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2006 Fire depth and tree height analysis in Block C, Central Kalimantan, using small-footprint airborne LiDAR data

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Abstract: The aim of this study is to demonstrate how measures derived from small footprint airborne Light Detection And Ranging (LiDAR) data can be used: a) to analyze the peat fires in 2006; b) to estimate the Above-Ground Biomass (AGB); and c) to investigate the dependence of tree height and peat dome slope. Our test site is a typical Peat Swamp Forest (PSF) landscape located in Central Kalimantan, Indonesia near the province capital Palangka Raya. In August 2007 we mapped by helicopter different PSF locations with Riegl LiDAR Technology LMS-Q560 in both Block C of the Ex-Mega Rice Project (EMRP) and at the Sabangau National Park Cimtrop transect. Results showed that the AGB regression analysis of the 100mx100m samples measured parallel to the Taruna channel ranged from 85 to 390 Mg/ha which still has to be validated with measurements on the field. The PSF tree height of the Cimtrop transect increases by approximately 5m when the peat dome slope increases from 0.5m pro km to 1.5m pro km at the river level (e.g. Sabangau River) to the peat dome. The 2006 fires on the two areas in Block C showed a fire depth varying from 15cm to 30cm. An extrapolation of the fire damages was done using ancillary Landsat scenes of 2007 to the entire Block C and approx. 150 Mio ton of C were release to the atmosphere in 2006. This LiDAR-methodology can be used in the frame of the REDD knowledge of tropical forests (Reducing Emissions from Deforestation and forest Degradation).

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. tree height and canopy diameter which are strongly correlated with above-ground biomass and leaf area index (LAI) (Hajnsek et al., 2009). In peatland areas the great variety of ecosystems and its 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: a) the peat fires in 2006; b) the estimation of the above-ground biomass (AGB); and c) the dependence of tree height and peat dome slope.

2. Study Area description

Our study areas consist on three LiDAR transects located inside the Central Kalimantan province, Indonesia (Fig. 1). One Landsat image acquired on August 5, 2007 shows the remaining forest in the region in dark-green colour. In fact, PSF 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, especially during peat fires in 1994, 1997, 2002, 2006 and 2009.

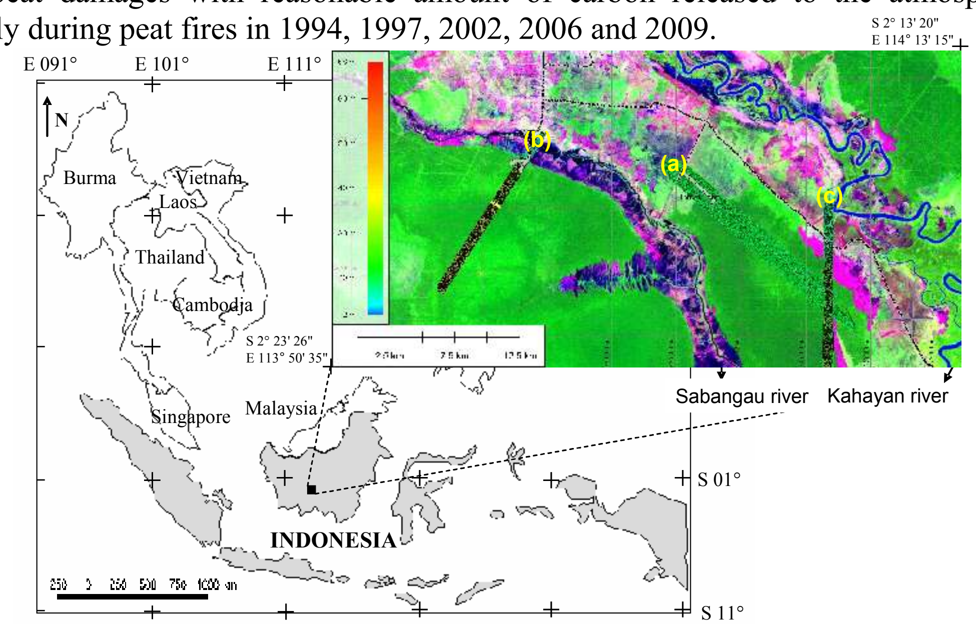

Figure 1: Study area location with detail to a Landsat subset acquired on August 5, 2007. In this subset two letters indicate the location of three LiDAR transects under investigation, a) Taruna channel in Block C, b) CIMTROP at Sabangau and c) Tumbang Nusa transect.

