REMOTE SENSING SENSORS AND APPLICATIONS FOR FOREST MAPPING & MODELLING IN MALAYSIA

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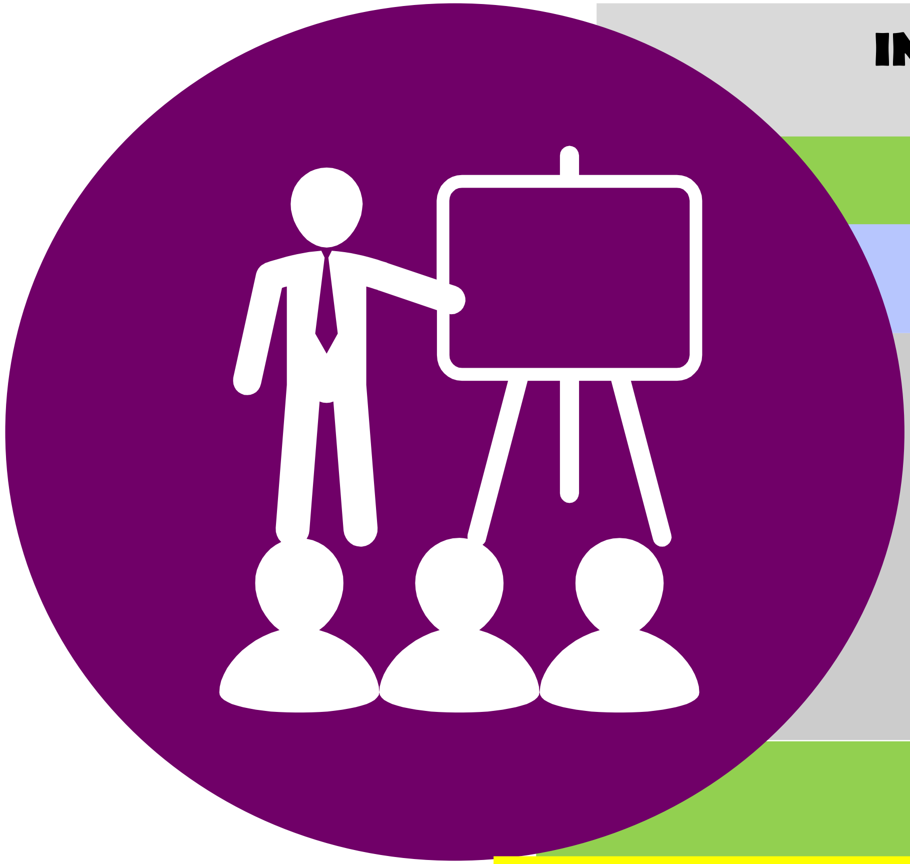
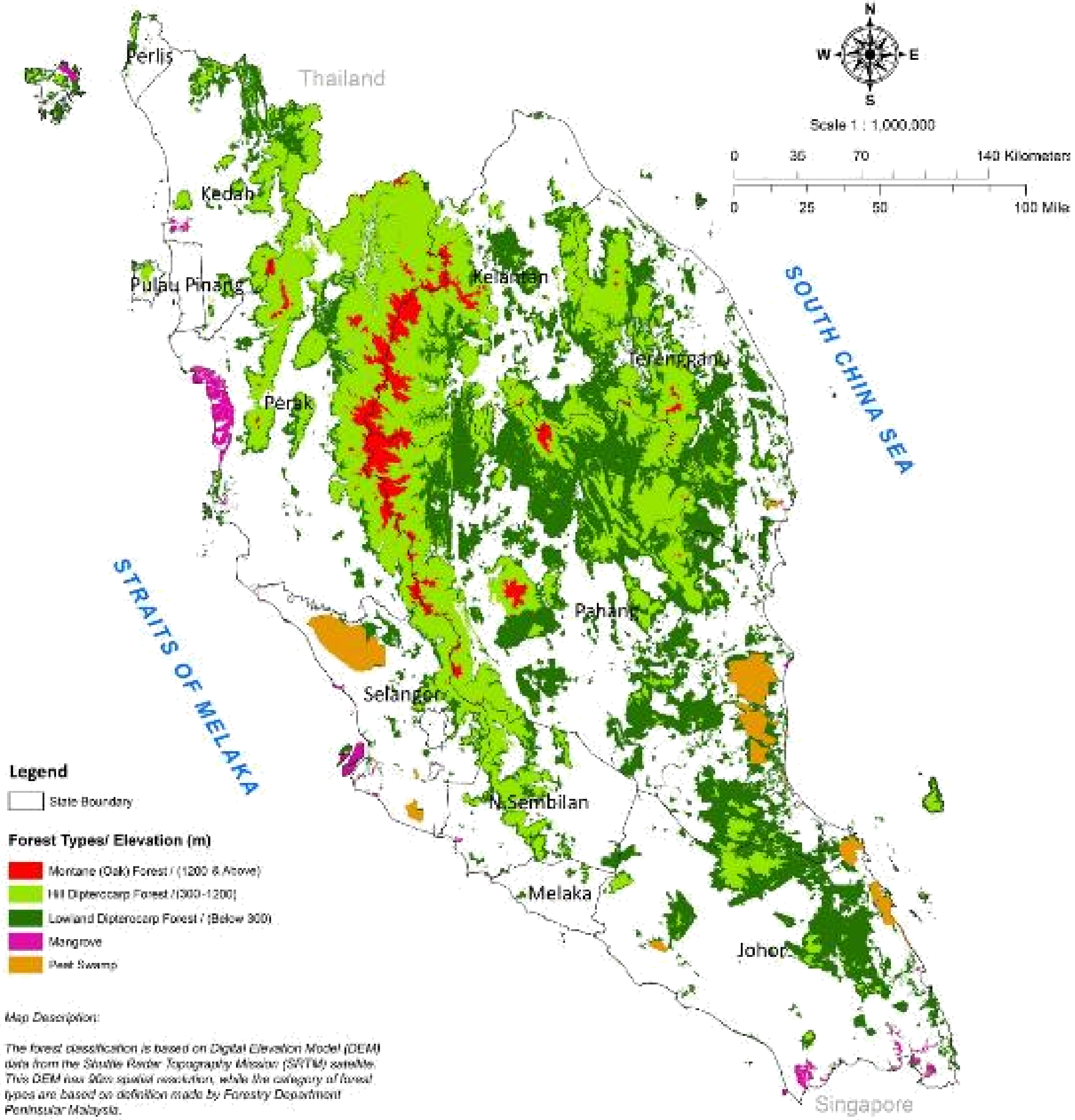


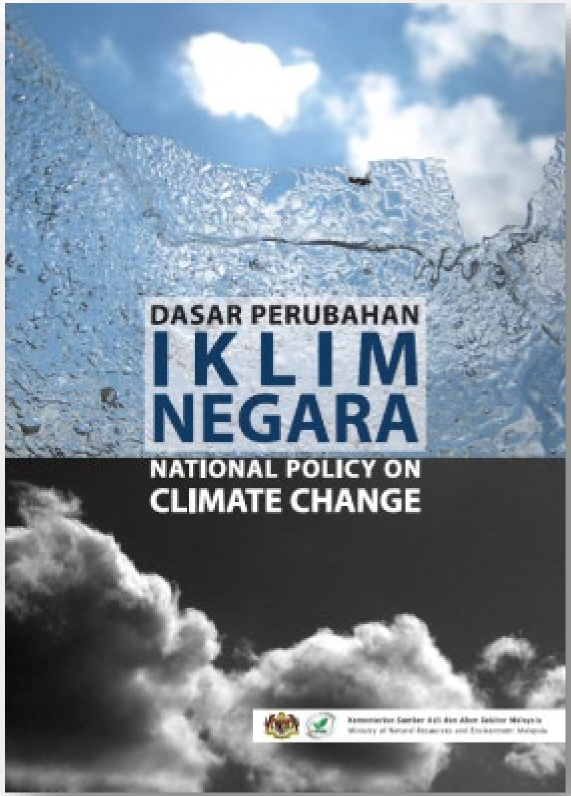
FORESTS IN PENINSULAR MALAYSIA

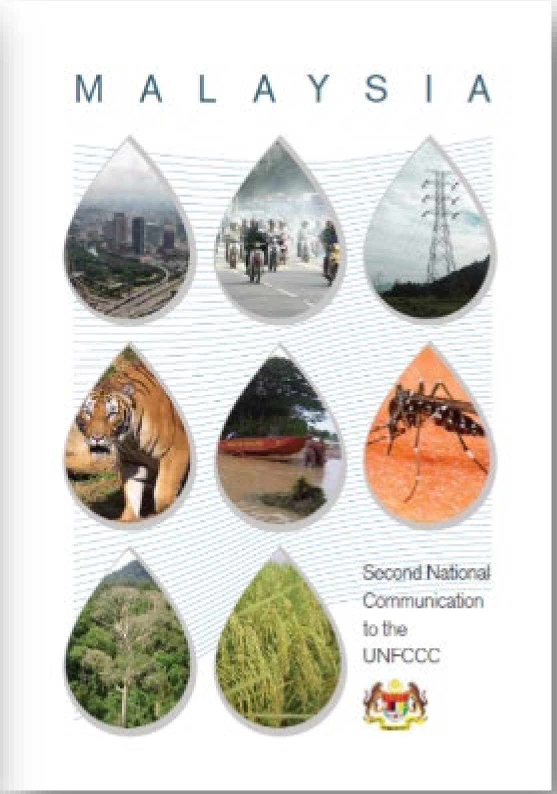
- More than 60% of the area is undulating lowland <300 m above sea level
- About 35% is hilly with elevations of 300 to 1300 m, and
- The balance is very mountainous Forests in this region comprises mainly inland dipterocarps, which consist of lowland, hill and upper hill, which are categorized based on land altitude, i.e. < 300, 300–750 and 750–1200 m respectively.
- Dominant trees family: Dipterocarpaceae.
- Other types of forests montane, peat swamp, and mangrove.

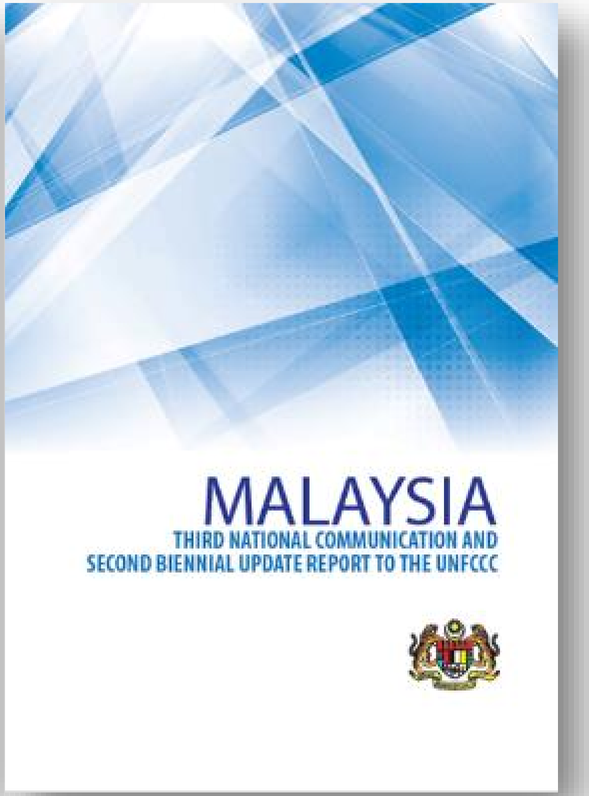


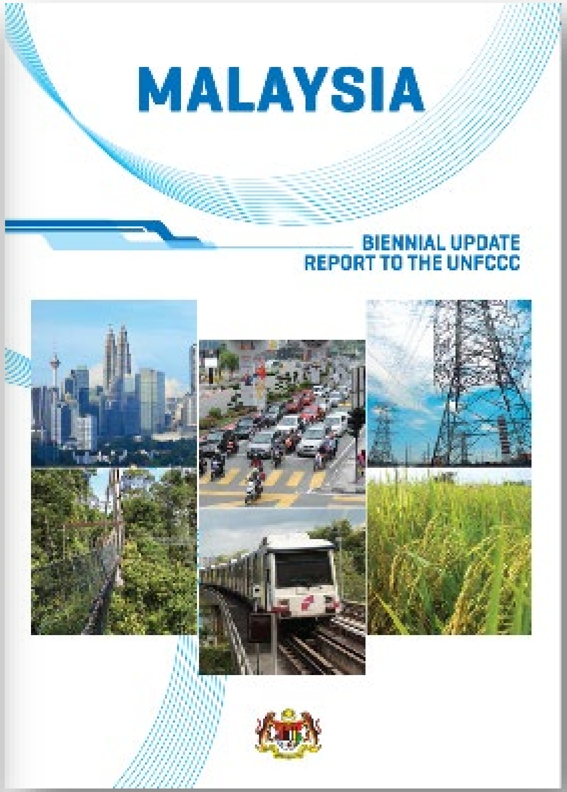
Malaysia has made a voluntary pledge to reduce emissions intensity of GDP by up to **40% compared based on 2005 levels by 2020** during the 15th Conference of Parties (COP15), 2017.

This demonstrates Malaysia's willingness to address GHG emissions in the context of sustainable development.









Issues related to forests

- GHGs emissions; Impact on climate
- UNFCCC, Kyoto Protocol (192 countries)

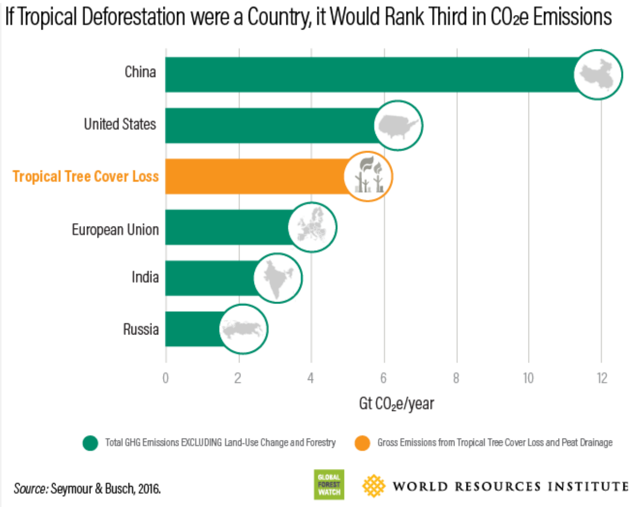
Issues related to forests

Deforestation and forest degradation

- The biggest threats to forests worldwide.
- Over half of the tropical forests worldwide have been destroyed since the 1960s, and every second, more than one hectare of tropical forests is destroyed or drastically degraded.
- The degradation and loss of forests threatens the survival of many species, and reduces the ability of forests to provide essential services.
- Deforestation and forest degradation impact the lives of 1.6 billion people whose livelihoods depend on forests. One billion of them are among the world's poorest.
- Nature-based solutions such as forest landscape restoration (FLR) can reverse the effects of deforestation and degradation and regain the ecological, social, climatic and economic benefits of forests.

