BIOMASS SITUATION OF MAWAS REGION IN CENTRAL KALIMANTAN BETWEEN 2007 AND 2015 USING LIDAR- AND TERRASAR-X DATA

Viktor Boehm 1.), Michael Schlund 2.), Veraldo Liesenberg 3.) and Steffen Kuntz 2.)

1.) Kalteng Consultants, Munich, Germany, 2.) Airbus Defence & Space, Friedrichshafen, Germany, 3.) Santa Catarina State University, Brazil

Abstract

Southeast Asian tropical peat swamp forests (PSF) are important for their large carbon stock storage and rich biodiversity. Therefore, the key importance of PSF to ecological processes, their resilience for forest degradation and logging highlights the need for a comprehensive forest monitoring in which LiDAR- and SAR technology may play an important task. Small-footprint LiDAR transects were acquired in August 2007 and 2011 using the Riegl system. The research transects are located at the Mawas Reserve in Central Kalimantan, Indonesia. The transects encompass an ecological peat dome gradient ranging from the river system to the peat dome. The transects faced in the past different forest degradation intensities. Our main objectives were to map changes in the vertical structure of the PSF with the multi-temporal LiDAR, in order to identify both sources and sinks of carbon across the peat dome-shaped gradients.

In addition, TerraSAR-X time series were analyzed, whereas TerraSAR-X is a X-band SAR providing consistent and high repetitive coverage due to time and weather independent acquisitions. Subtle changes in the forest canopy are detected with TerraSAR-X due to the high-resolution and radiometric stability. The analysis of TerraSAR-X data between December 2010 and October 2015 show forest logging activities mainly close to the forest edges and channels, where the loggers can transport the logs easily. Analysis of changes between January 2015 and October 2015 resulted in high forest disturbances exceeding the forest disturbance from the four previous years due to possibly increased illegal logging, but also to forest fires in 2015. Further research is needed in order to quantify forest degradation in larger regions in the Central Kalimantan.

Introduction

Tropical lowland ombrogenous peat lands in Southeast Asia are known for their rich biodiversity and huge amounts of stored carbon. In recent years, large natural areas of this endangered ecosystem has been converted into oil palm and rubber plantations. Hence, forest remnants are currently threatened by extensive drainage, logging, hunting and strong peat fire as in 2015. Remote sensing data can provide useful information in such environments for hydrological and wildfire modeling, retrieval of biophysical parameters and the management of natural resource. Multi-temporal airborne Light Detection and Ranging (LiDAR) data acquired in August 2007, and August 2011 were used to characterize the peat swamp forest in Central Kalimantan, Indonesia.

In this study our main objectives were: a) to characterize ground-measured and LiDAR-derived biophysical properties of PSF and b) information from TerraSAR-X data to present an approach to carbon change assessment.

Materials and Methods

Study area description

The study area encompasses two LiDAR transects in Mawas test sites located in Central Kalimantan, Indonesia (Fig. 1). The Mawas area is located at the northeast part of block E of the Ex-Mega Rice Project (EMRP) (Figs. 1a, 1b) between river Kapuas and towards river Barito. Mawas km238 (south of equator) transects were partially damaged by peat fires during the El Niño Southern Oscillation weather effect in 1997 (Page et al., 2002, Usup et al., 2004, Hajnsek et al. 2009).

The test sites are relatively flat. Estimates conducted by Jaenicke et al. (2008) using GIS techniques showed that the peat thickness varies from 0 to 18m at Mawas sites.

