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Seasonal Effects of Backscattering Intensity of ALOS-2 PALSAR-2 (L-Band) on Retrieval Forest Biomass in the Tropics

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Abstract

This research has used the L-band radar from ALOS-2 PALSAR-2 and field work data for evaluation of seasonal effects of backscattering intensity on retrieval forest biomass in the tropics. The effects of seasonality and HH, and HV polarizations of the SAR data on the biomass were analyzed. The dry season HV polarization could explain 61% of the biomass in this study region. The dry season HV backscattering intensity was highly sensitive to the biomass compared to the rainy season backscattering intensity. The SAR data acquired in the rainy season with humid and wet canopies were not very sensitive to the in situ biomass. Strong dependence of the biomass estimates with season of SAR data acquisition confirmed that the choice of right season SAR data is very important for improving the satellite based estimates of the biomass. This research expects that the results obtained in this research will contribute to monitoring of the quantity and quality of forest biomass in Vietnam and other tropical countries.

Keywords

L-Band SAR, ALOS-2 PALSAR-2, Backscattering Intensity, Tropical Forest Biomass, Vietnam

1. Introduction

The role of forests to mitigate climate change has been strongly recognized again in the Paris Agreement in 2015 like as “key components of landmark climate deal agreed as well as an instrument to contribute to reducing emissions and enhancing carbon sinks" on Paris Agreement (COP 21, 2015). The information of forest biomass is essential for increasing understanding of the terrestrial carbon cycle and judicial management of forest resources. Forests sequestrate atmospheric carbon dioxide in the form of biomass during photosynthesis (IPCC, 2003; FAO, 2009; Way & Pearcy, 2012). Therefore, forest biomass has an important role in the global carbon cycle (Brown, 1997; IPCC 2006; Gibbs et al., 2007). When forests are destroyed, more carbon is added to the atmosphere which accelerates climate change. Accurate monitoring of forest biomass and CO_2 sequestration rates are immensely important for increasing understanding of global carbon cycles, improving climate change forecasting models, and climate change mitigation and adaptation strategies (FAO, 1997; GCOS, 2006; Gibbs et al., 2007; FAO, 2009, 2010; Stone & León, 2011). Global monitoring of forest carbon is also urgently needed for the United Nation program on Reducing Emissions from Deforestation and Degradation (REDD+), a financial payment mechanism for environmental services (Stone & León, 2011; UN-REDD Vietnam, 2012). However, estimating biomass from satellite data is challenging due to the diverse nature of forests, especially tropical forests (Lefsky et al., 2002; Lu, 2006; Gibbs et al., 2007; FAO, 2010; Sinha et al., 2015).

Satellite remote sensing technology has many advantages for biomass estimates over traditional field survey based methods, particularly at larger scales. Therefore, it has been used by many researchers for biomass estimates (Lu, 2006; Gibbs et al., 2007; Ghasemi et al., 2011). Satellite based estimation of biomass relies on optical, radar, and more recently lidar techniques. Limitations of optical data based biomass estimates have been reported by researchers including saturation over large biomass regions, very low correlation, and difficulties in detecting vertical structure (Ripple et al., 1991; Vincent & Saatchi, 1999; GCOS, 2006; Gibbs et al., 2007; Gonzalez et al., 2010; Brewer et al., 2011; Sinha et al., 2015; Pham et al., 2019).

Lidar sensors have performed excellent estimates even in forests with high biomass and woody volumes by directly measuring the structure of the forest, i.e., canopy height and vertical distribution (Vincent & Saatchi, 1999; Lefsky et al., 2002; Zhao et al., 2009; Bortolot & Wynne, 2005; Moskal & Zheng, 2011; Kankare et al., 2013; Sheridan et al., 2014; Hansen et al., 2013). However, large scale application of lidar data is not economically feasible at present (Lu, 2006; Gibbs et al., 2007; Brewer et al., 2011).

