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Research Article

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Characterizing Peat Swamp Forest Environments with Airborne LiDAR Data in Central Kalimantan (Indonesia)

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1. Introduction

Natural tropical Peat Swamp Forests (PSF) are important for their rich biodiversity and because they represent important carbon pool [1]. However, PSF are decreasing due to conversion into farm land, by excessive draining, the use of shifting cultivation on a large scale, pal oil plantation, illegal logging and forest fire. 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 [1-5].

According to Hyde et al. airborne Light Detection And Ranging (LiDAR) data is nowadays the best remotely 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) [6,7]. In peatland areas the great variety of ecosystems and its ecological rule is still not fully understood. The influence of selective logged areas (e.g. species composition, their structures and canopy properties) on global change issues also remains therefore a big challenge. Consequently, to optimize the biophysical properties characterization, a better understanding of how LiDAR measurements could be useful for ecological studies in such critically endangered forests is still necessary.

In August 2007 we mapped by helicopter different PSF transactions with Riegl LiDAR Technology LMS-Q560 in Central Kalimantan, Indonesia. In this study, our main objectives were:
a) to evaluate the peat surface/profile and their associated domes; b) to estimate the dependence of tree canopy height with both peat dome thickness and peat dome slope variations; c) to estimate Above Ground Biomass (AGB) variations based on tree canopy height and physiognomy variations according to optical remotely sensed spectral signatures and field inspection; and d) to demonstrate the applicability of LiDAR technology to detect logging activities in tropical peat swamp forest environments. Additionally, we would like to demonstrate first results of our second LIDAR survey made in August 2011. We found that in an undisturbed tropical PSF area the average tree-height increased from 15.32m to 17.18m by difference of 1.86m which is 12%.

2. Study Area Description

Our study areas consist on one LiDAR transects located inside the Central Kalimantan province, Indonesia (Figure 1). One Landsat image acquired on July 16, 2000 shows the remaining forest in the region in different green colour for 2000. In fact, PSF over the region were impacted with extensive logging activities in the 90th using railways in the swaps for logging roads by the big concessions. The logging 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.

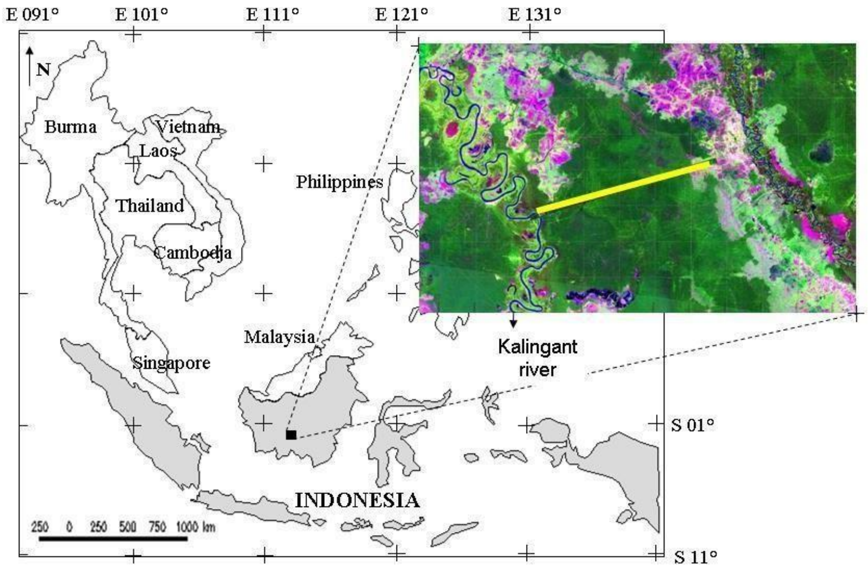


Figure 1: Study area location. (a) Indonesia and (b) subset of Landsat image for Central Kalimantan and the yellow line indicates the LiDAR transect

