Relating tree height variations to peat dome slope in Central Kalimantan, Indonesia using small-footprint airborne LiDAR data

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Abstract: We investigated how measures derived from small footprint airborne Light Detection and Ranging (LiDAR) data can be used to evaluate the relationships between tree height (represented by the digital surface model, DSM) and peat swamp dome slope (digital terrain model, DTM). In August 2007 we mapped by helicopter different peat swamp forest (PSF) environments with Riegl LiDAR Technology LMS-Q560 in the Mawas area of the Ex-Mega Rice Project (EMRP) and in the Sabangau National Park (Central Kalimantan, Indonesia). In each LiDAR transect we used sample plots of 100x100m along the flown acquisition with a distance of 200m from each other. In each sample plot we calculated the peat dome slope and the tree height and we evaluate linear regression between both parameters. Our results showed that: a) the tree height increases by approximately 5m if the peat dome slope increases from 0.5 to 1.5m pro mille (m/km) from Sabangau River to the peat dome; and b) there is a relationship between both variables ($r^2 \geq 0.60$) that may be related with the permeability, interflow, water storage capability and nutrient availability in the domes. In a near future we intend to conduct regression analysis considering the field-measured stem volumes against together with LiDAR-derived tree height and Ortho-photos in the frame of the REDD knowledge.

1. Introduction

Natural tropical Peat swamp forests (PSF) are important for their rich biodiversity and because they represent important carbon pool (Page et al., 2002). However, PSF are decreasing due to conversion into farm land, by excessive draining, the use of shifting cultivation on a large scale, illegal logging and forest fire. Furthermore, managed land cover types, degraded ecosystems and large deforested areas have been also reverted to successional forest stages. This increases the interest for understanding in an ecological point of view and mapping such environments as they are recognized as an important source of carbon released in the atmosphere (Sorensen 1993, Page et al., 2002, Jaenicke et al., 2008, Ballhorn et al., 2009).

According to Hyde et al. (2007) airborne Light Detection and Ranging (LiDAR) data is nowadays the best single sensor to investigate biophysical parameters (e.g. three height and canopy diameter which are strongly correlated with above ground biomass and leaf area index). In peatland areas the great variety of ecosystems and is ecological rule is still not fully understood and the influence of different degrees of succession and the influence of selective logged areas (e.g. species composition, their structures and canopy properties) on global change issues also remain a big challenge. Consequently, to optimize the biophysical properties characterization, a better understanding of how LiDAR variations measurements could be useful for ecological studies in such critically endangered forests is still necessary.

In August 2007 we mapped by helicopter different PSF locations with Riegl LiDAR Technology LMS-Q560 in Central Kalimantan, Indonesia. In this study, we evaluated the relationship between tree height and peat dome slope in distinct relief conditions described in the next section. To demonstrate such relationship we extracted the tree height information (e.g. average and dominant) as well the slope from sample plots of 100x100m (i.e. divided in subplots of 50x50m) along the flown direction in a minimum distance of 200m.

2. Study Area description

Our study areas consist on four LiDAR transects located inside the Central Kalimantan province, Indonesia (Figure 1). One Landsat image acquired on February 15, 2003 shows the remaining forest in the region. In fact, peat swamp forests over the region were impacted with extensive logging activities in the 90th and by the implantation of the Ex-Mega Rice Project (EMRP). The failed EMRP with its 4000km channel system leads to severe peat damages with reasonable amount of carbon released to the atmosphere.

Two transects are located in Block E of the EMRP, locally known as Mawas. The Mawas area has a North-South Channel and the BOS Tuannan Station near river Kapuas which can be identified in the LiDAR data. The main forestry areas are characterized by altered primary forest patches, in which trees had been logged selectively until the end of the 1990s. Forest ground truth data were collected in this area in frame of the INDREX-II campaign (Hajnsek et al. 2009). The last transect is located in the Sabangau National Park along the CIMTROP (Centre for International co-operation in sustainable

Management of TROpical Peatland) transect. This PSF was selective logged by the concession company Setia Alam Jaya using an extraction railway system up to 1997.

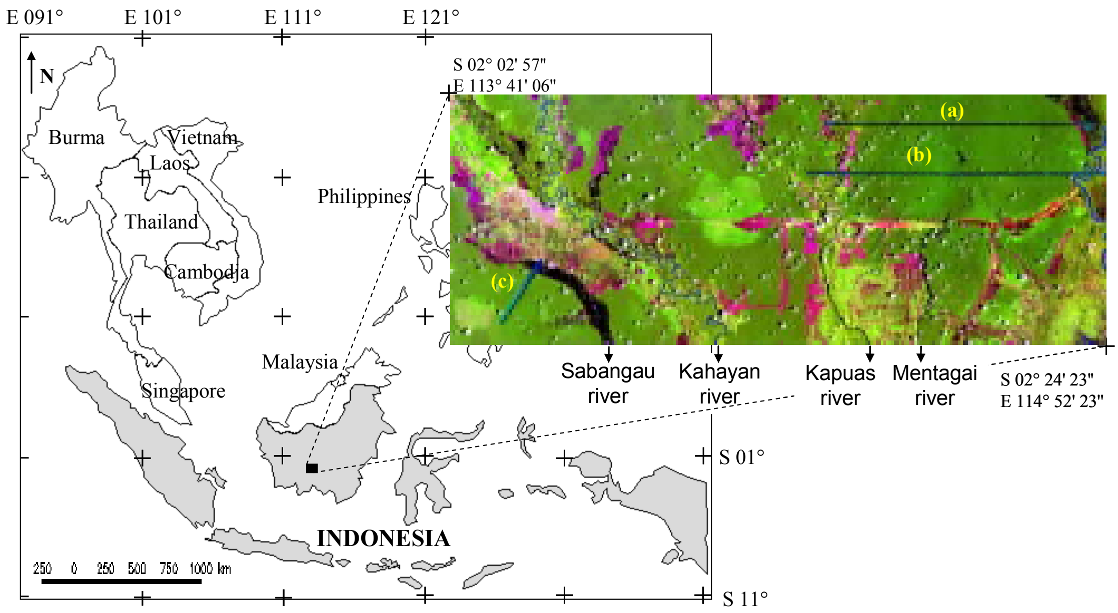

Figure 1. Study area location with detail to a Landsat subset acquired on February 15, 2003. In this subset three letters indicate the location of three different LiDAR transects under investigation.

