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Abstract: Airborne Laser Scanning (ALS) has been established as a valuable tool for the estimation of biophysical vegetation properties such as tree height, crown width, fractional cover and leaf area index (LAI). It is expected that the conditions of data acquisition, such as viewing geometry and sensor configuration influence the value of these parameters. In order to gain knowledge about these different conditions, we test for the sensitivity of vegetation products for viewing geometry, namely flying altitude and scanning (incidence) angle. Based on two methodologies for single tree extraction and derivation of fractional cover and LAI previously developed and published by our group, we evaluate how these variables change with either flying altitude and scanning angle. These are the two parameters which often need to be optimised towards the best compromise between point density and area covered with a single flight line. Our testsite in the Swiss National Park was overflown with two nominal flying altitudes, 500 and 900 m above ground. Incidence angle and local incidence angle were computed based on the digital terrain model using a simple backward geocoding procedure. We divided the raw laser returns into several different incident angle classes based on the flight path data; the TopoSys Falcon II system used in this study has a maximum scan angle of ±7.15o. We compare the derived biophysical properties from each of these classes with field measurements based on tachymeter measurements and hemispherical photographs, which were geolocated using differential GPS. It was found that with increasing flying height the well-known underestimation of tree height increases. A similar behavior can be observed for fractional cover; its respective values decrease with higher flying height. The behavior for incidence angles is not so evident, probably due to the small scanning angle of the system used. LAI seems to be most affected by incidence angles, with higher values for locations further away from nadir. Incidence angle seems to be of higher importance for vegetation density parameters than local incidence angle. We conclude that a more detailed knowlegde of beam-canopy interaction is needed, be it through empirical test such as ours or through using numerical models such as ray tracers.

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ASSESSMENT ON THE INFLUENCE OF FLYING HEIGHT AND SCAN ANGLE ON BIOPHYSICAL VEGETATION PRODUCTS DERIVED FROM AIRBORNE LASER SCANNING

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ABSTRACT

Airborne Laser Scanning (ALS) has been established as a valuable tool for the estimation of biophysical vegetation properties such as tree height, crown width, fractional cover and leaf area index (LAI). It is expected that the conditions of data acquisition, such as viewing geometry and sensor configuration influence the value of these parameters. In order to gain knowledge about these different conditions, we test for the sensitivity of vegetation products for viewing geometry, namely flying altitude and scanning (incidence) angle. Based on two methodologies for single tree extraction and derivation of fractional cover and LAI previously developed and published by our group, we evaluate how these variables change with either flying altitude and scanning angle. These are the two parameters which often need to be optimised towards the best compromise between point density and area covered with a single flight line. Our testsite in the Swiss National Park was overflown with two nominal flying altitudes, 500 and 900 m above ground. Incidence angle and local incidence angle were computed based on the digital terrain model using a simple backward geocoding procedure. We divided the raw laser returns into several different incident angle classes based on the flight path data; the TopoSys Falcon II system used in this study has a maximum scan angle of ±7.15º. We compare the derived biophysical properties from each of these classes with field measurements based on tachymeter measurements and hemispherical photographs, which were geolocated using differential GPS. It was found that with increasing flying height the well-known underestimation of tree height increases. A similar behavior can be observed for fractional cover; its respective values decrease with higher flying height. The behavior for incidence angles is not so evident, probably due to the small scanning angle of the system used. LAI seems to be most affected by incidence angles, with higher values for locations further away from nadir. Incidence angle seems to be of higher importance for vegetation density parameters than local incidence angle. We conclude that a more detailed knowlegde of beam-canopy interaction is needed, be it through empirical test such as ours or through using numerical models such as ray tracers.