The selected LiDAR transect is located between Katingan river and the transmigration village Habaring Hurung (Figure 2). This PSF was selective logged by the concession in the 90th. 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 [8]. Areas of pasture, small agricultural fields, small villages at the rivers and actual degraded forest resultant from selective logging can be also observed in the surroundings of the selected area

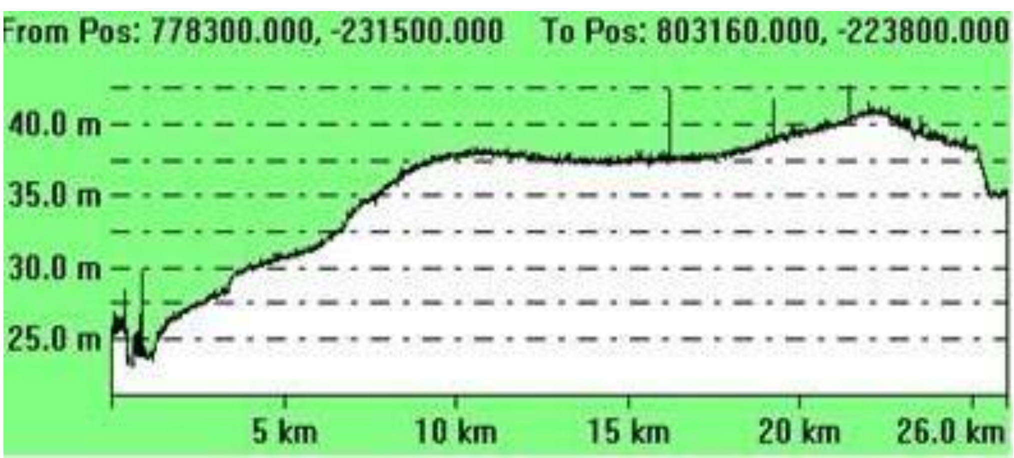


Figure 2: Peat Surface profile of the selected LiDAR transect

Peat surface profile of the analyzed transect starting left from the river Katingan (23m) reaching to the transmigration village Habaring Hurung, right (Figure 2). A double peat dome is found at 38m and 41m. Between the kilometres 10 and 23 a high plateau is also visible. More south to this a small river can be monitored on the peat area, which is draining the high water content. The transect shows an asymmetrical peat dome on the right with a terrain peak close to 41m; Table 1). The peat surface increases quickly with a maximum of 1.8m/km and an average of 1.0m/km from the Katingan to the first peat dome with 38m.

Transect	River Level	Peat Domes	Transect Length	Max. Slope	Av. Tree Height	Max. Tree Height
Katingan – Rungan	23m	38m to 41m	26km	1.8m/km	15.8m	34.5m

Table 1: Summary of the LiDAR transect under study

2.1. Material and Methods

2.1.1. LiDAR Data Processing

The airborne LiDAR transects were acquired on August 8th, 2007 in a helicopter campaign conducted by Kalteng Consultants and Milan Geoservice GmbH. We collected for the above described tracks approx. 1300ha 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 [9,10]. 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.

Complementary we explore a second LiDAR dataset acquired on August 5th, 2011 using the same sensor system as 2007 in order to demonstrate change detection over the time. 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.

2.1.2. Data Analysis

2.1.2.1. Peat Drilling, Peat Surface and Landsat signatures

A total of 31 peat drilling measurements were conducted in order to determine the peat depth of our selected transect. The spatial distribution of the samples keeping an average distance of 600m as well as the peat depth results is shown in Figure 3.

