Remote sensing of tropical forest biomass: The Malaysian experiences

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Abstract. The role of forests as potential sinks of atmospheric carbon has been studied across varying scales. In 2017, Malaysia with a total of 52% of her land is covered by tropical forest is very important not only as a source of national revenues but also as environmental protection and conservation areas. In Malaysia attempts to estimate the Above-Ground Biomass (AGB) biomass density of different forest types have been made actively as an action to meet the UN Framework Convention on Climate Change (UNFCCC). Remote sensing is a constantly evolving technology being regularly introduced where high-resolution space-borne and air-borne satellite data have provided an opportunity to better estimate and map AGB across different spatial and temporal scales. The quantification, mapping, and monitoring of biomass are now central issues due to the importance of biomass as a renewable energy source. However, the estimation of biomass is a challenging task, especially in areas with complex stands and varying environmental conditions. Remote sensing offers the technology to enable rapid assessment of biomass over large areas relatively quickly and at a low cost. This paper highlights a review of tropical forest biomass assessment techniques using remote sensing with special emphasis in Malaysia. The successful studies and key work that has been undertaken has been discussed.

Keywords: Tropical forest, above ground biomass, remote sensing, Malaysia

1. Introduction
The Malaysian effort on the environmental issue started since the United Nations (UN) Conference on the Human Environment in 1972. Following up to that, Malaysia shows a commitment at the UN Rio Earth Summit in 1992 where the Malaysian National Environmental Policy was established. Under this policy the commitment of Malaysia is to maintain 50% of its land area (33 million ha), which means retain forests coverage at 16.5 million, therefore these forests can continue to serve as effective carbon sinks. Malaysia has promised to cut the country’s carbon emissions by as much as 45% by the year 2030 and targeted to a low-carbon, and eventually carbon-neutral society, with spirits to cut carbon dioxide (CO₂) emissions by the year 2050. In fact, in an area of 0.5 ha forests comprise about 480 trees of trees and able to stores about 2,600 kg of carbon/year [1]. Previousy the biomass of forest type in Malaysia was estimated from the product of area and biomass density where the density includes provision for both roots and shoot. The changes in mean biomass density were calculated by extrapolating the long-term trend in biomass carbon density presented by Richard et al. [2].
Nowadays modern remote sensing has become the primary source for forest resource management and development. Generally, forests contain about 70% to 90% of terrestrial above ground and below ground biomass. Because of being a large percentage of biomass in the forest ecosystem, trees are more emphasized in the biomass studies [3]. The importance of forest biomass in the carbon cycle makes it an object of interest for a wide range of reasons. It is not only clean renewable energy but also important for determines the carbon amount that will be emitted to the atmosphere in form of carbon dioxide, carbon monoxide or methane and used for removal of carbon that is already available in the atmosphere [4].

The use of remotely sensed data is crucial in obtaining pertinent information on forest cover and biomass which can lead to uncertainties [5]. However, with the appropriate approach, the accuracy can be achieved desirably at the highest acceptable level. Under the United Nations Framework Convention on Climate Change (UNFCCC) for implementation of a reliable mechanism to reduce emissions from tropical deforestation and forest degradation (REDD+), accurate biomass estimates are also required [6,7]. Thus, this paper is discussed the tropical forest biomass assessment techniques using remote sensing with special emphasis in Malaysia. Particular attention is focused on the use of SPOT-5 data, ALOS PALSAR, and LiDAR sensor.

1.1. Forest AGB with field studies and remote sensing
As a central to the global carbon cycle, forest AGB plays a role as atmospheric carbon sinks or sources in local to regional scales is critical to understand. Therefore, an accurate inventorying and monitoring of forest aboveground biomass in needed [8]. The early studies on forest AGB biomass were conducted in the 1930’s. [9] reported that the methods used are called a “harvest method” where the tree was harvested in a plot and then weighting them after the oven drying process. [10] claimed that by using harvest method in high biomass density areas is feasible for repeating a measurement. Therefore, to overcome these problems, the indirect method is developed in order to estimate the AGB. The most common approach is using an empirically based allometric equation based on destructive samples that allow the estimation of tree biomass density from more easily measured properties, such as diameter at breast height (DBH) and height [11]. Although conventional techniques generally provide accurate estimates of forest AGB, it is still limited to the accessibility, time-consuming and largely applicable to small sample sizes. The use of conventional methods for the AGB estimation is not totally rejected but incorporating them with modern remote sensing data would considerably help in quantifying, monitoring, and understanding forest AGB at various scales [12, 13]. Thus, a more comprehensive and reliable approach for estimating biomass change is to combine new field studies with analysis of high-resolution remotely sensed data. Remote sensing of tropical forest biomass: Malaysian case studies.