The monsoon occurs between November and April and the average annual rainfall and air temperature are 2500mm and 25°C respectively (Usup et al., 2004). The selected LiDAR transects consist of altered primary forest patches, in which trees have been already selectively logged until the end of the 1990s. However, drainage channels (main and secondary) from the Ex-Mega Rice Project at Mawas are still being used for illegal logging activities up to date.
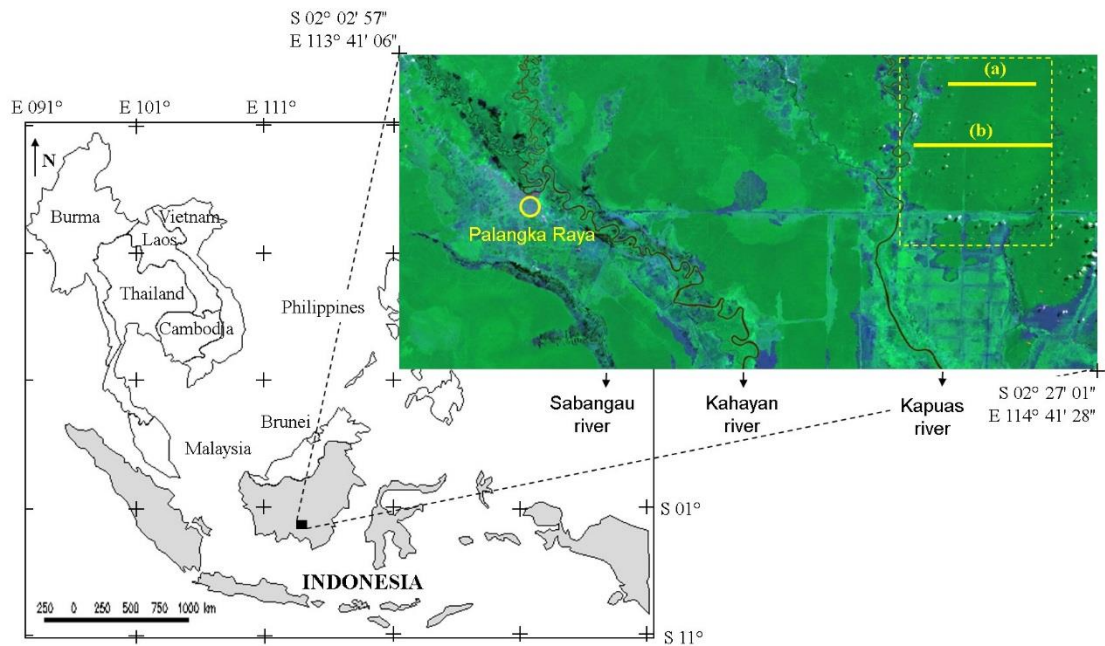
Fig. 1 Location of the study area in Central Kalimantan, Indonesia. The yellow circle shows the location of the Palangaka Raya city. The solid yellow lines indicate the LiDAR transects a) and b).

LiDAR acquisition and preprocessing

The LiDAR transects were surveyed twice by Kalteng Consultants and Milan Geoservice GmbH from August 5 to 7, 2007, and August 4 to 5, 2011, using a Laser Scanner System Riegl LMS-Q560. It was attached to a Bell 206 helicopter for the first flight and a BK117 helicopter on the second flight. The nominal height was in average 530m for both surveys. A differential global positioning system (DGPS) reference station was mounted at the airport of Palangka Raya city considering an elevation of 25.0m or 82 feet. The position and orientation of the LiDAR system on the helicopter was measured by an Inertial Navigation System (INS) and a differential GPS located on the tail boom respectively on the cockpit roof with 256Hz. A complete description of the LiDAR survey can be found in Boehm et al. (2008, 2013).

TerraSAR-X acquisitions and preprocessing

The LiDAR transects were continuously monitored by the space borne SAR (synthetic aperture radar) satellite TerraSAR-X (partially as an acquisition of the close formation of TanDEM-X/TerraSAR-X). The acquisition dates used in this study are December 21, 2010, April 21, 2011, January 18, 2013, October 07, 2014, November 20, 2014, January 03, 2015 and October 16, 2015. The data were acquired in StripMap mode with a resolution of 3m in HH polarization. All images were co-registered and the intensity ratio of image pairs was calculated. Changes were detected on basis of the known distribution function of intensity ratio (Weihing et al. 2010, Poncet et al. 2014). Changes detected by TerraSAR-X in forest areas are mainly related to forest canopy disturbance due to the high resolution and low penetration depth of the SAR sensor. Therefore, any disappeared tree crown in the forest canopy can be reliably detected identifying even small scale logging or other disturbances. In order to assess the degree of forest disturbance, forest extent at the initial monitoring date December 21, 2010 was assessed with the SAR data using the amplitude and interferometric coherence of TanDEM-X with an accuracy of about 90% (Schlund et al. 2014). A regular grid with a grid cell size of 1ha within the forest area was created and the proportion of changes within each 1ha grid cell was calculated in order to estimate the degree of forest disturbance.