One transect is located inside the Block C of the EMRP, locally known as Taruna. The Taruna transect runs parallel to a channel and it is located in between Sabangau and Kahayan rivers (Fig. 2a) For the fire analysis we used the Tumbang Nusa transect. The second 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 (Fig. 2b). Finally, we the third transect is known as Tubang Nusa and it is located from the North to South parallel to the Sabangau river.

According to MODerate Imaging Spectroradiometer (MODIS) products, the Leaf Area Index (LAI) of the logged peat swamp forest at the region is in average close to 4, typical for tropical rain forested areas although close to 6 in undisturbed areas (Liesenberg et al., 2010). Areas of pasture, small agricultural fields, small villages and actual degraded forest resultant from selective logging can be also observed in the surroundings of the selected area.

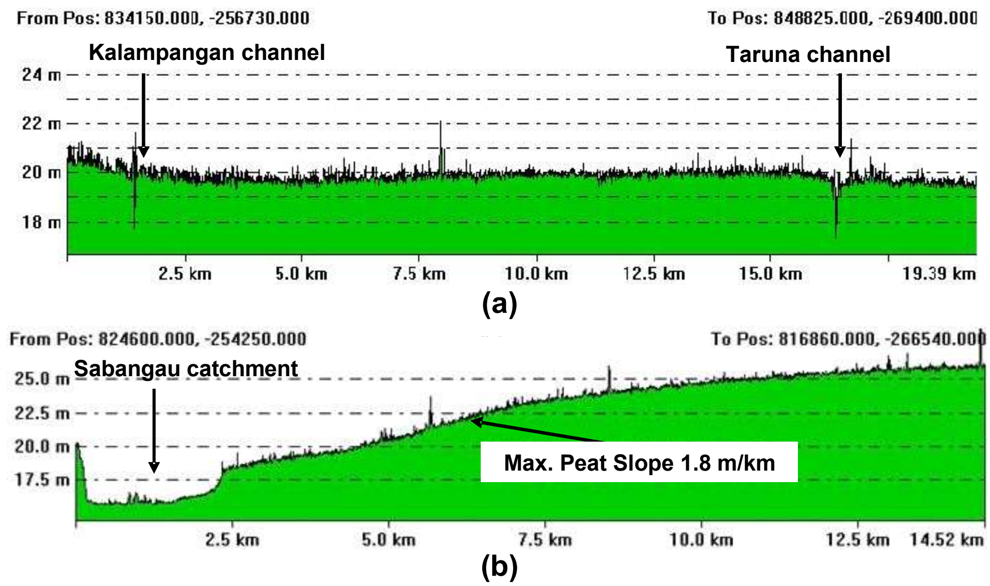

Figure 2. LiDAR-DTM profiles for (a) Taruna transect near to peat dome and (b) Sabangau area. We selected for the cross-section a profile parallel to the visible logging transects. Arrows indicate both location and maximum slope, respectively. Transects were acquired with different lengths and have different x- and y-scales.

The first transect shows a regular topography (average of 20m) and the two channels located at the extremes (Fig. 2a; Table 1). Fig. 2 also shows an asymmetrical peat dome on the right with a terrain peak close to 26m (Figure 2b; Table 1). The peat surface increases quickly with a maximum of 1.8m/km and an average of 0.7m/km from the catchment to the end of the LiDAR transect.

Table 1. Summary of the two 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
Taruna, Block C (a)	15.5m	20m	19.5km	0m/km	11.2m	27.2m
Sabangau (b)	15.5m	26m	12km	1.8m/km	14.0m	29.4m

3. Material and Methods

3.1 LiDAR Data processing

The airborne LiDAR transects were acquired on August 6th and 7th, 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 over ground 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

3.2.1 Peat fires analysis

The Peat fire analysis was conducted using a similar methodology proposed by Ballhorn et al. (2009). Initially a visual interpretation was performed on mosaics of ortho photographs collected simultaneously with the LiDAR data in order to delimit the burnt areas over the Taruna and Tumbang Nusa transects (Fig. 2a, 2c). Since the burned areas are easily identified over the LiDAR transect (Fig. 3), different measurements were considered and an average of the peat depth was then determined.