Climate mitigation and adaptation

- The world's forests absorb 2.4 billion tonnes of carbon dioxide (CO2) per year, one-third of the annual CO2 released from burning fossil fuels.
- Forest destruction emits further carbon into the atmosphere, with 4.3–5.5 GtCO2eq/yr generated annually, largely from deforestation and forest degradation. Protecting and restoring this vast carbon sink is essential for mitigating climate change.
- Forests also play a crucial role in climate change adaptation efforts. They act as a food safety net during climate shocks, reduce risks from disasters like coastal flooding, and help regulate water flows and microclimates.
- Improving the health of these forest ecosystems and introducing sustainable management practices increase the resilience of human and natural systems to the impacts of climate change.



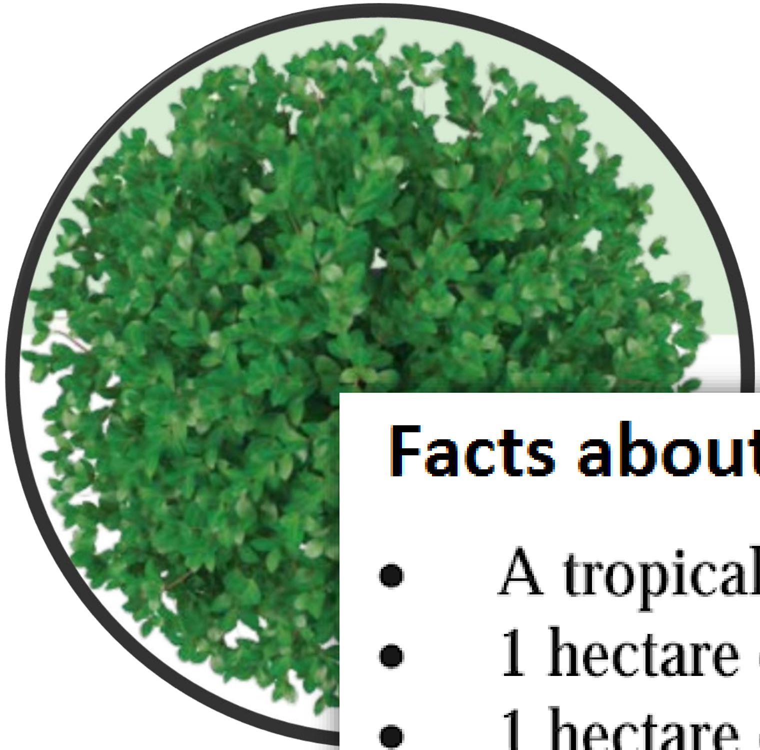
20% of the world carbon emission is due to deforestation and over exploitation of forests

▪*The International Union for Conservation of Nature (IUCN)*


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
SUSTAINABLE DEVELOPMENT GOALS

The first UN Strategic Plan (2017-2030) for Forests

On 20 January, 2017, during the UN Forum on Forests, 197 Member States reached agreement on the first UN Strategic Plan for Forests that provides an ambitious vision for global forests in 2030. This plan will significantly improve the outlook for the world's forests, including a target that would expand the world's forests by 120 million hectares - an area about the size of South Africa - by 2030.



Facts about carbon and forest

- A tropical forest absorbs 5.5 kg of CO_2/year.
- 1 hectare of tropical forest captures 4.3 t CO_2/year.
- 1 hectare of tropical wetland absorbs 1.48 t CO_2/year.
- 1 tree absorbs approximately 1,000 kg of CO_2.
- 1 acre of trees stores 2,600 kg of carbon/year, where tree cover for urban area is about 204 trees/acre; for forests, it is about 480 trees/acre.

Source: www.coloradotrees.org and www.conservationfund.org/gozero

Forests contain about 70% to 90% of terrestrial above ground and below ground biomass.

FOREST AGB WITH FIELD STUDIES AND REMOTE SENSING

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.

Not totally rejected! Incorporating them with modern remote sensing data would considerably help in quantifying, monitoring, and understanding forest AGB at various scales.

More comprehensive and reliable approach for estimating biomass change is to combine new field studies with analysis of high-resolution remotely sensed data. The remote sensing data could be useful to delineate forests into different biomass strata.

Constraints in Forest Biomass Assessment

- Assessment of forest biomass at landscape level are usually tasked to produce timely and accurate estimates for a wide range of forest resource.
- Now, many of the recent innovations have involved remotely sensed data and related statistical estimation techniques.

COST

- Field data collection
- Data & Equipment
- Staff/Labor

TIME

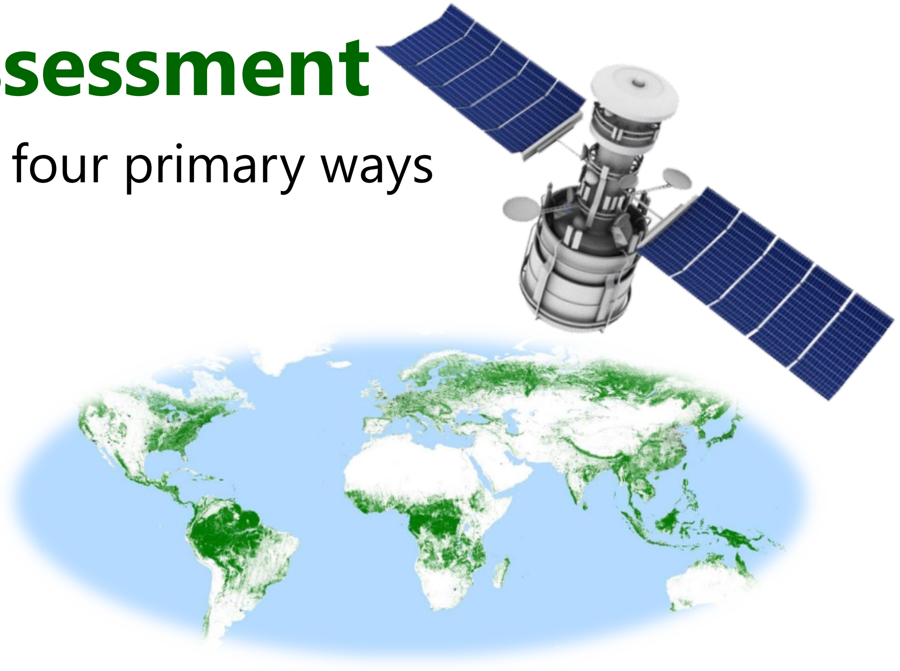
- Frequency of measurements
- Area of coverage
- Processes flow

ACCURACY

- Frequency of measurements
- Processes flow
- Reporting

Remote Sensing for Forest Biomass Assessment

Remote sensing currently enhances forest biomass assessment in four primary ways

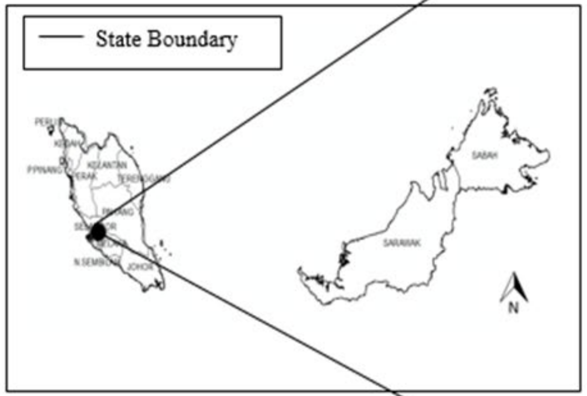


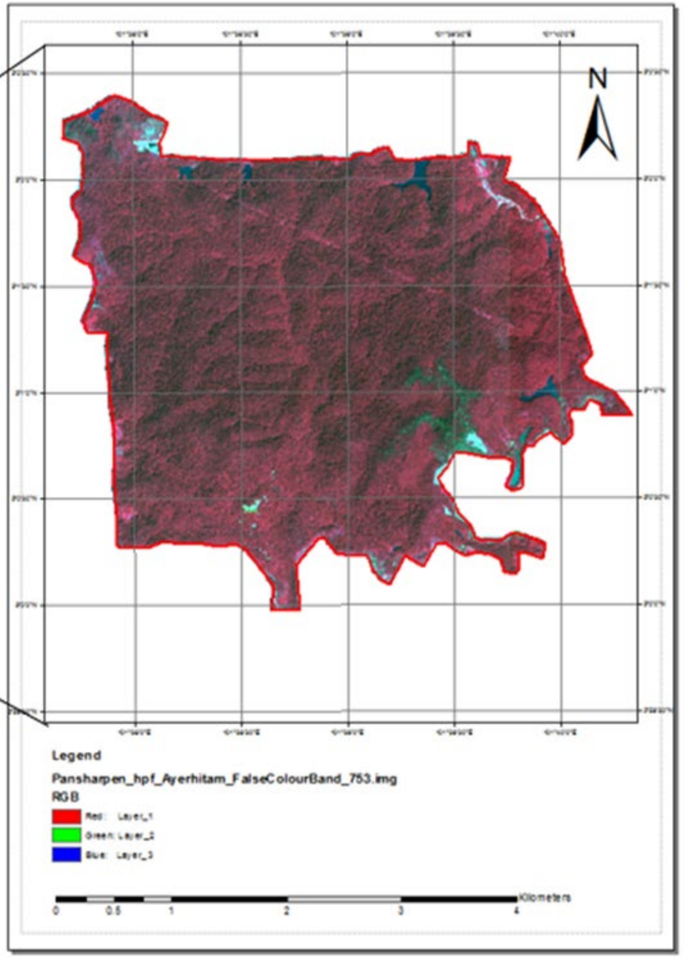
- Providing faster and less expensive observation or measurement of some forest attributes.
- Increasing the precision of large area inventory estimates, often via stratified or weighted estimation
- Providing inventory estimates with acceptable bias and precision for small areas for which sufficient field data are not available (minimum field data collection)
- Thematic maps that can be used for purposes such as for forest inventory, timber production, procurement, ecological studies, and management

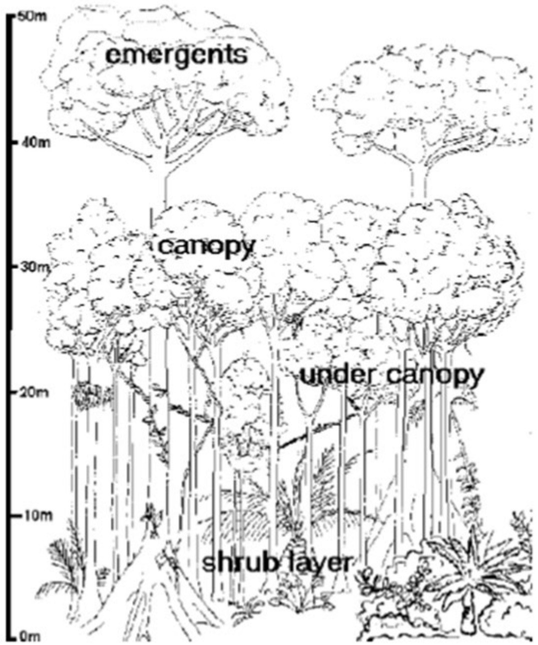
REMOTE SENSING OF TROPICAL FOREST: MALAYSIA CASE STUDY

- ✓ **AGB estimation with airborne LiDAR & WORLDVIEW-3 in lowland tropical forest**
- ✓ AGB estimation with airborne and terrestrial LiDAR scanner in lowland tropical forest
- ✓ Airborne LiDAR mapping of Universiti Teknologi MARA Selangor Campus

- The AGB estimation study using airborne LiDAR was conducted in 2015 in the spirit of collaboration between Faculty of Forestry, Universiti Putra Malaysia.
- The objective of the study is to assess the accuracy of estimation of forest inventory parameters and AGB derived from airborne LiDAR at Ayer Hitam Forest Reserve (AHFR), Malaysia .
- The AHFR is a logged over lowland dipterocarp forest, which covers an area of 1,176.1 ha.
- AHFR has about 430 species of seed plants from 203 genera and 73 families.



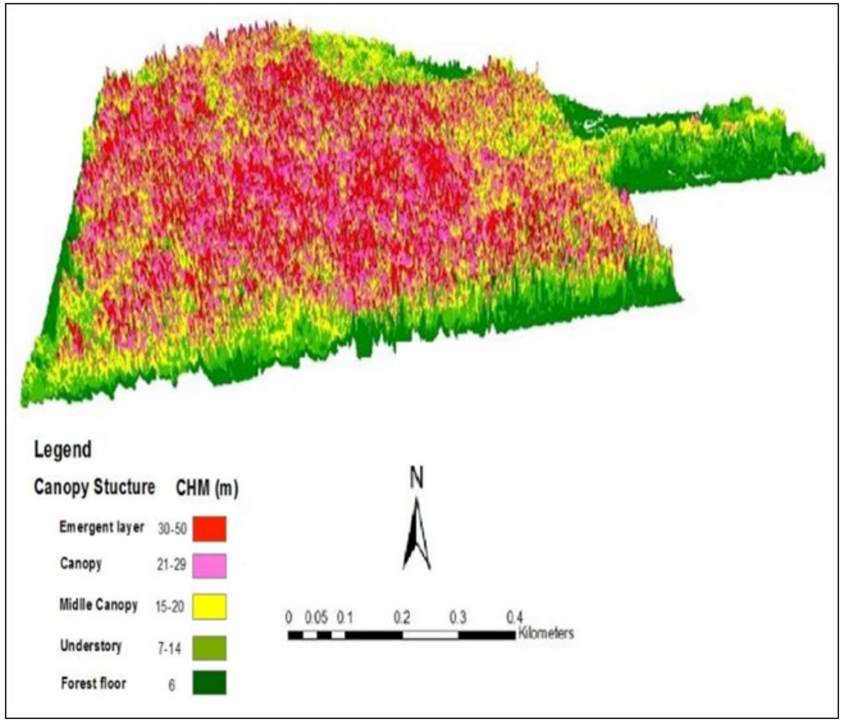




Tropical rainforest structure
Source: (Bennett, 2009)

MATERIAL AND METHODS

- **Airborne Laser Scanning (ALS) Data and WV-3 data**
- The ALS survey had been flown using a Eurocopter 120 on August 2013. The LiteMapper-Q560 that consist of RIEGL LMS-Q560 laser scanner for LiDAR scanner was mounted on the aircraft, along with the Hassleblad digital camera 39 megapixel with 50mm focal length.
- The projection used is WGS1984 UTM Zone 47N. The ALS survey of raw files was pre-processed using AeroOffice IGI to analyse the quality of IMU and GPS data. Terrasolid tools were used to process the ALS dataset (Bentley Systems, 2015) into LIDAR 3D point clouds.