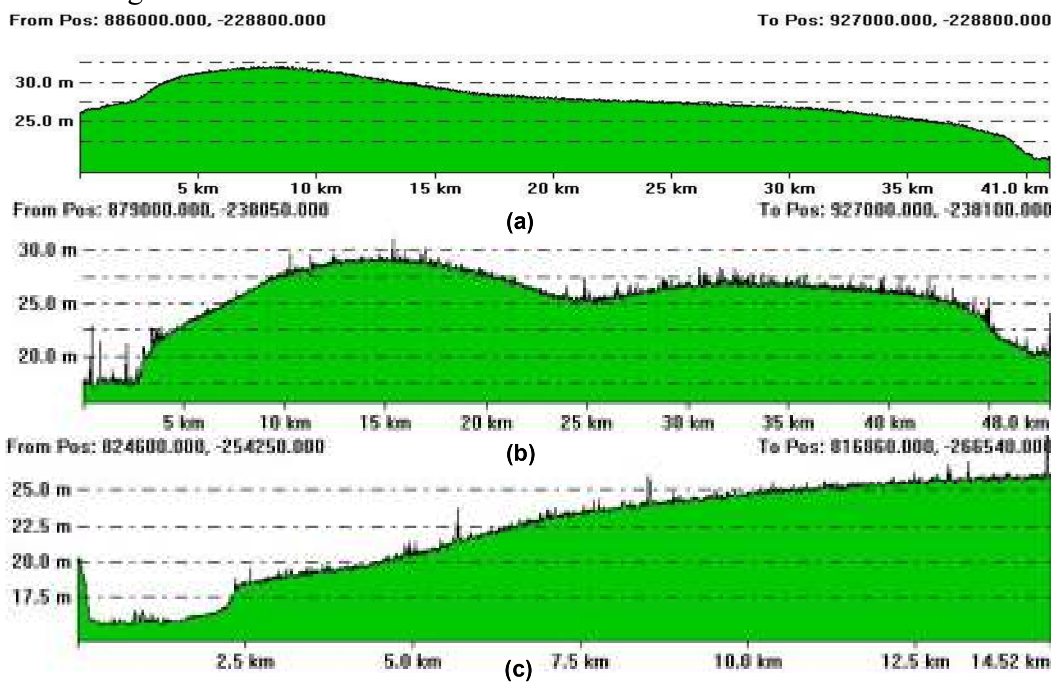

Figure 2. LiDAR-DTM profiles for Mawas area in (a) km228.8 and (b) km238 and (c) Sabangau area. We selected for the cross-section a profile parallel to the visible logging transects. Transects were acquired with different lengths and have different scales.

According to Hirano et al. (2007) the leaf area index of the peat swamp forest in the region in the dry monsoon is close to 6, typical for advanced and dense tropical rain forested areas. Areas of pasture, small agricultural fields, small villages and actual degraded forest resultant from selective logging can be also observed in the surroundings.

The three transects were selected based on the sample of three different relief conditions showed in Figure 2. In this figure we may noticed an asymmetrical peat dome on the left with a terrain peak close to 32m (Fig. 2a and Table 1). The second peat dome shows a double peat dome to the left with a peak close to 29m and with the upper part of Mentangai river (~25m) located in the middle. At the Kapuas river left the water level was 17.1m and on the right at Barito 20m on August 5, 2007 (Fig. 2b and Table 1). The third figure shows on the left side the Sabangau Catchment which up to 2.5m (18m) deep with the Sabangau river (15.5m) (Figure 2c and Table 1). The peat surface increases quickly with 0.17% up to 26m and further to the peat dome to 31m (results not shown in Fig. 2c).

Table 1. Summary of the three LiDAR transects under study.

Peat area transect	River level	Peat dome	Used trans. length	Max. slope (m / km)	Avg. avg. tree height	Avg. max. tree height
Mawas km228S (a)	17.8m	32m	41km	2.1m/km	12.8m	27.5m
Mawas km238S (b)	17.1m	29m	42km	1.3m/km	9.4m	26.3m
Sabangau km256S (c)	15.5m	26m	12km	1.7m/km	14.0m	29.4m

3. Material and Methods

3.1 LiDAR Data processing

The airborne LiDAR transects were acquired from August 5 to 7, 2007 in a helicopter campaign conducted by Kalteng Consultants and Milan Geoservice GmbH. We collected for the above described tracks approx. 4200ha of PSF with approx. 1.4 laser beams per square meter. The Riegl-airborne laser-scanner LMS-Q560 was mounted under the Bell 206 helicopter. Small footprint LiDAR data was collected for a flight altitude of approx. 500m with a scan angle of 60° with produced a swap-width of approx. 500m (Boehm et al. 2007, 2008). We used for this analysis the first and last pulse Laser echoes only, but the full-wave data are available for more detailed analyzes. The Laser scanner had a pulse rate of 66kHz resp. 100kHz with a beam divergence of 0.5mrad or a footprint of 0.25m.

The ground backscattering in PSF through the canopy was responsible for 1 to 3% of the 0.5mrad Laser beams.