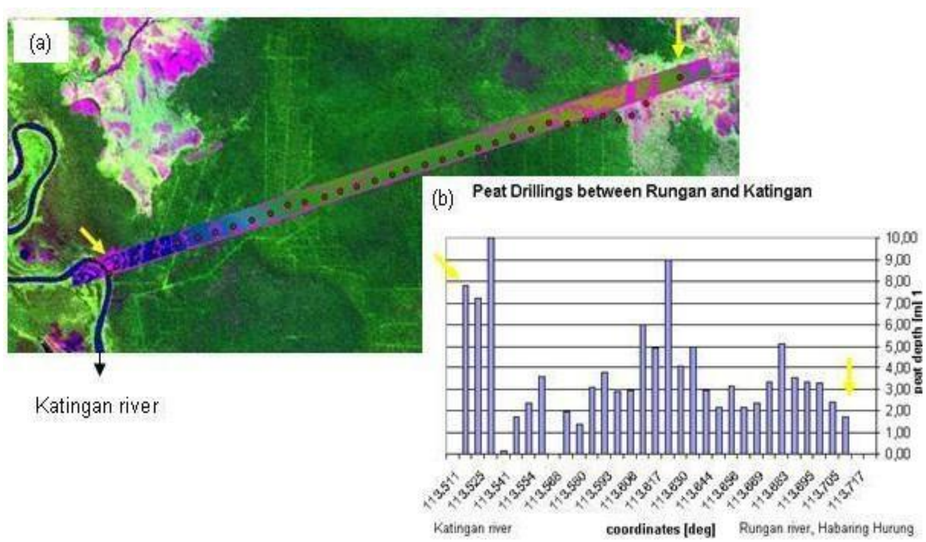
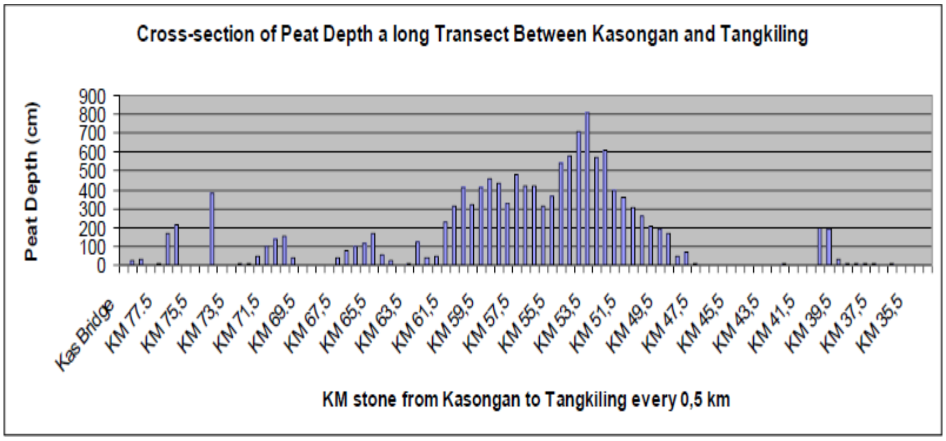


Figure 3: (a) Spatial distribution of the Peat Drilling Samples over the LiDAR transect. Arrows indicate the first and last sample of the peat depth. (b) Results of the Peat drilling measurements showing the Peat depth results up to 10m.

According to this figure, we observe a high variability with the highest values occurring close to the Katingan River and a double dome is also visible compared to peat surface showed in Figure 2. We related the peat drilling measurements with the tree canopy height establishing 1-ha plot over each measurement and the peat dome slope as described better in the next section. A detailed explanation about the procedures in the field may be found in Page et al. [11].

Complementary, we also conducted peat drilling analysis in a second transect whose spatial distribution as well as peat depth is shown in Figure 4. In this figure, 91 peat drillings along the Kalimantan highway from Kasongan to Tangkiling were measured and related with chemical properties [12].