2. Methodology
The studies used three types of imageries namely SPOT-5, ALOS PALSAR and LiDAR. All the studied articles were analysed and discussed. The approaches and result were summarised based on the three sensors.

3. Results and discussion
3.1. Mangrove forests AGB estimation using vegetation indices from SPOT-5 imagery
The study by [14] was conducted at Kuala Sepetang (South) Forest Reserve, Malaysia. This study utilized the SPOT-5 satellite image, which was acquired on 13 December 2014. The imagery was supplied by the Malaysian Remote Sensing Agency. The imagery comprised four multispectral bands and one panchromatic band, which had a spatial resolution of 10 and 5 m respectively. The four bands in multispectral were green (band 1, wavelength 0.51–0.59 μm), red (band 2, 0.61–0.68 μm), NIR (band 3, 0.78–0.89 μm) and short-wave infrared (band 4, 1.58–1.75 μm). Species-specific allometric
equations were applied to estimate the total AGB [15, 16]. This study correlated certain variables from vegetation indices derived from imagery with the measured AGB. These vegetation indices were (1) NDVI, (2) soil-adjusted vegetation index (SAVI), (3) green NDVI (GNDVI) and (4) global environment monitoring index–NDVI (GEMI–NDVI). The VI’s maps are shown in figure 1.

The total AGB estimated is varied from 24.35 to 462.40 Mg ha⁻¹ where the highest value was observed in plots with high density of adult trees of *R. apiculata* with the minimum value for DBH was 7.6 cm while the maximum value was 25.9 cm with the total number of stand trees in the area of the plots were about 140 (table 1). The regression analysis was performed to estimate the relationship between the NDVI, SAVI, Green GNDVI and GEMI-NDVI. The linear regression analysis is shown in table 2.

![Image](image_url)

**Figure 1.** Four VI’s image of the study area; NDVI = normalised difference vegetation indices, SAVI = soil-adjusted vegetation indices, GEMI–NDVI = global environment monitoring index–NDVI and GNDVI = green NDVI.
The overall AGB of Kuala Sepetang (South) recorded approximately 1.3 million Mg ha\(^{-1}\), and entirely the AGB of MMFR is 5.3 million Mg. (41,000 ha). The developed model could be utilized for an accurate estimation of AGB. The validation model obtained is \(R^2\) value of 0.42 with RMSE 107.26 Mg ha\(^{-1}\)). The \(R^2\) of coefficient regression in the developed model increased by about 2% and reduced the value of RMSE by 48.30 Mg ha\(^{-1}\). The model provides higher accuracy with the reduced value of RMSE, thus it was considered compatible with the previous studies.

3.2. Mangrove forest AGB estimation using ALOS PALSAR

This study has been carried out to evaluate the relationship between Advanced Land Observing Satellite (ALOS) Phased Array L-band SAR (PALSAR) backscattering coefficients and the aboveground biomass (AGB) of a Matang Mangrove Forest Reserve Malaysia [17]. The empirical relationship then was used to map the AGB by using L-band SAR data. The mosaic of the L-band PALSAR fine beam dual (FBD) 2010 with 25 m pixel spacing data was provided by the Japan Aerospace Exploration Agency’s (JAXA). The calculated plot based AGB from 320 samples. The estimation of the AGB for each plot ranged between 9.53 and 340.82 Mg ha\(^{-1}\) and most of the plots measured AGB of b 100 Mg ha\(^{-1}\). The distribution of the AGB within all the sample plots is shown in table 3.

The study used all the variables [HH/HV, HV/HH, (HH + HV)/2 and \((HH*HV)\)] and then correlated with the AGB. Results showed that the correlations were of relatively low significance. The HV backscatter gave the highest correlation with a coefficient of determination (\(R^2\)) of 0.427, followed by \(\sqrt{(HH*HV)}\), (HH + HV)/2 and the original HH. For the HH/HV and HV/HH variables, no significant relationships were observed. The summary of all the correlation models and \(R^2\) of AGB is shown in table 4 [17]. Based on the model, the backscatter of HV polarisation was selected as the AGB prediction model as it gave the best \(R^2\) compared to the other variables.

The study indicates that the variations in the AGB in the study area were closely related to the succession levels of the mangrove stands. The different images variables of PALSAR polarisations has been produced from different sets of image variables (figure 2) where each of them showed the mangrove forest in different condition.

The HH/HV and \(\sqrt{(HH*HV)}\) imageries can show a patch of newly planted mangroves that appeared darker than matured mangrove stands. Meanwhile, the mangrove’s spatial AGB distribution is depicted in figure 2b [17]. The study found that the estimated AGB in Matang Mangroves ranged between 2.98 and 378.32 ± 33.90 Mg ha\(^{-1}\) with an average of 99.40 ± 33.90 Mg ha −1 and a total AGB of about 4.25 million Mg.

