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Research Article

A Review: Forest Aboveground Biomass (AGB) Estimation Using Satellite Remote Sensing

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ABSTRACT

Forest ecosystems act as a significant carbon cycle because they constitute large amount of biomass. Though many recent studies have accessed the aboveground biomass (AGB) estimation using remote sensing platform, field in the saturation level of different bands at certain amount of forest biomass and validation from a enough ground truth data remain a huge challenge where non have successfully addressed it. On the other hand, utilizing in-situ data are very costly and tedious as it required a lot of labor to collect the forest tree parameters. Hence, this paper aims to conduct a review on to develop a multi-objective integration of different remote sensing platform to estimate AGB in different region and the existence number of plot samples. A review focused on the relationships between AGB measurements at ground level and available remote sensing data were conducted where recently published article and reports (both printed and electronic materials) were gathered. From the past studies, variety of model was applied using three main methods namely image pre-processing, processing and post-processing. From this review paper, it was found that utilizing L-band SAR data outperformed optical remote sensing satellite in estimating forest aboveground biomass. The backscattering from the SAR or microwave platform shows significant with AGB where the HV polarization was dominance in discriminating forest structure as compare to the HH polarization. Therefore, in the real study the proposed model needs to be assessed with the presence of sufficient amount of field data and in-depth investigation with the application of different remote sensing sensors.

Keyword: Forest, aboveground biomass (AGB), remote sensing, polarization, validation

INTRODUCTION

Forest ecosystems play a significant role in carbon sequestration and global climate regulation due to its large amount of biomass constitution where tropical rainforests are the largest forest in the world and they are the primary carbon sink ecosystem which cover approximately fifteen percent (15%) of earth's surface (FAO, 2009). There are some layers of mature tropical forests that make them rich in biomass. According to Pan et al. (2011), tropical forests store approximately 56 % of carbon in biomass and 32 % in forest soil.

On behave of that, many studies have gained much interest in estimating biomass and carbon stock in the tropical forest due to its vital role in earth's carbon cycle (Basuki et al., 2013). There are some approaches to estimates biomass and carbon stock such as utilizing remote sensing data and/ or in-situ data.

AGB estimation via remote sensing has been widely used due to its promising results. It is convenient; accurate and efficient in term of time and cost, so it can be very helpful for the users in decision making process. Remote sensing is referred to the data analysis of information gain of objects without physical contact to it (Jensen, 2000; Lillesand and Keifer, 1987). Electromagnetic (EM) power reflected or emitted from the objects of interest at

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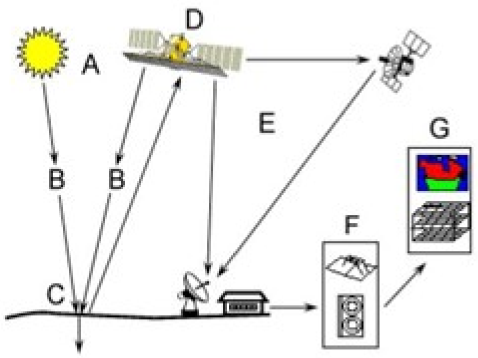
the surface of the earth is reliable. Treasured data over huge region in a quick time on resources, meteorology and environment offered by remote sensing to manage resources efficiently and develop the country.

Figure 1: Remote Sensing Process Components (Source: Canadian Centre for Remote Sensing, CCRS).



Passive or optical remote sensing utilizes daylight as its supply of power (A), whilst microwave or active remote sensing does not. B represents emission of electromagnetic radiation, or EMR (sun/self-emission). Next, interaction of EMR with the earth surface: reflection and emission occurred at C. Once the strength makes its way to the target via the atmosphere, it interacts with the target by relying on the properties of each target and the radiation. D is the recording or transmission of energy from the surface to the remote sensor; E represents transmission, reception, and processing; F represents interpretation and evaluation and ultimately G refers to the utility of remote sensing (Jensen, 1996).

Meanwhile, several studies utilized in-situ approaches for estimating aboveground biomass (AGB) and evaluating carbon stocks in forests area such as by Matthew et al. (2018); Hamdan et al. (2014); Lydia et al. (2014) and many more via allometric equation invented by Chave et al. (2005). In some extent, this studies and many other studies shared the same opinion in estimating forest biomass throughout field measurement provided the most accurate results (Kumar et al., 2019), it includes high measures of resources and neighborhood inclusion when contrasted with remote sensing-based estimation (Herold & Johns, 2007; Avitabile et al., 2012).