System	LiteMapper-Q560
Scan angle	45 º
Pulse frequency	150kHz
Overlap	Side overlap 40,frontal overlap 60
Swath width	1155m
Ground Speed	90knot
Flying height[a]	1000m
Laser scan angle	Min 426º max 60 º

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- **Field sampling plot**
- Field sampling plot were conducted on May 2015 at 2-hectare rectangular plots that consist of 50 number of subplots (20 x 20 m) using stratification number of sampling.
- In each plot, every tree that has more and equal to 10 cm DBH were inventoried and recorded.
- The parameter - tree id, tree location, species, stem diameter at breast height, crown base height, crown diameter, tree height and leaf area index of the subplot area.
- The field plot and tree coordinates were tied by the traversing using total station from a known Global Positioning System (GPS) reference stations.
- The reference stations were observed using GPS using Topcon GTS with static L1/L2 and L5 bands.

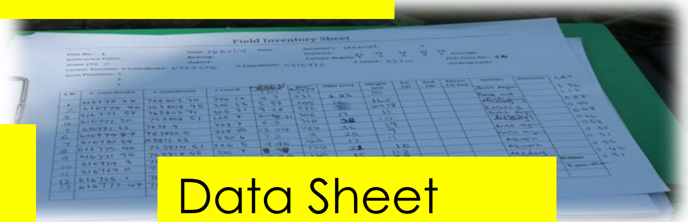
Height of the tree

Leaf Area Index (LAI)

GPS Observation

Hemispherical Photo

DBH of the tree



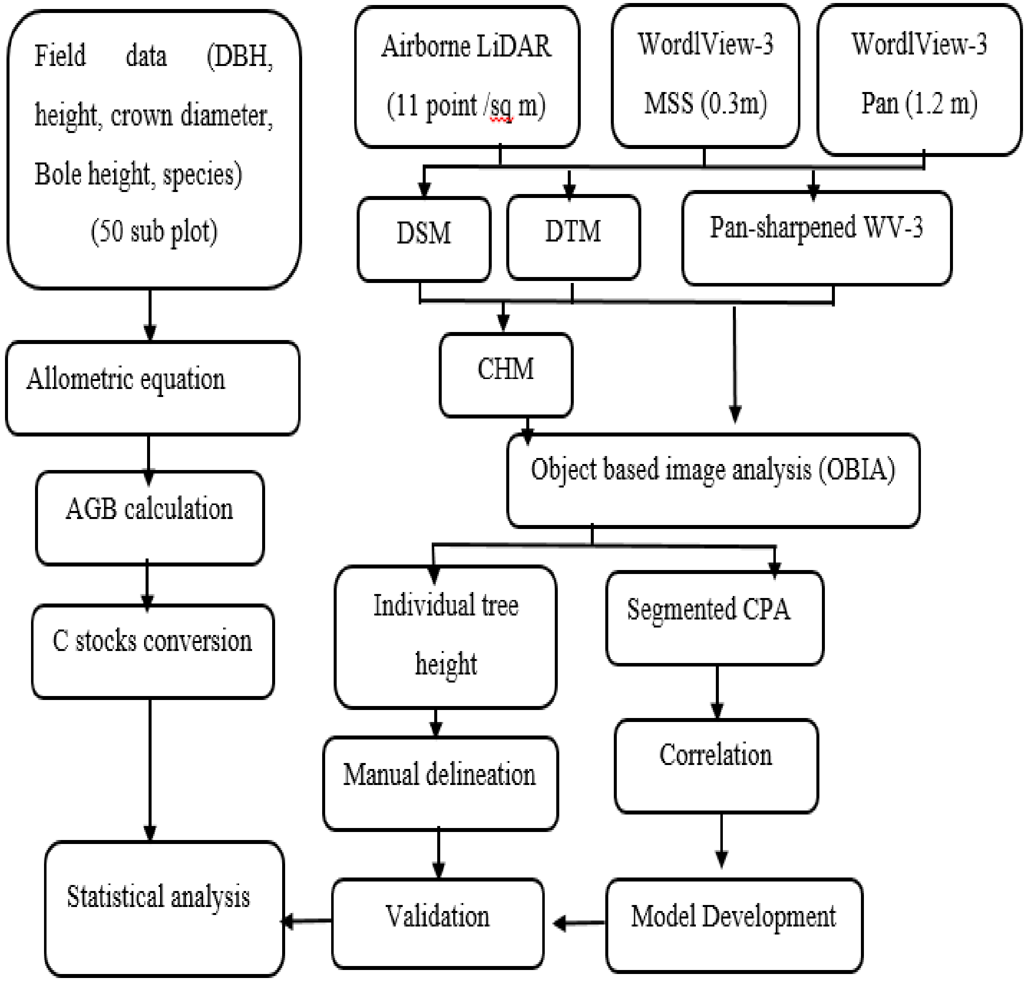
Data Sheet

Traversing to central plot

MATERIALS AND METHOD

Data Preparation and Analysis

- This study was performed according to three major phases.
- This comprises of the data collection of the forest stands, data acquisition, pre-processing of the data, object based image analysis (OBIA), model development, validation of the data and finally the statistical analysis.



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MATERIAL AND METHODS

Canopy Height Model generation

- Canopy height model is generate from the highest echo of first return laser pulse known that create the digital surface model (DSM) subtract with the lowest echo of last return which is known as digital terrain model (DTM).
- Normalization is applied to the CHM which gives the absolute point of height of tree height on Z-axis, and according to the dataset, the maximum tree was 44m.
- The CHM was created using LAStools software in ArcGIS plug-in.

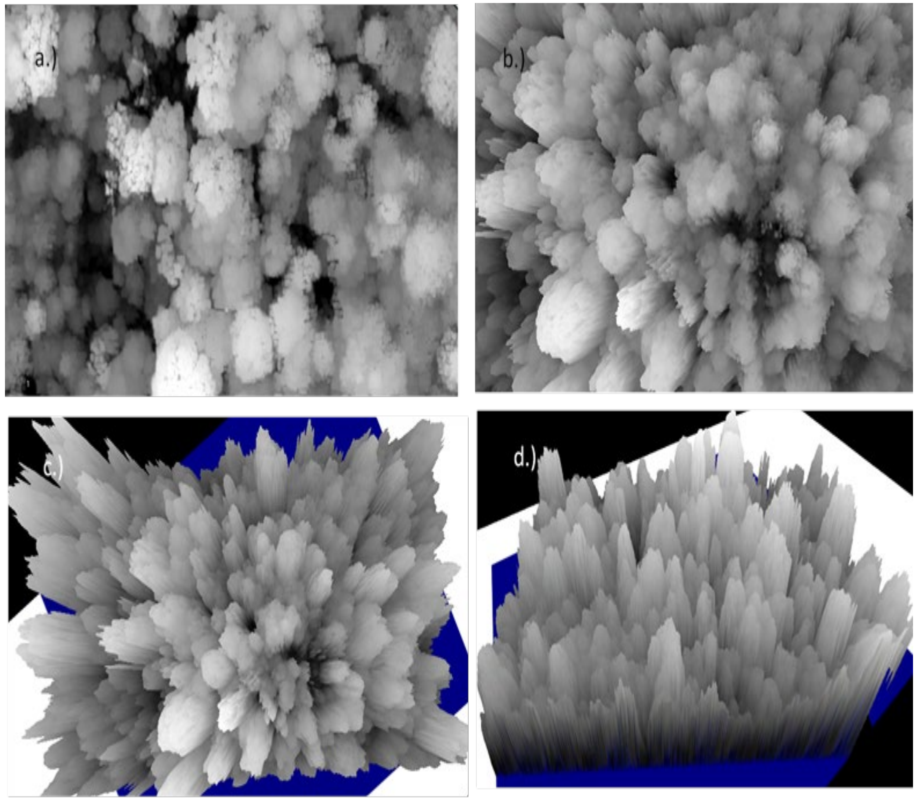


Figure A map of the location of the study area. Figure 2a. Shows the location of Selangor District, at Peninsular Malaysia. Fig. 2b shows a location of Ayer Hitam Forest Reserve Lowland Dipterocarp forest covered by the WV-3 satellite image data.

MATERIAL AND METHODS

- **Estimation Carbon stocks using allometric equation**
- AGB estimation were calculated using allometric equations (Chave et al., 2014) that uses wood density, height and DBH as predictors.
- Wood density is an important predictor in the calculation of AGB based on species despite of the height and DBH.
- On the basis, carbon were converted by applying the conversion factor of 0.47 which represents 47% of the dry biomass assumed to be carbon for all part of the tree as the default value that had been recommend by IPCC (IPCC, 2006).

$$AGB_{est} = \exp[[-1.803 - 0.976\,E + 0.976 \ln \rho + 2.673 \ln(D) - 0.0299\,[\ln(D)^2]]]$$

Where AGB = Aboveground biomass (kg / tree), ρ = wood density, E = Bioclimatic variables and D = diameter at breast height (DBH).

MATERIAL AND METHODS

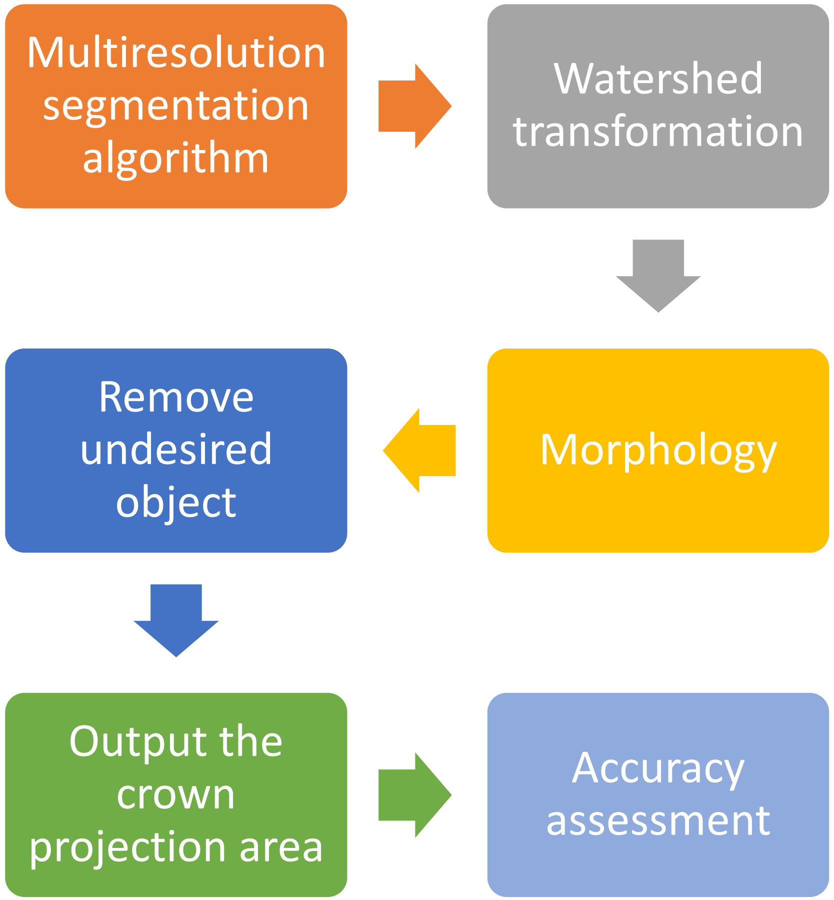
Crown Projection Area (CPA) delineation and validation:

- Segmentation accuracy is measured based on distance index (D) ranging from 0 to 1, where 0 shows that the classification is an ideal match between xi and yi, while 1 is the minimum mismatch.

$$Over\ segmentation = 1 - area\frac{(xi \cap yj)}{area\ (xi)}$$

$$Under\ segmentation = 1 - area\frac{xi \cap yj}{area\ (yj)}$$

$$D = \sqrt{over\ segmentation^2 + under\ segmentation^2\ /2}$$



MATERIAL AND METHODS

Statistical analysis

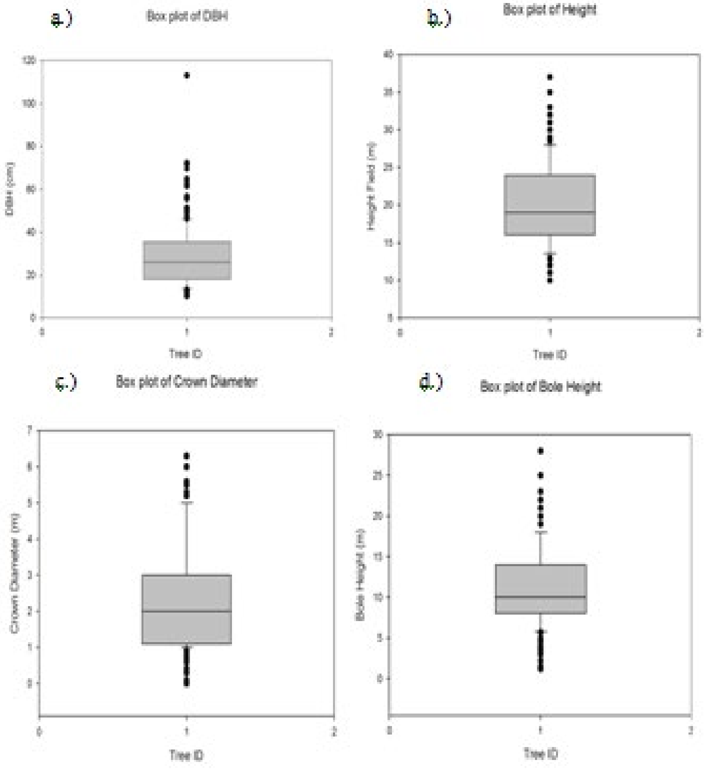
- The correlation between CS stocks, height, DBH and CPA were analysed using Pearson's correlation as well as multiple linear regression model.
- The statistical analysis is proceeded by performed by calculating statistical parameter such as residual R^2, adjusted R^2, Root Mean Square Error (RMSE).
- The multi-collinearity test also had been done in order to avoid any collinearity problem between variables, with a tolerance cut of value of variance inflation factor (VIF) should be less than 10.