### Table 1. Summary of measured AGB within all sample plots.

| Sample plot | Minimum (Mg ha\(^{-1}\)) | Maximum (Mg ha\(^{-1}\)) | Average (Mg ha\(^{-1}\)) | Total (Mg ha\(^{-1}\)) |
|-------------|--------------------------|--------------------------|--------------------------|------------------------|
| 150         | 24.35                    | 462.40                   | 168.93                   | 25339.80               |

### Table 2. Summary of simple linear regression models using single independent variable.

| Vegetation indices | Model                   | Multiple R | \(R^2\) | Adjusted \(R^2\) | Residual error (± Mg ha\(^{-1}\)) |
|--------------------|-------------------------|------------|---------|-----------------|---------------------------------|
| NDVI               | \(y = 973.87x–190.62\)  | 0.78       | 0.60    | 0.60            | 54.62                           |
| GEMI-NDVI          | \(y = 2491.00x–1789.50\)| 0.71       | 0.51    | 0.51            | 60.47                           |
| SAVI               | \(y = 183.31x–7.51\)    | 0.23       | 0.05    | 0.04            | 84.02                           |
| GNDVI              | \(y = -266.83x + 268.11\)| 0.30       | 0.09    | 0.08            | 82.43                           |
The use of L-band PALSAR can provide a rapid assessment of AGB in large areas where access is restricted. This study highlighted that L-band PALSAR has successfully quantified aboveground biomass at Matang Mangroves forest. The AGB in the Matang Mangroves is ranged from 3.0 to 378.3 ± 33.9 Mg ha\(^{-1}\), with an average of 99.4 ± 33.9 Mg. The errors associated with the AGB estimation were also observed when AGB exceeded 150 Mg ha\(^{-1}\). The best backscatter among variables in predicting AGB is HV polarization due to the highest R\(^2\).

3.3. AGB estimation with airborne and terrestrial LiDAR scanner in lowland tropical forest.

Recently, much attention has been focused on the use of Light Detection and Ranging (LiDAR) sensor in estimating AGB due to its potential to capture the vertical structure of vegetation. No other biophysical variable has received as much interest in LiDAR for forest biomass. Estimating the carbon content of forests and its dynamics is the primary driving force behind the growth of LiDAR technology. The potential application of LiDAR in forestry has grown rapidly which can benefit in managing natural resources [18].

In Malaysia, the AGB estimation study using terrestrial LiDAR was conducted in 2016 in collaboration between Faculty of Forestry, Universiti Putra Malaysia and Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, Enschede, The Netherlands. The objective of the study is to assess the accuracy of estimation of forest inventory parameters and AGB derived from terrestrial laser scanner (TLS) in the 1,176.1 ha tropical rainforest of Ayer Hitam Forest Reserve (AHFR), Malaysia (figure 3).

This study conducted by [19] uses the complementary strengths of airborne LiDAR and the TLS system to assess the upper and lower canopies of the forest. The upper canopy layer was assessed by generating tree parameters using airborne LiDAR to obtain height from CHM and segmenting the Orthophoto to obtain crown projection area (CPA). For further processing in LAS tools, this file format was converted to a las file format, then the canopy height model (CHM) was generated to create a pit-free raster CHM. For TLS a RIEGL-VZ-400 was set on the tripod with the NIKON D610 camera mounted on top. A multiple regression DBH was modelled through using the derived parameters (CHM and segmented CPA) as independent variables and the field DBH as the dependent variable.

### Table 3. Summary of AGB in sample plots.

| Sample size | 320 |
|-------------|-----|
| Min. AGB (Mg ha\(^{-1}\)) | 9.53 |
| Max. AGB (Mg ha\(^{-1}\)) | 340.82 |
| Mean AGB (Mg ha\(^{-1}\)) | 114.38 |
| Standard deviation AGB (Mg ha\(^{-1}\)) | 68.10 |

### Table 4. A correlation and R\(^2\) of AGB, and derived PALSAR polarization image variables from L-band [17].

| Variable | Model | R | R\(^2\) | Adjusted R\(^2\) | Residual error (± Mg ha\(^{-1}\)) |
|----------|-------|---|--------|----------------|-------------------------------|
| HH       | \(y = 0.472 \ln(x) - 12.326\) | 0.407 | 0.166 | 0.163 | 63.05 |
| HV       | \(y = 0.800 \ln(x) - 19.305\) | 0.654 | 0.427 | 0.427 | 61.32 |
| HH/HV    | \(y = 0.006 \ln(x) + 0.625\) | 0.101 | 0.010 | 0.007 | 64.93 |
| HV/HH    | \(y = -0.014 \ln(x) + 1.604\) | 0.099 | 0.010 | 0.007 | 64.99 |
| (HH + HV)/2 | \(y = 0.595 \ln(x) - 15.621\) | 0.512 | 0.262 | 0.260 | 62.50 |
| √(HH*HV) | \(y = -0.569 \ln(x) + 15.206\) | 0.481 | 0.233 | 0.230 | 63.52 |
Figure 2. (a) The image composites of PALSAR from the original HH and HV backscatter are shown in a) and b), the derived images are shown in c), d), e), and f) for HH/HV, HV/HH, (HH + HV)/2 and √(HH*HV), and (b) Showing spatial distribution of AGB for Matang Mangrove Forest Reserve [17].