However, in many cases conducting field surveys such as measuring the mean diameter at breast height (DBH), mean tree height, tree species, mean age, crown density, volume, land use and cover, and even ecological conditions has end up being troublesome as it is costly and tedious. To get the all-out volume or biomass of forest, the volume or biomass of one tree is determined, and afterward the volumes or biomasses of the considerable number of tress in the sample plot are included. Clearly, this strategy requires a high measure of labor and material resources (Lu et al., 2019; Zhu et al., 2019). What's more, for developing countries, such practices are not sustainable (Waqar et al., 2019). Additionally, inventory data cannot completely reflect forest information (Fang et al., 2001).

Thus, this paper were reviewing and investigating the current trend of forest aboveground biomass (AGB) estimation using available multi-platform satellite remote sensing and along with the plot samples for validation. Secondary data were collected from the recent publish paper by focusing to satellite remote sensing platform and the study were analyze so that this review paper are able to give a rough idea on which satellite platform are available for estimating forest AGB based on the users goal.

MATERIALS AND METHODS

AGB estimation using L-band backscattering SAR data

The study in AGB estimation using L-band backscattering SAR data has been done by many researchers over the past few years. In this paper, it reviews from the oldest to the latest investigation in this field as shown in table 1. Previously, Hamdan et al. (2014) had established an empirical correlation between AGB and PALSAR data in a mangrove forest and apply this model to map the AGB by using ALOS PALSAR-2 data along with field data for validation. The data were preprocessed and extraction of backscatter value for the modeling and mapping purposes were done. The study found that the HV backscatter gave the highest correlation with AGB follow by some modified polarization using band math.

Hamdan et al, (2015), further their study through Alos Palsar L-band data along with the presents of supporting data which comprises compartment boundaries and validation data of tree DBH and height. In this study stratify and multiply (SM) and direct remote sensing (DR) approach were used for preprocessing. Findings showed that HV backscattering coefficient shows a significant correlation with the AGB.

The study continued to further research this area by undergoing prediction equations for AGB in the dipterocarps forests of Peninsular Malaysia using PALSAR and PALSAR-2 along with 334 sample plots for validation (Hamdan et al., 2018). The SAR images undergo ortho-rectification, slope correction, and, calibration. Validation of AGB estimates using K-fold cross validation method was assessed. Hence, HV polarization was proven to be useful method in delineating forest cover. The study had identified that HV backscatter's value increased at low AGB levels.

Similarly, Suresh et al. (2014) conducted a similar study in estimating level of biomass through the application of statistics analysis and produce map via SVM (Support Vector Machine). Field data were also present. The SAR backscattering values were retrieving through radiometric calibration. Further analysis such as SVM and GLCM texture measures for HV gamma nought and regression analysis were done lastly accuracy assessment using confusion matrix. The study found that the result shows same as from the previous study where HV polarization shows significant with AGB.

Baghdadi et al. (2015) also assessed the potential of PALSAR L-band data in their study and utilized in-situ measurements of DBH, tree height and basal area. The SAR data were radiometric calibrated for retrieving the backscattering values, biomass for the PALSAR acquisition dates and it was measured using linear interpolations based on the inventory plot measurements and lastly nonlinear nonparametric regression were done. Results showed that PALSAR signal increases as the AGB reaches threshold saturation as the HV polarization produced better relationship with the biomass. Besides, the application of PALSAR signal alone does not effectively predict the biomass of the plantation. Yet, the estimation of biomass can be inaccurate because the SAR images were acquired at different seasons.

Bouvet et al. (2018) estimated woody AGB using ALOS PALSAR 2010 mosaics and 144 field plots of DBH, tree height and basal area. Image processing was done and the multi-image filter developed by Bruniquel and Lopes (1997) and Quegan and Yu (2001) was applied. Lastly, radar backscatter and AGB estimation was analyzed separately in the wet season and dry season using Bayesian inversion correlation. The study showed the relative accuracy error is higher for low AGB areas and AGB map and this was generated using SAR and LIDAR.

