Terrestrial LiDAR Derived Allometric Models for Guyana and Suriname

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1. Introduction

Tropical forests play a role in climate mitigation and ecosystem services. For that, international funding has been set up to support forest monitoring, specifically in developing countries through Reducing emissions from deforestation and forest degradation (REDD+) (Nesha et al. 2021). Countries (like in this study Guyana and Suriname) who are establishing a REDD+ program, need to design and implement a national Measurement, Reporting and Verification (MRV) system as part of their REDD+ program. Within the MRV systems, aboveground biomass (AGB) estimations are mostly calculated using allometric models, which are largely dependent on the data used, producing uncertainties and systematic errors of tree AGB estimations when applied to other species, size, structure, or geographical conditions (Lau et al. 2019).

Terrestrial Light Detection and Ranging (LiDAR) along with quantitative structure models (Raumonen et al. 2013) have been proven to be a valuable tool to assess the woody structure of trees (Brede et al. 2017) and to estimate tree AGB (Burt et al. 2021) regardless of the tree species, size, structure, or geographical conditions. Lau et al. (2019) proved the feasibility to develop country-specific TLS-derived allometric models and it is of interest now to explore the inclusion of more validation trees; for that, the aim of this study is to develop allometric models from TLS-derived parameters which estimates AGB of trees in Guyana and Suriname in a reliable and accurate way.

2. Data and Methods

2.1 Study area

Four forest types were used in this study which aimed to increase the representativity of trees in Guyana and Suriname. One study area was located in Guyana, with a mixture of white sand plateau and mixed forest, with a dominance of evergreen trees (Guyana Lands and Surveys Commission 2013). The other three areas were located in Suriname; a moist ever green forest, a high and low swamp forest and a periodic swamp forest (Atmopawiro 2016).

2.2 TLS-derived attributes and QSM-derived aboveground biomass

Terrestrial LiDAR datasets were collected with a RIEGL VZ-400 3D terrestrial laser scanner (RIEGL Laser Measurement Systems GmbH, Horn, Austria). We scanned a total of 155 tropical trees (Guyana n = 72 and Suriname n = 83) following TLS data acquisition and plot design described in Lau et al. (2019). Trees were identified and manually isolated from the pointcloud. These trees were field inventoried and diameter at breast height (D), total tree height (H), and crown diameter (CD) were estimated directly on the standing tree. Tree species specific wood density (WD) was matched using the recorded WD from the fieldwork and the Global Wood Density Database – GWDD (Zanne et al. 2009).

Likewise, D, H, CD were estimated directly on the individual pointcloud. Finally, aboveground biomass was estimated from volume using quantitative structure model *TreeQSM* (Raumonen et al. 2013) and their respective wood density from GWDD.

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2.3 Tree Inventory and fresh mass sampling

A total of fifty-one trees (Guyana n = 23 and Suriname n = 28) were chosen as validation data. Those trees were destructively sampled and weighed. Fresh mass was measured directly in the field while the larger branches and parts were measured through volume estimation. Moreover, we collected wood samples to estimate water content and were weighed in the field.

2.4 TLS-derived and pantropical allometric models

We developed two model forms based on the work in Lau et al. (2019). For that, we used TLS-derived attributes (D, H and CD) and WD to evaluate the accuracy of AGB estimation by only using TLS-derived parameters. The first model uses diameter at breast height, tree height, wood density, and crown diameter (hence, D.WD.H.CD), while for the second one, we removed tree height (D.WD.CD). The allometric models were based on data transformed to the natural logarithm and built using least-squares linear regression. In addition, we estimated AGB using pantropical allometric models from Chave et al. (2005) as seen in Table 1.

Table 1. Pantropical models from Chave et al. (2005), including diameter at breast height (D), species specific wood density values according to the GWDD (WD), and total tree height (H) to estimate aboveground biomass (AGB).

