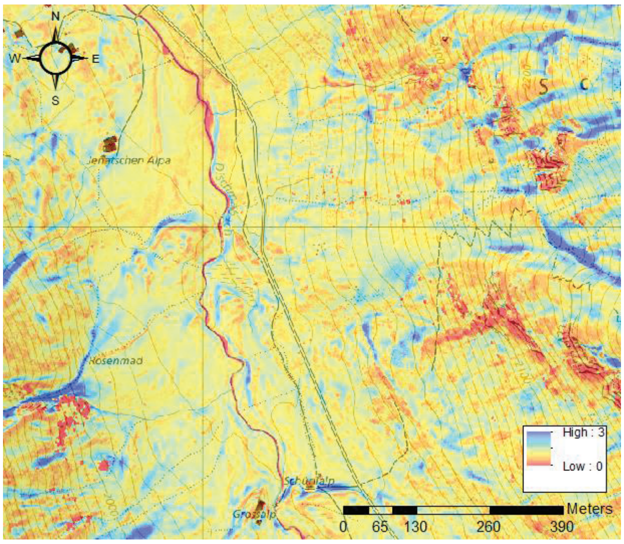

Figure 4: Preliminary results for the snow depth distribution in the Schürlialp area calculated with eBee+ UAS images from the 7 April 2018. The values are displayed in meters. The channels that wind down the slopes are clearly visible.

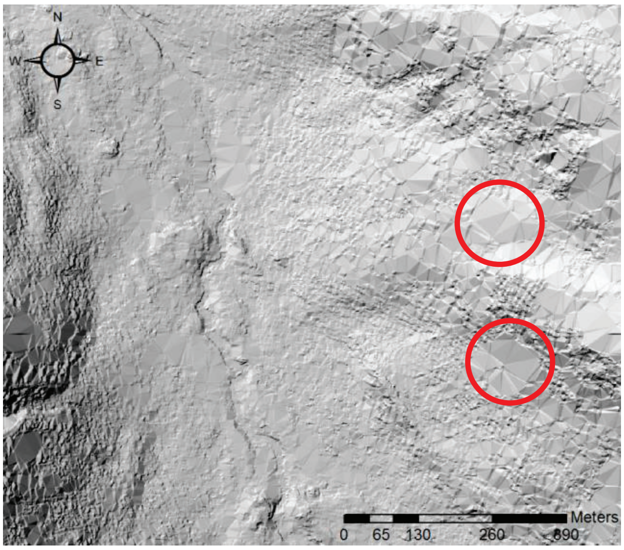

Figure 5: Hillshade of the Pléiades satellite DEM from the 7 April 2018. The mapping performance of the algorithm is quite poor and there are many holes or surfaces without information in the DEM (red circles).

Figure 4, Figure 5 and Figure 6 show the same detail of the Schürlialp area. You can clearly see the poor performance of the matching algorithms for the satellite images compared to the matching algorithm of Agisoft PhotoScan for the eBee+ UAS images.

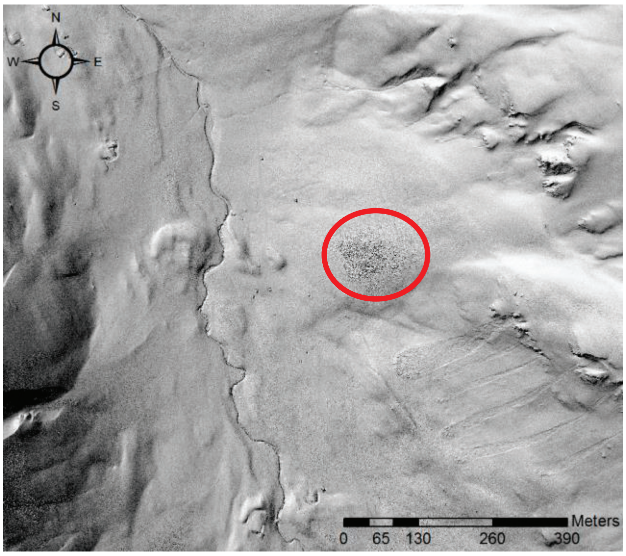

Figure 6: Hillshade of the eBee+ DEM from the 7 April 2018. The mapping performance is good and there are only a few areas with noise in it (e.g. red circle).

8. CONCLUSIONS

This study shows that UAS data is the most accurate method for rapid snow depth distribution measurements in complex, high alpine terrain at present. The differential GNSS on the eBee+ UAS opens new mapping possibilities in terrain which is barely accessible and prone to avalanche danger in winter because it is not necessary to distribute ground control points all over the area. Ground-based photogrammetric data also works for a fast and rapid snow depth measurements, but the imagery has to be acquired nearly perpendicular to the surface for good results. That is not always easy and applicable for every type of terrain. Satellite and airplane data are much more difficult to obtain flexibly and are more expensive. If for example airplane data is wanted, the order has to be made 1 – 2 weeks in advance. But the big advantage compared to UAS is the possibility to cover much larger areas. Therefore, the analysis of satellite and airplane data has to be investigated further. In the field of snow depth mapping with UAS and ground-based cameras more investigations have to be done especially for homogenous snow surfaces and suboptimal illumination conditions. On homogenous snow surface distinct features are often missing and so feature extraction algorithms are not always working correctly and produce noise. Especially with reduced illumination conditions images of snow surfaces exhibits even less contrast and makes feature extraction more difficult. This will be investigated in more detail within the running PhD project.

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