In in the other hand, Cassol et al. (2018) had evaluated the uses of this data for estimating AGB and also utilized tree parameters. SAR data was pre-processed and processed. Regression models were analyzed using NL, MLR and the semi-empirical EWCM (dependent (Y) using AGB and independent (X) using SAR parameters). The study found that the selected polarimetric attributes of the MLR model did not have the highest correlation with the AGB and the semi-empirical EWCM had the lowest value of Akaike AIC = 395.62 among the three models. This might be due to the limitations that in term of parameter interpretation and overfitting. The study did not generate a map from EWCM because of the low accuracy of the model. Overall, MLR model presented the best performance. There is 70% improvement of the model performance in compare to nonlinear model.

Furthermore, it was affirmed by Ningthoujam et al. (2018) that forest structure estimation can be validated using AGB from L-band backscatter data from PALSAR mosaic 2007 through the acquisition of field plot data at stand level of DBH ≥ 10 cm, canopy heigt and tree species. In order to make the estimation, SAR data had to undergo preprocessing and processing before the backscattering relationships with forest structure and biomass using linear regression model were finally examined. Findings revealed that, a significant relationship was determined along L-band backscatter with the highest value in HV polarization. On the same time, a weaker relationship between both polarizations and average canopy height was spotted. In that event, PALSAR data is deem as suitable method in deriving forest structure data.

Andropov et al. (2017) examined the multitemporal behaviors of PolSAR parameters that are suitable for forest biomass mapping and estimate forest stem volume using a non-parametric regression approach. The study had also utilized forest inventory for validation purposes. ALOS PALSAR data were polarimetrically calibrated for extracting the backscattering values, geo-reference and speckle filtered by using median filtering of 3×3 windows. It was identified in the result that HV-backscatter, RVI, co-polarization coherence magnitude and surface scattering fraction show significant results. Polarimetric coherence "winter" is much more accurate, as compared to summer co-polarization. However, there are certain issues should be considered in this case, such as the geo-location information.

Furthermore, the estimation of plantation and Natural forest using the application of remote sensing with ALOS PALSAR L-band backscatter and forest biomass for a large range of AGB along with field data of DBH and tree height validation was estimated by Marina et al. (2017). As for SAR processing, radiometric calibration for retrieving HH and HV backscattering values and correlation analysis between SAR polarizations and AGB was done through Pearson correlation coefficient. It was concluded in the study, that HV band has strong correlation between Natural forest and HH band. Further study should be done to determine the strength effect of these factors in relationship between AGB and Alos Palsar backscatters. Conclusion revealed that ALOS PALSAR images are advantageous for its active microwave sensor using L-band frequency to achieve free imageries.

Recently, Golshani et al. (2019) combined ALOS-2 PALSAR-2 variables to biomass and forest shape by using 115 circular sample plots of tree species and DBH > 7.5 cm and use the allometric equations to estimate forest biomass. The image processing was run using radiometric calibration for retrieving the backscatter value, Lee adaptive filter 7 × 7 pixel size for smoothen the image, Pauli's target vector and terrain correction. Further analysis was performed using statistical analysis. It indicates that the response of backscattering coefficient to biomass is affected by using the wooded area type and cover shape where HH polarization backscatter is higher acceptable for sparse areas, whilst HV polarization backscatter is certified for dense areas. The study had summarized that full polarimetric records are extra efficient than dual-polarization SAR images. Some major stratification used to cover shape or wooded area type needs to be carried out to provide higher regression relationship between biomass and SAR data.

Darmawan et al. (2019) developed a SEA region model using the ALOS PALSAR 25-m mosaic for aboveground mangrove forests biomass estimation. Visual interpretation using open sources data is used to replace the field data acquisition. Image processing was done by preprocessing in converting DN to dB, characterization (46 ROIs), mean and standard deviation. Rule-based classification method is used and direct model of Hamdan's empirical relationships model as well as indirect model of Takeuchi's empirical relationships model were applied for the analysis.

The study found that there are significant results between HV polarization and AGB model with average of 140.5 ± 136.1 Mg/ha. However, in this study the backscatter value of mangrove forest is affected by tidal height topography. Hence, whenever the AGB volume exceeds a certain critical value, the backscatter intensity becomes saturated. For this reason, applying an interferometry technique is seen to be appropriate but this method is not widely tested. In short, based on mangrove topography the direct model is more precise and has outperformed the indirect model for AGB estimation. Future studies should focus on procedures and an approach on AGB estimation development and it needs to be conducted for field measurement.

