TROPICAL RAIN FOREST TREE HEIGHT MEASUREMENT USING ALS AND TLS FOR ESTIMATING FOREST BIOMASS AND CARBON STOCK IN AYER HITAM FOREST, MALAYSIA

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ABSTRACT: Forests play a major role in climate change through their unique nature of carbon sequestration which regulates the global temperatures. Climate change is directly attributed to changes in global atmospheric conditions over a given period. This requires actions towards its mitigation and hence various bodies have come up with a number of initiatives geared towards comparting climate change, for example the UNFCCC with its REDD+ (Reducing Emissions from Deforestation and forest Degradation) program. REDD+ aims at accurately quantifying the sources and sinks of carbon, and therefore has designed Measurement Reporting and Verifications (MRVs) system for its implementing countries. The REDD+ MRVs require accurate measurements. This help in quantifying the biomass/carbon stock and establish the amount of carbon sequestered. The biomass estimation equations require tree parameters like Height and Diameter at Breast Height (DBH) as an input. Therefore, there is a need to measure tree height and diameter at breast height accurately. Studies have shown that, the tree height is one of the most difficult forest parameters to be measured, yet can be mapped and measured accurately using remote sensing most notably LiDAR Technology. There is no standard set for the height measurement using the hypsometers. However, the data collected using the hypsometers are considered as the data for validation of the remotely sensed data. This possibly leads to errors which must be minimized. The error is then transferred in to the AGB biomass/ carbon estimation. This study is therefore aimed at establishing methods that ensure reasonable accuracy of tree height measurement using both Airborne LiDAR and Terrestrial Laser Scanner.

1. INTRODUCTION

REDD+ has evolved and transformed as a Climate Change mitigation framework (REDD, 2012). With its many objectives aimed at conserving nature. The main focus is on forest carbon sequestration in order to mitigate emissions. However, the amount of carbon in the forest has to be quantified (Angelsen et al., 2012), hence MRVs that ensure accurate measurements in order to quantify and value the ecosystem services or conservation value notably the forest biomass.

The MRVs seek accurate data mainly to quantify the forest biomass. This is through the AGB and consequently carbon stock. Estimating AGB requires models that are based on forest parameters. These forest parameters include; tree height, DBH, crown diameter among others. These can be measured directly or indirectly. However, direct measurement consumes a lot of time and cost. In order to efficiently and quickly quantify the AGB, remote sensing tools have been used. These tools observe directly the tree height which contributes about 50% input to the biomass estimation models (Chave et al., 2014). Chave et al., (2005) confirmed that tree height measurement in tropical rain forest is very problematic. However, the remotely sensed data has to be validated using the ground truth measured from the field using instruments like hypsometers. The bottleneck is that the hypsometers possess measurement errors, with no standard acceptable accuracy to their measurement (Vic et al., 1995). This potentially affects the accuracy of height and consequently the AGB estimation of the tropical rain forests.

Ensuring reasonable accuracy in the height measurement is critical since tree height contributes 50% towards estimating AGB and carbon stock. The forest biomass is estimated based on forest inventory which requires, statistical inventory of growing trees, models to evaluate biomass from the dimensions of the individual trees measured and an evaluation of the biomass contained in standing dead wood and under storey vegetation (Breu et al., 2012). Based on the inventory, two methods are used to estimate tree carbon (Dietz & Kuyah, 2011): 1) using biomass content table, 2) use of models to estimate tree volume, wood density and nutrient content. These approaches are used to construct the allometric equations where height measurement is very essential. Inaccurate tree height measurement leads to inaccurate estimation of the AGB and consequently carbon stock (Molto et al., 2013). Despite the fact that various studies have been undertaken on forest biomass estimation using airborne LiDAR and TLS, a limited number of studies to the knowledge, have compared the accuracy of tree height measurement using the two approaches (ALS and TLS) as well field measurement in a low land tropical rain forest of Ayer Hitam, Malaysia and thereby assess their height measurement accuracy on the amount of AGB/Carbon stock.

Therefore, the aim of this study was to establish methods that can ensure reasonable accuracy of the tree height measurement using the field measurment, TLS and the airborne LiDAR. Further compare the accuracy of tree height measurements from field, TLS and airborne LiDAR, and assess its effects on the estimation of tropical rain forest above ground biomass and carbon stock.

