SFM-BASED 3D POINT CLOUDS IN DETERMINATION OF SNOW DEPTH FROM HIGH-RESOLUTION UAS DATA AS ALTERNATIVE METHODS: IS IT POSSIBLE TO USE?

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ABSTRACT: The DEM of Difference (DoD) method is most common technique used to obtain snow depth (HS) maps obtained from remote sensing data such as unmanned aerial system (UAS) data. But in the present study, M3C2 method, an advanced point cloud comparison method, was tested. For this aim, data of two UAS flights carried out in the upper Dischma valley (Davos, Switzerland) were used: one for snow free data in 6th June 2016 and one for snow covered data in 17th May 2017. HS values also were able to be measured by using snow probe for only 7 points at same day of UAS flight. DoD-based and M3C2-based HS values were compared to reference data. While M3C2-based HS values had 12.3 cm of RMSE, DoD-based HS values had 5 cm of RMSE. Even though the quite less number of field data for the comparison of the results, HS maps were compared at 30 points located over boulders without snow cover, where the vertical difference between two DSMs is expected to be zero. According to results, M3C2-based HS values were obtained less than DoD method (19 cm in average). However, M3C2 distance at 30 snow free points had values that close to zero than DoD, as expected. While 90% of M3C2 distance values of those snow free points varied between -4 cm and 4 cm, only 17% of DoD values varied between -4 cm and 4 cm. All remaining points were obtained higher than 4 cm.

KEYWORDS: DoD, M3C2, Point cloud, Snow depth, UAS

1. INTRODUCTION

In the field of snow science, remote sensing has been used as an advanced tool. Recently, the use of an unmanned aerial system (UAS) technology in snow and avalanche studies has come to be commonly reported in the literature (Vander Jagt et al., 2015; Bühler et al., 2016, 2017; de Michele et al., 2016; Eckerstorfer et al., 2016; Harder et al., 2016; Adams et al., 2017; Miziǹski and Niedzielski, 2017; Wainwright et al., 2017). The combination of UAS-based aerial photos and structure from motion (SfM) software can provide an efficient, low-cost and rapid framework for snow and avalanche studies. This technology provides a means to generate digital surface models (DSMs) and orthophotos with high spatial resolution (centimeters to decimeters), but is only able to cover relatively small areas (< 1 km^2) in one flight block with copters.

UAS has been gained popularity, especially in snow depth (HS) mapping due to its great potential. Calculation of HS from UAS data is generally based on the difference of two high-resolution digital elevation models (DEMs), one each for snow-free and snow-covered dates, in a similar way to aerial and terrestrial laser scanning techniques. The method used for this aim is called as "DEM of Difference (DoD)" method, which amounts to measuring a vertical distance on a pixel-by-pixel basis (Lague et al. 2013). This method requires gridding or meshing of point clouds to obtain DEMs. However, gridding 3D point cloud is not an easy task because the choice of a representative elevation in a cell is not simple due to high variability in point density and roughness. Also, a DEM cannot cope with overhanging parts and decreases information density (i.e. imposes limits on the level of details retained) proportionally to surface steepness (Lague et al. 2013).

The methods used for measuring the distance between two point-clouds without meshing or gridding are the direct cloud-to-cloud comparison with closest point technique (C2C) and cloud-to-mesh or cloud-to-model (C2M)

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(Lague et al. 2013). C2C is the simplest and fastest direct 3D comparison method of point clouds (Girardeau-Montaut et al., 2005). The C2C is also used in cloud matching techniques such as the ICP (Iterative Closest Point) (Besl and McKay, 1992). The C2M method is based on the calculation of the distance between a point cloud and a reference 3D mesh or theoretical model (Cignoni and Rocchini, 1998, Monserrat and Crosetto 2008). This approach works well on flat surfaces as a mesh corresponding to the average reference point cloud position can be constructed (Kazhdan et al. 2006). However, creating a surface mesh is complex for point clouds with significant roughness at all scales or missing data due to occlusion. In addition, as with the DoD technique, interpolation over missing data introduces uncertainties that are difficult to quantify. (Lague et al. 2013). Another advanced and latest method used for direct point cloud comparison is Multiscale Model to Model Cloud Comparison (M3C2), introduced by Lague et al. (2013).