$$VIF = \frac{1}{(1 - R_j^2)}$$

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(yi - \hat{yi})^2}{n}}$$

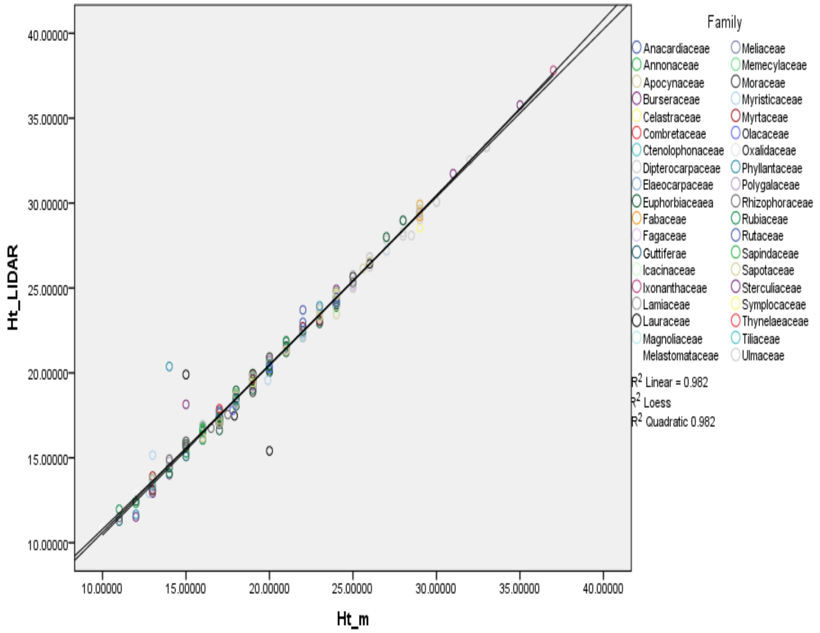
ANALYSIS AND DISCUSSION

- **Descriptive statistics**
- The accuracy of GPS observation at the base station was 3 mm for horizontal (x and y) and 5mm for vertical (z) plot. In total, 911 of tree had been measured from the observation where six dominant genuses had been identified: *Dipterocarpaceae*, *Euphorbiaceaea*, *Burseraceae*, *Sapotaceae*, *Moraceae*, *Rhizophoraceae* and *Rubiaceae*.
- Dominant species nominated by *Endospermun diadenum*, *Hopea Sulcata*, *Shorea Macroptera* and *Dipterocarpus Verucosus*.



Validation of LiDAR derived tree height

- With regards to the analysis, the highest positive r value was recorded for LiDAR tree height versus field tree height which is 0.995
- Results show that there is no significant difference ($p > 0.01$) between height measured from field and height derived from LiDAR.
- However, there is a strong correlation between height measured from field and height derived from LiDAR.

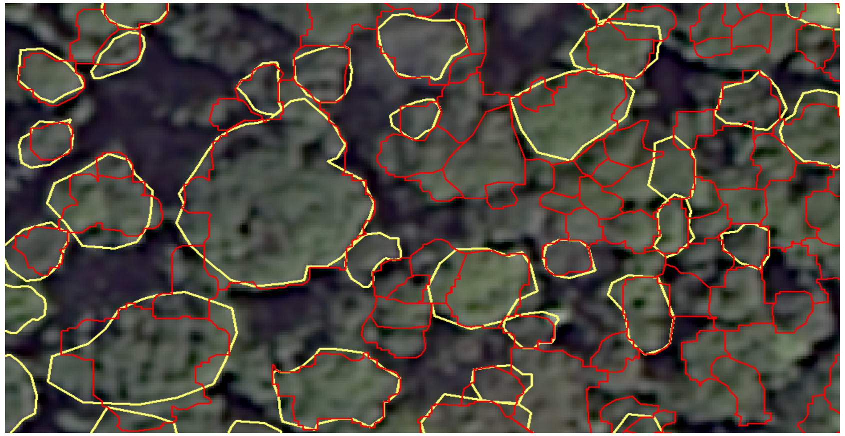


Correlation of coefficient	0.991
R^2 Linear	0.982
Adjusted R^2	0.982
Standard Error	0.699
RMSE	0.486
Intercept	0.739
Number of sample	245

Accuracy assessment of segmentation output

- Accuracy assessment of the tree crown segmentation had been applied in two techniques, which is i.) By using techniques 1:1 matching of the references and segmentation polygon
- ii.) Quantify the goodness of fit (D) which represents the ideal segmentation.
- The average accuracy of the segmentation is 79.5%. Out of 288 manually delineated of the crown, only 266 were matched 1:1 (78% match).
- The over segmentation and under segmentation value for this output is 0.19 and 0.11 respectively,thus D-value for the classification is 0.19 which is 81%

Table Head	Accuracy Segmentation				
	Total Reference Polygon	Total 1:1 match	OS	US	D
1:1	288	266			
Goodness of fit			0.19	0.11	0.19
Total accuracy		78%			81%



The segmented (Red colour) and Reference (Yellow) polygon

Multiple linear regression analysis

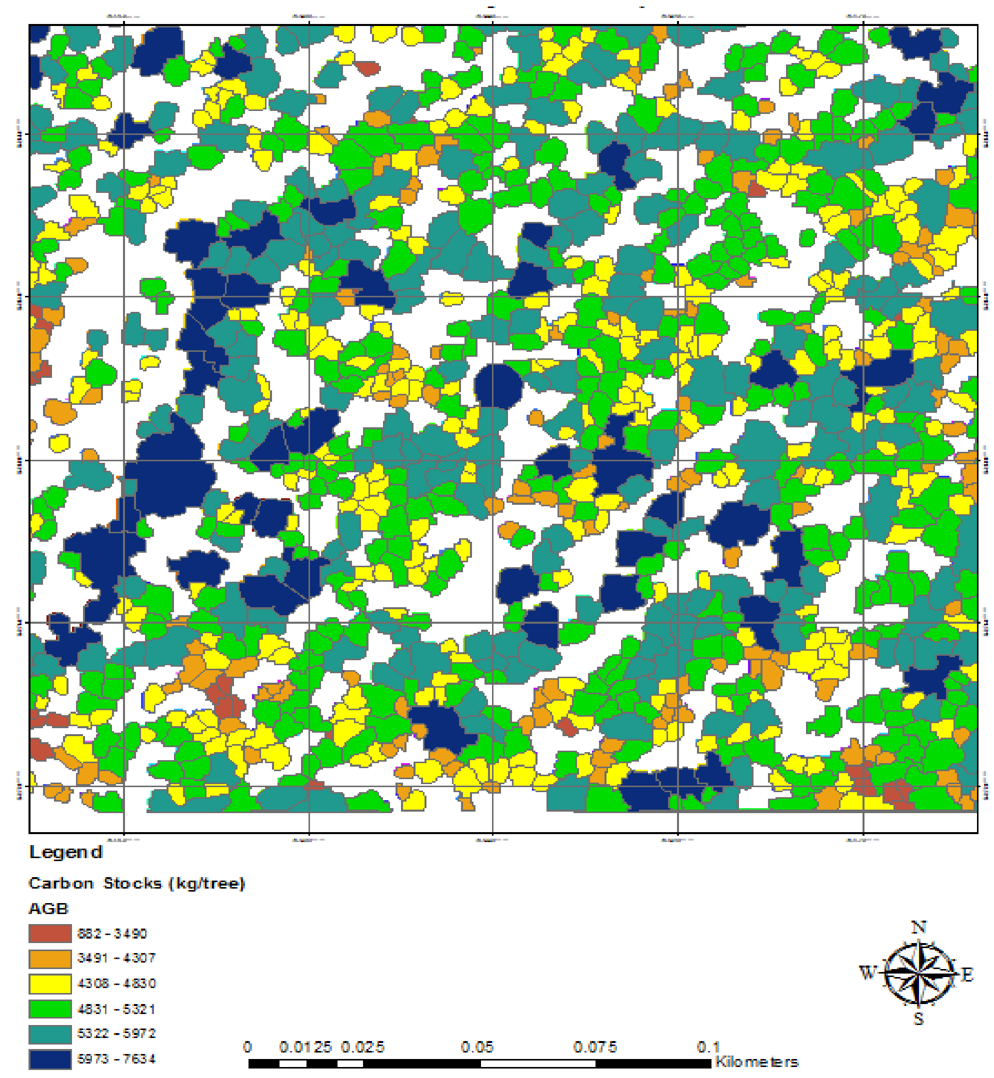
- Based on the regression, there was a negative linear relationship between predictor and output variables, β = -2971.429, ρ = 0.000 (p < 0.01).
- Multi-collinearity between the two variables had been checked by applying the variance inflation factor (VIF) test where the result shows that there was no sign of multi-collinearity found between these two variables (VIF= 1.363).
- By using multiple regression model to predict the carbon stocks estimation over the height derived from LiDAR and crown projection area was a negative predictors, β = -2971.429, p = 0.000 (p < 0.01) disputed that every unit increase of carbon stocks, the height from LiDAR and CPA were decreased by -2971.429m.

$$\ln \text{Carbon} = \beta 0 + \beta 1 + \ln(\text{Ht}_{\text{LIDAR}}) + \beta 2 \ln \text{CPA}.$$

$$\ln \text{Carbon} = -2971.429 + 1847.432 \ln(\text{Ht}_{\text{LIDAR}}) + 630.330 \ln(\text{CPA})$$

Carbon Stock Map

- The range of the predicted carbon is around 800 kg / tree to 7634 kg / tree where it can be concluded that the higher the CPA and height value, the greater the amount of carbon it would make.
- The darker colour of the CPA which indicates the highest value of carbon, while the white colour of the background of the map is the gap of each individual tree.



REMOTE SENSING OF TROPICAL FOREST BIOMASS: MALAYSIA CASE STUDY

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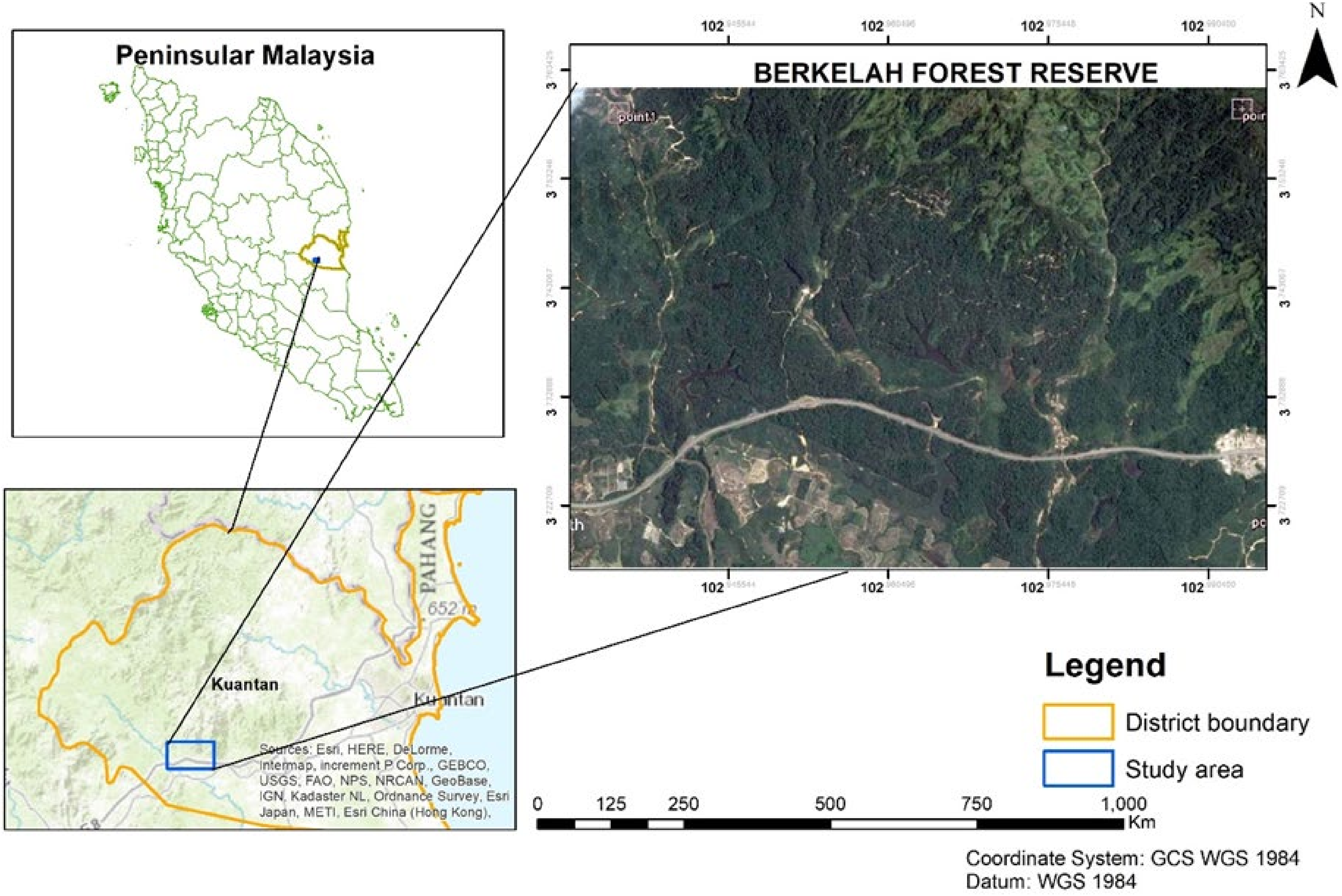
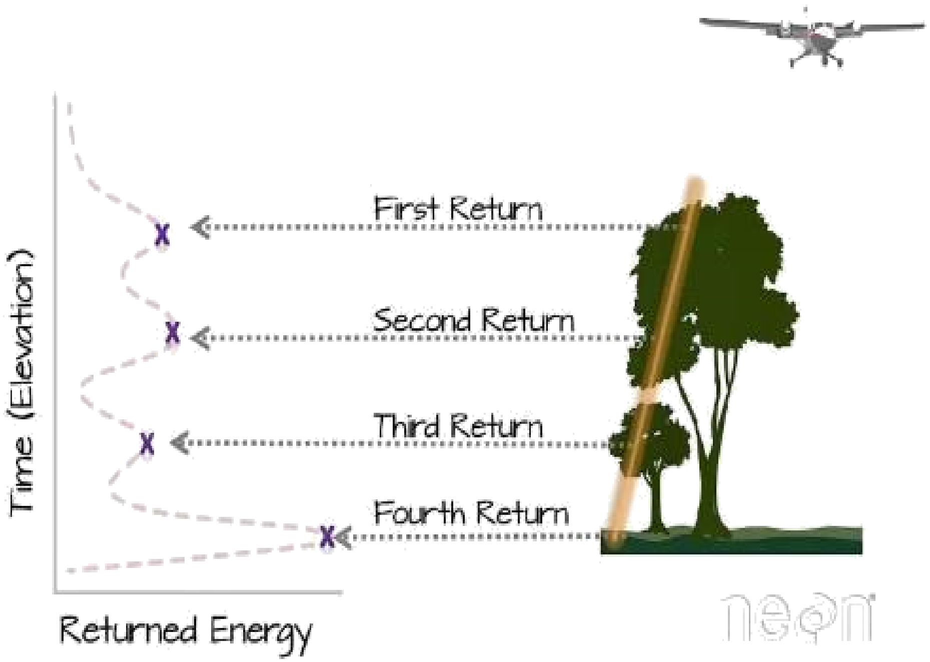
- ✓ Airborne LiDAR mapping of Universiti Teknologi MARA Selangor Campus

