Linking snow distribution and forest canopy characteristics by way of hemispherical photography

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ABSTRACT: Snow accumulation and ablation processes are strongly influenced by forest canopy. Larger variability of snow depths and snow depletion rates are found under the canopy in comparison to open areas. However, the interactions between forest snow processes and the impacts on snowpack evolution under canopy are not fully understood. This study investigates the temporal and spatial dynamics between the forest canopy and the underlying snow pack. A series of field areas under various canopy and elevation classes centered around Davos, Switzerland containing approximately 2000 geo-rectified (+/-50cm) and labeled points have been setup to allow for repeatable measurements of total snow depth, new snow depth and snow depletion rates. Canopy coverage characteristics have been estimated by a variety of methods, (1) hemispherical photography, (2) manual characterization and (3) airborne light detection and ranging data. The canopy characteristics derived from these methods were analyzed for correlation to approximately 45,000 manual snow measurements collected at the field sites during the 2012/2013 winter season. These methods were then intercompared and evaluated for applicability to large scale forest snow studies.

KEYWORDS: snow, canopy, forest, hemispherical photography, light detection and ranging (LiDAR)

1 INTRODUCTION

Forested areas represent a significant portion of areas with seasonal snow cover. 30% of area of Switzerland is covered by forests. These areas act as vast snow and water storage reservoirs. However, the interactions between forest snow processes and the impacts on snowpack evolution under canopy are not fully understood increasing the need for further investigation of this storage component for hydropower production and natural hazard protection.

This study focuses on the relation between snow distribution and canopy characteristics. It is based upon field measurements of snow cover and canopy characteristics at several sites surrounding Davos in Switzerland as well as subsequent data processing and analysis schemes. The aim of this work is to develop, test and compare methods for canopy characteristics determination using (1) hemispherical photography (HP), (2) manual characterization and (3) airborne light detection and ranging data sets. These methods are then used to compare snow and canopy characteristics (acquired from field measurements) as well as study the relationships between them.

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2 STUDY AREA

The data analyzed in this study comes from measurements at 9 sites surrounding Davos (46.8045° N, 9.8367° E) in eastern Switzerland (Figure 1). Two open reference sites and 7 forested sites cover a large distribution of canopy density and several altitude bands. We chose sites with minimal slope to reduce influence of other topographical factors (slope and aspect) in order to focus solely on vegetation influence. The sites are divided into 3 generalized groups according to average canopy density and elevation (Table 1).

A precisely geo-located 50 x 50 m square measurement grid was set up at each site. 6 lines from north-south and 6 lines from west-east divide the sampling grid into 25 quadrants, each 10 x 10 m. Lines are attached to poles placed at each crossing point (every 10 meters). There are sampling points every 2 meters along the lines and are marked on the rope for a total of 276 per site. All poles in the measuring grid were located by a DGPS giving a total error for all points per site of +/-50cm. There are two 50m long reference sampling transects at open sites with 25 sample points per transect, one located near the low elevation forested sites and the other adjacent to the high elevation forested sites.

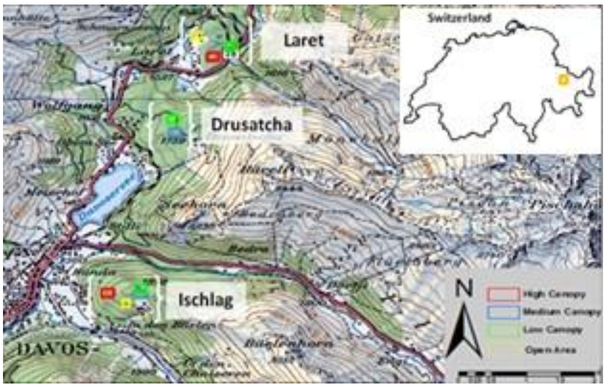

Figure 1. Map of measuring sites

Field Area	Elevation	Canopy Coverage			
		Low	Med	High	Open
Laret	1546	√	x	√	√
Drusatcha	1764	√	√	x	x
Ischlag	1874	√	√	√	√

Table 1: Measuring sites

3 DATA AND METHODS

3.1 Snow measurements

Snow depth (SD) and snow water equivalence (SWE) values were taken during a series of 16 measurement campaigns in the 2012/2013 snow season and took place after each snow storm or melting event.

SD is measured by a manual snow probe at all 276 sampling points per each site. When the conditions were good and the interface between new and old snow was clear, two values – new (total storm depth) and total SD – per point were taken. Otherwise only total SD was measured.