2. MATERIALS AN METHODS

2.1 Study Area

The study was done in Ayer Hitam Tropical Rain Forest Reserve, Selangor, Malaysia. The Ayer Hitam Forest is situated in the southern edge of Kuala Lumpur City, Malaysia approximately at 3º 01′29.1”N 101º38′44.4”E. It covers around 1248 hectares of pristine rainforest and consist of mainly tropical rain forest tree species. The altitude in the forest ranges between 15 meters to 233 meters above sea level (Nurul-Shida et al., 2014). It is one of the oldest tropical rainforest. According to UPM (2015), the forest is the only lowland forest that exists naturally within Klang Valley and Putrajaya area. It is a unique forest due to the fact that it has maintained the history of Orang Asli community. It also documented the history of the Second World War. The forest reserve is also attractive due to the geological make-up of exciting soils and land formations. Figure 1 shows the study area location map.

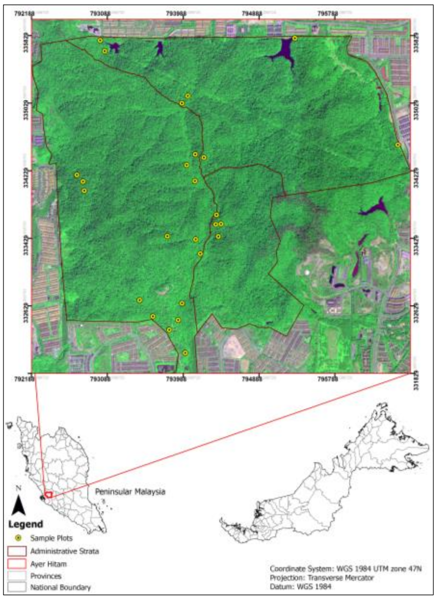


Figure 1. Study area location map

2.2 Data

The study used Airborne LiDAR data, TLS data as well as the field measurements. The Airborne LiDAR data used for the study was acquired by the University Putra Malaysia (UPM), for the purpose of their on-going forest inventory activities. The LiDAR data was collected with approximately 5 – 6 points/m^2 with Ortho-photos. The data was used for the derivation of Canopy Height Model (CHM) from the Digital Surface Model (DSM) and Digital Terrain Model (DTM) in this study. Other data sets for the study include: Tree height and DBH measurements collected from the field in Ayer Hitam Forest and point clouds (multiple scans) from TLS from a total of 26 sample plots.

2.3 Field instruments and software used

Various field instruments and equipment were used to measure forest inventory parameters. Field instruments used for the study include: RIEGL VZ-400, iPAQ, GPS, Leica DISTO 510, Diameter tape (5 meters), Measuring tape (30 meters) and data recording sheet. The details of field instruments and their uses are given in Table 1.

Table 1: List of instruments and image used in field for data collection

Instruments	Purposes/Use
RIEGL VZ-400	Terrestrial laser scanning
Garmin GPS	Navigation and positioning
Leica DISTO D510	Tree height measurement
Diameter tape (5 meters)	DBH measurement
Measuring tape (30 meters)	Plot delineation
Worldview-2 satellite image (Date of acquisition: 12-09-2014)	Sample plot identification
Suunto Clinometer	Bearing and slope

During this study several software packages were used for processing and analysis of datasets. This ranges from the field, TLS and Airborne LiDAR datasets. Table 2 shows the software packages and the purposes of the use.

Table 2: List of software and purpose of their use

Software	Purposes/Use
ArcGIS 10.2.2	GIS and Mapping tasks
ENVI Suite/ERDAS Imagine 2015	Image processing/Airborne LiDAR data analysis
RiSCAN PRO	TLS data processing
CloudCompare	Slicing, cylinder fitting, manual measurements
CompuTree	Creating digital terrain model, automatic DBH measurement
LP360	Airborne LiDAR data processing
LasTools	Airborne LiDAR data processing
R Studio	Statistical analysis

2.4 Methods

The method of this study comprised of mainly four (4) parts. The first component was field data collection which involved observation and measurements using field instruments especially Leica DISTO 510 for tree height measurement and DBH using the diameter tape. The second part of the study involved the use of TLS in various sampled plots for tree scanning (point clouds) and processing of the point clouds, from the processed TLS data, tree height and DBH were measured. The third component of the study involved processing and measurement of tree height from the Airborne LiDAR CHM. The measured tree height from field, TLS were validated using the height measurement from Airborne LiDAR CHM, the errors associated with field measurement and TLS were quantified during the accuracy assessment. Calculation of AGB and carbon stocks was done using the validated actual height measurements from field, TLS and Airborne LiDAR. The fourth part of the study involved the sensitivity analysis of the AGB and carbon stock to changes or variations in tree height measurement due to the errors associated with the methods. Tree height measurements for the different methods were varied by the standard errors quantified from the accuracy assessment, the height adjustments were done by adding or subtracting the threshold based on the errors from field and TLS height measurement. Figure 2, shows the detailed flow chart for the methods/processes and outputs for this study.