The DGPS reference station was located at the airport of Palangka Raya which has an elevation of 25.0m above sea level. The position and orientation of the LiDAR system on the helicopter was measured by an Inertial Navigation System (INS) and a GPS located on the tail boom with 256Hz. The Riegl LMS-Q560 airborne Laser scanner system itself allows height measurements with an accuracy of ±0.02m. After the correction of the attitude of the helicopter, the elevation accuracy of each Laser beam was ±0.15m with a root mean square error (RSM) of ±0.5m in both x- and y-direction. The processed laser beams were divided into ground surface and overground classes and converted in order to digital terrain model (DTM) and digital surface model (DSM), respectively, at a spatial resolution of 1m.

3.2 Data Analysis and Sampling Criteria

Observation data were compiled from sample plots of 100x100m collected in the flown acquisition. For validation purposes we divided each sample plot in four subplots of 50x50m for statistical analyzes. The spacing between each sample plot and/or subplot was 200m res. 500m in part of the Mawas area. We extract both DTM and DSM values for each measurement subplot and transect. In the slope determination we only account for the lowest values of the DTM in order to minimize the inclusion of the return signal coming from tree trunks and branches lying on top of the peat surface.

We calculated the slope by counting the difference between the DTM values of two samples and converted the altitude difference in a space of 200m and when applied to 500m into per mille (m per km). We proceed with the extraction of tree height for the DSM where we just account the signal coming from the dominant trees. Complementary we also calculated the average of all tree heights inside the sample and/or subplots. The number of plots varies according to each transect under study due to differences in length acquisition. The data from each transect was divided into training (70%) and validation (30%) datasets for statistical purposes described in the following section.

3.3 Statistical Modeling

The relationship between tree height and peat dome slope employed a linear regression analysis (i.e. yj=ax+b). The slope value for each sample plot was used as the predictor for tree height determination. The linear regression analysis was applied to the test dataset in order to perform the accuracy statistics. The accuracy statistics include the root mean square error (RMSE) (Eq. 1), Bias (Eq. 2) and their relative counterparts $RMSE_r$ (Eq. 3) and $Bias_r$ (Eq. 4) (Muukkone and Heiskanen, 2005).

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - j_i)^2} \qquad \text{Eq. 1}$$

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(y_i - j_i) \qquad \text{Eq. 2}$$

$$RMSE_r = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - j_i)^2}}{y_m} \times 100 \qquad \text{Eq. 3}$$

$$Bias_r = \left[\frac{1}{n}\sum_{i=1}^{n}(y_i - j_i)\right] y_m \times 100 \qquad \text{Eq. 4}$$

where: j_i is the predicted value, y_i is the observed value, y_m is the mean of observed value and n is the number of plots in test dataset.

Complementary we also evaluated the analyses of the residuals (i.e. Observed value minus Predicted value) and we apply Cook's distance to identify outliers. Based on this distance we disregard up to 0.5% of the samples from the statistical analysis. In fact, some outliers were noticed in flat areas where no slope was observed. To examine if there were significant differences between the observed forest attribute (e.g. tree height) and those estimated from the linear regression, a non parametric test was applied. We expect the results might reject the hypothesis that the mean values of the observed and modeled forest properties differ significantly.

4. Results and Discussion

4.1 Mawas Peat swamp area at km 228

Initially we analyzed the asymmetrical peat dome located at km228.8 (South of the Equator) in the Mawas transect between Kapuas and Barito rivers (Figure 2a). We resampled the distance of our samples to 500m instead of 200m to facilitate graphic representation of the average tree height and peat dome slope (Figure 3). In this figure we found the highest tree height at km888.5 with 18.3m and the overall tree height average was 12.8m for 82 samples in the transect of 41km

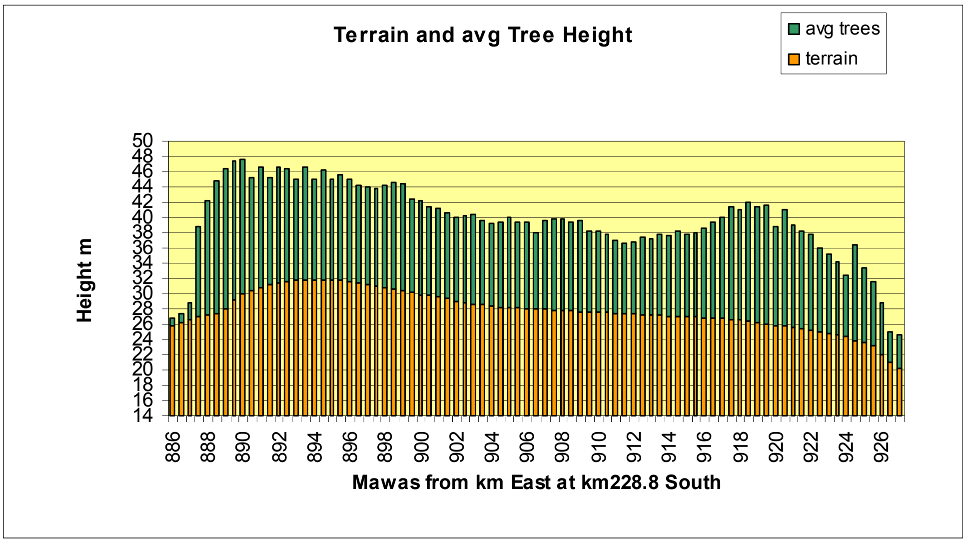

Figure 3. Average tree height coupled with the terrain of the peat surface analyzed in 500m steeps over the Mawas transect of 41km, at km228.8 south. Sample size was 100x100m.