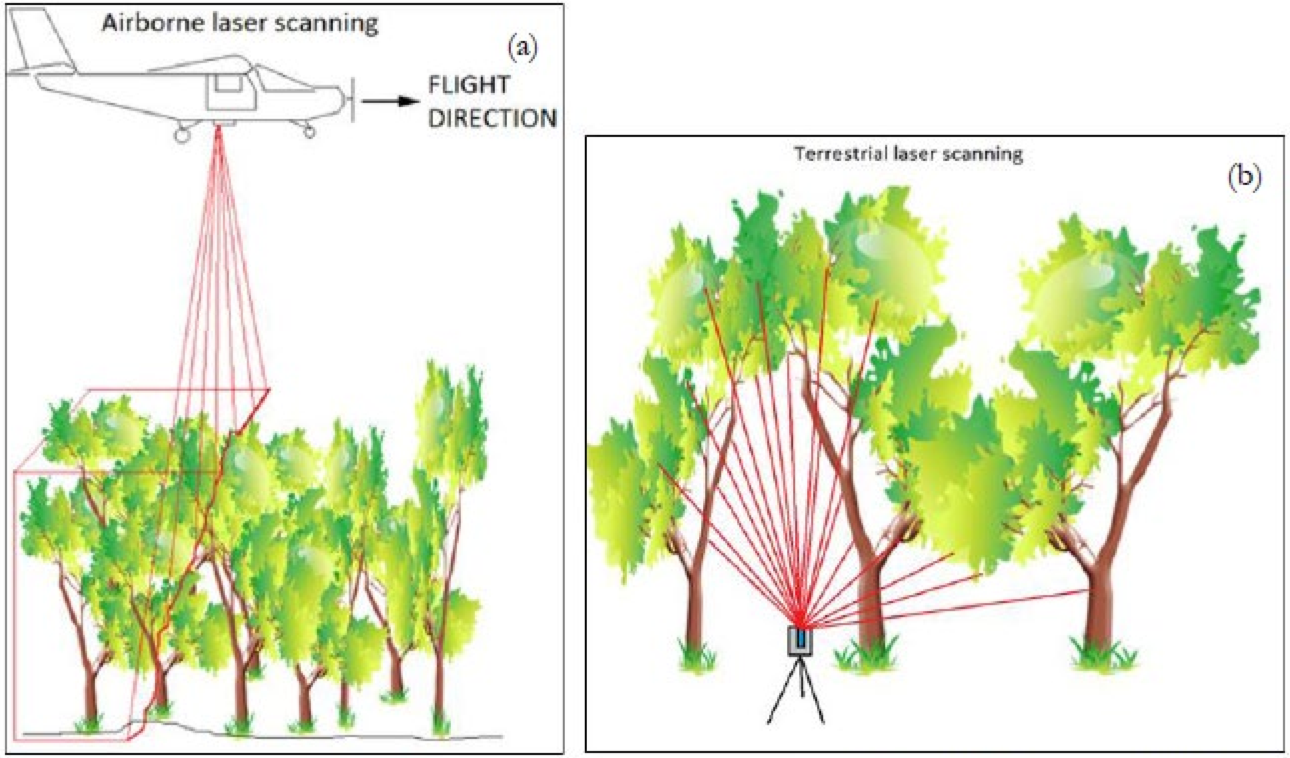

Peninsular Malaysia
BERKELAH FOREST RESERVE
point.1
Kuantan
PAHANG
652 m
Kuantan
Sources: Esri, HERE, DeLorme, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong),
N
102
Legend
District boundary
Study area
0 125 250 500 750 1,000
Km
Coordinate System: GCS WGS 1984
Datum: WGS 1984

LiDAR data acquisition



Lidar:

- Active sensor system that determine distance by using speed of light and emitted laser to travel to a target object.
- Differences in laser return times and wavelengths can then be used to make digital 3-D representations of the target.



Independent application LiDAR in simple structure forests (a)-ALS, (b)-TLS; Source: (AWF-WIKI, 2016)

Airborne LiDAR and terrestrial laser scanning system

Integrating these two technologies to a common coordinate frame enhances the detail of structural information obtained.

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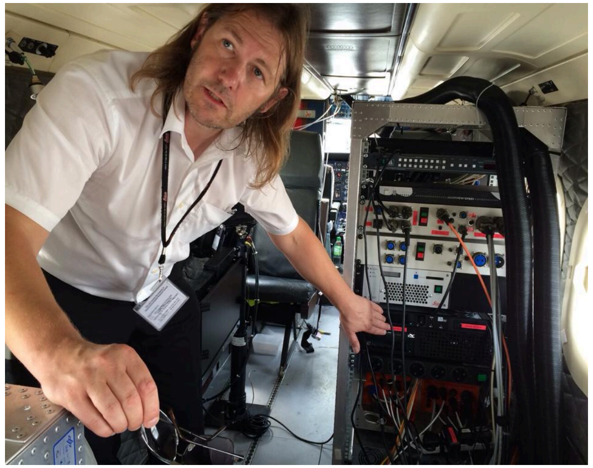
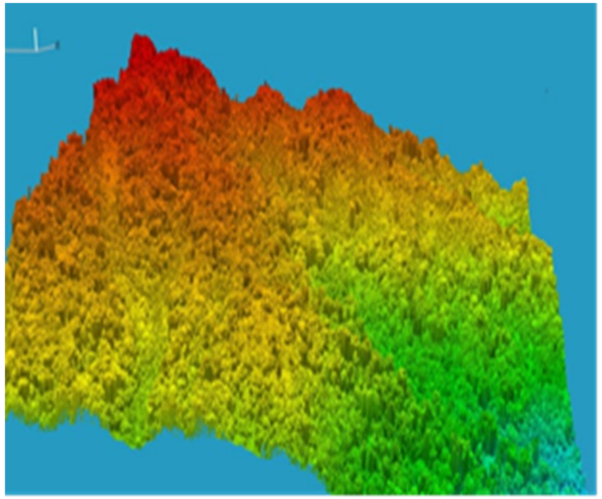
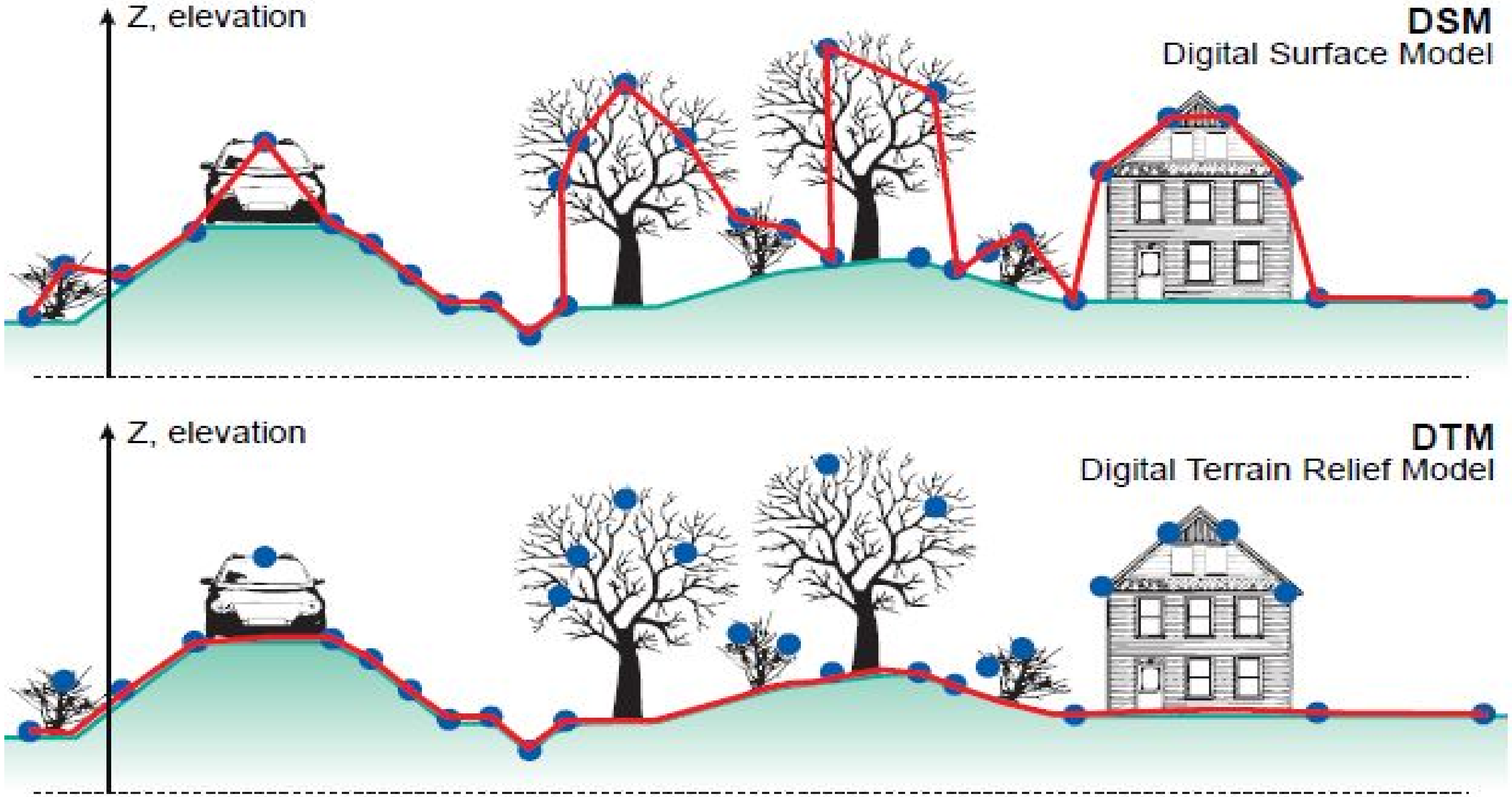
LiDAR data collection 2014

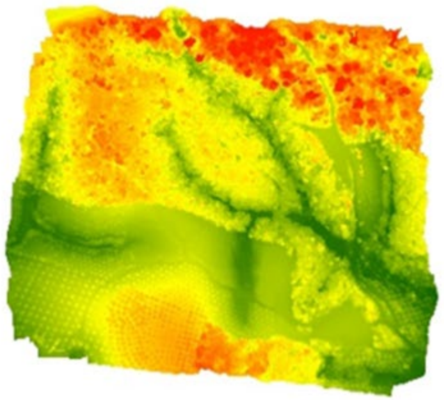




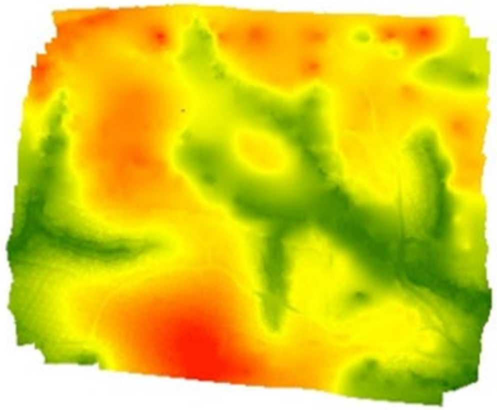


(Solomon, 2018)