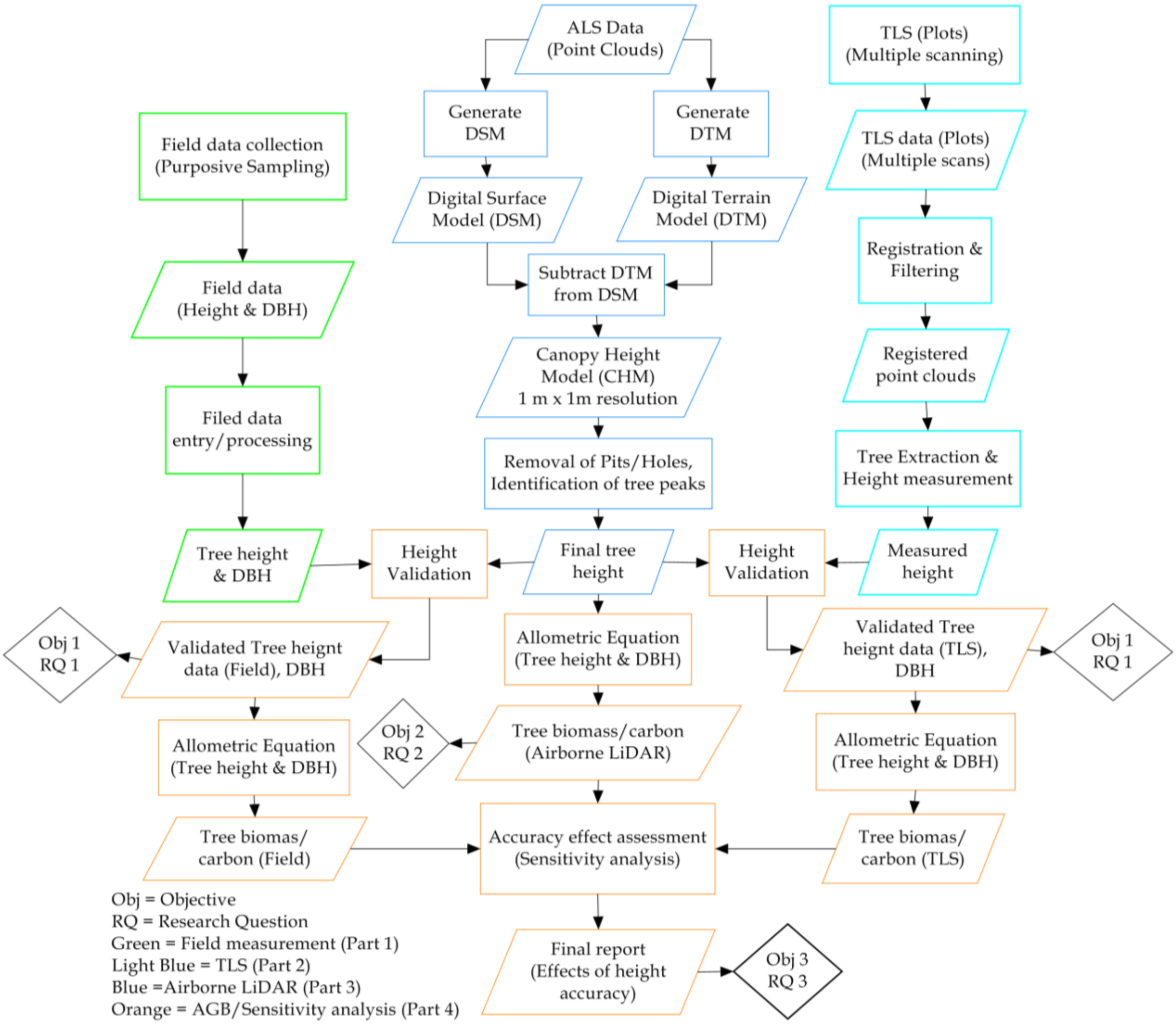


Figure 2. Flowchart of the methods

In this study, purposive sampling approach was used, based on the terrain orientation, stand density and existing strata based on the administrative setup of the study area by the management. Field data was collected between September and October 2015. The manual measurements of tree height, DBH were conducted using the various field instruments. The GPS coordinates of the center of the plot was measured with Mobile Mapper GPS. A diameter tape was used to measure DBH. In addition, other important observations like slope and bearing were noted. Field measurement/tree parameters mainly; tree height was measured from the circular plots of 12.62 m radius using the Leica DISTO 510. DBH for trees in the plot were measured especially the trees with diameter greater or equal to 10 cm were measured using diameter tape at the 130 cm above ground (Chave et al., 2005).

