Characteristics of satellite LiDAR waveform in tropical rain forests from the comparison with canopy condition derived from high resolution satellite data

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1. Introduction

Tropical forest plays an important role in providing various functions, such as carbon sink, maintenance of biodiversity, but deforestation and forest degradation occur in many developing countries. The importance of a robust transparent national monitoring system was recognized in COP 16 of United Nation Framework Convention on Climate Change and a combination of remote sensing and ground-based forest carbon inventory approaches for estimating, as appropriate, anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks, forest carbon stocks and forest area changes was required. The expectation for the remote sensing technology has risen for monitoring of forest carbon stocks and their changes in developing countries.

While land-cover change can be identified using optical sensors, it has been difficult to identify forest stand structure using conventional remote sensing. LiDAR remote sensing opens a new era for monitoring of three-dimensional forest structure. Particularly, airborne laser scanning has made it possible to reconstruct it widely and spatially. Airborne laser scanning is a remote sensing technique used to acquire three-dimensional data on forest structure, from which a digital surface model (DSM) of the forest canopy and a digital terrain model (DTM) of the ground surface can be obtained. The laser profiler system carried on aircraft on the other hand is a technology that obtains information on canopy height along travelling course. Though increasing information to estimate forest carbon stocks accurately by using airborne LiDAR, various issues such as the cost, the operation, and the regulation remain unsolved to introduce it to monitoring forest carbon stocks in developing countries.

To avoid such issues, use of satellite LiDAR system is another possibility to estimate forest structure. This study aims to investigate characteristics of satellite LiDAR waveform in tropical forests by comparing with canopy structure derived from high resolution satellite data.

2. Method

2.1 Study area
Study area is located in the Tangkulap Forest Reserve, Sabah, Malaysia, which is managed by the Sabah Forestry Department under the Deramakot Forestry District. This forest reserve had been degraded due to intensive and unplanned harvesting in the past. Concern about the current status of the forest reserves has grown considerably in the past decade and therefore, has resulted in some initiatives to reverse the trend and to develop strategies and actions for sustainable forest management (SFM). Within this context, the SFD prepared a 10-year Forest Management Plan (2006-2015) hoping that if properly managed, restored or rehabilitated, the forest reserves have the potential to generate significant environmental and socio-economic benefits (Sabah Forestry Department, 2010).

We established 20 sample plots with 15m radius in the study area and determined the coordinates at the centre of each plot by using a global positioning system (GPS) receiver. DBH and tree height of all standing trees with more than 10 cm DBH were measured. Allometry between tree height and diameter at breast height (DBH) was investigated from field measurement in sample plots (Figure1).

![Figure 1. Relationship between DBH and tree height from field data in sample plots.](image)

2.2 Remotely sensed data

2.2.1 Satellite LiDAR data

ICESat GLAS data (release 31), which were acquired on 8 October 2008, were used in this study. ICESat was launched in January 2003 and the mission was terminated in 2009 because of the instrument trouble. ICESat had the orbit of 600km on the ground and it emitted 532 and 1064 nm wavelength laser pulse at 40 Hz simultaneously. The footprint of laser pulse was around 65 m and the interval was about 170 m.

The data for the study area were prepared and provided by the National Snow and Ice Data Center (NSIDC). GLA01 data and GLA14 data were used for this study. While GLA14 data file involves the record index, acquisition time latitude, longitude, elevation, range, offsets of signal beginning, signal ending, waveform centroid, and fitted Gaussian peak, original waveform in
each shot of laser pulse was included in the GLA01 data file (Sun, et al., 2008). All waveforms within the study area were plotted to investigate the characteristics for canopy conditions, and they were related to individual footprints 65 m in diameter.

2.2.2 High resolution satellite data

QuickBird panchromatic and multispectral data, which have ground resolutions of 0.61 and 2.44 m, respectively, at nadir were used for this study. The multispectral sensor observes in the following wavelength bands: 450 to 520 nm (blue, band 1), 520 to 600 nm (green, band 2), 630 to 690 nm (red, band 3), and 780 to 900 nm (near infrared, band 4). The QuickBird data were acquired on 10 October 2007 for the study area.

In the satellite data, treetops showed stronger reflectance than the edges of the crowns. This results from differences in crown geometry and canopy structure. Because the digital number (DN) in the satellite data represents the relative intensity of reflectance, the DN values are larger for the treetops than for the edges of the crowns.