Results and Discussion

Forest disturbance maps based on TerraSAR-X time series analysis showed mainly low to medium disturbance during the acquisitions of December 21, 2010 and January 03, 2015. Main parts of the Mawas area were low disturbed, whereas this could be assumed as natural mortality. However, forest disturbances generally increase to the forest edges. A large patch of medium to high forest disturbance was detected in south-eastern part of Figure 2 left. It could be assumed that the forest disturbance in these areas exceeded the natural mortality. The medium to high forest disturbance was mainly detected at forest edges and

close to the canals, where logs could be transported easily. It is worth noting, that Mawas is a conservation area where the forests are supposed to be under protection. The forest disturbance map between the acquisitions of January 03, 2015 and October 16, 2015 revealed a substantial increase in the forest disturbance compared to the previous acquisitions.
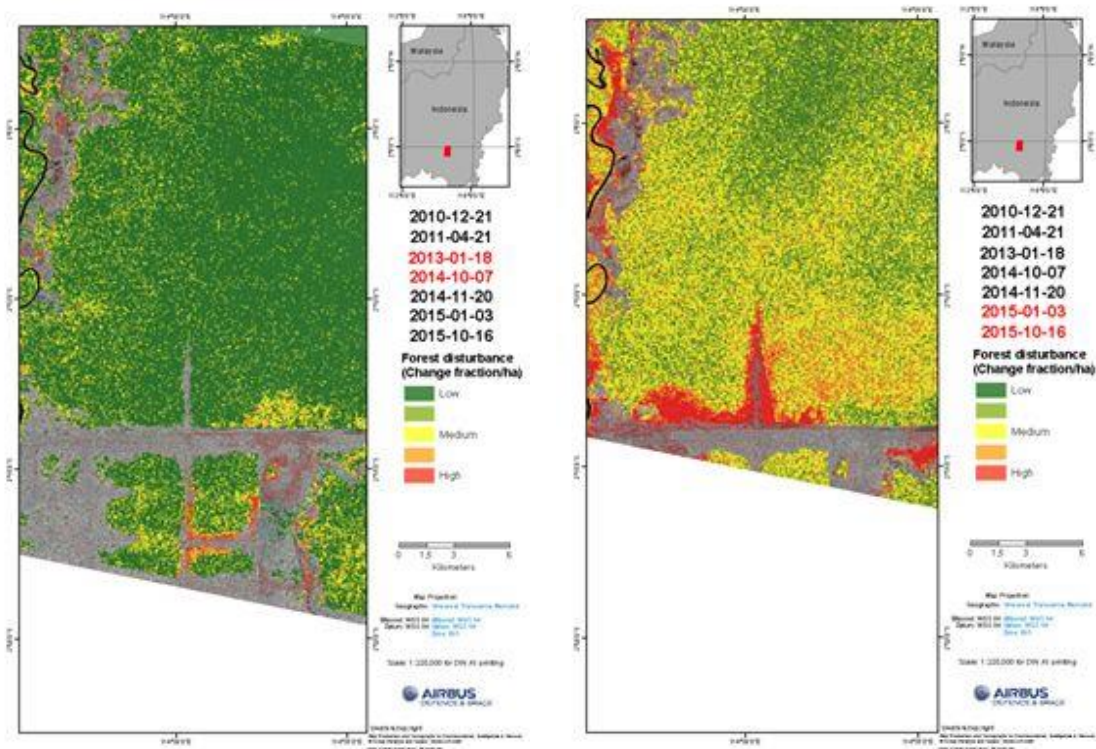