The TLS scans were downloaded from the scanner using the RiSCAN Pro software. The point cloud data obtained from the multiple scan positions in the sampled plot were registered to central scan position to form the 3D of the plot. Individual trees extracted. Locating central position after identification of plot, the center of the plot was established in a position where there was minimum occlusion in the scanning. The reference/home scan was carried out from the central part of the plot and the three other scans carried out of the plot placed in an angle of 120° determined using the TLS Tripod stands to each other in a convenient location due to the elevation of the plots. 12 Cylinder retro-reflectors and 4 Circular retro-reflectors placed with then the plot, the reflectors were used for registration and geo-referencing of the multiple scan positions in a plots (Figure 3).

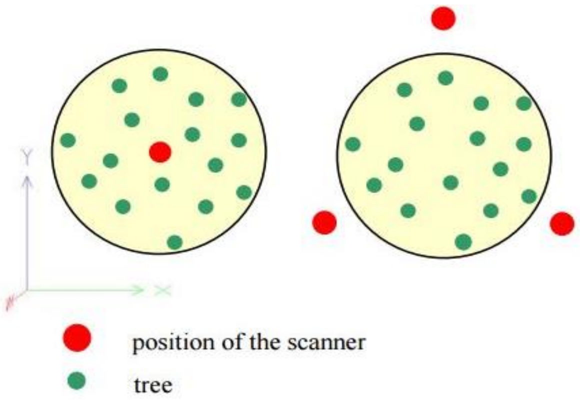


Figure 3. TLS scan positions

The airborne CHM derived tree height was considered as the most accurate tree height measurement to validate the field and the tree height obtained from the TLS. Various studies have shown that airborne LiDAR is very accurate compared to field and TLS measurements (Leitold et al., 2015) with accuracy 0.19 ±0.97 m when field data was collected using a GNSS solution. Leitold et al., (2015) further indicates that, the accuracy reduces with the footprint size and therefore biomass from such CHM are sensitive to the errors.

The AGB was calculated using the allometric equation established by (Chave et al., 2005) which is applicable to mixed tree species. Tree height and DBH from the field were used as input in the model. Then the validated Field, TLS and Airborne LiDAR measured tree height were used to estimated AGB as well as carbon stock. The results were statistically compared for significance. Sensitivity analysis of the amount of AGB/carbon was carried out by adjusting the values of tree height based on the accuracies obtained.

Equation 1: Allometric equation (Above Ground Biomass)

$$AGB = 0.0509 \text{ x } \boldsymbol{\rho} D^2 H$$

The carbon stock for the tree units were derived from the biomass obtained. Carbon content approximately 50% of the total forest biomass (Houghton, 2005). A conversion factor was used to obtain the amount of carbon for the identified trees. In this study, a value of 0.47 was used based on the IPCC guidelines (IPCC, 2007).

The basis of the sensitivity analysis were the tree height measurements, effects of the errors resulting from the different height measurement technologies were assessed. The errors were quantified and the sensitivity of AGB to variability or changes in height measurements and the error associated were done using the scatter plot method of sensitivity analysis. The height obtained from the airborne data was used as the base for height measurement error estimation. Then, the field and TLS height were varied to assess the sensitivity and uncertainty associated with the amount of biomass to the changes in the height. How much biomass was lost or underestimated was assessed by comparing the tree heights and assessment of the accuracy. Different height measurements varied by error margin were input in to the allometric equation, then change in the AGB was observed and assessed.

3. RESULTS AND DISCUSSIONS

3.1 Trees DBH and height measurements

Validation of the DBH was done using the relationship between field and TLS measurements. Field DBH was used as the independent (*x*) variable while the TLS DBH was use as the dependent (*y*) variable to assess their relationship. The DBH measured from the field was then used as an input to the allometric equation that was used for calculating the individual tree AGB and consequently carbon stocks. The result in Figure 4, revealed that the R^2 was 0.96 with 0.98 correlation coefficient when field DBH was plotted against the TLS measured DBH.

Tree height was measured using mainly 3 different instruments, namely the Leica DISTO 510, Terrestrial Laser Scanner (TLS) and from the Airborne LiDAR CHM. All trees within the plots with DBH equal or greater than 10 cm were measured. In total 799 trees were measured during the field work within the 26 plots. 614 of the 799 were detected and extracted from the TLS scans. 345 of the same field and TLS measurement were identified on the CHM and matched. The CHM was created from the Airborne LiDAR point cloud data. From the point clouds, a DTM and

DSM were created, the DTM was then subtracted from the DSM. Based on the field measured tree height the DSM was generated with point clouds that contained the height (*z – value*) between 0 and 50 meters. Using the DSM and DTM, a 1 meter x 1 meter resolution CHM was created. The standard CHM had pits and holes which were removed using a pit free algorithm as shown in Figure 4.