Figure 4 shows the average tree height over the Mawas area. The highest average tree height at km888.5 was 18.3m (left side of the figure) and at km919 with 15.6m. This transect is relatively very flat and the tree height ranged mostly from 9 to 11m only. However, the average of the tree height over the 41km transect was close to 13m.

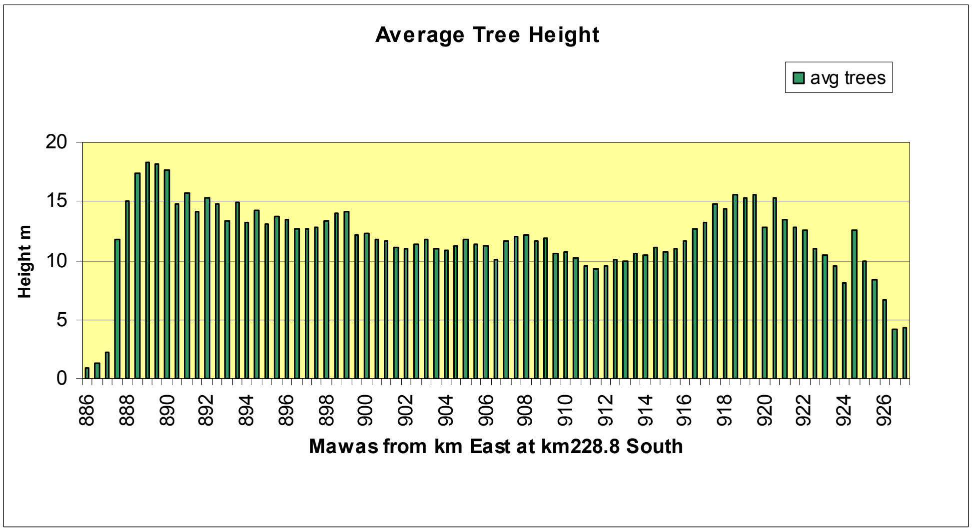

Figure 4. Average tree height over the Mawas area of 41km, km228.8 South.

Figure 5 shows the relationship between tree height and peat dome slope over the Mawas area. Although height distributions of individual plots have not been fully investigated in our study, we noticed a stronger correlation with the maximum tree height (coefficient of determination of 0.78) with the slope than the average tree height (0.59). Maximum tree height is related to dominant height, a common parameter in forest inventories to asses the quality of forest stands over a certain region (Lefsky et al. 1999).

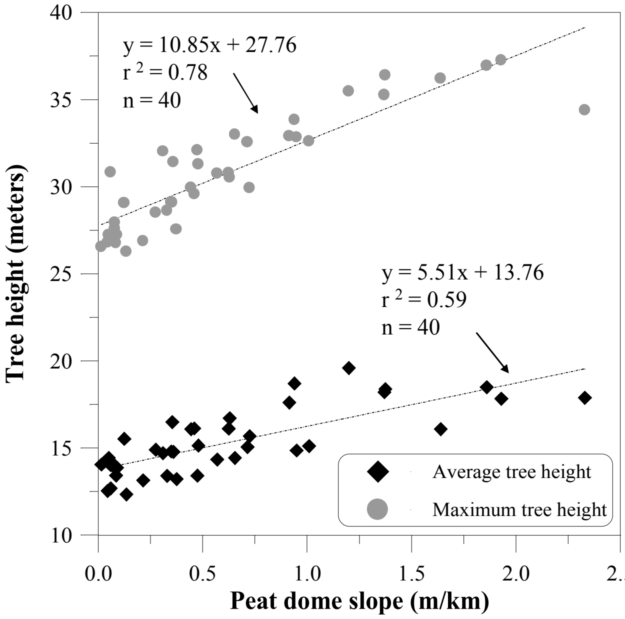

Figure 5. Average and Maximum tree height as function of the peat slope for Mawas transect. The sample plots of 100x100m were analyzed every 200m from km887 to km895. The peat slope correlation between both tree heights are very good.

4.2 Mawas Peat swamp forest area at km 238

The second peat dome cross-section was analyzed at km238 of the Mawas area. Figure 6 shows the average tree height coupled with the ground surface altitude. At km890.2 we identify the North-South channel of the Ex-Mega Rice Project. Forestry stands close to the channel had been logged in the past (indicated by the first arrow). Such interventions are better identified if we consider the average tree height information (Figure 7). The Mentangai river has his source at km904 with an altitude of 25m (indicated by arrow in the middle) and this river allows an easy access to this area with boots. At this Mawas cross-section the average tree height is not so high probably due to the selective exploitation of the forest in the past. In this transect we noticed the highest of 13m (Figure 7). The average tree height over the 42km transect showed a value of 9.4m only.

This indicates more logging activities compared to the Mawas transect illustrated in Figure 2a.