Sivansankar et al. (2019) determined the influence of the Earth's surface using ALOS-2 PALSAR-2 data with spatial resolution of 9.1m×5.3m (Range × Azimuth) backscatter dan SRTM 30m DEM for forest AGB estimation. Study also utilized 150 sampling plots (height, species and girth at breast height (GBH) of 1 Ha plot. SRTM was used to generate slope, aspect and terrain correction of the HV polarizations. Study concluded that HH backscatter has lower significance compares to HV backscatter with AGB. Without the range Doppler terrain correction some inaccuracy need to take into account. Still PALSAR-2 time-series approach is proven to be effective in enhancing the AGB saturation points which can be improvised using L-band SAR data.

ICESat/ GLAS were utilized as an ancillary data (Hayashi et al., 2019 & Luis et al., 2019). In both studies, single HV Image,AGB estimation model via temporal resolution data, regression analysis using polarization, GLCM 5 × 5 pixels spatial filtering of PALSAR-2 images and comparison between HV alone and the HH/HV ratio was used by Hayasi whereas Luis used some pre-processing technique, refined Lee filter (11 x 11 pixel size) was applied for smoothen the image and lastly multiple linear regression analysis (AGB (Y) as dependent variable and Alos/ Palsar-2 (X) as multiple independent variable). Overall, both studies reported that there were significant results by using the data in the AGB mapping.

RESULTS

Table 1: In-situ and remote sensing parameters for forest AGB estimation.

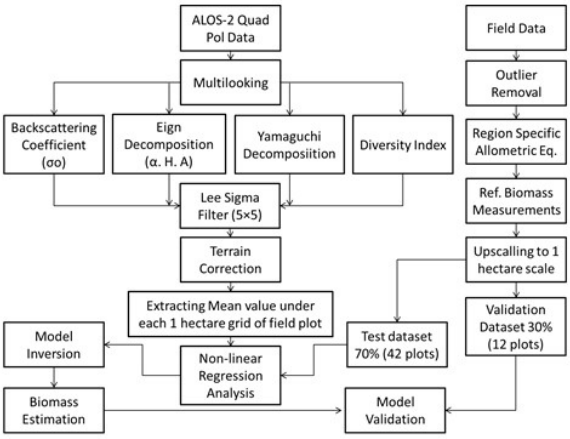
In-situ data: No. of plot		115	-	150	23		144		√	334	√	√	√	√	√	√
Size plot (ha)		0.1(4)	-	1.0	√		√		√	√	√	√		√	√	√
Diameter at breast height, DBH (cm)	2.55 - 150	> 7.5	-	√	√		√	√	≥10	√	√	√	√	√	√	√
Tree height (m)	√		-	√	√		√	√	√	√	√	√	√	√	√	√
Basal area							√	√	√						√	
Tree species	√		-	√				√								√
Forest types																√
GPS	√		-													
RS data: Alos-palsar-2	√	√	√	√	√	√	√	√	√	√	√	√				
Alos-palsar										√			√	√	√	√

ICESat/ GLAS					√											
Lee sigma filter	5×5															
Lee adaptive filter		7×7														
Refine Lee filter						11×11		11×11								
Median filter														3×3		
Enhanced Frost filter									5×5							
GLCM					5×5					√	√					√
Results: Aboveground biomass, AGB (Mg ha-1)	200		140.5 ± 136.1							200						
Saturation level (t ha-1)		700			280											150
Significant backscattering polarization		HV	HV	HV	HV				HV	HV	HV	HV	HV	HV	HV	HV

Recently, Waqar et al. (2020) had uses backscatter, polarimetric parameters, and diversity indices from ALOS-2 PALSAR Quad-Pol and SRTM 30m DEM data to estimate aboveground biomass in tropical peatland forest. The study utilizes 56 tree plots of dimensions 20m × 20m (DBH and tree species). Allometric equations were applied to estimate the overall AGB. Among the methods that were being used are inter-quartile range (IQR) to remove outlier, POLSAR (Corresponding surface and volumetric scattering power; average angle alpha α; Entropy; anisotropy; Backscattering Coefficient; Shannon Index; Simpson Index; Gini Simpson Index; Reyni Entropy; & Perplexity), lee sigma 5 × 5 speckle filter and correlation matrix between polarimetric parameters.