Snow water equivalence was measured manually using a US federal snow sampler at 12 fixed sampling points per site..

The HS and SWE data base contains approximately 45000 manual measurements from the 2012/2013 campaign.

3.2 Canopy survey

Three different methods were used to obtain information about canopy structure at the field sites – HP, simple manual classification and airborne light detection and ranging (LiDAR).

3.2 Hemispherical photography

16 upward-looking hemispherical pictures of canopy (Figure 2) were taken for each site – at all inner intersection points of the measurement grid lines using a Canon 600D DSLR camera with a Sigma 4.5mm F2.8 EX DC HSM circular fisheye lens mounted on a specially designed tripod for quick leveling and orientation to north. Pictures were taken approximately 1.2m above the ground in May 2013 under low light conditions to favor the sky-canopy contrast (Fleck, S. et al., 2009).

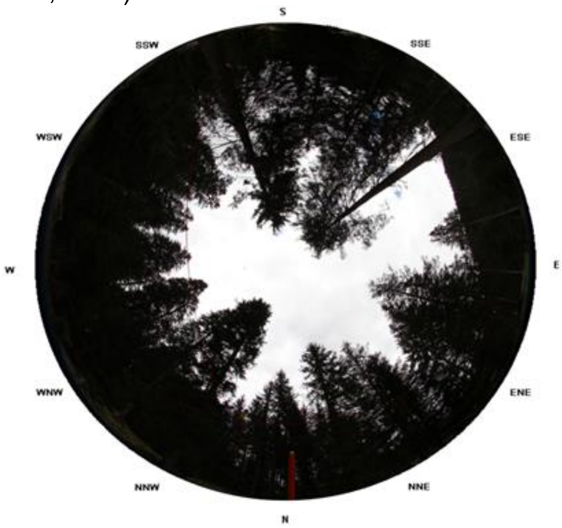

Figure 2. Hemispherical picture of the canopy

The pictures were then processed in a Hemispherical photo processing software package, Hemisfer (Schleppi et al., 2010; Thimonier et al., 2010) to arrive at leaf area index (LAI) and fractional cover (FCO) values. All methods used in Hemisfer are based on the classification of pixels to either white (sky) or black (canopy). Specifically LAI was calculated by the guidelines outlined by Miller J.B. (1967). FCO values were calculated from looking at the ratio of white and black pixels. Both LAI and FCO were also calculated for specific sectors as well as zenith angles within the photos.

3.2 Manual canopy classification

A simple manual classification was proposed as an alternative method for a quick evaluation of canopy characteristics as compared to the typically time consumptive HP process. A set of 6 classes were utilized: Open to the sun/south (OS), Open to the north (ON), Under the tree with high branches (UH), Under the tree with low branches (UL), Drop-off zone of high tree (DH), Drop-off zone of low tree (DL). See Figure 3.

The objectivity was tested to estimate the influence of different observers. A small group of testers independently evaluated the same area (276 points) with variable canopy structure after reading the guidelines for manual canopy classification (where detailed description of all classes is provided). The results show a favorable correlation between different observers. After this experiment, the manual classification was carried out for all measuring points in each field area.

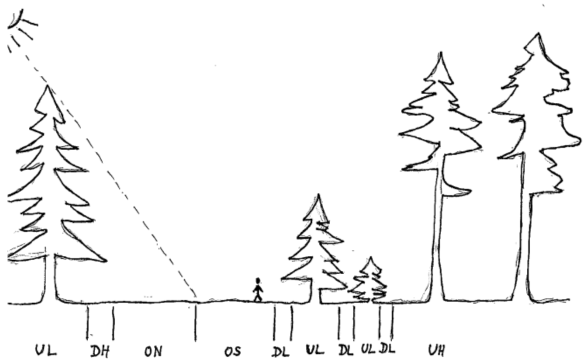

Figure 3. Manual canopy classification

3.2 Aerial LiDAR

Previous methods are based on direct observation in the field. But information about canopy can also be obtained from remote sensing techniques. We have integrated two aerial LiDAR data sets with average rasterized resolutions of 0.5 m (Figure 4) and 2 m respectively.

LiDAR data were processed to derive LAI and FCO using methods published by Morsdorf et al., (2006). These values were estimated for various bounding box sizes in order to find the best match of values with values obtained from hemispherical pictures. We compared LiDAR derived FCO values to hemispherical photo derived FCO values for the different view angles (0-90°). LAI however was always calculated for the entire viewshed.