Model	Form AGB =
Ch05.II.3	$WD \cdot e^{(-1499 + 2.1481 \cdot \ln(D) + 0.207 \cdot \ln(D)^2 - 0.0281 \cdot \ln(D)^3)}$
Ch05.I.5	$0.0509 \cdot WD \cdot D^2 \cdot H$

2.5 Model assessment

Finally, we assessed how well the TLS-derived allometric models predict AGB using R-square (R^2), root means square error (RMSE), and concordance correlation coefficient (CCC). For comparing with the allometric models in Table 1, our assessment included the estimation of the model error (in Mg, 1) and the standard deviation (SD) of error.

$$AGB_{error}\ (Mg) = AGB_{est} - AGB_{ref} \tag{1}$$

3. Results and Discussion

TLS-derived allometric models D.WD.H.CD and D.WD.CD were able to estimate AGB with high accuracy (R^2 = 0.94, RMSE = 1.39 Mg, CCC=0.96 and R^2 = 0.95, RMSE = 1.25 Mg, CCC=0.97, respectively, see Figure 1a and Figure 1b). On the other hand, pantropical model Ch05.II.3 and Ch05.I.5 also performed with high accuracy (R^2 = 0.92, RMSE = 1.54 Mg, CCC=0.96 and R^2 = 0.88, RMSE = 1.88 Mg, CCC=0.94, respectively, see Figure 1c and Figure 1d); although slightly lower than the TLS-derived allometric models.

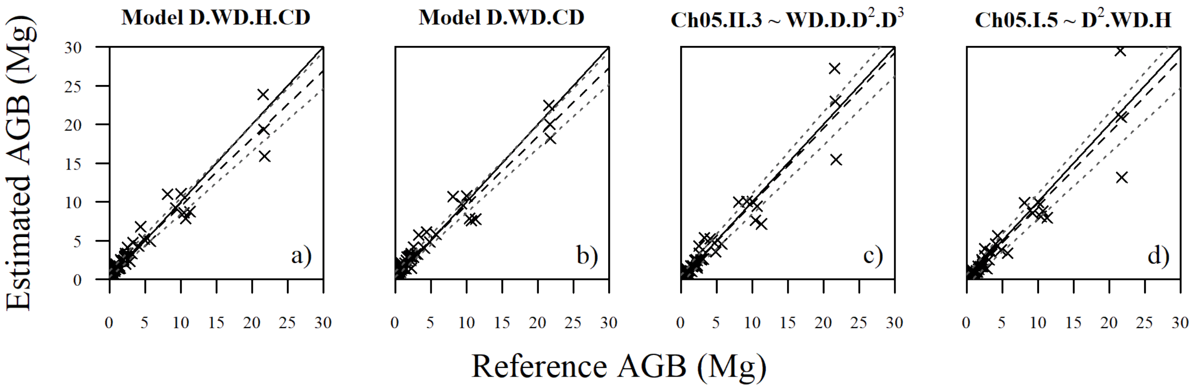

Figure 1: Relationships between AGB from harvested trees (X-axis) and AGB from allometric models (Y-axis). TLS-derived models with D, WD, H and CD (a), and without H (b), pantropical model Ch05.II.3 (c), and Ch05.I.5 (d). Black solid line is 1:1 relationship; dashed lines depict linear fit; and dotted lines indicate 95% confidence interval for the linear fit.

TLS-derived allometric models have a mean model error of -0.22 Mg (slight underestimation), while pantropical model Ch05.II.3 and Ch05.I.5 have a mean model error of -0.05 Mg and -0.24 Mg (slight underestimation), respectively. Regarding SD of error, TLS-derived allometric model D.WD.H.CD and D.WD.CD showed an SD of error of 1.38 Mg and 1.24 Mg, respectively, and pantropical model Ch05.II.3 and Ch05.I.5 showed and SD of error of 1.56 Mg and 1.88 Mg, respectively.

The slightly underestimation of the TLS-derived allometric models in this study might be due to the limited number of samples used (n = 155) as opposed as the hundreds (or even thousands) of samples used to calibrate these pantropical models. With the advances on tree segmentation and semi-automatization of tree modelling, a larger sample size can be used to update and calibrate TLS-derived allometric models. TLS helps to increase the sample size of without increase the destructive sampling of tropical trees.

4. Conclusions

TLS-derived allometric models were developed for Guyana and Suriname which estimate aboveground biomass of trees in a reliable and accurate way. As mentioned in Lau et al. (2019), pantropical model Ch05.II.3 provides a good AGB estimate using only WD and D. With the advances of tree segmentation and semi-automatization of tree modelling, we can increase our sample size without the need of destructive sampling. Finally, more research needs to be done to provide robust local TLS-derived allometric models which allow the reduction of uncertainties and increase efficiency of MRV system in REDD+ countries.

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