The study found that Shannon Index, Reyni Entropy, Perplexity, IQV, and GSI are highly correlated. A significant correlation was found among diversity indices, polarimetric parameters, and backscattering coefficient with referenced biomass measurements. Other than that, perplexity, Shannon index, and entropy are most correlated with the referenced aboveground biomass with R2 0.67, 0.67, and 0.66, respectively. The study needs more reference field measurements in order to improve the accuracy level. Previous study explained that L-band SAR signal saturates at 250 Mgha-1. However, most of the field-based biomass measurements used was under 200 Mgha-1. Thus, the study concludes that there is a need to investigate more advanced polarimetric parameters to have an in-depth understanding of biomass potential in the region.

Figure 2: Methodology framework for AGB estimation using L-band backscattering SAR data (From Waqar, et.al, 2020).



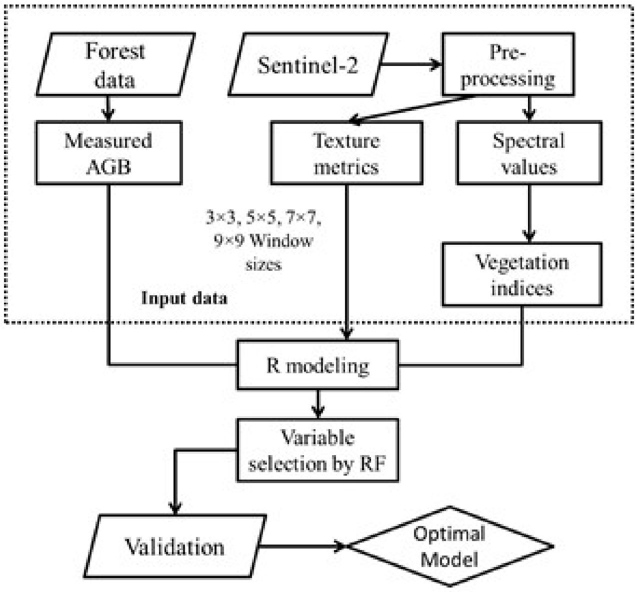
From the study the data used had shown significant results in forest AGB estimation in many aspects. Firstly, it can be applied and as utility to help in an efficient decision making process especially by manager for a sustainable method in forest conservation, which assists in providing the tree parameters data. Secondly, it was seen as an applicable method in achieving optimal goals, provide reliable accuracy, has low operational cost and display consistent available satellite data. Where, through the help of empirical relation between ALOS PALSAR HV backscatter and AGB, the above ground biomass can be estimated accurately up to 150 t/ha (Suresh et al., 2014).

DISCUSSION

Utilizing Sentinel-2 band in AGB estimation

Utilizing Sentinel-2 band in AGB estimation had been widely demonstrated by recent study due to its very high resolution. Santa Pandit et al. (2019) addressed the potential of Sentinel-2 derived texture metrics in improving AGB in the sub-tropical forest country. This study utilized 113 primary inventories and 60 secondary data by systematic random sampling technique. Image processing and analysis had been done and the results of the study brought new insights and understanding of AGB estimates in sub-tropical that use VIs and raw spectral bands could be challenging whereas Sentinel-2 MSI can be better approach.

Figure 3: Flow chart showing the image analysis steps in forest AGB Estimation using Sentinel-2 data (From Santa Pandit, et. al, 2019).



In regard to that, Norovsuren et al. (2019) also developed model using Sentinel-1B SAR data for C-band and Sentinel-2B multispectral data for estimating forest biomass. The study was done through 161 tree samples (DBH, and tree height and species) and had estimated AGB using Alometric equations developed by Chave et al. (2005).

The authors had done the image processing through radiometric calibration to retrieve the backscattering value for VV and VH polarization, speckle filter for smoothen the image and some minor processing. NDVI and forest type classification was done for producing the map and analyze by regression analysis for AGB prediction and lastly accuracy assessment. This study found that the results of using VV, VH polarizations and NDVI has a good agreement which ground measurement (regression was 0.7) and the average of AGB resource is 41 tonn/ha over the study area (average AGB is 37.4 tonn/ha was found). The overall accuracy assessment was 92%. The authors concluded that the model will contribute to the estimation of forest coverage in small areas in their region of interest and for forestry economics.