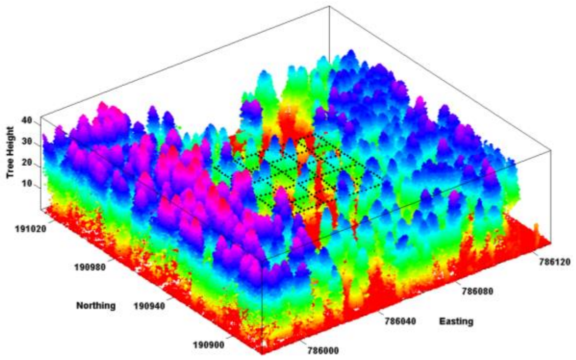

Figure 4. LiDAR cloud data of the Laret low field site. The geo-rectified sampling grid is the internal black dotted line and is 50m by 50m.

4 RESULTS

4.1 Comparison of methods to obtain LAI and FCO

Figure 5 shows the correlation between FCO and LAI calculated from hemispherical pictures and values derived from LiDAR data for different bounding box sizes. The correlations between results from both methods depend on the size of the box around the point for which the calculation is performed. Results for small box sizes are not highly correlated, because there is too much information missing relating to the areal canopy cover. The correlation of FCO is better than the correlation of LAI values and is less sensitive to box size change. The best match between the LiDAR and hemispherical photo derived FCO values are for the ~30 m box size and for a larger box size the correlation slowly decreases. The correlations of FCO for limited view angles reach the maximum with a slightly smaller bounding box size in which the difference is significant especially for small angles like 30 degrees. The differences between correlations for 60 and 90 degree angles are negligible. The best LAI value fit is for a 40m box size.

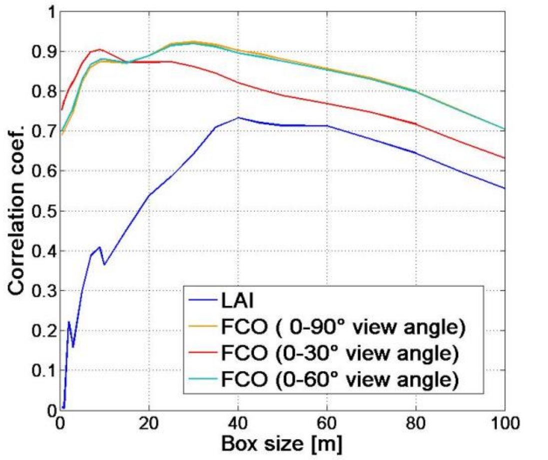

Figure 5. Comparison of LiDAR and hemispherical photo derived LAI and FCO for different bounding box sizes

4.2 Snow and canopy characteristic comparison

Figure 6 and 7 show the influence of canopy class (from the manual classification) on SD, relative SD and new SD. Relative SD is the ratio of SD in the forest to SD in a forest free open area. The analysis reveals the different influences of canopy classes on snow accumulation, ablation and interception.

Figure 6 shows significant differences between SD's for places with different canopy structures.

During accumulation the highest amount of the snow in the forest was at (partially) open area with no (or low) interception influences during the accumulation period. There is almost no difference between areas open to the north and open to the south. Lower SDs occurred in drop-off zones, Lower SDs can be explained by compression caused from falling snow. It corresponds with the fact that the SDs are lower for drop-off zones of high trees, where the velocity of dropping snow is higher and caused higher compression. As expected, the lowest SD values were observed below the trees due to interception. Higher SDs occurred under the trees with higher branches, which are less sheltered against the wind transport of the snow. SDs for all classes of forest canopy were lower than for open area during the whole accumulation period. (Relative SDs were more or less constant for the accumulation period.)

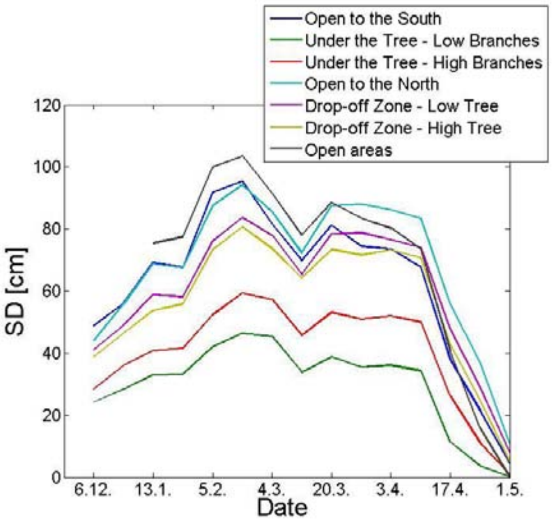

Figure 6. Influence of manual canopy classes on snow depth (SD)