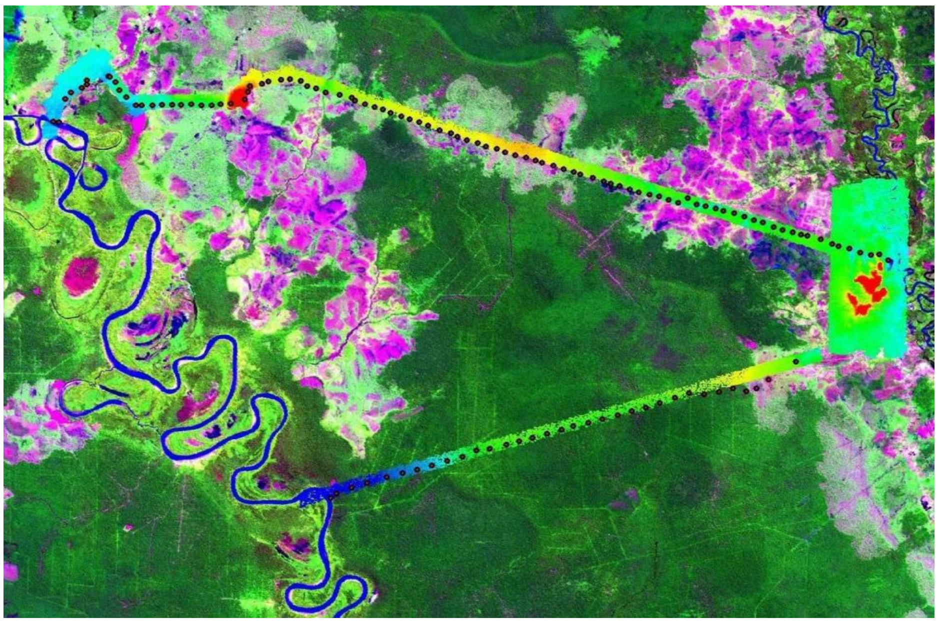


Figure 4: a) Results of the Peat drilling measurements showing the Peat depth results up to 8.1m parallel to the highway Kasongan to Tangkiling with 500m distance. (b) Spatial distribution of the Peat Drilling Samples over the LiDAR transects Kasongan to Tangkiling and Katingan and Habaring Hurung.

Digital Numbers (DN) from Landsat images covering different dates including pre- and after LiDAR acquisition were converted to radiance data and then converted to surface reflectance (hemispherical directional reflectance factor, HDRF) using the Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) algorithm. Input data for the radiative transfer code were collected by instruments in a tower maintained by the Asia Flux Network inside the study area as well as MODIS products. We selected different regions based on our LiDAR transect in order to characterize different spectral patterns.

2.1.2.2. Tree Canopy Height vs. Peat Dome Slope Analysis

We calculated the peat dome slope by counting the difference between the DTM values of two sample plots with 1-ha each and converting the altitude difference (e.g. m per km) in an equidistance of 250m. We proceed with the extraction of tree height for the DSM in four sub-plots (e.g. 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 [5].

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), Bias and their relative counterparts RMSEr and Biasr as described and explained in Muukkone and Heiskanen [13]. As the peat drilling procedure is very difficult to be determined in the field, we proceed with the analysis twice. The first approach was keeping a distance of the 600m as described in the section 2.1.2.1 and the second one the distance of 250m.

2.1.2.3. Biomass Determination

Above Ground Biomass (AGB) were compiled from sample plots of 1-ha collected in the flown acquisition of the transect keeping a distance of 250m between sample plots. We extract both DTM and DSM values for each measured sample plot. 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 Canopy height was determined by subtracting the DSM and the DTM. The AGB was obtained using an allometric equation proposed by Lefsky et al. (Eq. 1) and Uhl et al. (Eq. 2) [14,15]. Diameter at the Breast Height (DBH) was retrieved using the relationship with tree height (r2=0.754) considering field measurements. Finally, tree height and AGB values were plotted for the selected LiDAR transect and also related with the peat dome attributes.