Figure 3. Location map of Ayer Hitam Forest Reserve.
To estimate the AGB an allometric equation was applied to the modelled DBH together with LIDAR-derived height (canopy height model). Scanned trees in the plot were extracted. Then DBH and height parameters were measured using RiSCAN Pro software interface. These parameters were then used for the allometric equation to estimate the AGB. The correlation of the TLS measured DBH and field measured DBH was established and achieved an $R^2$ value of 0.99 and RMSE of 1.03 cm (figure 4). The AGB estimated for the 16 plots the upper and lower canopy were then combined and subsequently $R^2$ and RMSE values were also combined. The achieved average $R^2$ and RMSE are 0.98 and 188.35 Mg ha$^{-1}$ respectively. The AGB per ha is 263.80 Mg ha$^{-1}$ for the modelled and 264.54 Mg ha$^{-1}$ for the field measurement. Therefore, the total calculated AGB for the study area is 329,272 Mg ha$^{-1}$ for the modelled and 338,595 Mg ha$^{-1}$ for the field measurement.

The overall result shows that using the method of complementing the airborne and TLS LiDAR sensors would indeed provide accurate information to estimate AGB/carbon for a vertically complex tropical rainforest. The summary of the three sensors used, methodology and results are shown in table 5.

![Figure 4. Scatterplot of the TLS and field measured DBH [19].](image)

| Sensor type | Type of forest and plot size | Approach | AGB (Mg ha$^{-1}$) | Accuracy RMSE |
|-------------|-----------------------------|----------|--------------------|---------------|
| SPOT-5      | Mangrove Sample plot 0.1 ha. Established 150 sample plots (15 ha.) | Multi-linear regression by a combination between two or more independent variables from vegetation indices derived from SPOT-5 image with the measured AGB. | 168.93         | 0.64          |
| ALOS PALSAR | Mangrove 320 sample plots with the plot size of 20 $\times$ 50 m | L-band PALSAR fine beam dual with 25 m pixel spacing. | 99.4           | 0.43          |
| LiDAR       | Inland forest Circular plots of 12.62 m. Total 16 field plots. | Complementary of airborne LiDAR and the TLS system. | 263.80         | 0.98          |

Table 5. The summary of the three sensors used, methodology and results.
4. Conclusion

Tropical forests are still insufficient for important data on basic measurement for wood density, carbon content, biomass distribution and allometric equations. The advanced study is needed to be explored in order to set a standard guideline of the appropriate technique of the sampling, reliable sensor, and appropriate analysis and modelling to be used in estimating tropical forest AGB. The experience of using SPOT-5 data, ALOS PALSAR, and LiDAR sensor for forest AGB in Malaysia have been highlighted in this paper. The sensors have a limitation, but the motivation is to investigate the capability of the sensors to estimates forest AGB with an acceptable level. The use of a multilinear regression model on SPOT-5 by a combination of NDVI and GEMI-NDVI has increased the R² value to 0.64 compared to linear regression (only NDVI). Thus, the R² of coefficient regression is increased 0.04 and reduced the value of RMSE by 48.30 Mg ha⁻¹. The model provides higher accuracy with the reduced value of RMSE, thus it was considered compatible with the previous studies. From ALOS PALSAR data the L-band PALSAR has successfully quantified aboveground biomass at Matang Mangroves. However, by HV polarization of L-band is limited by a loss of sensitivity with increasing biomass and the errors associated with the estimation occurred largely when the AGB exceeded 150 Mg ha⁻¹. A study by using LiDAR sensors show an impressive result with very high accuracy. The AGB estimated achieved R² and RMSE are 0.98 and 188.35 Mg ha⁻¹. The ability to use airborne and TLS LiDAR sensors would indeed provide accurate information to estimate AGB/carbon for a vertically complex tropical rainforest. Aboveground biomass estimates depend on the sensor type, processing approach and forest characteristics and the sampling selection should depend on fundamental forest features. The use of LiDAR is significantly more accurate than using radar or optical data. The future research may focus radically on development of different methods by using multi-source data and improving the use of active data such as radar or LiDAR and fuse with hyperspectral sensor to get the best results for tree species and plot levels of AGB. This is a challenge to bring these aspects to be further addressed in future studies since it will have strong implications for the attractiveness of different forest management and conservation strategy.

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