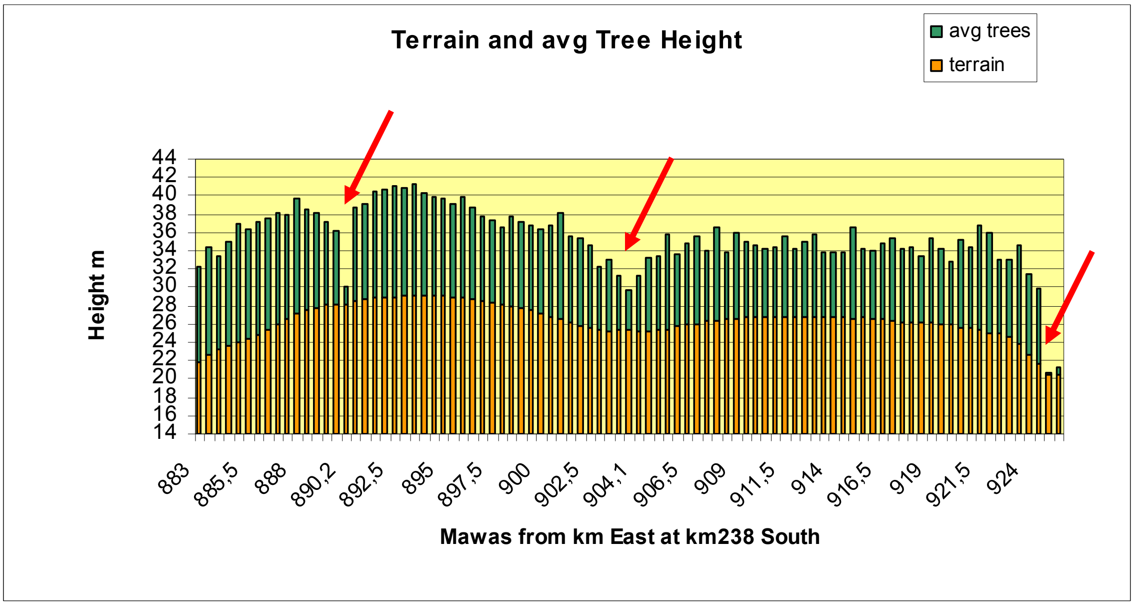

Figure 6. Averaged tree height with peat surface for Mawas area at km238 using LiDAR-DSM and DTM-data.

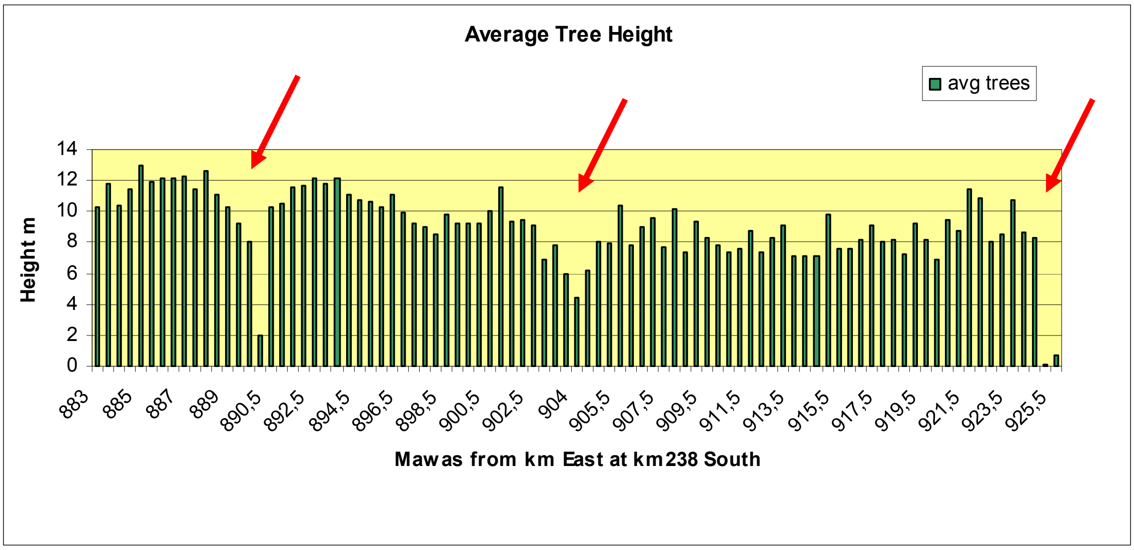

Figure 7. Averaged tree height without the peat surface in Mawas area at km238.

Due to the selective logging we did not found a strong correlation between tree height and peat dome slope. At km888 we found the highest averaged trees with 12.63m and a slope of more than 1.3m per km (Figure 8) that probably mask the relationship between both variables. At km890.2 the average tree height drops down, caused by the N-S channel and opened PSF. A similar result is shown on the right sight of the first dome to Mentangai river at km901 with 11.6m average tree height and slope down in order of 0.7m per km. At km911 on the second peat dome we found the lowest averaged tree height value with an average tree height of 7.5m. At km922 the average tree height increases again to 11.5m with the higher peat slope to river Barito.

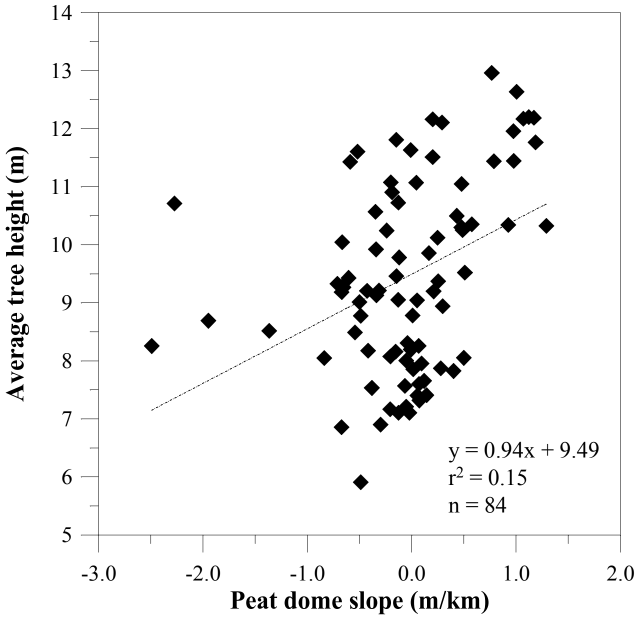

Figure 8. Average tree height as function of the peat dome slope for Mawas transect.