$AGB = 1.512 \times h(average)^2$ [14] (1)

$AGB = exp(-2.17 + ln\ 1.02(DBH\ )2 + ln\ 0.39H\ )$ [15] (2)

2.1.2.4. Characterization of Logging Activities using LiDAR

Since logging activities are a common practice in tropical rain forest environments, we evaluated the complementary use of both DTM, DSM and Aerial ortho-photographs acquired during the LiDAR survey to detect such practices. We compared it with Landsat images and the procedure was based on both visual interpretation and texture analysis (e.g. GLCM). Since no complementary information was provided by local agencies, such as concession information for forest exploitation, we did not classify whether such practices were legal or illegal.

3. Results and Discussion

3.1. Relationship between Peat Dome Depth and Tree Canopy Height

Linear regressions were carried out to establish the correlation between Peat Depth and both Tree Canopy height and Peat Dome Slope and are shown in Figure 5. A weak relation between the variables was found and explained up to 31% of the variation of the forest attributes (e.g. tree canopy height) and up to 16% the peat depth surface in the selected transect. As observed by Boehm et al. the results may reflect the high degree of forest intervention by previous logging activities in the region [5]. In this transect, both predictors height (e.g. tree canopy height averaged and dominant) were similar.

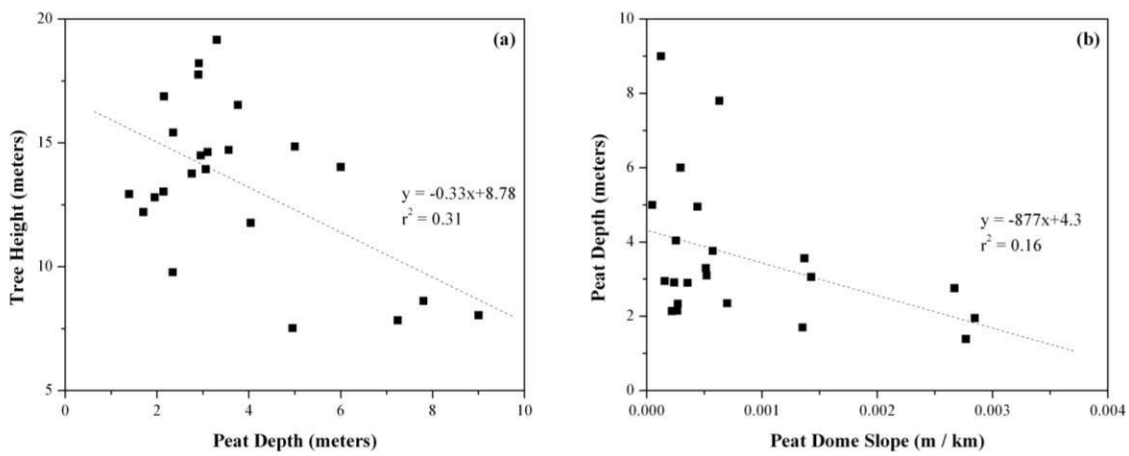


Figure 5: Relationships between (a) Peat Dome Depth and Tree Canopy Height; (b) Peat Dome Depth and Peat Dome Slope.

The relation between Tree Canopy height and Peat dome slope was not affected by the changing the distance between the peat drilling plots (e.g. 600m) and the sample plots (e.g. 250m). Figure 6 shows the relationship between Peat dome slope and both Tree canopy height and AGB. The relationship explains in both situations up to 30% of the variation. At least two non-mutually exclusive hypotheses for positive increase in tree canopy height with peat dome slope can be raised here: (1) soil properties and drainage; and (2) previous disturbance regimes that will be investigated in near future with additional LiDAR data from 2011 as well as field inventory data.