Keywords: incidence angle, flight altitude, LAI, tree height, fractional cover

1 INTRODUCTION

In recent years, Airborne Laser Scanning (ALS) was established as a valuable tool for the horizontal and vertical characterization of the canopy. A number of studies prove ALS to be capable of deriving canopy height, be it for stands or single trees. Furthermore, ALS was used to derive measures of vegetation density such as fractional cover (fCover) or leaf area index (LAI). Tree height and crown width are mostly directly computed from either a gridded canopy height model (CHM) or the point cloud itself, whereas approaches deriving fCover and LAI most often use regression models to link ground measurements with laser predictor variables. These products comprise site and instrument specific properties, such as different sensor types, vegetation types and viewing geometry. This makes the comparison of results from different sites and sensor configurations hard, if not impossible. For instance, it is expected that scan angle and flying height have an influence on the magnitude of these parameters. Some research has already been pointing in this direction. A study of Yu et. al. (2004) showed that tree height underestimation was larger for higher flying heights, as well as that fewer trees were detected the higher the flying altitude was. Ahokas (2005) showed that tree height estimations would vary to some extent with scan angle. It is expected that especially estimations of vegetation density will be influenced by variations of incidence angle, since the distance the laser pulse travels through the canopy will increase with scanning angle. One has to discriminate between the local incidence angle and the incidence angle. **Loca**l incidence angle is the angle between the slope of a surface (e.g. of a gridded height model) and the laser beam, while the incidence angle is the angle between the horizontal plane going through a point of a gridded height model and the laser beam. We expect the latter to have a larger influence on vegetation density estimations by ALS, while the local incidence angle will most likely have a larger influence on the accuracy of terrain height estimation, and thus on tree height estimation. Our objective is to study this effect empirically by computing incidence and local incidence angles for each flight strip and to assign differences between ALS estimates and field measurements for fCover, LAI and tree height to different angle classes of both incidence and local incidence angles.

2 LASER DATA

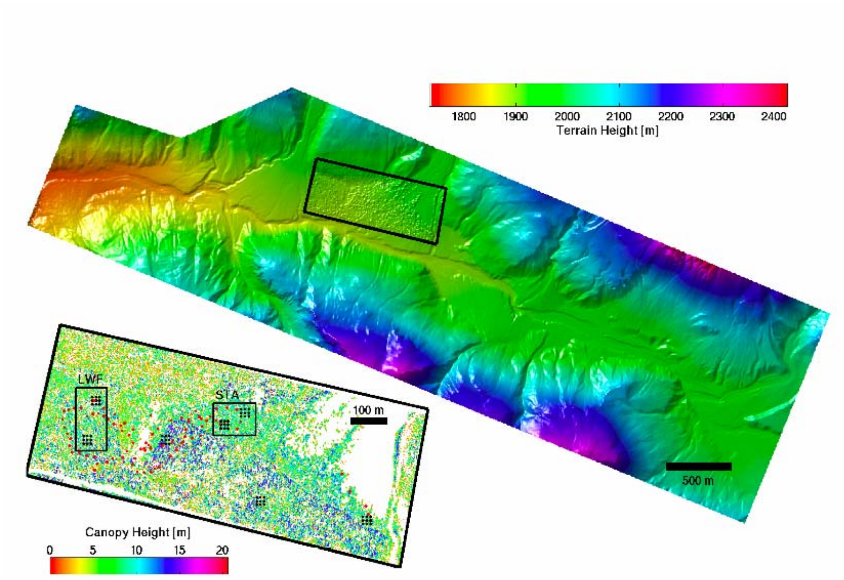

Figure 1: The Digital Terrain Model (DTM) of the Ofenpass area in the Swiss National Park. The smaller area marked by the black box was sampled with higher point density due to the lower flying height of 500 m above ground. A canopy height map of that area is displayed in the lower left. Black dots mark positions of hemispherical photographs that were taken in 2002 using a handheld GPS for georeferencing. Red dots indicate positions were hemispherical photographs were taken using differential GPS for georeferencing (2005).