4.3 Sabangau National Park (CIMTROP peat swamp area)

The Sabangau CIMTROP transect in the National Park is another transect which was selectively logged in the past. In this transect, the Sabangau catchment in located on the left side of the profile with lowest ground elevation (15.5m) and in other side peat dome with 26m (Figure 9). The highest slope in this transect was up to 1.7m per km. For the selection of the sample plots we take into account only forest stands approximately 350 to 500m parallel to the former railway assuming less or moderate logging influence. Samples were reduced therefore to 50x50m and were analyzed every 200m

The average of the average tree height of the sample plots for this 12km transect was 14m, and was relatively higher that in Mawas area at km238 where we observed the value of 9.4m. At km258.4 South we found the highest averaged tree height with 17.1m whereas 12.63m in the Mawas area. Furthermore, the maximum tree height was also higher in this transect. We found the value of 34m in this transect whereas 29m for the

Mawas area. Such results may be an indicative of logging severity in the past. As a result, the correlation between tree height and peat dome slope was better (Figure 11) than the Mawas area (Figure 8). In this transect the steepest peat surface was found at km259.2 with 0.30m-0.35m, that indicate a maximum slope of approximately 0.17%.

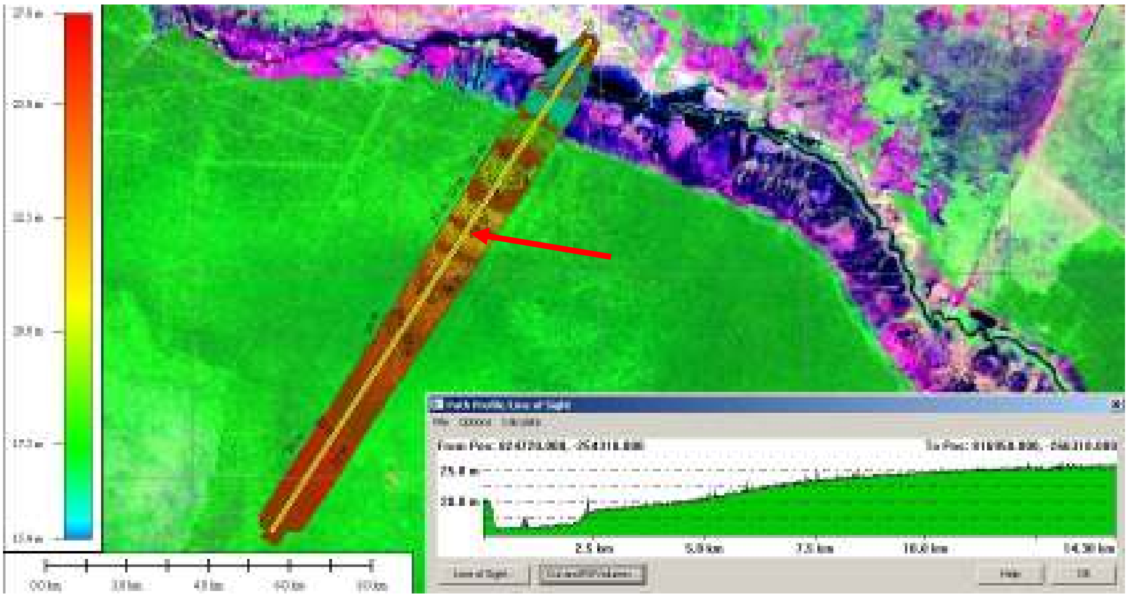

Figure 9. LiDAR-DTM of CIMTROP transect in Sabangau National Park with 1m contour-lines and peat topography profile, Landsat image from 5.8.2007. The red arrow shows the highest slope of the transect with 0.17%.

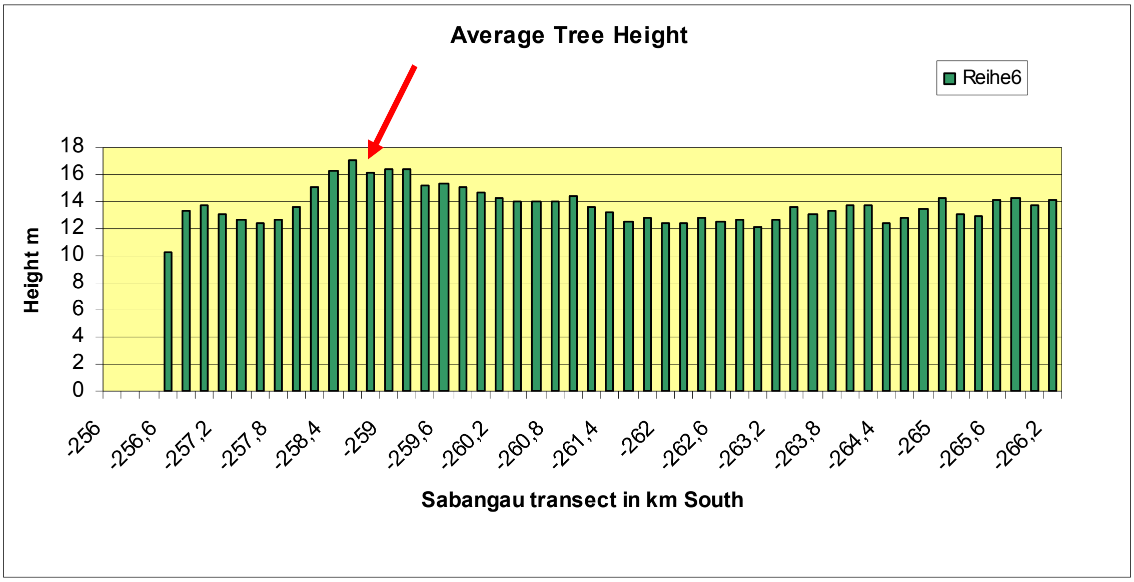

Figure 10. Averaged tree height without the peat surface in Sabangau transect.