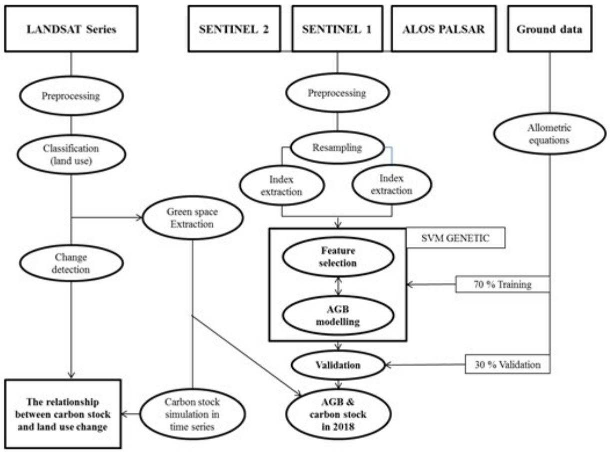
As Torabzadeh et al. (2019) determined the performance of spectrally-derived indices through the application of Sentinel-2 MSI that was combined with in-situ measurements (20x20m plot) in estimating forest AGB in the target area. The approached results show Sentinel-2 data effectively predicted the above-ground biomass of the study area and the study suggests species-specific allometric estimates for plot-level AGB values for further researches.

From the study, it can be concluded that some of the authors had succeeded in producing forest AGB mapping by utilizing Sentinel-2 data set. In this aspects, it had outperformed the L-band SAR data model. However, there are problem in term of accuracy level when it comes for AGB estimation. Later on, in new subtopic of this review paper the integration of both models were discussed.

Integrating optical and microwave or multiple microwave bands in AGB estimation

There are several studies had conducted AGB estimation through relationships of optical and microwave remote sensing.

Figure 4: Flowchart of AGB estimation using optic and radar imagery (From Tavasoli, et. al, 2019).



Tavasoli et al. (2019) contributed to the development of remote sensing-based predictive mapping techniques for urban forest AGB and carbon stock using Sentinel-2A and Sentinel-2B, and ALOS PALSAR (Sentinel-1A and Sentinel-1B). This study used 65 tree plots (tree species and DBH) and the AGB was calculated using the allometric equations developed by Chave et al. (2005). The image processing was done through radiometric correction, AGB modeling and Optical & Radar Indexes. This concludes that urban area has increased and vice versa (2000-2018), carbon cycle has decreased with the increment in deforestation (1202.35327 ton/ha of carbon have decreased since 2000 to 2018). Study also mentioned about the reduce number of studies with conventional approach in estimating AGB as compared to remote sensing.

In recent study, Zhu et al. (2020) 1431 sample plots integrated with multisource remote sensing data in modeling and mapping forest biomass. Image processing was done by extracting DN of the PALSAR and converted to dB in decimal units and the polarization parameters were analyzed and lastly validation. Data showed there is a significant results between HH and HV backscatter coefficients and HV backscatter coefficients of different forest has higher correlation compared HH backscatter coefficients. However, other variables like shrubs, and herbs were not considered in this study, therefore the estimation of biomass is believed to be relatively conservative. Also, terrain correction was not practically applied and thus affects the inaccuracy of the biomass models.

Rodríguez-Veiga et al. (2019) determined the amount and spatial distribution of Colombia's AGB using the current NFI sample and Earth Observation (EO) data with 300 plots and 26 PPMs including DBH, canopy height and tree species. ALOS-2 PALSAR-2, Landsat 7 and Landsat 8 multispectral 30 m, and 30 m Digital Elevation Model from the SRTM for slope correction were used in the study. Image processing was done through pre-processing calibration, multi-looking projection, ortho-rectification and an additional de-striping process. The study found that the combination of the models provide the best balance between analysis. The study suggests the need for more sample plots to reduce uncertainty. Overall, the initial results using a combination of SAR ALOS-2 PALSAR-2 and multispectral Landsat 7 and Landsat 8 annual composites showed promising results.

Kumar et al. (2019) assessed the spatial AGB estimation using SAR remote sensing namely the C band Sentinel 1A and L band ALOS PALSAR. The study also utilized tree parameters in their study. Image processing and processing were done and the study found that SAR parameters such as HH and HV polarization are more important as compare to sentinel 1A parameter when dealing with AGB.