Even though one output of SfM algorithm is 3D point cloud that can be exported to another software for processing point cloud (e.g. CloudCompare), there is no case study of HS estimation based on the direct use of point clouds without meshing or gridding. In the present study, it was aimed to show the usage possibility of M3C2 method for obtaining HS from high resolution UAS data.

2. MATERIAL AND METHODS

2.1. Study Area

The study area is located in the upper Dischma valley 13 km from Davos, in the Canton of Grisons, Switzerland (Figure 1). The area, where UAS flights were carried out, covers 267,000 m^2. Elevations vary from 2,040 m to 2,155 m a.s.l. There are no settlements in the area and it is covered by short alpine grass and sparse small shrubs. The selected area for this study is located in the middle of the area and comprises all HS measurement points.

2.2. Unmanned Aerial System Surveys and Data Processing

Two surveys were conducted using the AscTec Falcon 8 octocopter equipped with the Sony NEX-7 system camera featuring a 24MP APS-C CMOS: one for snow-free data in 6th June 2016 and one for snow-covered data in 17th May 2017. The ground control points (GCPs), necessary for image rectification and image geocoding, were surveyed using the Trimble GeoExplorer 6000 GeoXH differential GNSS device with an accuracy of better than 10 cm. In total, 15 GCPs, which had to be clearly visible in the base imagery, were applied in the field before the flight missions were carried out. All GCPs were measured according to the CH1903-LV03 Swiss Coordinate System. Following UAV flights, post processing including all office work were carried out in order to obtain the high-resolution DSMs and orthophotos from the UAS imagery. In the present study, the SfM algorithm was applied using Agisoft Photoscan Professional version 1.3.2.

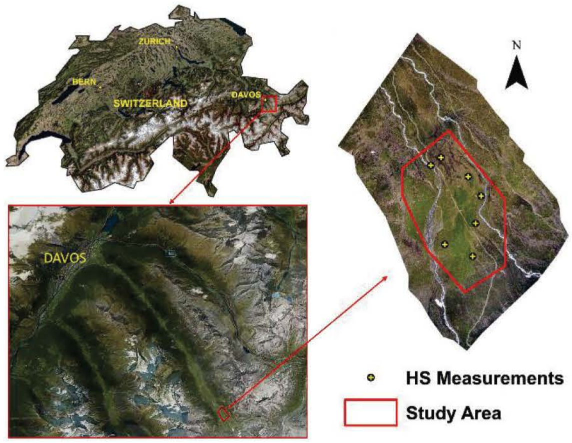

Figure 1: Location map of study area (HS Measurements with probe in the field)

2.3. HS Calculation with M3C2 method

In this study, cloud-to-cloud distance computation between two UAV flights was carried out using the M3C2 plug-in of CloudCompare 3D processing software in order to calculate HS. The required parameters in computing the distance between two point clouds by using the M3C2 algorithm include: (1) definition of the reference cloud and comparison cloud; (2) definition of the core points; (3) definition of the normal scale (D), the projection scale (d), and the cylinder depth; and (4) definition of the registration error (Esposito et al. 2017). To this aim, the UAV flight for snow free data in 6th June 2016 was set as the reference and the UAV flight for snow covered data in 17th May 2017 was set as the compared cloud. Both clouds were subsampled at 50 cm minimum point spacing for definition of the core points. For the cloud-to-cloud comparison, point clouds generated by Agisoft PhotoScan were exported as a text file (.txt). The parameters D and d were chosen based on the suggestions reported by Lague et al. (2013). In addition, the registration error (*reg*) was calculated by using Equation 1 (Esposito et al. 2017).

$$reg = \sqrt{\left(RMSE_{ref}\right)^2 + \left(RMSE_{comp}\right)^2} \qquad (1)$$

where RMSE is the root mean square error of the models calculated from the GCPs used in Agisoft Photoscan. In this study, the registration error was calculated as 0.07 m. The outputs of the M3C2 algorithm are the distance to the closest corresponding point, significant change, and distance uncertainty. The distance uncertainty is the 95% level of detection ($LOD_{95\%}$) and was calculated by the M3C2 algorithm using Equation 2 (Borradaile 2003).

$$LOD_{95\%} = \pm 1.96\left(\sqrt{\frac{\sigma_1(d)^2}{n_1} + \frac{\sigma_2(d)^2}{n_2}} + reg\right) \qquad (2)$$

where d is the projection scale, $\sigma_1(d)^2$ and $\sigma_2(d)^2$ are the local roughness of the point clouds n_1 and n_2. In this study, distance uncertainty values of higher than 15 cm and non-significant changes were removed and the remaining points were used to calculate HS.