 Fig. 2: Forest disturbance maps based on TerraSAR-X time series analysis (examples of forest disturbance between 2013-01-18 and 2014-10-07 (left) & 2015-01-03 and 2015-10-16 (right))

This could be due to the fact that the recent El Niño resulted in droughts and increased fire risks. Therefore, the substantial increase of forest disturbance between January 2015 and October 2015 compared to the four previous years could be related to possibly increased illegal logging, but also to forest fires. High forest disturbances were still mainly observed at the edges of the forests, whereas in contrast to the previous year's medium to high disturbance could be observed in the interior of the forest area (Figure 2 right). This suggests that those disturbances were mainly related to extensive droughts and higher fire risk in 2015. An exact answer of the forest changes related to illegal logging or forest fires would show an additional SAR image from July or August 2015.

LiDAR results

The averaged tree height varied widely over the selected transects (Figs. 3, 4, Table 1). This might be due to different intensities of past log intervention to the forest that may explain part of the heterogeneity in the roughness and the variations of tree height among the selected transects. While Mawas km228 has faced less intervention by forest logging, Mawas km238 experienced strong intervention by selective logging through different concession companies until 1997 (Boehm and Siegert, 2004). In such forest logging practices, the large trees are harvested what directly implies on large gaps in the canopy besides the damage of neighbours' trees that further causes a drastic loss in the amount of organic matter inputs. Thus, harvesting practices also includes the construction of small railways and channels to bring the logs out from the forest. These leads to significant changes of the peat floor heterogeneity and their eco-hydrological function. The forest disturbances are still visible on the LiDAR derived products (i.e. CHM and DTM) as well as based on the visual interpretation of Landsat images (Fig. 1).
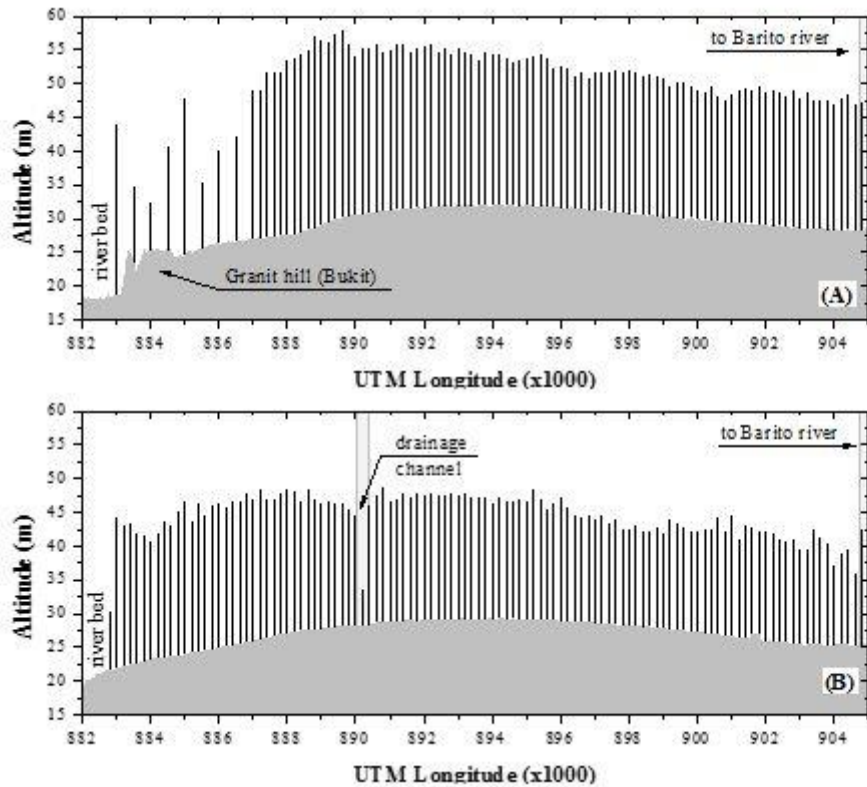
Figure 3. LiDAR derived digital terrain model (DTM) profiles and LiDAR derived canopy height model (CHM) parameter dominant tree height overlaid over the DTM for Mawas km228 south of equator (A) and Mawas km238 (B). Results are based on LiDAR measurements acquired in 2007. Each vertical bar is a 1-ha sample plot.
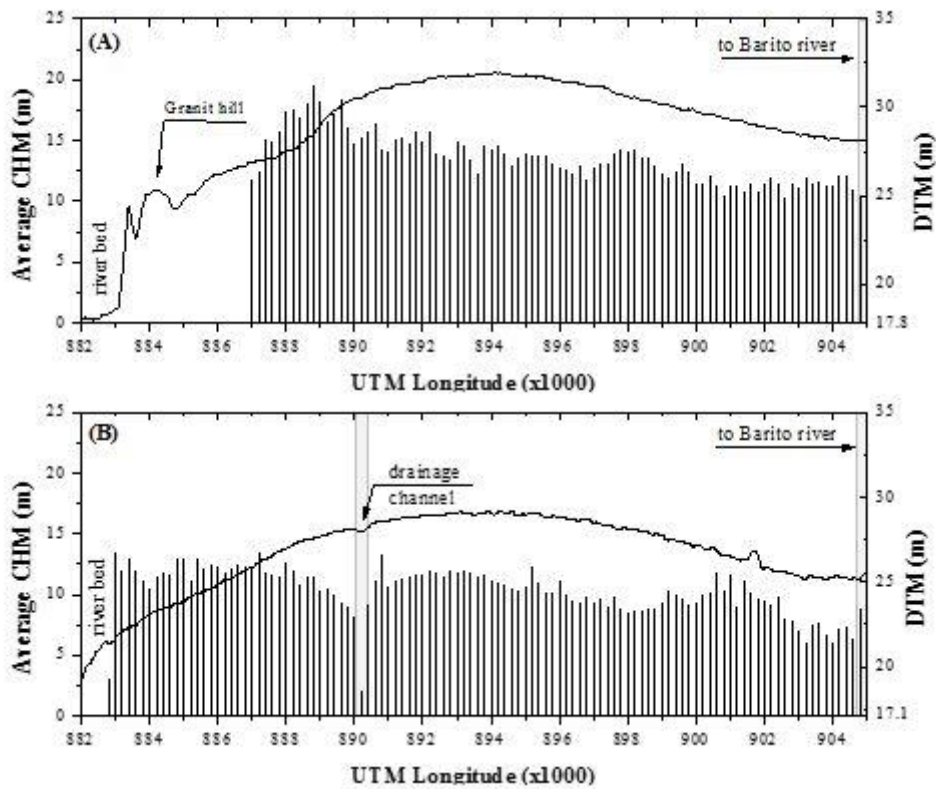