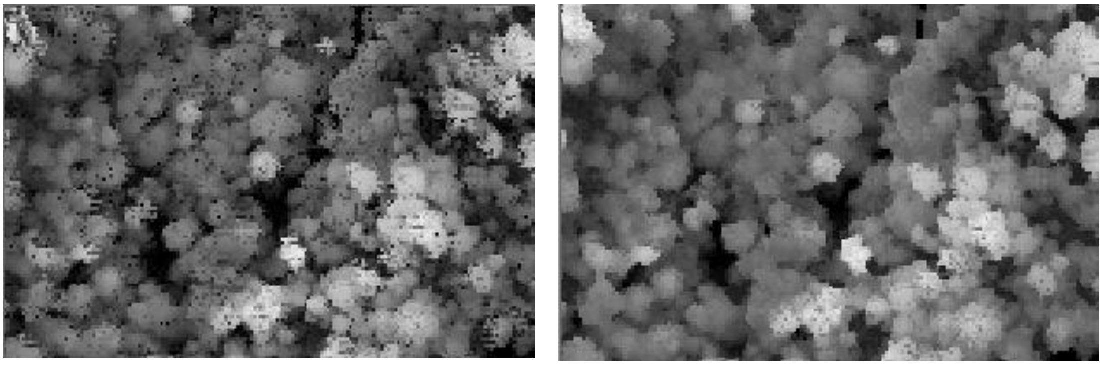
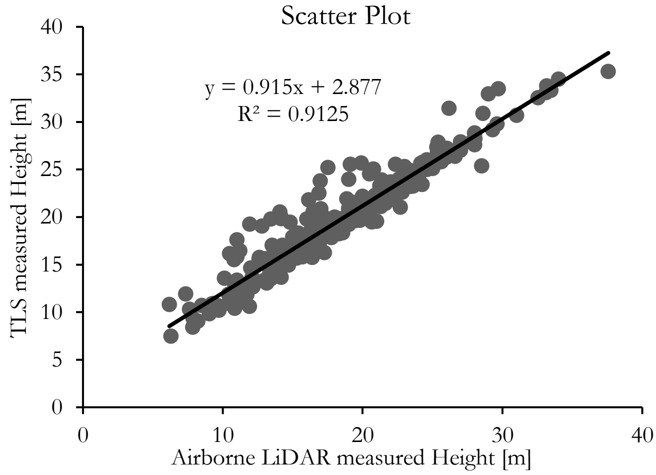
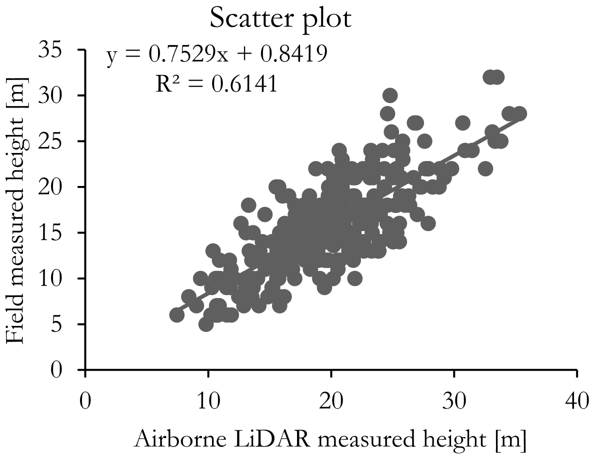
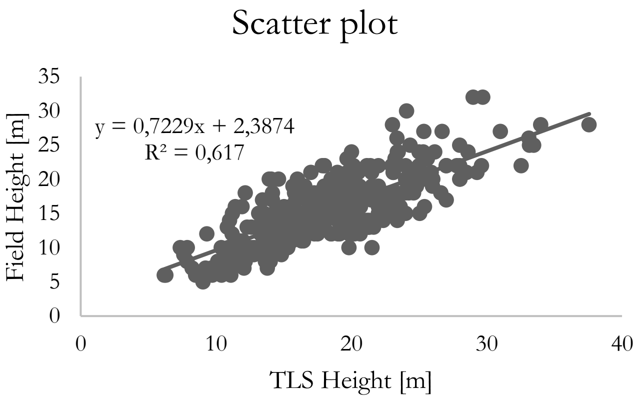


Figure 4: Airborne LiDAR CHM with pits (a) and Pit Free CHM (b)

The accuracy of tree height measured in the field and TLS were compared with the airborne Lidar scanning CHM measurements. Tree height in the field and TLS were compared too. All comparison show in Figure 5.