2.4 HS Calculation with DoD method and Field Measurements

The HS was simply calculated by applying DoD subtracting the snow-covered DSMs from those without snow. Snow depths were also measured by using snow probe for 7 points at same day of UAS flight made for snow covered data in order to use as reference data, even though the number of measurement is not enough for comparison. The locations of HS measurements were given in Figure 1.

3. RESULTS AND DISCUSSION

In the present study, two UAS flights were carried out for HS calculation and very high resolution orthophotos and DSMs were generated with SfM processing (Figure 2). While orthophotos had 5 cm spatial resolution, DSMs generated with 10 cm spatial resolution. HS maps obtained from both DoD and M3C2 methods were given in Figure 3. Histogram graphs of HS classes were given in Figure 4.

Both DoD-based and M3C2-based HS values were compared to reference data (Figure 5). While M3C2-based HS values had 12.3 cm of RMSE, DoD-based HS values had 5 cm of RMSE. But unfortunately, the number of reference data (i.e. HS measurements with the probe at 7 points) is quite less to make a confident result.

However, even though the quite less number of reference point for comparison of HS values for each method, HS maps were also compared at 30 points located over boulders without snow cover, where the vertical difference between two DSMs is expected to be zero. Thus, it was aimed to have an idea about the reliability of the resulted maps. According to results, M3C2-based the distance values were obtained less than DoD method (19 cm in average) (Figure 6). However, M3C2 distance at 30 snow free points had values that close to zero than DoD, as expected (Figure 7). While 90% of M3C2 distance values of those snow free points varied between -4 cm and 4 cm, only 17% of DoD values varied between -4 cm and 4 cm. All remaining points were obtained higher than 4 cm.