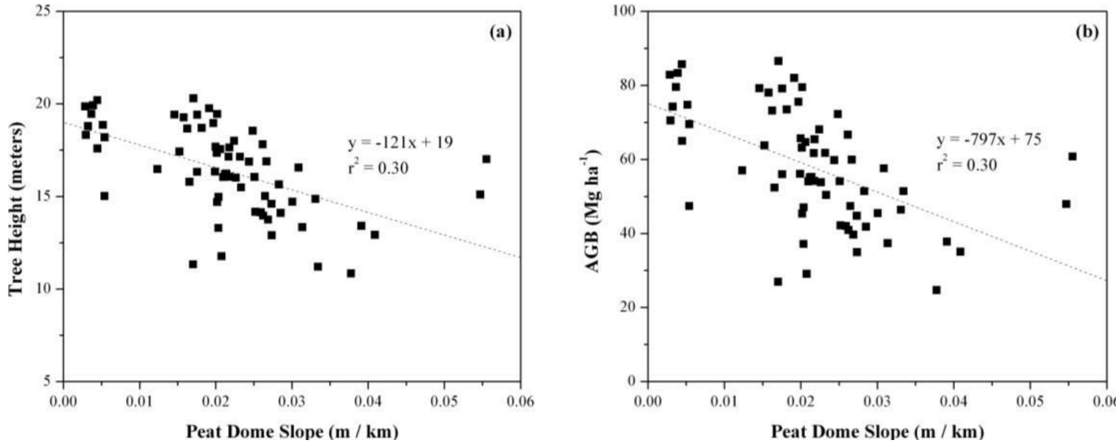


Figure 6: Relationships between (a) Peat Dome Slope and Tree Canopy Height; (b) Peat Dome Slope and Above Ground Biomass

Landsat signatures showed significant differences in their spectral profiles given samples from different parts of the peat dome (not shown). The highest differences were observed in the near infrared reflectance which increased from the beginning, middle to the top of the peat dome. This may be an indicative for the occurrence of different physiognomies and canopy architecture changes in the vegetation.

Peat dome slope as a result of the surface topography and peat thickness variations, explains only up to the 30% of the tree canopy height and AGB. Since it does not such forest attributes directly, it may also operate through changes that they may bring about or promote in other characteristics of the peatland, especially related to hydrology, chemistry and organic matter dynamics (balance between peat accumulation and peat degradation) [16,17]. An evaluation taken into account several LiDAR transects sampling different peat characteristics and forest under different disturbance levels should be evaluated for a better assessment of such ecological issues.

3.2. Estimation of Forest Attributes

Several 1-ha sample plots were obtained at the LiDAR transect. We noticed that the average tree height varies from 11 to 20m, whereas the dominant tree canopy height up to 30m (Figure 7a). The lowest tree canopy heights were found close to Katingan river. AGB varies in average from 15 to 200 Mg/ha (Figure 7b). 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 neither common nor available in tropical regions [6].

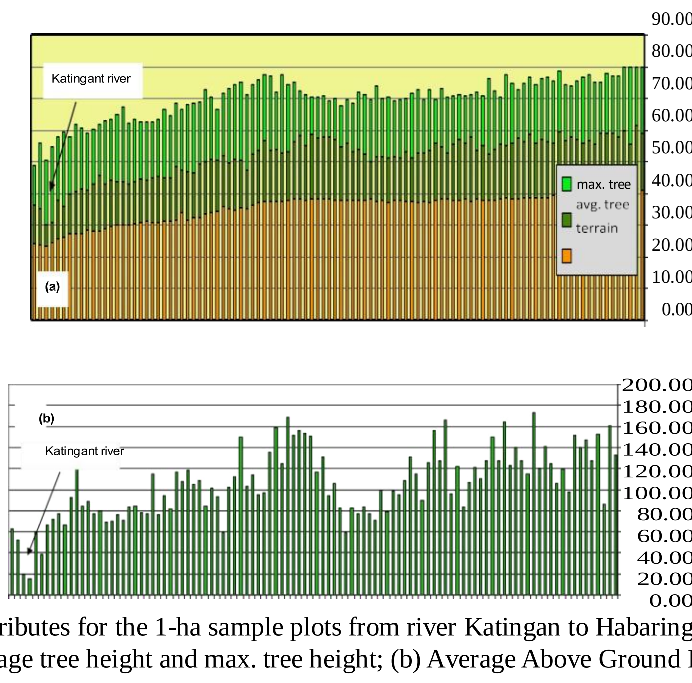


Figure 7: Forest attributes for the 1-ha sample plots from river Katingan to Habaring Hurung considering. (a) DTM, average tree height and max. tree height; (b) Average Above Ground Biomass (AGB).