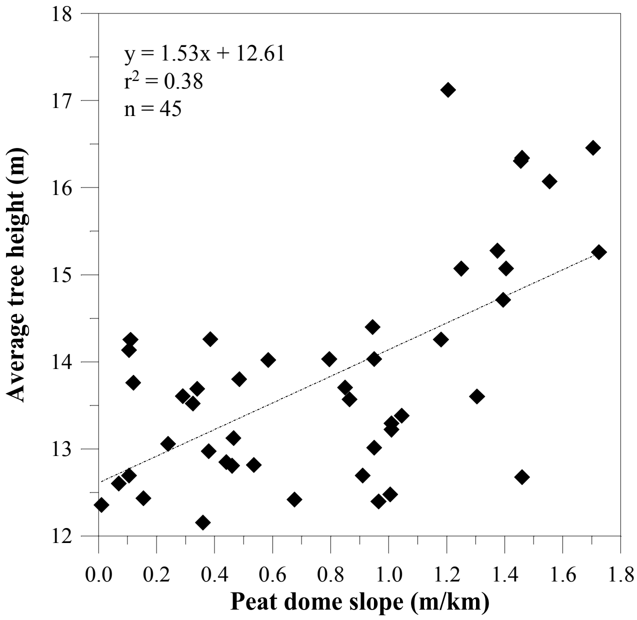

Figure 11. Average tree height as a function of the Peat dome slope. The slope of the peat dome is up to 0.17%.

4.4 Statistical approach for Mawas and Sabangau peat swamp areas

The maximum tree height of two less undisturbed peat swamp forest transects at Mawas and Sabangau transects were regressed against the predictor variable peat dome slope. Table 2 shows the main statistical results of the relationship between both variables using the validation dataset of both transects. The selected regression equations were obtained from the training dataset. The coefficient of determination (or explanatory power r^2) values of the maximum tree height were in order 0.51 and 0.65 for Mawas and Sabangau transects, respectively. These indicate that 51 and 65% of the variances in tree height were explained by the peat dome slope. The nature of this relationship may be noticed in Figure 12 for the entire dataset.

The tree height of each stand estimated from the peat dome slope (individual grid cell predictor) was compared to the ground-truth (Figure 13). Although the sample plots used to estimate the regression equation that related tree heights to the peat dome slope predictor variable were distributed independently throughout less disturbed peatland area, the mean difference between observed and predicted values for both transects were lower than 3m (Table 2 and Figure 14).

Table 2. Ordinary least square regression and RMSE calculated from the testing pixels.

Mawas transect							
Tree height	**Test statistics**						
	r^2	RMSE	RMSE r	Bias	Bias r	t	p-value
Maximum	0.51	1.93	7.00	0.08	0.31	3.27	<0.001
Sabangau transect							
Tree height	**Test statistics**						
	r^2	RMSE	RMSE r	Bias	Bias r	t	p-value
Maximum	0.65	2.78	11.37	-0.10	-0.43	-2.46	<0.001

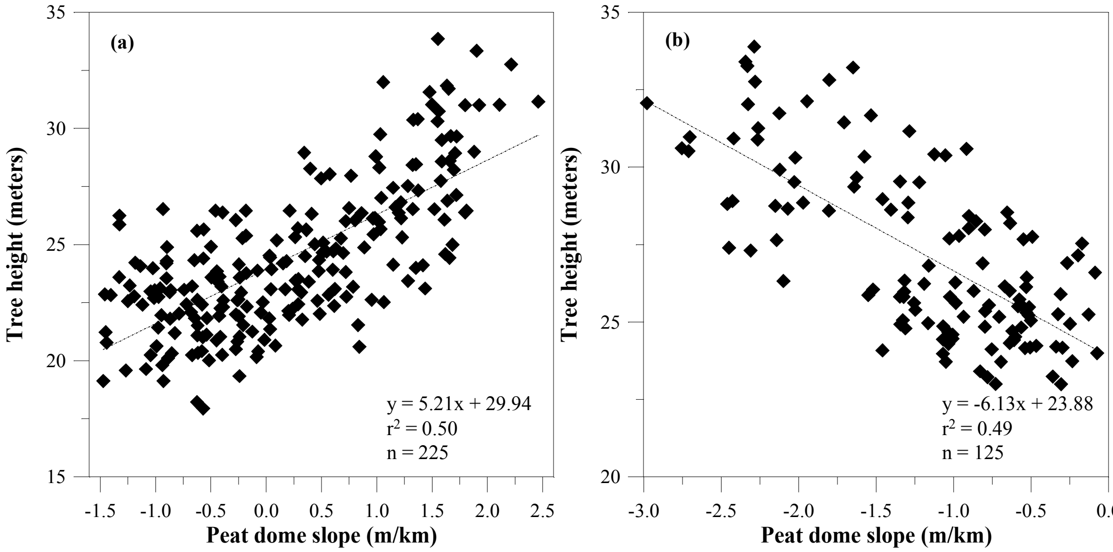

Figure 12. Relationship between maximum tree height against peat dome slope. The LiDAR attributes include complete dataset for (a) Mawas (Figure 2b) and (b) Sabangau (Figure 2c) transects. Negative and positive slopes values indicate in order descending and ascending relief.

The estimated biases confirm such results showing low values for both sites and the non-parametric test showed the linear regression estimates and the observed data were significantly different (Table 2). Although a strong correlation between tree height and peat dome slope exist it seems highly possible that in both transects the trees have different hydrological demands according to the dome position (e.g. beginning, middle or top) implying different growth forms due to variations in permeability, interflow, water storage capability and nutrient avaibility. Information on tree height variation due to peat dome slope changes may be useful for further forest inventory assessment since biophysical properties (e.g. above ground biomass) may vary significantly according to the peat dome position.