2.3 Data analysis

Reversed QuickBird panchromatic images for each plot by subtracting the DN for a pixel from the maximum DN for the whole image (Wang et al., 2004a) were obtained; then the watershed method (Wang et al., 2004a) to identify individual crowns and extract their areas was used. The watershed method was originally developed to address the influence of terrain on surface water hydrology by modelling the movement of water over a landscape and computing the local flow directions and the gradual accumulation of water moving down slope across the landscape. If we regard the reversed satellite image as analogous to a digital elevation model, the crowns of individual trees resemble depressions in the image. As a result, each crown area can be calculated by using the tools provided by the watershed method. Non-tree areas in the images should be removed during image processing because their presence can lead to overestimation of crown area. To permit this, we determined the threshold between tree crowns and non-tree areas in the satellite data on the basis of the frequency distribution of DN values in mangrove areas and a comparison of the satellite data with data from our field surveys in the study plots. A mask layer for the non-tree areas was then generated by using the threshold value determined by matching the field data to the DN values in the images.

Footprints of laser pulse from ICESat GLAS were identified on the QuickBird image and stand structures in the footprints were estimated from crown information. First, canopy closure within a footprint was calculated using the generated mask. Distribution of individual crown areas within a footprint was investigated for all footprints in the study area. Grade of degradation due to historical selective logging was decided from these two factors, namely, canopy closure and crown size structure. Waveform in each footprint was extracted from ICESat GLAS data and the relationship between stand structure, which was estimated from crown information, and the waveform was investigated. In addition, waveform in oil palm plantation, which was outside of the extent of high resolution satellite data, was also investigated. The condition of the area was identified using Google Earth.

3. Result

Rates of forest canopy closure within the footprints which were calculated from a mask for distinguishing forest area from non-forest area in high resolution satellite image ranged from 65% to 100%. It is considered that the difference of rates was caused by the intensity of selective logging. There was difference in distributions of crown areas in the footprints, which were extracted from the panchromatic data. Particularly, regenerated area, where heavy logging
had been conducted in the past, consisted of small crown trees.

The waveform of a mature forest in the study area, which canopy closure was more than 90% and had relatively large size of crowns, was shown in Figure 2 (a). In a mature forest, maximum tree height derived from LiDAR data was about 43 m. Intensity has a peak around 23m height and it means canopy layer. While there is some difference in height estimation, the waveform described the size composition. In a mature forest, main part of one shot of laser pulse was reflected by crowns of canopy layer and few part of laser pulse reached to lower layers and the ground. In some waveforms for mature forests, it was difficult to recognize the ground level due to weak signal.

The waveform of a degraded forest in the study area, which canopy closure was less than 90% and consisted of various sizes of crowns, was shown in Figure 2 (b). In a degraded forest, Maximum tree height derived from LiDAR data was about 42 m. Intensity was relatively weak through all layers. In a degraded forest due to historical selective logging of valuable trees, some trees which occupied canopy layer have remained. Waveforms in degraded forest were various due to canopy conditions which were recognized from the analysis of high resolution satellite data. It is considered from the result that intensity of a waveform peak of a laser pulse is regarded as an indicator for evaluating grade of forest degradation.

The waveform of a degraded forest in the study area, which canopy closure was less than 90% and consisted of various sizes of crowns, was shown in Figure 2 (c). In oil palm plantation, maximum tree height derived from LiDAR data was about 23 m. Intensity has a peak around 15m height and it means canopy layer. Waveforms in oil plantation were similar and obvious signals from the ground were confirmed in almost of them. In oil palm plantation, trees are planted regularly. There is constant space in a canopy due to this regularity although they have large leaves.
Figure 2. Waveforms from one shot of laser pulse in different canopy conditions.

4. Discussion

In this study, we investigated characteristics of satellite LiDAR waveform in tropical forests by comparing with canopy structure derived from high resolution satellite data. Stand structure was estimated from waveform of satellite LiDAR data. Length of waveform almost indicated maximum tree height. Peak position of waveform indicated the height of canopy layer. The height and position of peak of waveform indicated the grade of forest degradation. Further studies are required for identify the relationship between waveform of a shot of laser pulse from satellite LiDAR and canopy condition such as canopy closure and distribution of crown area quantitatively.

The application satellite LiDAR data to mapping of ecosystem structure is currently limited by the relatively small fraction of the earth’s surface sampled by these sensors (Lefsky et al., 2011). In addition, topographic effect on the data is considerably large in rugged terrain. Some models are required to apply the results concerning forest structure obtained from satellite LiDAR data.
to whole forest area spatially. Combination of different types of satellite data might be one possibility to solve this issue.

Acknowledgements

This research was supported by the Environment Research and Technology Development Fund (D-1006) of the Ministry of the Environment, Japan. We thank staffs of Sabah Forestry Department in Deramakot. We thank Dr. Imai for his valuable advice and kind support in the field survey.

References