Figure 4. LiDAR derived digital terrain model (DTM) profile and separately LiDAR derived canopy height model (CHM; average tree height) for Mawas km228 (A) and Mawas km238 (B). Results are based on LiDAR measurements acquired in August 5-7, 2007. Each vertical bar is a 1-ha sample plot.

Test Site's Name	**Mawas**		**Mawas**	
UTM Latitude	km 228		km 238	

LiDAR derived DTM parameters

	2007	2011	2007	2011
River level (m)	17.8	17.8	17.1	17.1
Altitude of the peat dome (m)	**32**	**32**	**29**	**29**
Max. slope (m/km)	2.41	2.90	1.41	1.57
Average slope (m/km)	0.62±0.57	0.63±0.60	0.61±0.37	0.55±0.41
Hummocks roughness (m)	0.73±0.33	1.16±0.22	1.42±0.53	1.12±0.38
Nominal transect length (km)	23		23	

LiDAR derived CHM parmeters

	2007	2011	2007	2011
Dominant tree height (m)	21.8±2.3	24.6±1.6	18.8±2.5	19.1±2.4
Averaged tree height (m)	13.5±1.8	16.1±1.5	10.9±1.6	13.1±1.6
Maximum tree height (m)	28.3±3.5	32.1±3.4	25.6±3.9	27.4±3.9
Number of sample plots	75		91	
Past activity log	slight		heavy/moderate	