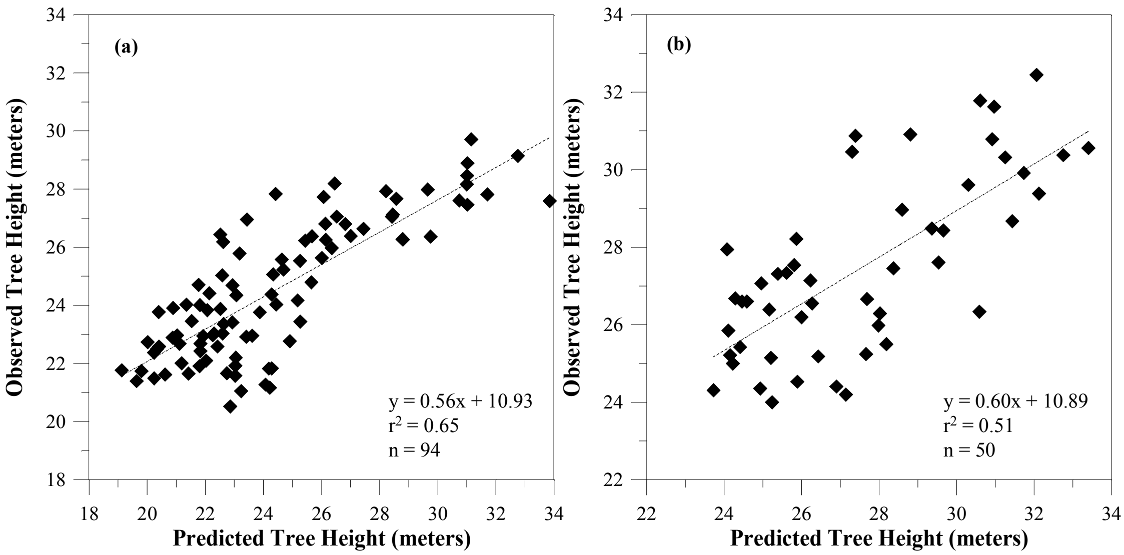

Figure 13. Relationship between observed and predicted tree height. The LiDAR and statistical attributes include validation dataset for (a) Mawas (Figure 2b) and (b) Sabangau (Figure 2c) transects.

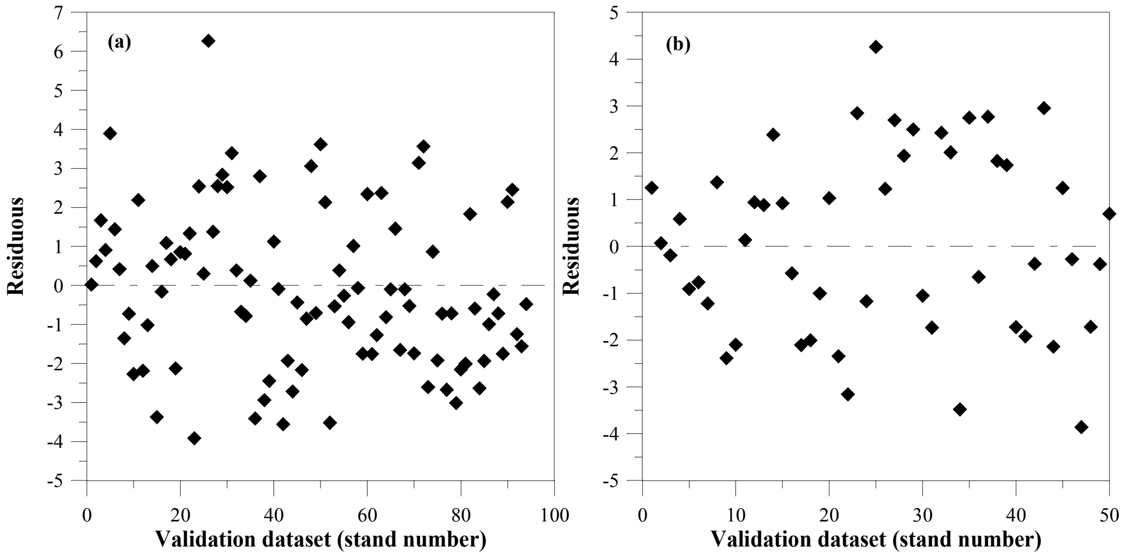

Figure 14. Residuous obtained from the difference of observed and predicted tree height. The statistical attributes include validation dataset for (a) Mawas (Figure 2b) and (b) Sabangau (Figure 2c) transects. Positive and Negative values indicate in order over- and underestimation of the tree height.

5. Final Remarks and implications for forest management

Regarding to the relationship between tree height and peat dome slope we observe a correlation in undisturbed forest areas, Fig.5. This relationship between both variables showed a coefficient of determination (or r^2) close or higher than 0.6. Such parameters reveals a strong correlation between both variables and may be related with the permeability, interflow, water storage capability and nutrient avaibility in the peat domes that needs to be investigated. In these transects, the intervention to the PSF was limitated and did not affect significantly the biophysical properties of the forest. In the linear regression analyses, the maximum tree height parameter showed to be a better predicted by peat dome slope than the average tree height. However, a lower correlation was found in transects where selective logging activities were common and take place in the past.

Information on tree height variation due to peat dome slope changes may be useful to assess the dependence of biophysical properties (e.g. above ground biomass) with peat dome slope in peatlands environments. Since peatlands act as a carbon sink, human interventions due to drainage practices for agriculture and selective logging of the peat swamp forest may have a stronger impact in the carbon release than relative flat areas.

Nonetheless, further research is still necessary in order to test the dependence of other biophysical parameters to peat dome slope and feature selection techniques for LiDAR data in different vegetation types in Indonesia as well as field work campaigns. In spite of the technique used for dependence assessment, interesting results will be probably achieved with the additional use of new LiDAR measurements over the area.

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