Figures 5. Tree height comparison

3.2 Above Ground Biomass and carbon estimation

The AGB for the individual 312 trees identified was calculated using the Allometric equation with the tree inventory parameters from field mainly DBH and height, TLS derived tree height and the Airborne LiDAR derive tree height from the CHM (Table 3). The field tree height and the TLS derived height were validated using the Airborne LiDAR derived height. The observed trees from the field were matched with Airborne LiDAR CHM using the TLS number tags and positioning. The global wood density (WD) of 0.57 (REDD, 2012) for Asia and South Eastern Asia was used as an input to the allometric equation.

Table 3: Estimated AGB for the selected trees

Statistics	Field Measurement	TLS	Airborne LiDAR
Mean Biomass [Mg]	0.47	0.55	0.58
Standard Deviation	0.62	0.74	0.76
Minimum	0.017	0.022	0.026
Maximum	5.869	7.127	7.229
Total Biomass [Mg]	146.33	170.86	179.85
Observations [Trees]	312	312	312

The amount of AGB (Table 3) from field height measurement, TLS and Airborne LiDAR were significantly different based on the statistical test done which indicated that there was significant difference between the AGB form field and Airborne LiDAR (18.6%), TLS and Airborne LiDAR (4.99%) and TLS compared with field (14.36%) difference. The result implies that field measured height only estimated 81.29% of AGB when Airborne LiDAR is used as the standard, meanwhile TLS estimates 95.02% of AGB that was obtained by the Airborne LiDAR.

The amount of tree carbon was obtained from the AGB as carbon is composed of 0.47 of the above ground biomass (AGB) for the trees (IPCC, 2007). Consequently based on the amount of AGB, there was also significant difference in the carbon stock (Table 4) basing on the different height measurements since carbon is a portion of the calculated AGB.

Table 4: Carbon stick for the selected trees

Statistics	Field Measurement	TLS	Airborne LiDAR
Mean [Mg]	0.2204	0.2574	0.2709
Standard Deviation	0.2893	0.3483	0.3569
Minimum	0.0082	0.0104	0.0123
Maximum	2.7586	3.3497	3.3980
Total Carbon stock [Mg]	68.7728	80.3054	84.5281

The results showed that for the 312 trees observed, the total carbon stock was 68.77 Mg for field height measurement, 80.31 Mg for TLS measurement and Airborne LiDAR was 84.53 Mg which showed significant difference between the measurements.

3.3 Effects of error propagation and sensitivity analysis

The errors in the tree height measurement range from the errors associated with the instruments, the actual measurements and the conditions in the forest especially the canopy/crown structure, slope/landscape that hamper accurate measurement of the tree height. These error once introduced, propagate in to the estimation of the AGB. In this study, the errors in tree height measurement were quantified and used for varying the actual height measurements to assess how they affect the overall estimation of AGB and consequently carbon stocks. The errors then propagate in to the estimation of the AGB. The amount of tree biomass was found to be sensitive to the changes in the height. Tree biomass for 25 selected trees were plotted for the different methods (field measurement) with an adjusted height by ±4 m due to the RMSE of 4.20 m (Figure 7-1), TLS height measurement was adjusted by ±1.5 m based on the RMSE of 1.33 m (Figure 7-2). The sensitivity of the actual height measurements from field, TLS and Airborne LiDAR were also assessed to see how sensitive AGB was to the different the measurements (Figure 7-3). In this case, biomass was underestimated or over estimated by the field measurement that was associated with standard errors of ±3.12 m as well as ±1.62 m for TLS to measure tree height.

The height measurements from field, TLS and Airborne LiDAR showed a great variation in the amount of AGB measured from the trees. The differences were regarded as a result of the operationalization of the methods (Figure 6), especially, the height data from TLS and field measurement were collected from ground surface level and posed difficulty in detecting the actual tree top that defines the tree height meanwhile the Airborne LiDAR allows the capture of the information about the top of the trees from the air above these trees. The use of Airborne LiDAR was considered as the most accurate since it detects the actual tree height from the top of the trees. The TLS and field measurement were affected by the critical challenge of occlusion which significantly influences the accuracy of measurements.