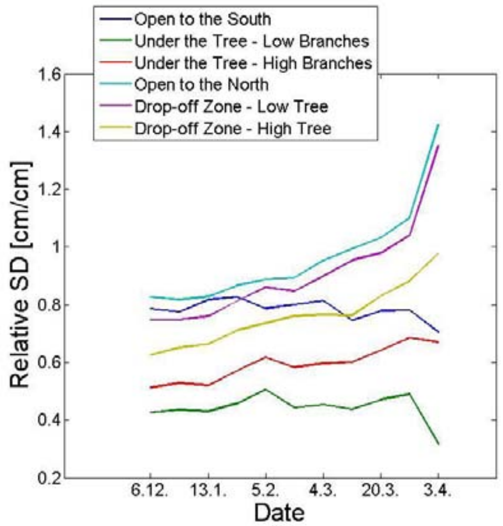

Figure 7. Influence of manual canopy classes on relative snow depth (relative to open areas)

The situation greatly changed during the ablation period, when varying SD depletion rates were observed for different canopy classes. This can be better seen in Figure 7, which shows SD relative to open areas. Within the figure, increasing relative SD corresponds to a lower SD depletion rate as compared to the SD depletion rate in the open. Much lower SD depletion rates were observed for both drop-off zones and for areas open to north. (The SD was higher for these classes than for the open area at the end of ablation period.) Also, SD depletion rates for the, 'under tree with high branches class,' was lower than in open areas. UH and ON classes represents areas protected against solar radiation by the canopy. Lower SD depletion rates for drop-off zones could be caused by higher density of snow compressed by falling snow. The SD depletion rate for open to the south and under low branches was slightly higher than for open areas.

Figure 8 shows the relationship between FCO and SD for selected days during the snow season. Of particular note, is the time of highest accumulation (21st February). Despite the scatter, there is a clear decreasing trend in SD with increasing FCO. Comparison of values for the maximum accumulation to values from the mid ablation period (10th April) shows higher differences at points with higher SDs, which are mostly the points with lower FCO. These higher SD differences correspond to higher SD depletion rate at spots with lower FCO. Scattering is caused by the fact that SD depends not only on FCO, but also on other factors like drop-off zones and openness to the sun.

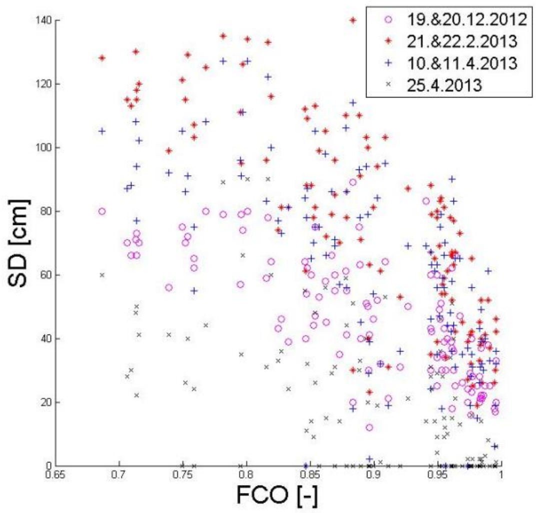

Figure 8. The relationship between fractional cover (FCO) and snow depth (SD)

5 DISCUSSION AND CONCLUSIONS

The results show that there is significant correlation between canopy characteristics and SD (representing accumulation or depletion rate). Small scale canopy variability causes the snow cover variability within the same scale. As expected, lower SD values were observed in denser canopy during the accumulation period. The situation turned around during the ablation period, when lower SD depletion rates in denser canopy held snow longer in comparison to open areas.

Canopy characteristics can be obtained by many different methods. Each method offers some advantages. HP which is well known considered a standard method created good results. However it requires a lot of field and data processing work, creating problems for characterizing large areas as well as more detailed survey areas. Manual canopy classification can rapidly reduce the amount of field work and post-processing time. Another advantage is considering drop-off zones, which may be difficult to assess from the other methods. A disadvantage of this method is that it is less exact and it is also not applicable for very large areas. Only remote sensing (i.e. aerial LiDAR) based methods are suitable to study very large or hardly accessible areas. However LiDAR can be costly.

This study also demonstrates that it is possible to use LiDAR data instead of hemispherical pictures to obtain canopy characteristics. The obtained results match very well to values derived from hemispherical pictures, when the proper box size for LiDAR data is used.

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