Total aboveground biomass (TAGB) estimation using IFSAR: speckle noise effect on TAGB in tropical forest

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Abstract. Total Aboveground Biomass (TAGB) estimation is critically important to enhance understanding of dynamics of carbon fluxes between atmosphere and terrestrial ecosystem. For humid tropical forest, it is a challenging task for researchers due to complex canopy structure and predominant cloud cover. Optical sensors are only able to sense canopy crown. In contrast, radar technology is able to sense sub-canopy structure of the forest with penetration ability through the cloud for precise biomass estimation with validation from field data including diameter at breast height (DBH) of trees. This study is concerned about estimation of TAGB through the utilization of Interferometry Synthetic Aperture Radar (IFSAR). Based on this study, it is found that the stand parameters such as DBH and backscattered on IFSAR image has high correlation, $R^2=0.6411$. The most suitable model for TAGB estimation on IFSAR is Chave Model with $R^2=0.9139$. This study analyzes the impact brought by speckle noises on IFSAR image. It is found that filtering process has improves TAGB estimation about $+30\%$ using several filtering schemes especially Gamma filter for 11x11 window size. Using field data obtained from a primary tropical forest at Gerik, Perak, TAGBestimation can be validated and the assessment has been carried out.

1. Introduction
Forest is the main source of biomass, carbon and home of many species of flora and faunas. It plays vital role in protecting the sustainability of the Earth’s ecosystem. Malaysia is a tropical country where the forest covers almost 60\% of the land, equal to 19.52 Mha\textsuperscript{1} where 3.21 Mha\textsuperscript{1} of overall forestry area is strictly preserved as the primary forest [1]. TAGB using conventional technique is inefficient as the measurement of DBH and other tree stand parameters are not practicable over the large region of dense forest which in turn causes time-constraint and ineffective cost.

The backscatter of IFSAR is one of essential element of TAGB estimation in tropical forest. Therefore, it is the prominent objective of this research where extensive potential of IFSAR in TAGB estimation was applied. The specialty of this study is obviously penetrated into the discovery of knowledge tunnel in revealing the airborne SAR in TAGB prediction for tropical climate forest which is highly dense with several crown canopy levels of forest trees. Previous study have been conducted in Pasoh Reserved Forest in Negeri Sembilan, Malaysia using optical satellite image of IKONOS, Landsat and Moderate Image Spectrometer(MODIS) to estimate TAGB using allometric model where the range of TAGB is from 0.3tha\textsuperscript{1} to 15tha\textsuperscript{1} for each plot of 4m x 4m on IKONOS [2].

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2. Data and material

The study area is located at Gerik in Perak state, northern part of Peninsular Malaysia. During field data acquisition, several parameters are recorded such as DBH, scientific and local name of the tree, x and y coordinate, plot number and line number. Using IFSAR scene of this area as primary data, it was projected in Rectified Skew Orthomorphic (RSO) and Kertau 1948 as its datum. With north latitude of 5°33’25.68"N and east longitude of 101°38’29.41"E, this area is about 230km from the Ipoh town and 430.5km from Kuala Lumpur. The IFSAR scene is about 50.0884km² or 5008.84ha but only 198ha involved in this research. The area is almost fully covered by forestry area and dominated by the species of Meranti and Keruing trees as recorded by the Forest Department of Perak Officer in 2010. Overall, 31 square plots of 80 pixels x 80 pixels were selected.

In processing stage, using DBH data from ground work, the measurement of biomass of tree structure are computed in order to obtain TAGB using allometric equation by Kato, 1978.

\[
\frac{1}{H} = \frac{1}{(1.5D)} + \frac{1}{61} \quad \text{[Tree height]} \quad (1)
\]

\[
W_s = 0.0313 (D^2H)^{0.9733} \quad \text{[Biomass on the tree’s stem]} \quad (2)
\]

\[
W_b = 0.039 (D^2H)^{1.041} \quad \text{[Biomass on the tree’s branch]} \quad (3)
\]

\[
\frac{1}{W_l} = \frac{1}{(0.124W_s^{0.794})} + \frac{1}{125} \quad \text{[Biomass on the tree’s leaves]} \quad (4)
\]

Finally, \( TAGB = W_s + W_b + W_l \) \( \quad (5) \)

where \( H = \) tree’s height, \( D = \) DBH, \( TAGB = \) Total Aboveground Biomass.