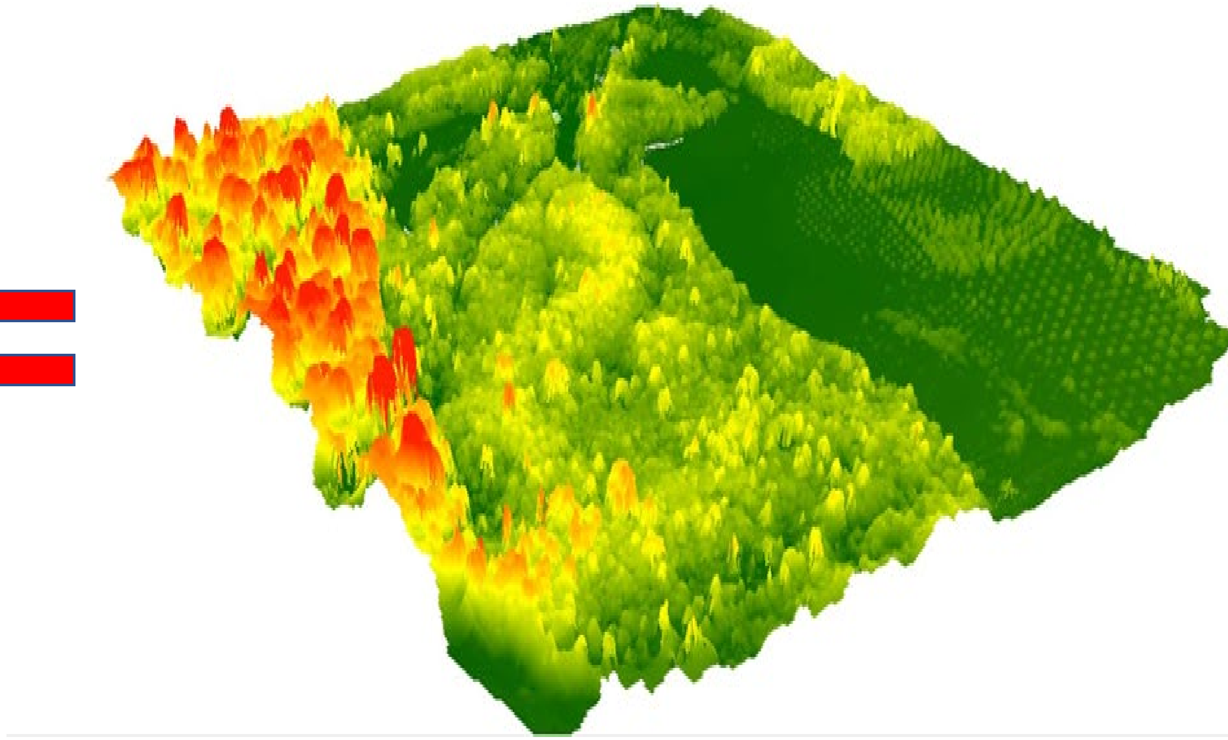
CANOPY HEIGHT MODEL (CHM)



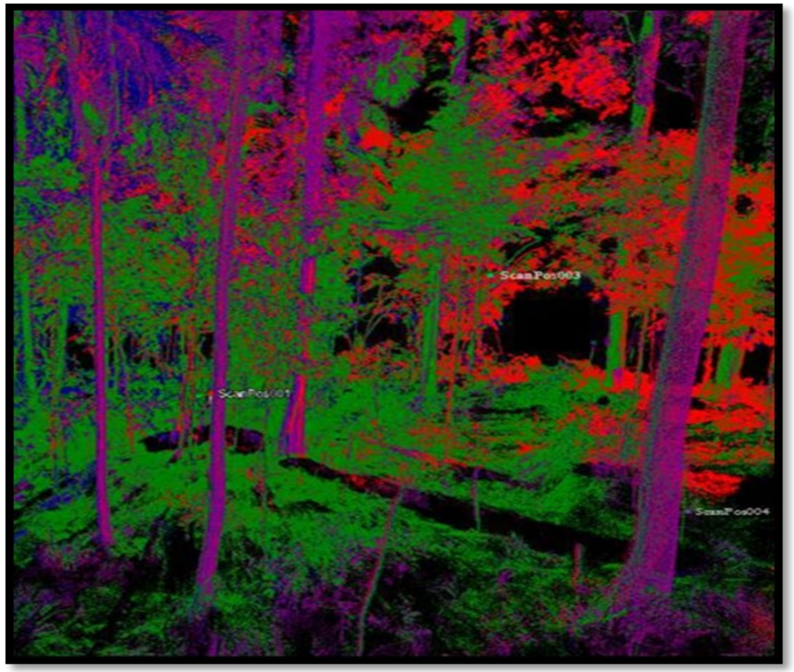
DSM



DTM

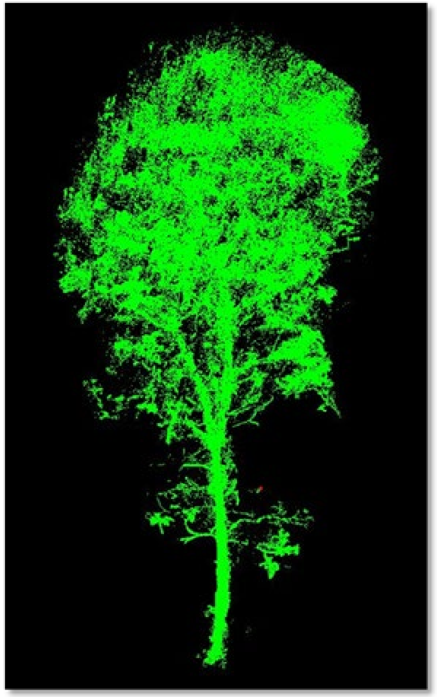



Hutan Lipur
Berkelah

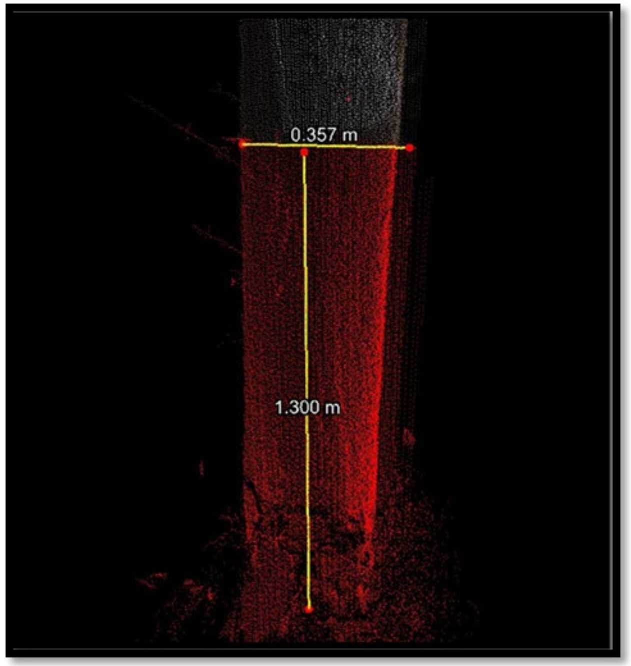


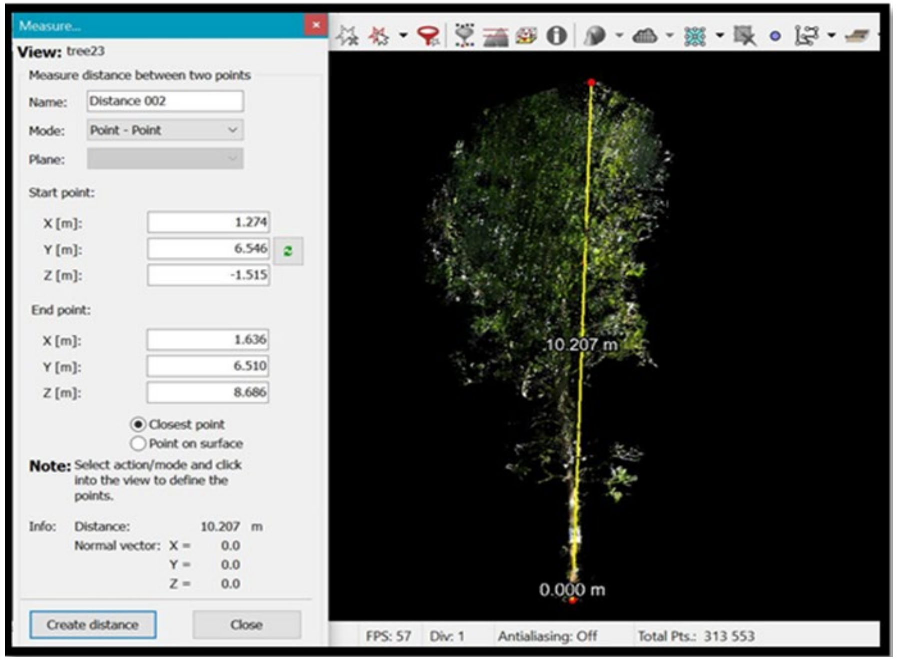
ABOVEGROUND BIOMMASS MAPPING

True color



False color

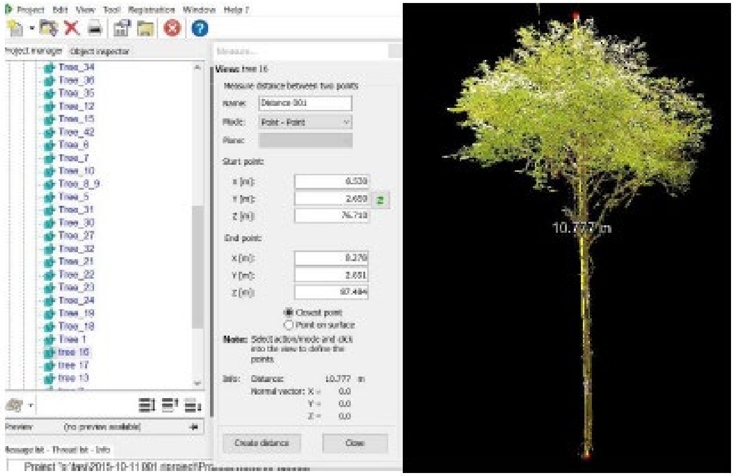




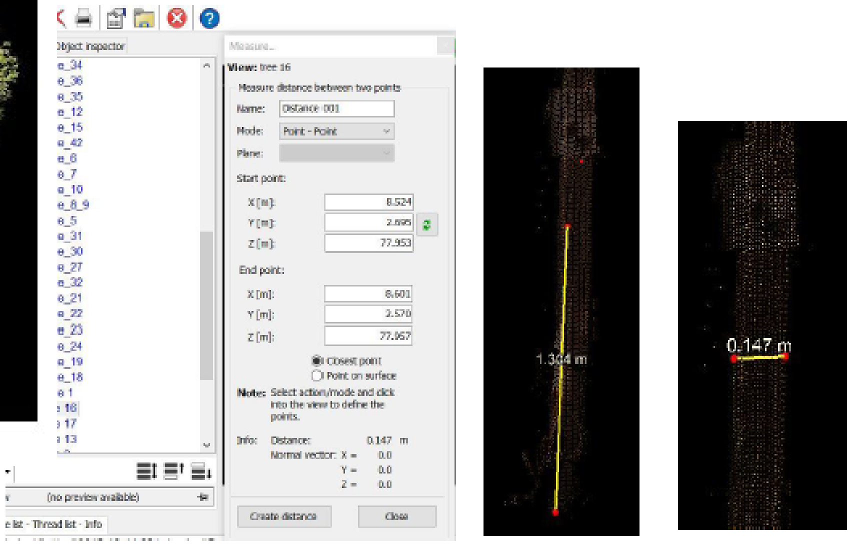
✓ AGB estimation with airborne and terrestrial LiDAR scanner in lowland tropical forest

Tree height and DBH

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 for the lower canopy.

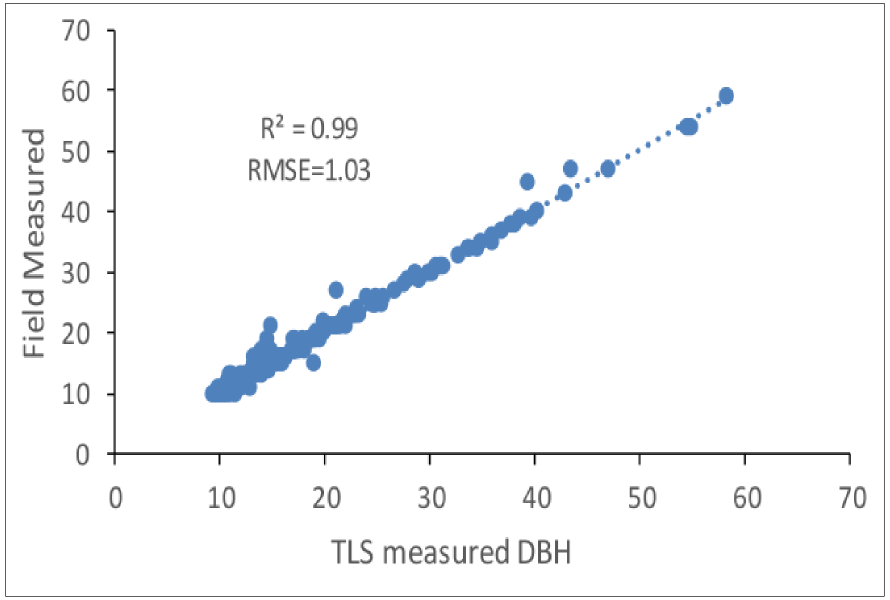


Tree height measurement of extracted trees.



DBH measurement of extracted trees.

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.



Scatterplot of the TLS and field measured DBH

✓ **AGB estimation with airborne and terrestrial LiDAR scanner in lowland tropical forest**

Results and discussion

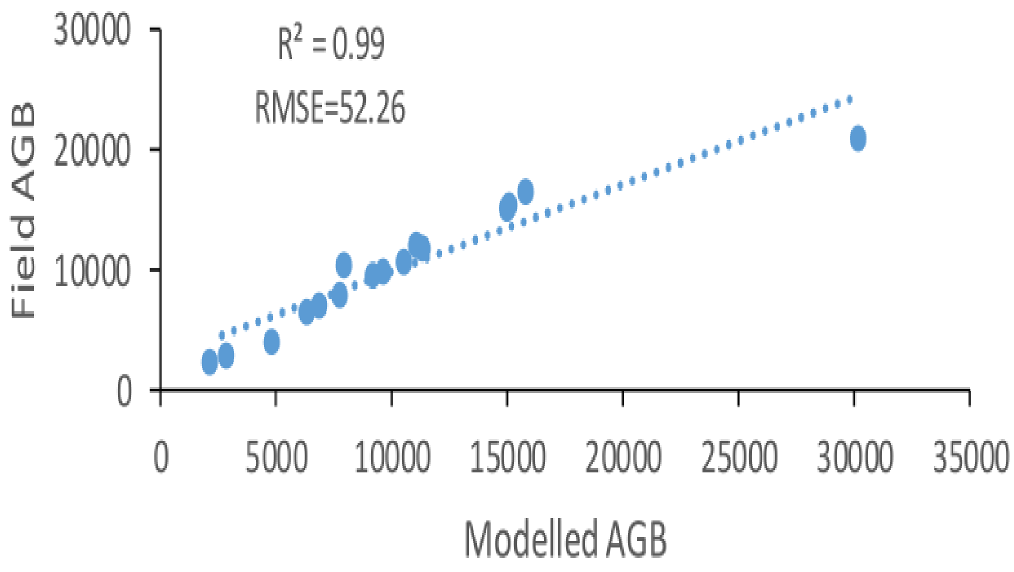
Modelled and field measured AGB of the upper and lower

To estimate the AGB an allometric equation was applied to the modelled DBH together with LIDAR-derived height (canopy height model).