Morin et al. (2019) built an automatic and generic method using freely available SAR and optical data at high resolution. The study utilized Sentinel-1, Sentinel-2, ALOS-PALSAR mosaics (10–25 m) along with 83 plots in-situ data consisting of DBH and tree height which were geo-located by using GPS. All data undergo preprocessing and processing for .extracting the correlation output between remote sensing data and forest parameters. The study found that MLR assumes that remote sensing features and forest variables have linear relationships. Meanwhile, forward selection performed better than backward selection. For the whole forest variables, it was found that L-band and textural metrics are very important than C-band (C-TI). The study had demonstrated that open access space borne data are able to provide precise estimations of forest parameters and AGB. It was suggested that when dealing with small reference data (forest inventory), forward selection is recommended compare to backward selection or PCA.

Braun et al. (2018) had derived AGB estimates for large parts areas. It also utilized data from ENVISAR, ALOS PASLSAR and SSMI/I along with field data of DBH and tree species for validation. The pre-processing and processing of remote sensing data were radiometric calibration, incidence angle normalization, Range-Doppler terrain correction, and correlation analysis. The images were all transformed into eight-bit integer format and leave-one-out cross validation were done. Study also identified higher correlation for the ENVISAT compare to ALOS where microwaves of shorter wavelength of ENVISAT. However, for larger wavelengths of ALOS it can only partially penetrate canopies and ground vegetation layers and typically has stronger reaction with objects of comparable size such as larger branches or stems. Meanwhile, the passive radar data (SSM/I) alone cannot predict the distribution of AGB to sufficient degree. Yet, some peculiarities should be considered in this study such as limitation of both satellite and field data availability. All in all, good correlation can be identified between spaceborne SAR backscatter and low biomass condition (below value 10t/ha).

Huang et al. (2018) tested the satellite data using the latest methods such as multi-temporal Sentinel-1, and relative biomass change detection and treatment sites along with the field data for validation. It also tried to investigate the relationship between AGB and the backscattering amplitudes (VH and VV) for both Sentinel-1 and PALSAR-2 data as well as Multiple

Linear Regression (MLR) through the application of exhaustive search algorithm to obtain the best model of AGB estimation. Results determined that that HV is much more sensitive to AGB as compared to VV, while C-band Sentinel-1 backscattering amplitude is hard to be used for operational purposes of AGB estimation. The study also had to face some limitations like low accuracy and different images were acquired from different sensors to avoid weather effects like the rain. Hence, L-band can provide much more consistent accuracy than the C-band. So, in the future, the fusion of the long wavelength SAR (L- or P-band) and optical can be used to achieve better AGB estimation along with better information.

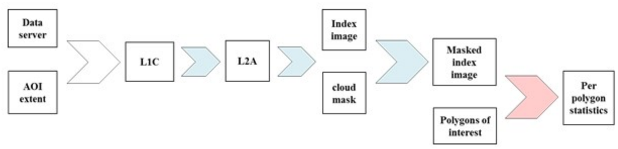
Sivasankar et al. (2018) had investigates the potential of multi-frequency multi-polarized (L-band and C-band) ALOS-2/PALSAR-2 and Sentinel-1 C-band SAR data for above ground forest biomass estimation along with field data of DBH and tree species for validation. Remote sensing data undergo with radiometric calibration using SNAP tools for retrieving backscattering values, Refined Lee filter for speckle noise reduction, Terrain correction using Range Doppler Terrain Correction and further analysis using regression analysis. The study found that ALOS-2/PALSAR-2 backscatter is more sensitive than Sentinel-1 SAR backscatter due to the higher saturation levels of longer wavelengths. Due to the limitation of field data, this work can be further continued with more number of sample data by considering Terrain characteristics along with multi-frequency cross polarized SAR data. Overall, the use of multi Polarization backscatter can significantly increase AGB retrieval accuracy rather than using single polarized SAR data. The multi-frequency cross polarized backscatter can significantly improve the AGB retrieval accuracy than single-band multi-polarized backscatter.

Overall, integrating both optical and microwave remote sensing data shown promising results. The studies had achieved and able to increase the accuracy level in estimating and forest mapping. Still L-band can provide much more consistent accuracy than the C-band. Although the result is accurate, in conventional approach it can be too costly, unpractical and time-consuming. So, in the future, the fusion of the long wavelength SAR (L- or P-band) and optical can be used to achieve better AGB estimation along with better information and the budget of projects need to be justify before using (processing) or purchasing the product.