For TAGB extracted from IFSAR, three models are selected:
Brown Model (1997), \( Y = \exp (-2.134 + 2.530*\ln (d)) \),
Chave Model (2005), \( Y = p * \exp (-1.499 + 2.148 \ln (d) + 0.207 (\ln (d)) - 0.081 (\ln (d))^3) \),
Basuki Model (2009), \( Y = \exp (-1.201 + 2.196*\ln (d)) \).

where \( d = \) DBH, \( p = \) specific wood density, 0.67g/cm.

Speckle noise image were minimized using several adaptive filter with widow size of 3x3, 7x7 and 11x11. Variation coefficient (CV) and Signal-to-Noise (SNR) of resultant images were tabulated. After
determine the best filter, the result of TAGB before and after filtering process were compared and analyzed to see the impact of filtering speckle noise on IFSAR. Finally, the TAGB on different range of slopes and aspects of topographic variation on this area were explored and analyzed.

3. Result

3.1. Relationship of tree parameters and backscattered of IFSAR to determine the best model for TAGB estimation on IFSAR

The result of several tasks was displayed below.

**Figure 2.** Mean TAGB of every selected plot by allometric model.

**Table 1.** Range of DBH value from backscattered obtain from IFSAR.

| Backscattered IFSAR (decibel, DB) | DBH (cm) | TAGB (t/ha) |
|-----------------------------------|----------|-------------|
| -20 to -10                        | 30-55    | 2.3 to <8.3 |
| -10 to -5                         | 56-70    | 8.3 to <11.9|
| -5 to 3                           | 71-90    | >11.9 to <30.8|
| 3 to 7                            | 91-170   | <135        |

**Figure 3.** Comparison of TAGB and its backscattered value on tropical forest region by Luckman et al., within moderately flat Amazon Forest (saturation at -7.7dB) and IFSAR at hilly forest at Gerik, Perak (saturation at -1.7dB).
Figure 4. Different model of TAGB estimation shows different regression coefficient. Chave model line shows highest correlation compared to tohers.

3.2. Speckle noise filtering effect on TAGB

As Chave model was determined as the best to be used for TAGB estimation on IFSAR image, the biomass map of tropical forest at Gerik Malaysia was then is tested using several adaptive filters and the statistical result was tabulated in the table below.

| Table 2 Summary of information obtained from post-filtered IFSAR image. |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| **Filter**      | **Window size** | **Mean**        | **Std. Dev**    | **Variation Coefficient (VC)** | **Signal-to-Noise Ratio (SNR)** |
| Original        | 3x3             | 63.054822       | 52.154227       | 0.827125117        | 1.209006932        |
| Lee             | 7x7             | 62.958742       | 50.558324       | 0.803038981        | 1.245269562        |
| Frost           | 11x11           | 62.866357       | 48.385716       | 0.769659931        | 1.299275121        |
| Kuan            | 3x3             | 62.808903       | 47.117486       | 0.750172089        | 1.333027467        |
| Local Sigma     | 7x7             | 62.519443       | 49.361000       | 0.789530387        | 1.26675697         |
| Gamma           | 11x11           | 62.174246       | 45.847429       | 0.737402252        | 1.35611943         |
| Kuan            | 3x3             | 62.710177       | 51.931134       | 0.828113338        | 1.410123661        |
| Kuan            | 7x7             | 61.774875       | 43.808126       | 0.709157663        | 1.410123661        |
| Kuan            | 11x11           | 62.808903       | 47.117486       | 0.750172089        | 1.333027467        |
| Kuan            | 3x3             | 62.808903       | 47.117486       | 0.750172089        | 1.333027467        |
| Kuan            | 7x7             | 63.023406       | 49.623627       | 0.787426928        | 1.269959109        |
| Kuan            | 11x11           | 63.023406       | 49.623627       | 0.787426928        | 1.269959109        |
| Kuan            | 3x3             | 63.158963       | 45.785997       | 0.724932691        | 1.379438412        |
| Kuan            | 7x7             | 63.158963       | 45.785997       | 0.724932691        | 1.379438412        |
| Kuan            | 11x11           | 63.158963       | 45.785997       | 0.724932691        | 1.379438412        |
| Kuan            | 3x3             | 63.023184       | 43.004939       | 0.682366968        | 1.465487115        |
| Kuan            | 7x7             | 63.023184       | 43.004939       | 0.682366968        | 1.465487115        |
| Kuan            | 11x11           | 63.023184       | 43.004939       | 0.682366968        | 1.465487115        |
4. Analysis and discussion