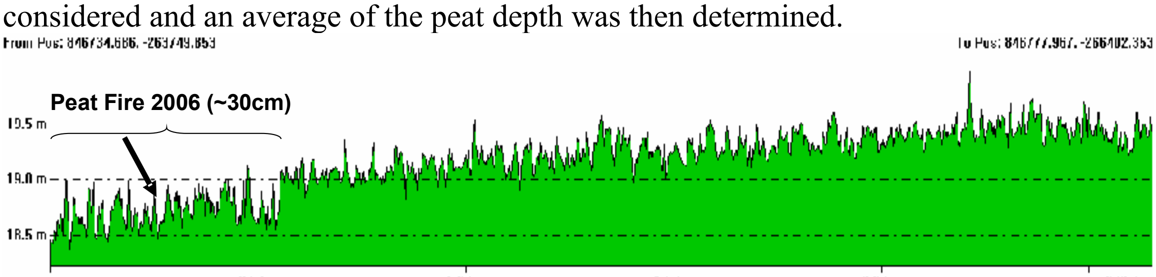

Figure 3. Subset of a LiDAR-DTM profile of the Tumbang Nusa transect. The arrow indicates the average burned depth of the peat swamp surface (~30cm) in comparison to undisturbed areas (not burned).

Due to the limited coverage of the LiDAR transects over the entire Block C, we used an ETM+/Landsat-7 image acquired on Aug. 5, 2007 to quantify the burned areas. We converted the digital numbers (DN) of the Landsat scene into radiance values using gain and off-sets values delivered with the image. After, radiance data were converted to surface reflectance using the Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) algorithm. Finally, a supervised classification procedure (Maximum Likelihood) was used in order to quantify the burned areas over the Block C.

3.2.2 Biomass determination

Observation data were compiled from sample plots of 100x100m collected in the flown acquisition of both transects. The spacing between each sample plot was 200m. We extract both DTM and DSM values for each measured plot and transect. Concerning to the DTM, we only account for the lowest values in order to minimize the inclusion of the return signal coming from tree trunks and branches lying on top of the peat surface.

Tree height was determined by subtracting the DSM and the DTM. The AGB was obtained using an allometric equation proposed by Lefsky et al. (1999) (Eq. 1). Both tree height and AGB values were plotted for the Taruna transect.

$$AGB = 1.512 \times h(average)^2 \quad \text{Lefsky et al., 1999} \quad \text{Eq. 1}$$

3.2.3 Tree height vs. Peat dome slope analysis

We calculated the peat dome slope by counting the difference between the DTM values of two sample plots (100mx100m) and converting the altitude difference in a space of 200m (m per km). We proceed with the extraction of tree height for the DSM in each sub-plot (50mx50m) where we just account for the signal coming from the dominant trees. The sub-plots were used in order to take a sample of each quadrant. The data from each transect was divided into training (70%) and validation (30%) datasets for statistical purposes (Boehm et al. 2010).

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. 2), Bias (Eq. 3) and their relative counterparts $RMSE_r$ (Eq. 4) and $Bias_r$ (Eq. 5) as described and explained in Muukkone and Heiskanen (2005).

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

$$Bias = \frac{1}{n}\sum_{i=1}^{n}(y_i - j_i) \quad \text{Eq. 3}$$

$$RMSE_r = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - j_i)^2}}{y_m} \times 100 \quad \text{Eq. 4}$$

$$Bias_r = \left[\frac{1}{n}\sum_{i=1}^{n}(y_i - j_i)\right] y_m \times 100 \quad \text{Eq. 5}$$

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.

4. Results and Discussion

4.1 Peat Fire Analysis

Burnt areas were easily identified in the Landsat images as showed in a Landsat subset in Fig. 4a. The spectral response of burnt areas, red colour, was generally lower than the peat swamp forest, mainly at the red and near-infrared (NIR) regions. Although few small areas were edited visually due to a misclassification into previous burned areas than 2006, a satisfactory result was achieved. A complementary image prior to the burnt event was not available due to the high cloud coverage of the region for additional analysis.

Landsat-measurements showed a total burnt area of 28667 ha that correspond up to 7% of the entire Block C. According to the methodology proposed by Ballhorn et al. (2009) we accounted the volume of organic material in peat taking into account its conversion to C and an averaged fire depth of 30cm (Fig. 3b). Based on this methodology we found then a total of 150 Mio ton of C released by the fires to the atmosphere in 2006.