Utilizing Commercial and open source sensors in AGB Estimation

There are limited studies that focus on the potential of commercial remote sensing in estimating AGB. Wittke et al. (2019) had distinguishes between two-dimensional multitemporal Sentinel-2 data with three-dimensional remote sensing data (Airborne Laser Scanning, TerraSAR-X-stereo and WorldView-2) for forest inventory parameter estimation and mapping area of interest more accurately. In the study, 119 sample plots in 2014 and 91 unchanged plots in 2016 (DBH and tree height) were utilized. Image processing were done using Random Forest algorithm, nearest neighbor and processed through Python packages rasterstats. The results showed that bands 11 and 12 as well as bands 5, 7 and 8A show significant results than other features for all parameters.

Figure 5: Methodology of forest AGB Estimation using machine learning (From Wittke, et. al, 2019).



However, the integration of all Sentinel-2 data outperformed the rest of the parameters. In the study some limitation were justify such that lacks of cloud-free data and the number of plots. The study concludes that the model generated from the data have benefit in terms of costs and regularly updated.

In 2019, Sinha and others had come out with statistics model that would integrate COSMO-Skymed X-band and ALOS PALSAR-2 data and estimate AGB with improved saturation level in order to achieve better accuracy. The field data were also utilized for validation purposes. As for the SAR processing, study applied multilooking, filtering using 3×3 mean filters, geocoding and further analysis. Study revealed that the result shows significant for both HH and VV polarizations with AGB.

Lucas et al. (2019) determined the same parameters in estimating AGB using Landsat TM and ETM+, JERS -1, ALOS PALSAR and ALOS-2 PALSAR-2 with forest inventory of DBH and height for validation. Other than that, landsat calibration and derivation of indices, speckle filtering and further analysis on the relationships with forest age were applied as part of the processing. Study showed a rapid increase followed by a decrease in LHHs° and LHVs° (over a period of 5-6 years), a period of high variability is 6-10 years after clearing and more coherent period of slight and steady increase to 10-20 years, with former slightly reduced.

Ningthoujam et al. (2017) investigated the S-band backscatter's sensitivities towards different forest types and biomass level along with field data DBH (>5 cm) and tree height. The SAR data was submitted for antenna pattern correction, speckle filtered using Enhanced Forest filter at 5×5 moving windows and geocoding and polarization calibration for retrieving the backscattering values. Furthermore, study found that S-band backscatters is influenced bt the forest AGB and signify different sensitivity based on polarization for each site; also, it is where the S-band backscatter against forest AGB provides a logarithmic model through the best result of conifer. Yet, there are some constraints that should be considered such as the inaccuracies of the field data, lack of information in soil moisture for all sites as well as the limitation of the first-order radiative transfer model. Overall, study concluded that S-band SAR might be able to contribute the information of forest biomass in low-biomass forests up to 100t/ha.

To sum up, utilizing commercial data in estimating forest AGB can be very expensive. This approach demonstrated only by a few studies since it was not sustainable and could be ineffective. However, several cases could be beneficial such that in country that do not had accessed or permit to use the open sources data.

CONCLUSION

This paper is about aboveground biomass (AGB) estimation using space remote sensing technique. This review paper discusses on the objectives, data acquisition, method and technique, results and discussion, GAP and limitation, and conclusion that had been applied from the recent application of remote sensing in estimating aboveground biomass (AGB) over different forests region. Different sources of remote sensing data had been studied to help decision maker for choosing the best model according to their goals.

From this review paper, it was found that utilizing L-band SAR data outperformed optical remote sensing satellite in estimating forest aboveground biomass. The backscattering from the SAR or microwave platform shows significant with AGB where the HV polarization was dominance in discriminating forest structure as compare to the HH polarization. As compare to optical remote sensing, ALOS PALSAR-2 or other SAR platforms (Microwave remote sensing) have several advantages such follows:-

However, in some extent there are only a few studies about the relationships between SAR data and forest AGB. On top of that, SAR platform is said to have problem in high volume of AGB where there is increment in saturation level. Some uncertainties also need to take into account such as users need to be careful when dealing with mangrove forest types as the tide season affect the estimation. Moreover, there is a limitation in producing forest AGB mapping using SAR data. For this reason, optical remote sensing such as Sentinel-2 with 10 meter resolution and Landsat ETM+ were recommended because it has many bands. Lastly, other than optical and microwave remote sensing, more studies need to be consider such as using LiDAR and hyperspectral remote sensing in AGB estimation.

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