Based on Figure 2, minimum TAGB is 1886.166 kg/ha at plot 17th and the maximum TAGB among selected trees is 116363.787 kg/ha at plot 8th. Through this graph, it was concluded that TAGB of this tropical forest was mostly less than 20 kg per hectare. Large DBH indicates that the trees can live longer at that area compared to the other plot but it is rarely found because of natural competition to obtain basic elements to grow like sunlight and its natural life-span. Table below shows the characteristics of trees at plot number 8 and 17.

Figure 4 shows that mean backscatter value of IFSAR for each plot with mixed species is positively correlated with TAGB estimated by allometric model with R² = 0.6411. The equation Y = 19.062e^0.124x then applied on IFSAR to estimate TAGB for further task.

Table 3: Summary of statistical information for different TAGB models.

| Allometric Model (Kato et al.) | R² (correlation coefficient) | RMSE | CV (%) | p-value |
|--------------------------------|-------------------------------|------|--------|---------|
| Brown Model (1997)            | 0.809                         | 0.484| 14.5   | 1.56E-11|
| Chave Model (2005)            | 0.9139                        | 0.370| 8.7    | 2.29E-16|
| Basuki Model (2009)           | 0.858                         | 0.417| 11.3   | 1.94E-13|

Null hypothesis for this task is the mean value of TAGB from census data and Chave models are the same, no different significantly. However, based on ANOVA table, F_{critical} < F_{computed} indicating that the null hypothesis is rejected at 95% confident level. It means that mean value of TAGB estimated from Chave model was significantly different with mean TAGB derived from ground data at high significance difference, 2.29E-16.

For speckle noise effect, different filter will give us different image in terms of their clarity and level ratio of signal to noise. VC represents variability extension with respect to mean of the population. Regarding to Table 2, it shows that smaller the variation coefficient, smaller the effects of speckle noise on the image. Standard deviation of all resultant figures is not broadly ranged due to speckle noises sources located on vegetation features area, a dominant feature of this area which in turn leads to small range of VC value. As VC is the inverse of SNR, lowest VC is the highest SNR value. The lowest VC where shown by Gamma 11x11 filter by 0.6824 is containing more signal rather than speckle noise on image with SNR value of 1.4655.
Figure 6. Regression line of TAGB of 24 plots before and after speckle noise reduction. It demonstrated that TAGB estimated was improved by +30%.

Null hypothesis for this task is the mean value of both TAGB before and after speckle noise reduction by filtering process using adaptive filter was no difference. For this, $F_{critical} < F_{computed}$ indicates that the null hypothesis is rejected at 95% confident level. It means that mean value of TAGB on raw IFSAR is significantly different with mean TAGB extracted from IFSAR after speckle noise filtering by Gamma 11x11 kernel size at $P=0.0161$.

5. Conclusion

To put it to the nutshell, TAGB can be predicted using IFSAR backscatter with 64.11% is true based on its correlation. The most suitable model to estimate TAGB on IFSAR is Chave Model with $R^2=0.9134$, $P<0.0003$ and the standard error is 1.981 t/ha. The reduction of speckle noise through filtering process has improves TAGB estimation to +30%.

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References

[1] Brown., S J Richard., Lugo1997. Estimating Biomass and Biomass Change of Tropical Forests, FAO Forestry Paper, 13454.
[2] Chave, J Andalo, C Brown, S Higuchi, N K Ogawa, H Puig, H Riéra, BYamakura, T. (2005). Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests. Oecologia 145, 87–99.