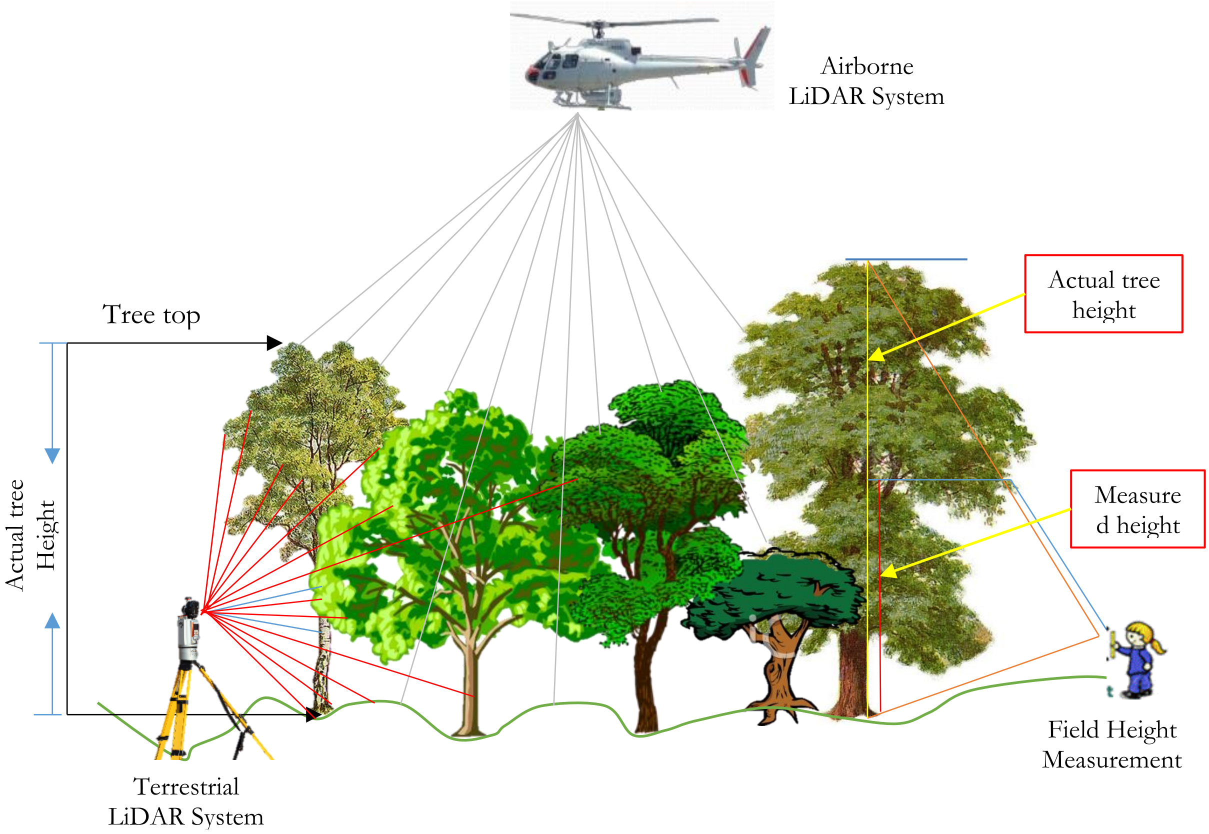


Figure 6. The operation of trees height measurement methods

The study area is a secondary tropical rainforest with varied tree species. It is one of the low laying tropical forest areas existing naturally. Field data was collected whereby tree height and DBH were measured using Leica DISTO 510 and diameter tape respectively. The 26 plots were also scanned using the Riegl VZ-400 scanner with multiple scans from all plots. The TLS plots were registered and georeferenced using the reflector tie points (15 tie points for each plot). From the TLS registered plots, tree height was measured alongside with the DBH. The Airborne LiDAR for the study area was also processed, the CHM was derived and tree height was measured and the same trees were matched with the field and TLS detected trees. In total 312 trees were matched on the field, TLS and Airborne CHM. The field measured DBH was related with the TLS measured DBH and it showed high correlation with high accuracy. R^2 of 0.97 and RMSE of 0.26 cm.

The CHM that was segmented with D value of 0.23 (77% accuracy) was used to identify trees which were considered as the basis for the assessment of the accuracy of the field measurement and the TLS measured tree height. When field measured height was assessed with the Airborne LiDAR CHM derived height, the accuracy of the field measurement was RMSE 4.20 m with R^2 of 0.61 and correlation coefficient of 0.76 mean while TLS measured height produced an accuracy of RMSE 1.33 m with R^2 of 0.91 and correlation coefficient of 0.96. The field measurement showed a relationship with TLS with R^2 of and correlation coefficient of when the two were compared. The various relationships imply that there is significant differences between the tree height measurements from field, TLS and Airborne LiDAR. The field and TLS underestimate tree height by 3.12 m and 1.62 m respectively as indicated by the respective standard errors when validated using Airborne LiDAR.