The spatial distribution of the forest attributes extracted from the selected LiDAR transect, such as the Tree Canopy height and AGB are shown in Figure 8. AGB are shown in Figure 9 and 10 employing the two different allometric equations, respectively. The figures show high variability results due to previous selective timber exploitation.

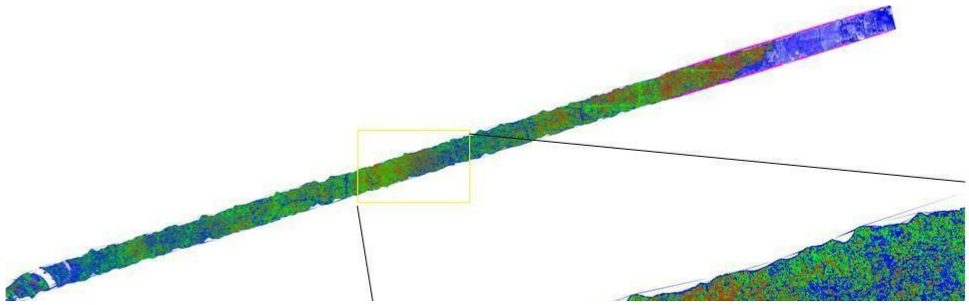


Figure 8: Tree Canopy height variations over the selected LiDAR transect.

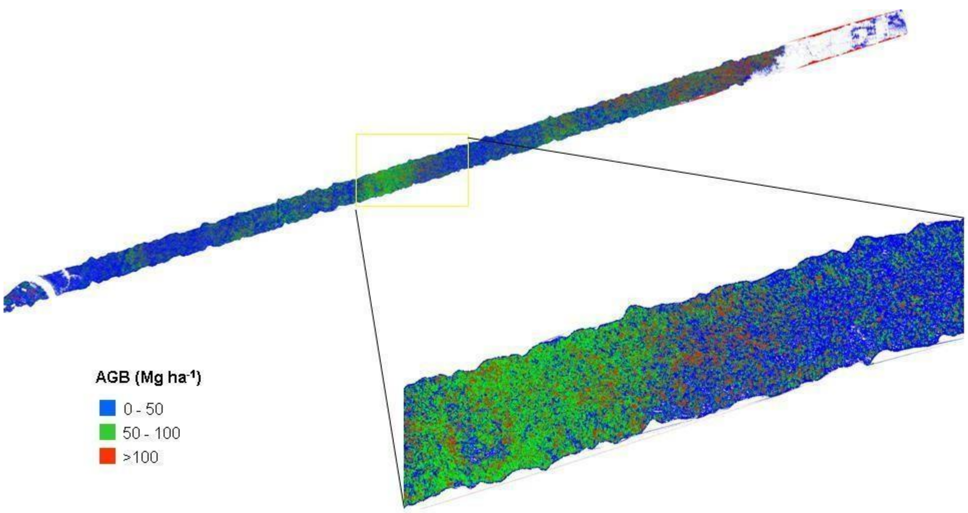


Figure 9: Above Ground Biomass (AGB) variations over the selected LiDAR transect (with Eq. 1).