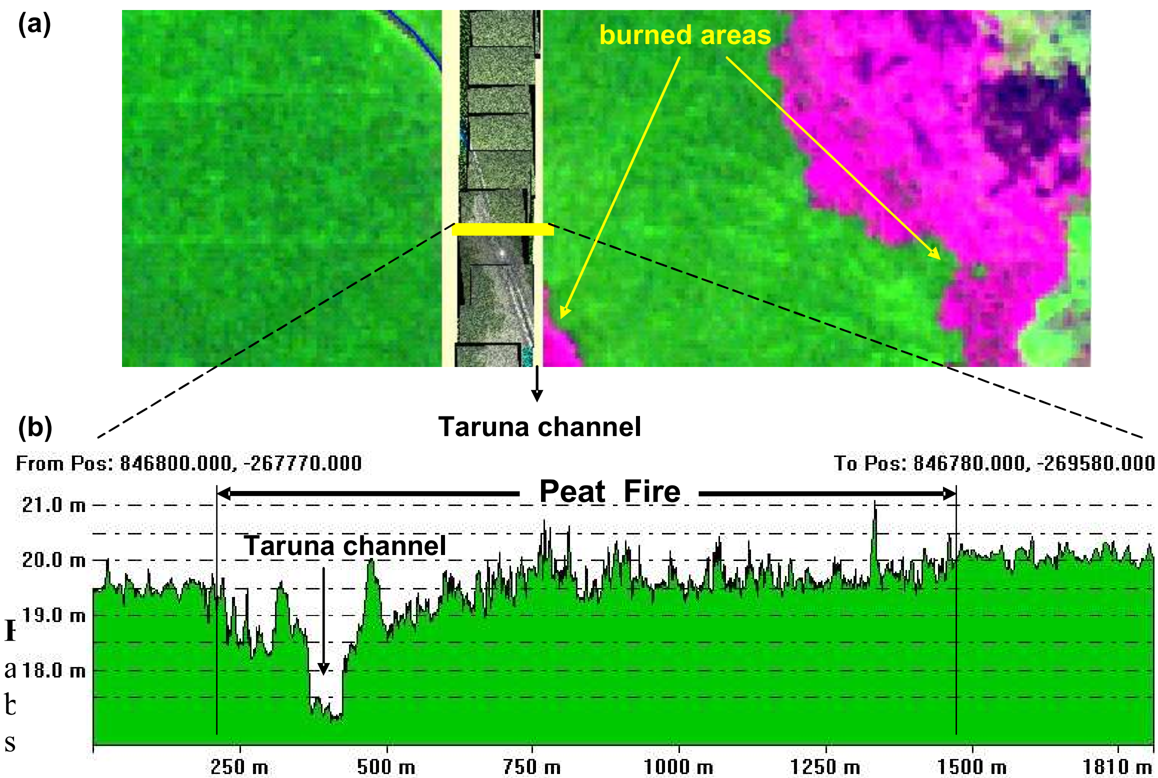

Figure 4. Subset of a ETM+/Landsat-7 scene acquired on 5.8.2007 with Ortho-Photos (a) and a subset of the Tumbang Nusa LiDAR-DTM profile (b). The arrows indicate the burned areas and the Taruna channel as well as the average burned depth of the peat swamp surface (~30cm) in comparison to undisturbed areas (not burned).

4.2 Above Ground Biomass determination

A total of 75 sample plots were obtained at the Taruna transect. We noticed that the average tree height varies from 7.5 to 16m (Fig. 5a), whereas the AGB from 85 to 390 Mg/ha (Fig. 5b) applying the Eq. 1 proposed by Lefsky et al. (1999). Although a proper field campaign is still necessary to validate the results, an indicative of the LiDAR potential is at least here demonstrated. We intend in near future investigate the potential of the full wave acquisition for the AGB determination instead of using only the first and last LiDAR pulse. A proper LiDAR campaign at ground level with ground LiDAR systems will certainly show promising results, since the accuracy of the AGB is strongly dependent on allometric equations that are normally not available in tropical regions (Chave et al., 2005, Hyde et al., 2007).