In October 2002, a helicopter based ALS flight was carried out over the test area, covering a total area of about 14 km^2. The ALS system used was the Falcon II Sensor developed and maintained by TopoSys.The system is a fibre-array laser altimeter recording both first and last intensity peaks from the laser return signal (first/last echo **FE**/**LE**) with a fixed scan angle of ±7.15 degrees.

A flight of higher altitude was conducted with a nominal height over ground of 900 m, leading to an average point density of more than 5 points per square meter. A smaller subset of the area (0.6 km^2) was overflown with a height of 500 m above ground, resulting in a point density of about 10 point per square meter in each flight strip. The footprint sizes were about 0.9 m in diameter for 900 m flight altitude and about 0.5 m in diameter for 500 m altitude. The raw data delivered by the sensor (x,y,z - triples) was processed into gridded elevation models by TopoSys using the company's own processing software TopPIT. The Digital Surface Model (DSM) was processed using the first pulse reflections, the Digital Terrain Model (DTM) was constructed using the last returns and filtering algorithms. The grid spacing was 1 m for the large area and 0.5 m for the smaller one, with a height resolution of 0.1 m in both cases. A quality analysis of the raw data was done using six artificial reference targets and is described in detail in Morsdorf et al. (2004). The standard deviations of height estimates based on raw echos on these targets were as low as 6 cm, with the internal accuracy of the ALS data being well below the pixel size, which is 0.5 m.

3 METHODS

3.1 Field measurements

We took hemispherical photographs as field samples using a Nikon Coolpix 4500 with a fish-eye lens. The small plot in Figure 1 shows a canopy height model (CHM) of the area over flown with the lower altitude. Black dots indicate positions where hemispherical photographs were taken in 2002. In 2005, another data collection was carried out at locations marked by red dots. In 2005, a total of 83 hemispherical photographs were taken, and the location of each image was estimated by differential GPS measurements. We used three Trimble GPS receivers (one 5700 receiver and two 4700 receiver types) stations for GPS measurements. The GPS was utilized using varying occupation times according to satellite availability. GPS RMS achieved was in the range of 0.5 to 5.4 centimeters with a mean of 1.84 centimeters. For tree heights, a dataset of about 2000 dominant and subdominant tree locations was provided by the Swiss Institut for Snow and Landscape Research (WSL). The dataset included tree height and crown diameter for each tree. We only used the dominant trees for our statistics, since tree clumping is a major issue in the study area and we were only interested in tree height understimation and not in the number of correctly identified trees. Dominant trees were selected from groups of trees in a radius of 1.5 meter as the tallest tree of that group. Out of originally 1984 trees, 1138 were selected as being dominant.

3.2 Derivation of geophysical properties

We derived tree height, fractional cover (fCover) and leaf area index (LAI) for each of the flight tracks separately. For the estimation of the tree heights, we used the single tree extraction algorithm presented in Morsdorf et al. (2004). This approach uses local maxima extracted from a Digital Surface Model (DSM) as seedpoints for a clustering algorithm being applied to the raw data. Thus, for each flight strip we computed a DSM using only returns from the respective flight track. The raw laser echo heights were transformed into vegetation height by subtracting interpolated terrain heights from the DTM Toposys provided for the lower overflight. fCover and LAI were computed directly from the laser returns, without the need of utilizing a DSM, as presented in Morsdorf et al. (2005). The algorithms include the computation of echo ratios (e.g. number of vegetation echos divided by number of total echos for fCover) for defined areas containing the raw data. We set up a grid of two meter resolution for both fCover and LAI computation. Again, for each flight track a single grid of these two parameters was computed. For both LAI and fCover, we used regression models derived from all data from the lower overflight. The regression models were used as they are presented in Morsdorf et al. (2005).