The modelled AGB of the upper canopy and lower were validated using the field DBH and LiDAR-derived height. A robust model with an R^2 of 0.99 and RMSE of 52.26 Mg ha^{-1} was achieved for the 16 plots

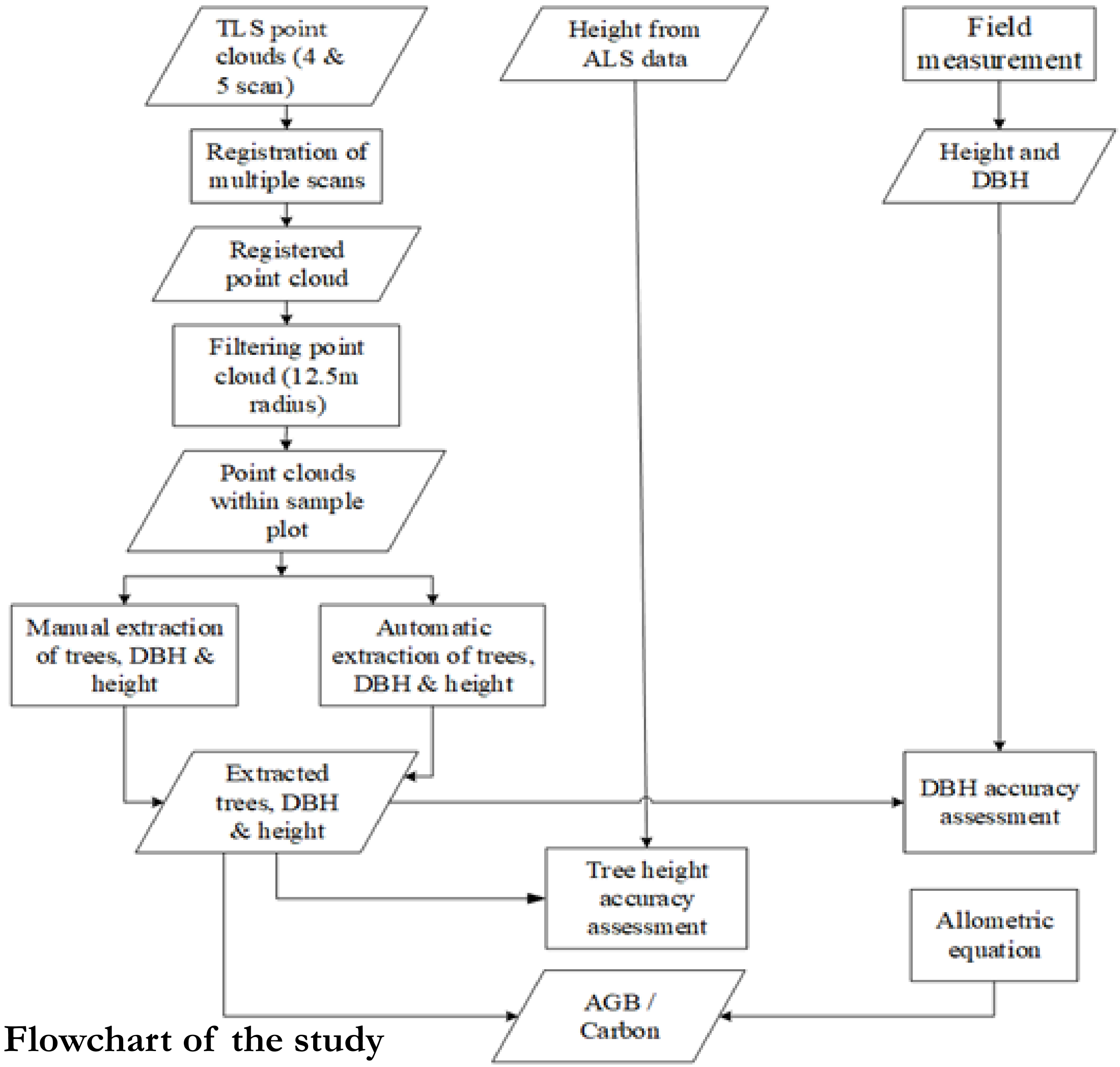
The high accuracy results has meet meet the objective of the study which made use of the combined data to assess the AGB of the upper canopy.

Result signifies that the use of height from airborne LiDAR indeed can provide accurate result because its strength is towards the upper layers of the forest stand high resolution images.



The relationship between the modelled and field measured AGB of the upper and lower

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



Flowchart of the study

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).

The data contains a point cloud data in the .xyz format. For further processing in LAS tools, this file format was converted to a .las file format, then the CHM was generated by adapting the method of Khosravipour, et al., (2014) using the algorithm to create a pit-free raster CHM.

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.

Results and discussion

Modelled and field DBH

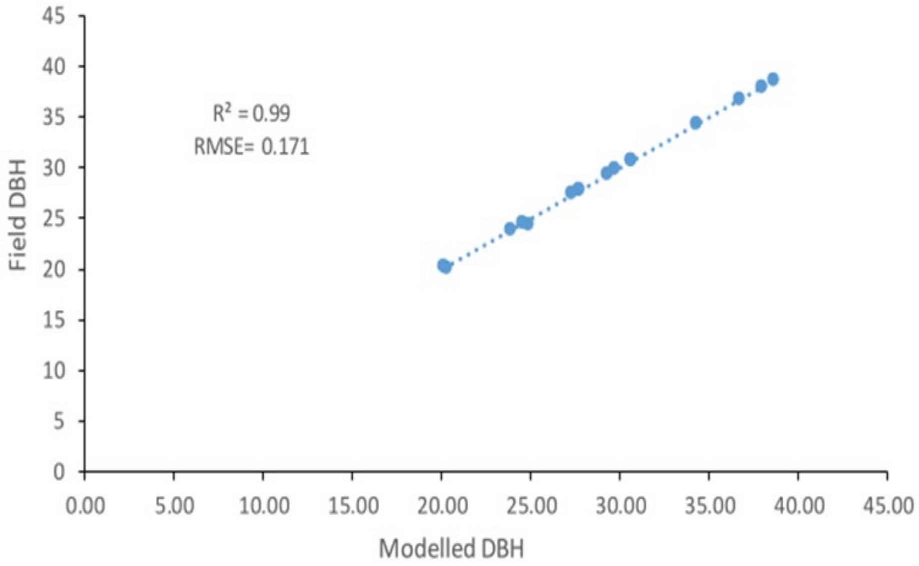
Modelling the DBH for the upper canopy layer employed multiple regression analysis. This was done using the above mentioned parameters. Height from CHM and segmented CPA were used as independent variable and the field measured DBH as the dependent variable.

The upper DBH model achieved an average R^2 value of 0.99 and RMSE of 0.171 cm.

The results are greater than the values obtained by Popescu, (2007) who obtained an R^2 of 0.87 and RMSE of 4.9 cm.

There is indeed a strong relationship between height and CPA to model DBH. This further signifies that for the upper canopy layer DBH models can be accurately modelled from LiDAR derived height and CPA derived from Orthophoto and have the potential use for subsequent AGB estimation.

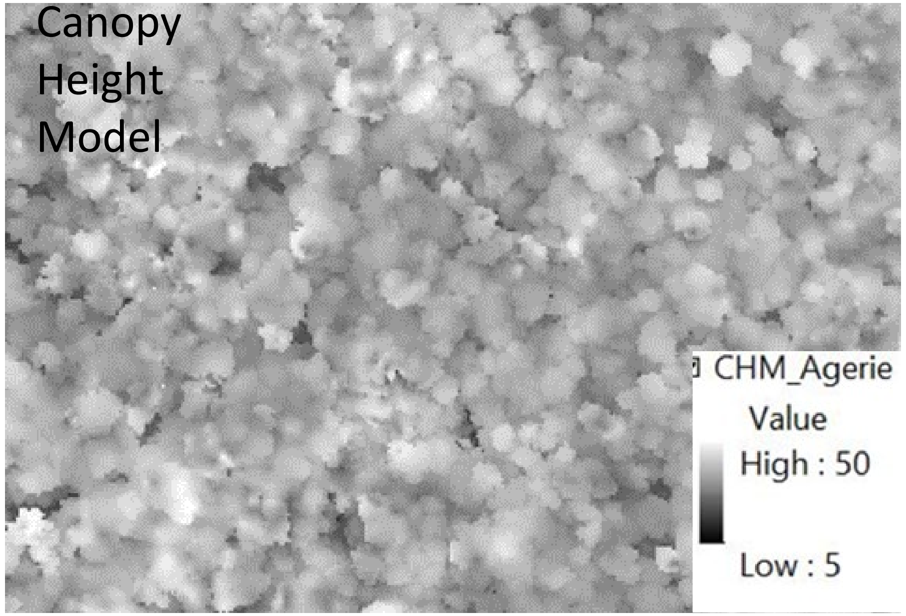
The highly accurate values can be attributed to the fact the derived parameters come from trees measured from the upper canopy layers only

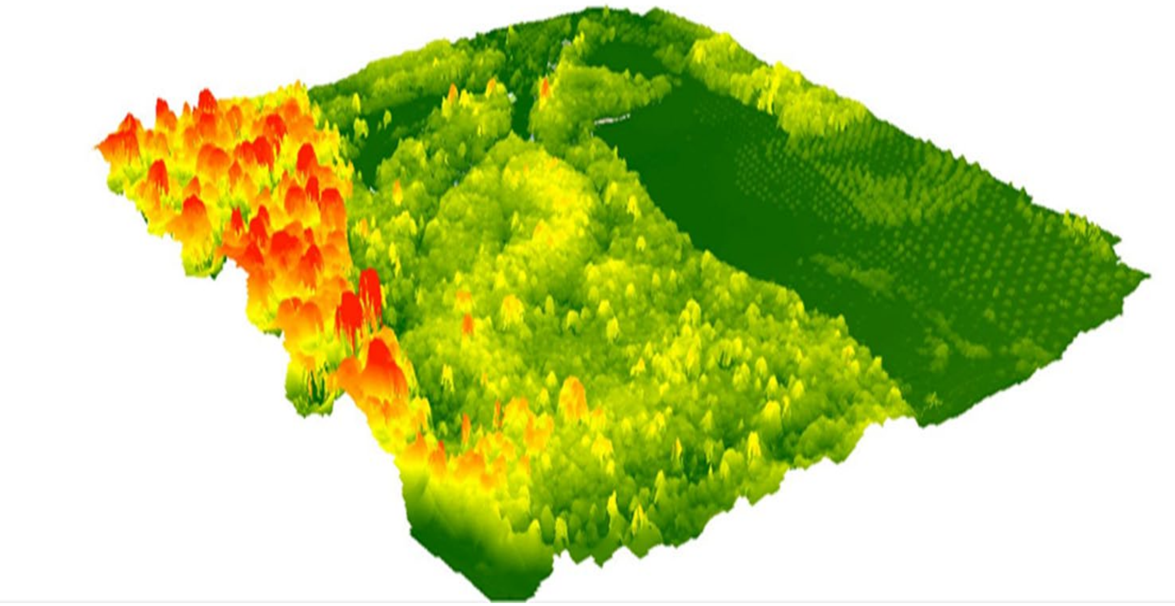


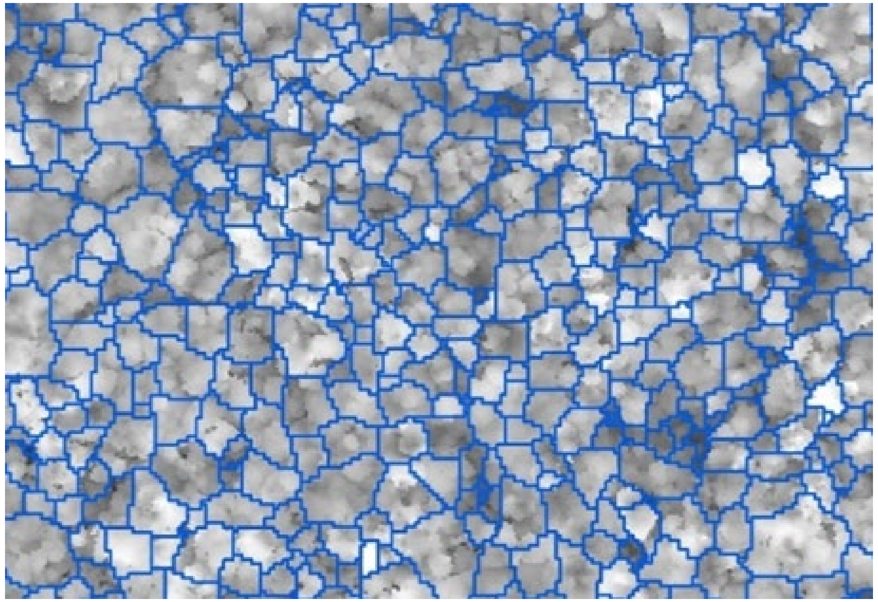
The relationship between modelled and field DBH

Statistic	Modelled DBH	Field DBH
Mean	29.03	29.03
Minimum	20.17	20.09
Maximum	38.62	38.61
Standard Deviation	5.72	5.76
Number of plots	16	16

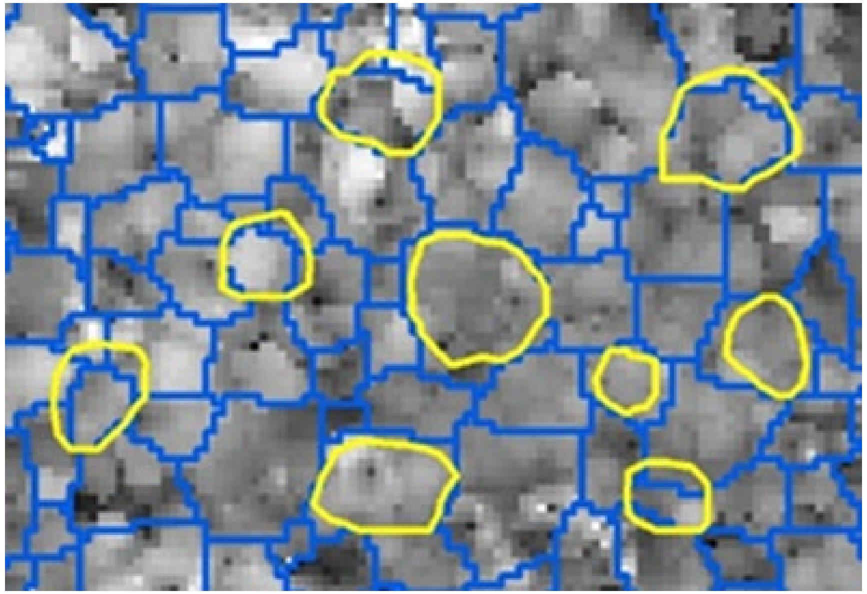
Descriptive statistics of averaged modelled and field DBH.