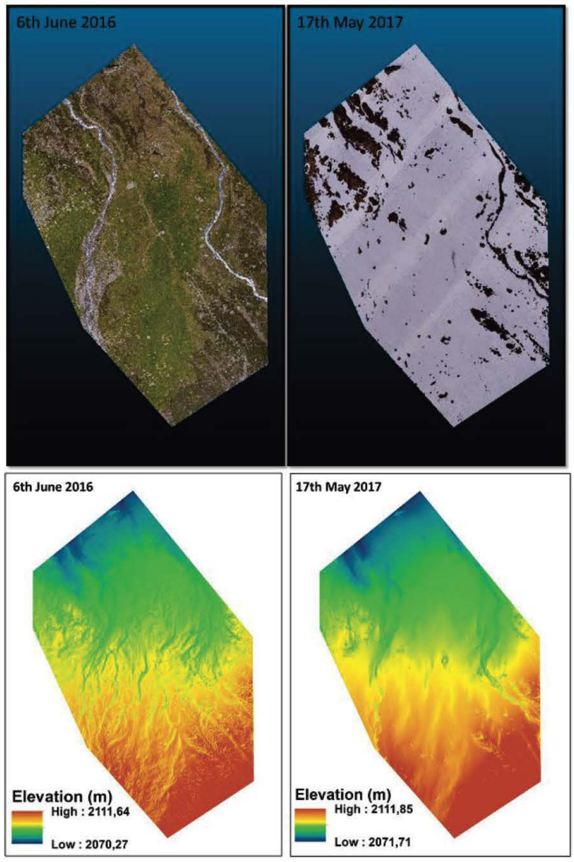

Figure 2: DSMs and orthophotos generated from UAS data

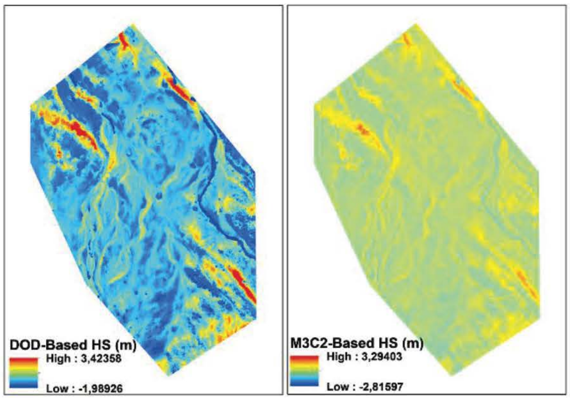

Figure 3: HS maps generated with both DoD and M3C2 methods

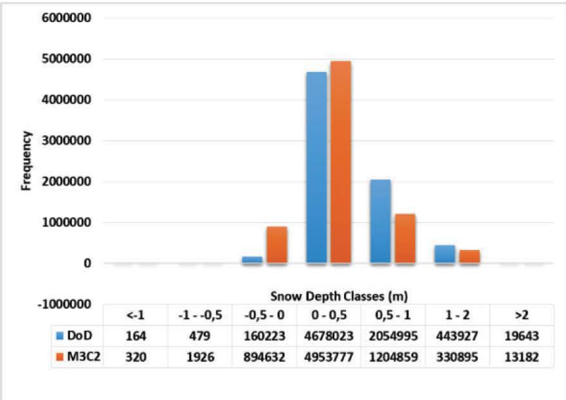

Figure 4: Histograms of HS values for two methods: DoD and M3C2.

4. CONCLUSION

Many studies in the literature demonstrated that accurate orthophotos and DSMs of an area for HS mapping can be obtained by processing overlapping UAV images through the application of SfM algorithms. These techniques allow the collection of a reliable time series of orthophotos and DSMs that can be routinely used to monitor rapidly changing snow covers. The DoD method is most common technique used to obtain HS maps from UAS data. But in the present study, M3C2 method, an advanced point cloud comparison method, was tested. Even though the quite less number of field data for the comparison of the results, HS maps were compared at 30 points located over boulders without snow cover, where the vertical difference between two DSMs is expected to be zero. The M3C2 method provided more correct distances at these points where it is expected that difference value should be zero. It can be concluded that direct use of 3D point clouds is possible in determination of HS from high resolution UAS data. But with a future study, the usage possibilities will be tested comprehensively.

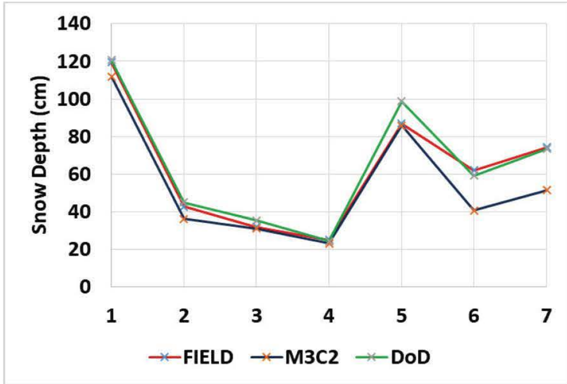

Figure 5: Comparison of HS values with field data

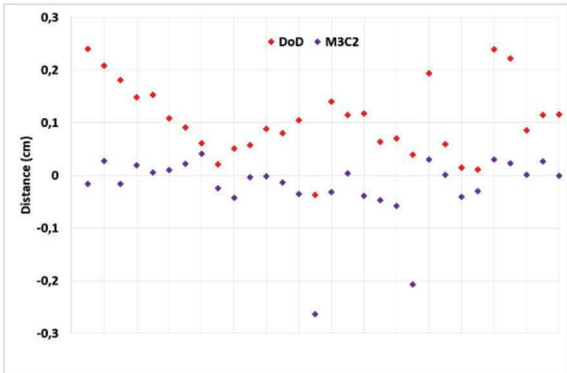

Figure 6: Distance values (cm) at 30 points located over boulders without snow cover, which vertical difference between two models is expect to be 0.

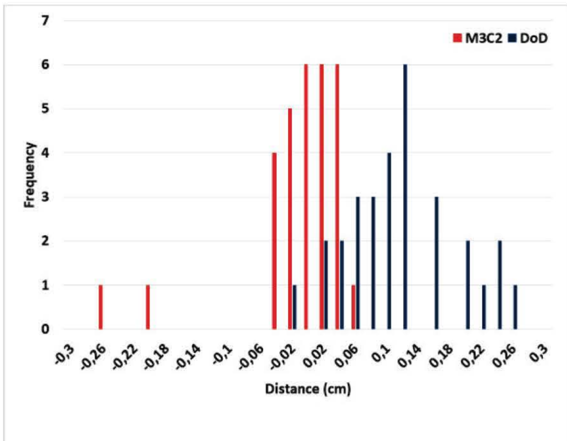

Figure 7: Frequency graph of pixels without snow cover that are expected to be 0.

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