3.3 Computation of the incidence angle

Toposys provided us with the original flight path data, including sensor location and sensor attitude at a sampling rate of about 200 Hz. We used this information together with the DTM of the lower flight to reconstruct the viewing geometry for each of the selected flight tracks. A simple backward geocoding algorithm was implemented for the computation of the incidence angle and the local incidence angle for each pixel of the DTM. For the lower overflight, a total number of five flight tracks were used to compute the incidence angle of the laser beam for every pixel of a ALS-derived DTM, while for the higher overflight only three flight strips were necessary to cover the area of the DTM. These angles were then used to classify differences between ALS estimates of fCover, LAI and tree height into different angle classes. For each of these angle bins being one degree wide, mean and standard deviation of the differences were computed.

4 RESULTS

Figure 2 shows the differences of fCover and LAI estimations for different angular classes of incidence angles from flight tracks being 500 m above ground level (AGL). Figure 2 a shows the difference of fCover (upper panel) and LAI (lower panel) between ALS based estimations and field measurements. One can note that there is no significant increase of differences for both fCover and LAI towards smaller incidence angles (meaning larger scan angles). The standard deviations are much larger than the differences itself, being between 30 and 50 % for fCover and between 0.2 and 0.6 for LAI, while the differences are in the range of -10 to 20 % for fCover and -0.3 and 0.2 for LAI. Values at the smallest incidence angles (80-82 degrees) should be taken with caution, since only few samples contribute to the estimates. Figure 2 b shows the relative difference of the fCover and LAI estimations from all the data compared with the largest incidence angle (smallest scan angle). This comparison is based on the assumption that the values of fCover and LAI are distributed in each class in the same way. One can note that there is no increase of fCover towards smaller incidence angles, but a slight increase of LAI of about 30 % towards incidence of about 80 degrees. The standard deviations are again large, thus this increase of LAI might only be a hint, but not a proof of an angular influence on the computation of LAI. Tree height did not show any angular behavior in the small range of incidence angles we computed, and thus, we do not show it here. It is expected that the accuracy of ALS based tree height derivation might be influenced by terrain slope, but since we did not compute a DTM for each flight strip, we could not single out this effect.

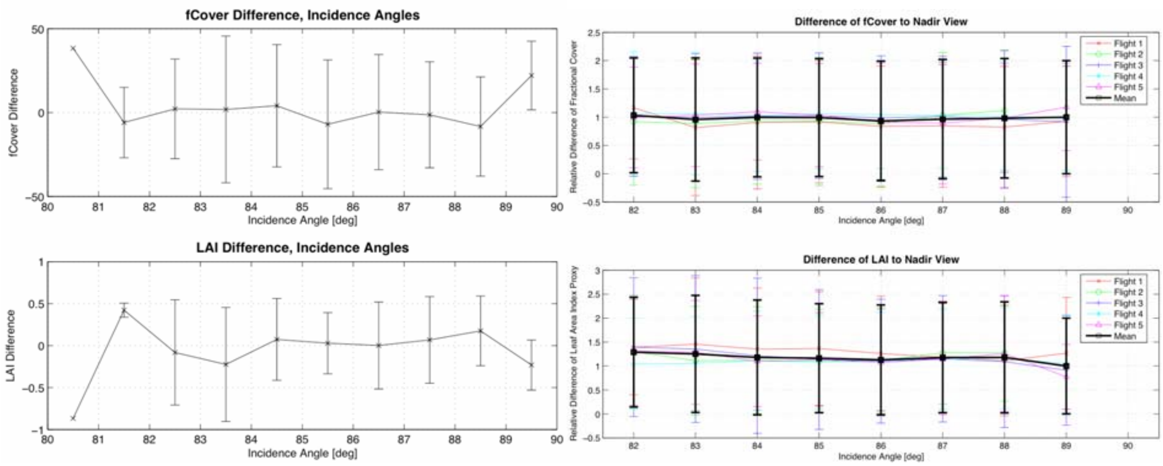

Figure 2 a and b: Difference of fCover and LAI for each incidence angle class at 500 m above ground level (AGL). Vertical bars indicate the standard deviation for each class, while the star marks the mean value. Left figure displays differences with field measurements, right figure displays differences solely based on ALS data, assuming spatial homogeneity of both fCover and LAI in each angle class.