Table 1. Averaged LiDAR derived DTM and CHM parameters for the selected transects in Central Kalimantan

Conclusive Remarks

The results lead to the conclusion that degraded PSF might result in dramatic changes to the eco-hydrological function of the peat domes requiring management counteractions in this endangered ecosystem. The effect of forest logging activities on PSF environments and their effects on climate change should also be investigated and confirm whether this disturbance may increase the flux of CO_2. Since peat swamp degradation may enhance peat respiration more than net primary production, more and more areas will become carbon sources rather than carbon sinks, which may have an impact on climate change. In the coming years, as indicated by political support for Reducing
Emissions from Deforestation and forest Degradation (REDD) long-term monitoring of the peat domes will be crucial to quantify changes in carbon stocks of the PSF, and to evaluate forest growth response to climate and land use change in which LiDAR measurements and SAR-data can play an important task.

TerraSAR-X alone has limited capabilities of estimating biomass. However, the combination of LiDAR with high capabilities for forest biomass estimation could be seen as high potential and effective. Usually the aerial coverage and repetition frequency of LiDAR is limited. The biomass could be estimated and changes of that biomass are frequently monitored on a large scale with space borne SAR sensors like TerraSAR-X. In addition, the space borne monitoring could support future planning and sampling of LiDAR acquisitions by indicating hot spot areas.

References

Boehm, H.-D.V., Siegert, F., 2004. The impact of logging on land use change in Central Kalimantan, Indonesia. International Peat Journal, 12, 3-10.

Boehm, H.-D.V., Frank, J., 2008. Peat Dome Measurements in Tropical Peatlands of Central Kalimantan with a high-resolution Airborne Laser Scanner to achieve Digital Elevation

Models. In: Proceedings of 13th International Peat Congress, 8-13 June 2008, Tullamore, Ireland, Section 5: Tropical Peatlands.

Boehm, H.-D.V., Liesenberg, V., Limin, S., 2013. Multi-Temporal Airborne LiDAR-Survey and Field Measurements of Tropical Peat Swamp Forest to Monitor Changes. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, VOL. 6, No. 3, June 2013, 1524-1530

Hajnsek, I., Kugler, F., Lee, S.K., Papathanassiou, K.P., 2009. Tropical-forest-parameter estimation by means of Pol-InSAR: The INDREX-II campaign. IEEE Transactions on Geoscience and Remote Sensing, 47(2), 481-493.

Jaenicke, J. Rieley, J.O., Mott, C., Kimman, P., Siegert, F., 2008. Determination of the amount of carbon stored in Indonesia peatlands, Geoderma, 147(3-4), 151-158.

Page, S., Siegert, F., Rieley, J.O., Boehm, H.-D.V., Jaya, A., Limin, S., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature, 420(6911), 61-65.

Poncet, F. von, Schlund, M., Kuntz, S., 2014. Synergy of TanDEM-X bistatic data & TerraSAR-X to map the state and evolution of forest degradation. In ForestSAT 2014, November 4, 2014 – November 7, 2014, Riva del Garda, Italy.

Schlund, M., Poncet, F. von, Hoekman, D.H., Kuntz, S., Schmullius, S., 2014. Importance of bistatic SAR features from TanDEM-X for forest mapping and monitoring. Remote Sensing of Environment, 151, 16-26.

Usup, A., Hashimoto, Y., Takahashi, H., Hayasaka, H., 2004. Combustion and thermal characteristics of peat fire in tropical peatland in Central Kalimantan, Indonesia. Tropics, 14, 1-19.

Weihing, D., Poncet, F. von, Schlund, M., Lang, O., 2010. Change analysis with TerraSAR-X. In: Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS, Vienna, Austria, July 5–7, 2010, IAPRS, Vol. XXXVIII, Part 7B.