The accuracies of the height measurement methods mainly field and TLS are mainly due to the errors in the process of the height measurement in the field. The field measurement is associated with challenges of failure to see the top of the tree that is used to measure exact height due to occlusion, the crown projection and mixture with the crowns of other trees hence making if difficulty to hit the exact top for determining the exact tree height, slope. Meanwhile the TLS in a tropical forest is hindered by the occlusion of the individual trees within the plots, manual extraction methods that introduce bias in the tree extraction.

Tree AGB and carbon stock was calculated using the height measurement from the field, TLS and Airborne LiDAR. This statistically showed that there was difference among the AGB from the different methods when ANOVA and protected t-Test was done. The total AGB for 312 trees was 146. 33 Mg (field), 170. 86 Mg (TLS) and 179.85 Mg (Airborne LiDAR). The respective carbon stocks were 68.77 Mg (field), 80.31 Mg (TLS) and 84.53 Mg (Airborne LiDAR). The difference between the AGB form field and Airborne LiDAR (18.6%), TLS and Airborne LiDAR (4.99%). The result implies that field measured height only estimated 81.29% of AGB when Airborne LiDAR is used as the standard, meanwhile TLS estimates 95.02% of AGB that was obtained by the Airborne LiDAR. 25 trees were selected randomly out of the 312 to carry out the sensitivity analysis of the AGB to tree height measurement with different error thresholds that were quantified. The field measure tree height was varied by ±4.00 m based on the RMSE of 4.20 and the TLS height was also varied by 1.5 m based on the RMSE of ±1.33 m. The three actual measured tree heights for the same selected trees were also plotted to see the response of the AGB to the measurement. The results revealed that AGB is significantly sensitive to the height measurements and the height measurement vary due to the different margins of error.

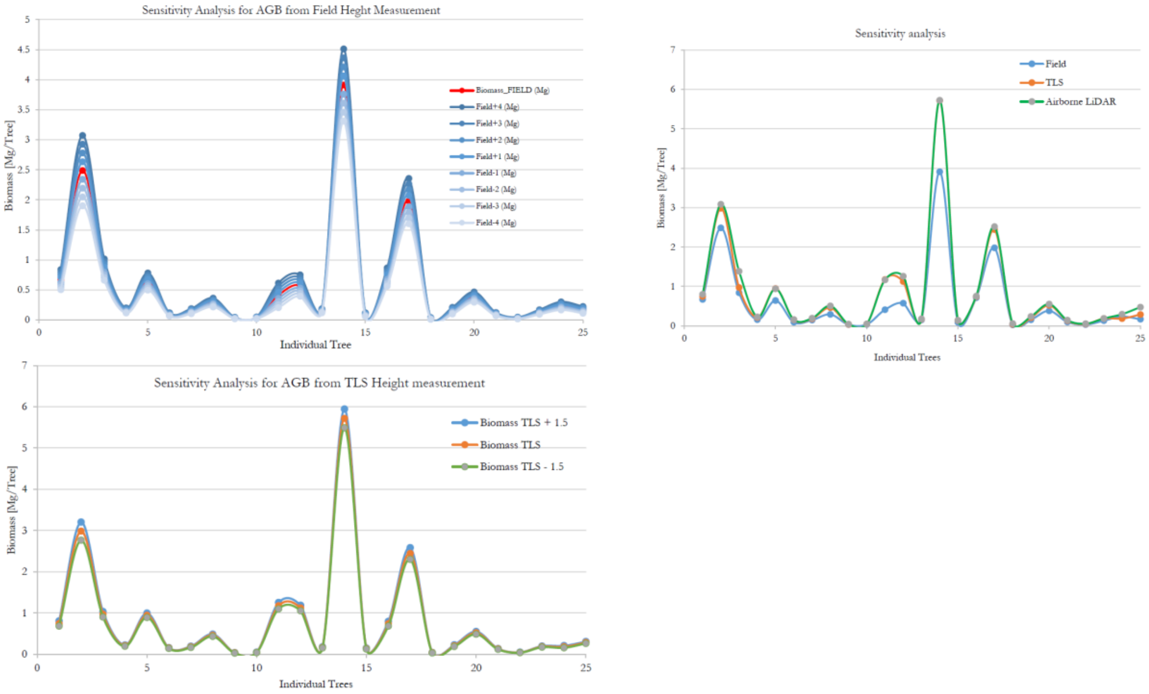


Figure 7. Sensitivity Analysis (upper left 7-1), lower left (7-2) and upper right (7-3).

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