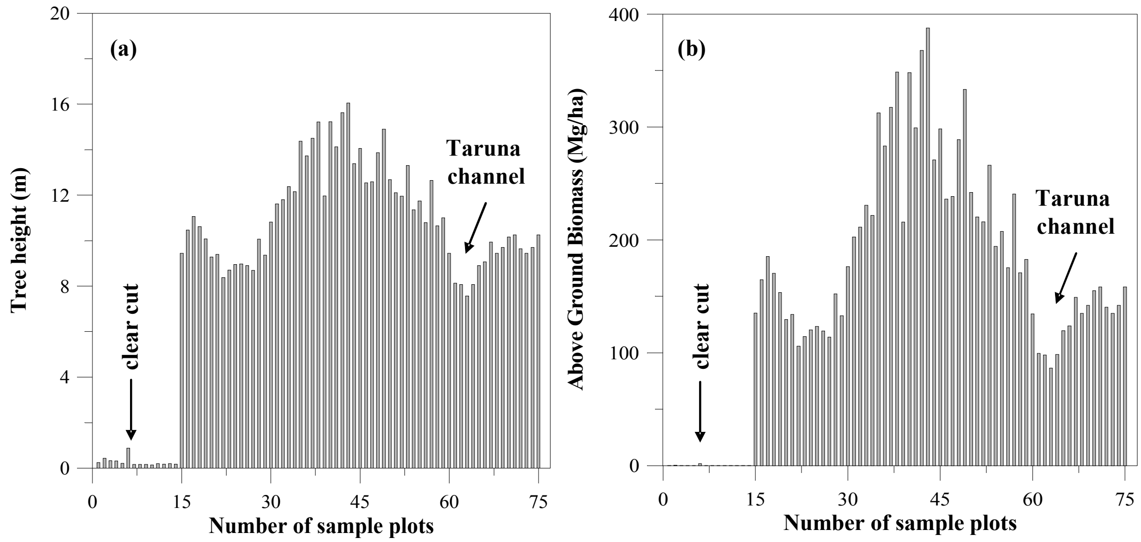

Figure 5. Average tree height from 75 sample plots, each 1ha parallel to Taruna channel (a) and AGB for the same dataset based on Lefsky et al., 1999 allometric equation.

4.3 Tree height vs. Peat dome slope analysis

The maximum tree height was regressed against the predictor variable peat dome slope for the Sabangau transect (Fig. 2b) which was selective logged in the 90th. The selected regression equation was obtained from the training dataset (Fig. 6a). Table 2 shows the main statistical results of the relationship between both variables using the validation dataset. The coefficient of determination (or explanatory power r^2) values of the maximum tree height was 0.51. These indicate that more than 50% of the variances in tree height are explained by the peat dome slope.

The tree height of each stand estimated from the peat dome slope (individual grid cell predictor) was compared to the ground-truth (Fig. 6b). 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 (results not shown).

The estimated biases confirm such results showing low values and a 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 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 availability. 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.

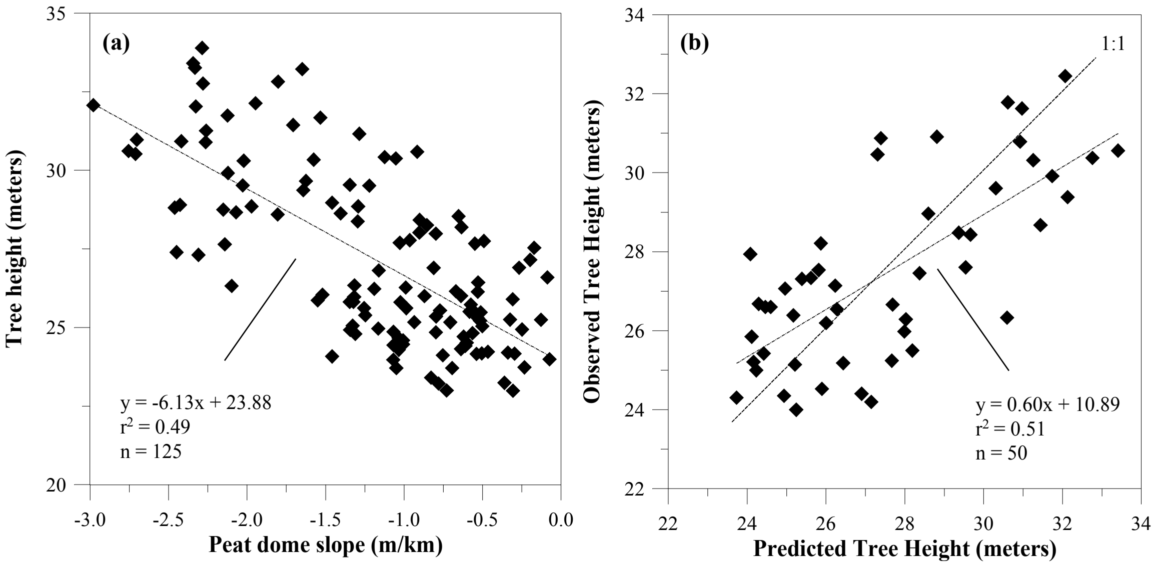

Figure 6. Relationship between: a) Tree height vs. Peat dome slope and b) observed and predicted tree height. The LiDAR statistical attributes include in order training and validation datasets.

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

5. Final Remarks for forest management

Results showed that LiDAR is an interesting instrument to analyze peat fire depth, biomass estimation and relationship between tree height and peat dome slope. Information on such variables may be useful to assess the dependence of biophysical properties (e.g. tree height, stem diameter and above ground biomass) 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 that still has to be more investigated with LiDAR technology.

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 to confirm the results. 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. These multi-temporal surveys can determine the growth or loss of vegetation and the peat surface. LiDAR-methodology showed promising results in the frame of the REDD knowledge of tropical forests (Reducing Emissions from Deforestation and forest Degradation).

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