Segmentation from LiDAR

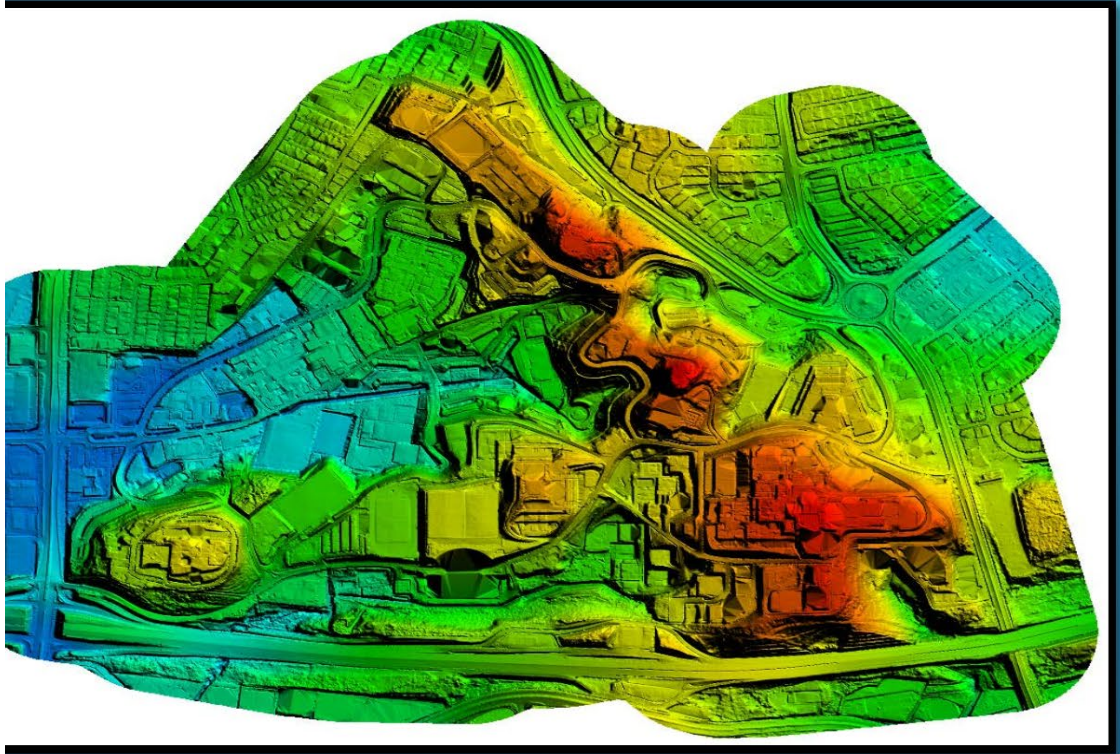


Matching with manual delineated tree crowns

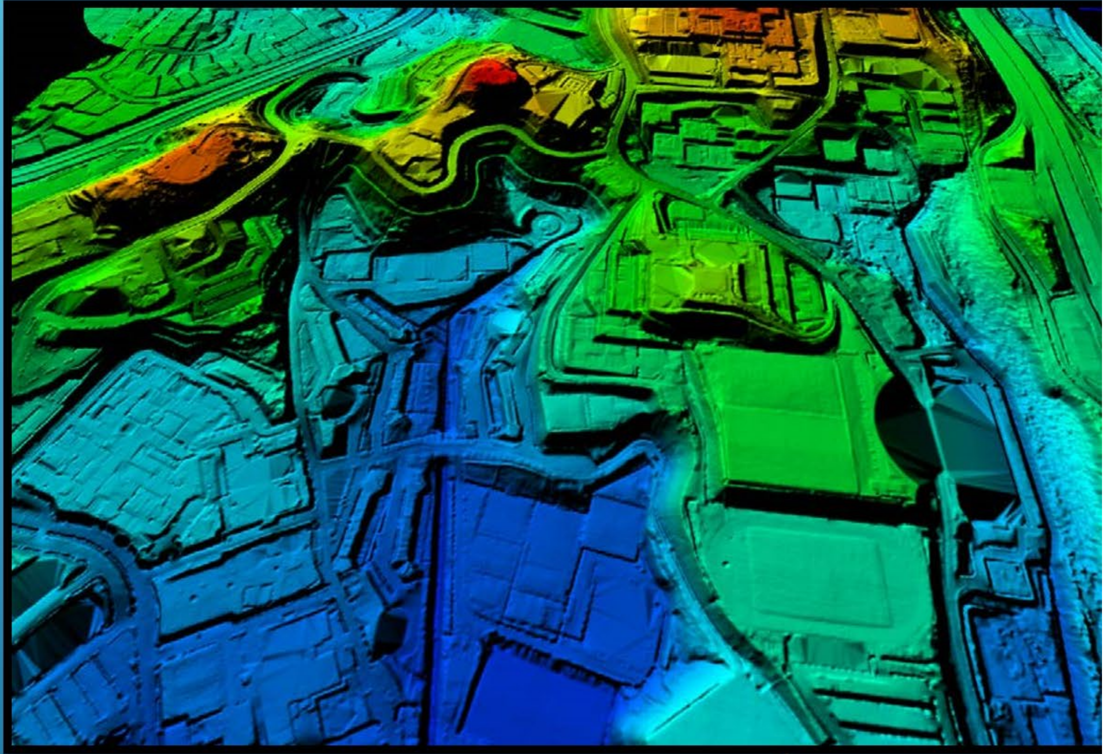
REMOTE SENSING OF TROPICAL FOREST BIOMASS: MALAYSIA CASE STUDY

- ✓ Mangrove forests AGB estimation using vegetation indices from SPOT-5 imagery
- ✓ AGB estimation with airborne and terrestrial LiDAR scanner in tropical forest
- ✓ **Airborne LiDAR mapping of Universiti Teknologi MARA Selangor Campus**

UiTM SHAH ALAM



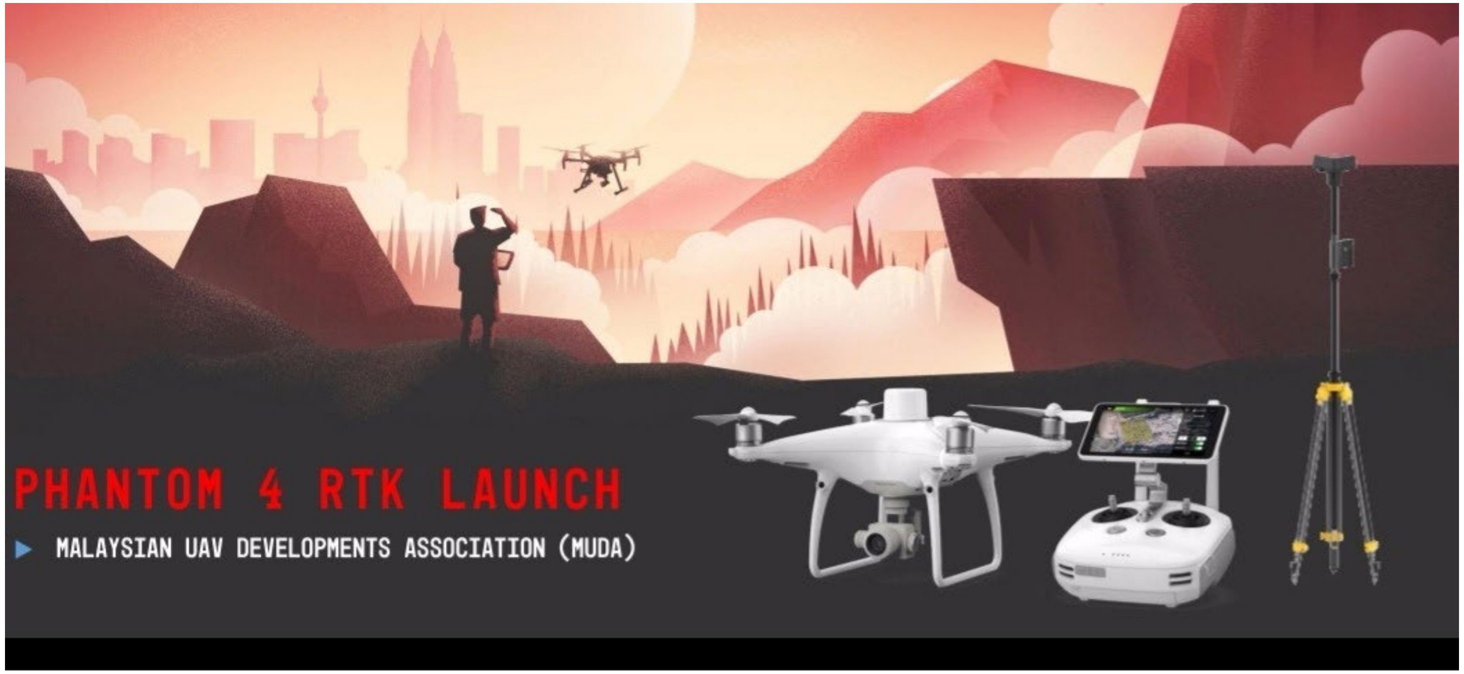
Area: Uitm Shah Alam in 2D view



Area: Uitm Shah Alam in 3D view

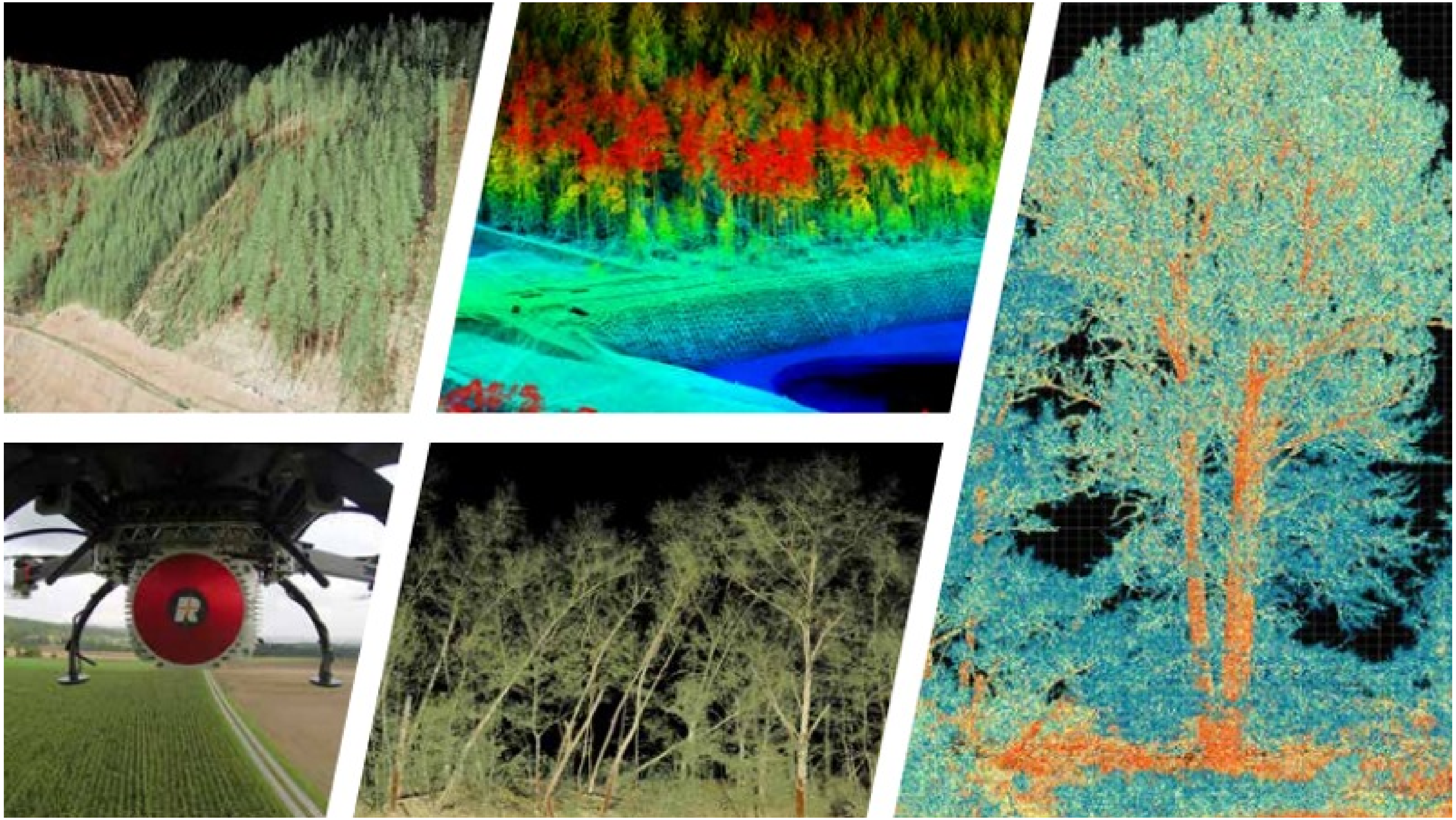
Cont

A WAY FORWARD



3D Handheld Mobile Mapping System – GeoSLAM Horizon

UAV LiDAR: The Groundbreaking Technology That's Changing The Way We See The World



https://www.youtube.com/watch?v=ri3iXxEbNsY

SOURCE: RIEGL

Terima kasih

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