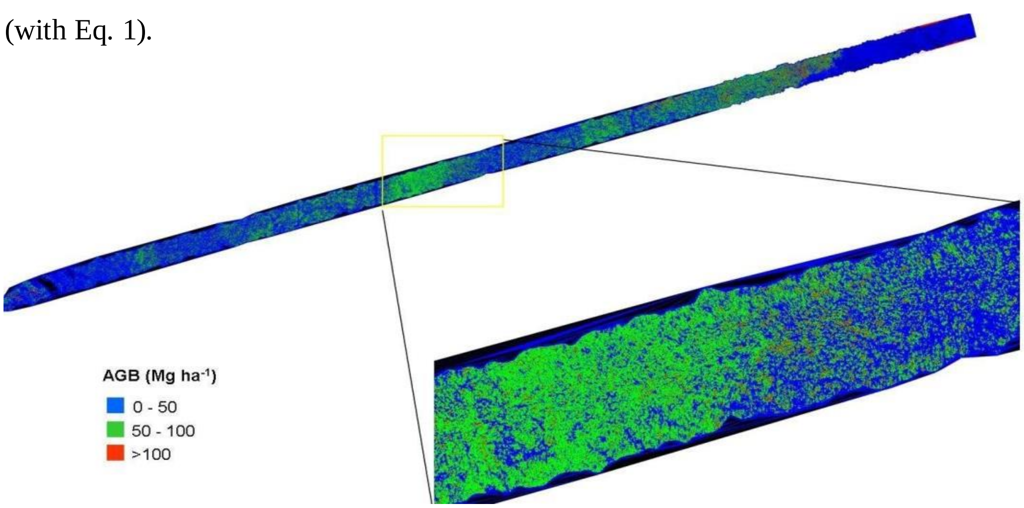


Figure 10: Above Ground Biomass (AGB) variations over the selected LiDAR transect (with Eq. 2).

3.3. Characterization of Logging Effects

Small logging effects on the forest were evident on LiDAR DTM than LiDAR DSM. An assessment of aerial ortho-photographs was also very useful to identify small patches used for wood storage and camping. On the other way, Landsat images were not sufficient to capture such small details besides large and structured channels. The use of texture parameters (e.g. GLCM) and other spectral techniques were also experimented on Landsat images. Figure 11 shows a subset of the LiDAR transect. In this figure, we observe that LiDAR DTM (Figure 11a) capture better the logging tracks than LiDAR DSM (Figure 11b). Such information on regular basis may help local environmental agencies for the monitoring of the endangered forest as well as for REED/MRV practices.

Figure 11: Subset of (a) LiDAR Digital Terrain Model (DTM); (b) LiDAR Digital Surface Model (DSM); and (c) Subset of Aerial Ortho-photograph indicated by yellow square. A yellow line indicates logging channel.

4. Final Remarks

Results showed that LiDAR is an interesting instrument to analyze peat profiles, biomass estimation and relationship between peat dome slope, peat dome depth and tree canopy height. 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 distinct peatlands environments. Since peatlands act as a carbon sink, human interventions due to drainage practices for agriculture and selective logging practices 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 which we did in a new survey conducted last August 2011.

Nonetheless, further research is being conducted 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 Central Kalimantan, Indonesia. In this regard, we will perform a proper analysis with field inventory data conducted from middle July to August 2011. This will allow us to evaluate multi-temporal analysis and to determine the growth or loss of vegetation as well as the peat surface changes.

In our ongoing analysis, we found out that the tree height changes for a selected transect at Sabangau Forest in Central Kalimantan after a period four years was in average up to 2m. This represents a change of 12% (e.g. from 15.32m to 17.18m, difference of 1.86m). The analysis was performed measuring 20 sample plots of 1ha over a 12km transect for 2007 and 2011. This clearly shows the forest recovery capacity in secondary tropical peat swamp forest under protected conditions (e.g. conservation status). The presented LiDAR-methodology can be promising in the frame of the REDD (Reducing Emissions from Deforestation and forest Degradation) knowledge of tropical peat swamp forests [18].

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