Table 1 contains the differences between fCover LAI and tree height due to change of flight altitude. For each flight altitude, we computed the difference of field estimates and ALS based estimates using data from all angle classes. fCover is overestimated by ALS at 500 m AGL, while values derived from data acquired with 900 m AGL underestimates absolute fCover values by about 10 %. Thus, one can state that ALS based estimates of fCover will decrease with flying height. LAI shows a different behavior, with a small underestimation by ALS at 500 m AGL (-0.06 and -0.18 for mean and median), but a larger overestimation for 900 m AGL with a mean of 0.29 and a median of 0.18. The standard deviation is large for both fCover (33.7 / 30.7) and LAI (0.56 / 0.63) and is not much influenced by flying altitude. For tree height, we find a small underestimation of field values by ALS for 500 m AGL (-0.38 m mean and -0.05 m median), which is getting larger for 900 m AGL with a mean underestimation of 0.69 m, while the median difference is at -0.29. The standard deviation is only a little larger for 900 m AGL, being 1.49 m, while the standard deviation at 500 m is 1.39 m.

Table 1: Differences between ALS estimates and field measurements for fCover, LAI and tree height. The mean, median, standard deviation and number of samples are given for each property and flying altitude. Negative values denote underestimation by ALS.

Absolute difference: ALS estimates - field measurements	Mean	Median	Std. Deviation	Samples
fCover 500 m AGL [%]	1.21	10.7	33.7	139
fCover 900 m AGL [%]	-10.2	-8.3	30.7	166
LAI 500 m AGL	-0.06	-0.18	0.56	156
LAI 900 m AGL	0.29	0.18	0.63	177
Tree Height 500 m AGL [m]	-0.38	-0.05	1.39	658
Tree Height 900 m AGL [m]	-0.69	-0.29	1.49	485

5 DISCUSSION AND CONCLUSIONS

Using flight path data and sensor attitude together with field measurements of biophysical properties, we studied the influence of incidence angle and flying height on fCover, LAI and tree height. Probably due to the small scan angle (±7.15 degrees) of the system used, we could not find significant differences of ALS based estimates of fCover and tree height for different incidence angle classes. This is backed by the results from Ahokas et al. (2005), who found significant differences only for scan angles larger than 15 degrees. LAI estimates showed a small increase of values for larger incidence angles, but further studies are needed to test whether this finding is robust. Flight altitude dependencies were much more evident in our data. Tree height underestimation by ALS increased from 500 to 900 m flying altitude by about 30 cm, which is in good agreement with previous findings. ALS based LAI estimates were overestimating true LAI for the higher overflight by about 0.2, opposed to underestimation at 500 m AGL. ALS based fCover estimates decreasd with flying altitude by about 10 %. It should be noted that the errors of the biophysical parameters are still in a tolerable range at 900 m AGL, and that flying at 500 m does not improve that much on the differences. Yu et.al. (2004) made similar observations in a study using three flight altitudes (500,900 and 1500 m AGL), the quality of the ALS based data dropped only significantly when changing from 900 m AGL to 1500 m AGL. In order to study further the effect of scan angle on vegetation density products, we propose using ALS data acquired using larger scan angles. This is especially necessary, as for smaller scanning angles errors induced by field measurements are probably in the same order of magnitude as the variations induced by scan angle changes. Furthermore, it might be helpful to utilize radiative transfer models such as the ones which are commonly used in the passive optical remote sensing community. These should enable one to simulate individually the effects of acquisition properties such as incidence angle, point density, terrain slope, laser footprint size, laser wavelength and canopy reflectance on the accuracy of biophysical vegetation data products opposed to real-world scenarios, where all these effects contribute indifferently to differences between ground truth and ALS based estimations of biophysical parameters.

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