Radar remote sensing from satellites has high potential for biomass estimates at large scale because of its penetrability through clouds, applicability with night time, coverage at large scale, availability of seasonal data, and lower saturation in dense forests (Ulaby et al., 1981; Wu, 1987; Jensen, 2005; Kellndorfer et al., 2004; Ramankutty et al., 2007; Gibbs et al., 2007; Le Toan et al., 2011; Brolly & Woodhouse, 2012; Sinha et al., 2015; Luong et al., 2016; Luong et al., 2019). The long-wavelength SAR satellite is expected to have much promise for estimates of forest biomass (Ramankutty et al., 2007; FAO, 2009; Le Toan et al., 2011; Pham et al., 2020).

The backscattering intensity of L-band and P-band SAR data have demonstrated sensitivity to structure, cover, volume, and biomass of the forests penetrating into the branches and stems of trees (Jensen, 2005; Sun et al., 2002; Balzter, 2001; Balzter et al., 2007; Luong et al., 2016). A number of previous studies have shown an impressive relationship between the SAR data and biomass (Wu, 1987; Le Toan et al., 1992; Dobson et al., 1992; Ranson & Sun, 1994; Luckman et al., 1997; Santos et al., 2002; Mitchard et al., 2011; Sandberg et al., 2011; Peregon & Yamagata, 2013). On the other hand, several researchers have reported saturation problems with the L-band SAR backscattering over high biomass regions. The major techniques for SAR based estimates of biomass attempted by a number of researchers so far are regression modelling (Le Toan et al., 1992; Morel et al., 2011; Englhart et al., 2011; Carreiras et al., 2013), dual-wavelength SAR interferometry (Balzter et al., 2007); image texture analysis (Champion et al., 2008); random volume over ground model (Hajnsek et al., 2009), water cloud model (Cartus et al., 2012), combination of forest structure and radiative transfer models (Brolly & Woodhouse, 2014), electromagnetic modelling (Mermoz et al., 2015), multivariate relevance vector regression (Sharifi et al., 2016). SAR data have been used for estimating biomass at different scales from local to region-al/country level: pine plantation in Southwest Alabama (Wu, 1987), Mount Sharsta region of Northern California (Richards et al., 1987), plantation forest of the Landes forest in southwestern France (Le Toan et al., 1992), Brazilian Amazon (Luckman et al., 1997; Santos et al., 2002), Nuuksio Natural Park in Southern Finland (Mika et al., 2008), the Queensland in Australia (Lucas et al., 2010), Mozambique in Zambézia province (Carreiras et al., 2013), Cambodia (Avtar et al., 2013), and Cameroon (Mermoz et al., 2015).

Several studies have shown that: backscattering intensity is also affected by a number of site conditions such as environmental temperatures (Ranson & Sun, 1994), moistures (Bindlish & Barros, 2001; Kasischke et al., 2009; Koyama, 2011; Huang et al., 2015).

In this research used the Advanced Land Observing Satellite-2 (JAXA, 2014), a Japanese satellite launched in 2014, which operates in L-band radar and collects very high spatial resolution. Currently, satellite image data from ALOS-2 is available and meets the global supply capability to many different applications.

The objective of this study was to assess the effects of seasons in the tropics on the quality of the ALOS-2 PALSAR-2 (L-band) satellite imagery.

2. Study Area and Data

2.1. Study Area

This research was carried out in Yok Don National Park (YDNP) is located in Dak Lac and Dak Nong provinces, Central Highlands of Vietnam. This park was chosen for this study because of several reasons: 1) It is located in the tropical forest with characteristics of the typical structure in Vietnam; 2) This park is the largest national park in Vietnam; 3) It is located on relatively flat ground, average slope from 7˚ - 10˚, thereby minimizing the effect of topography on this study; 4) The road network around and inside the study area is not too difficult to transport, and perform fieldwork.

The Yok Don National Park is located between latitude 12˚45' - 13˚10'' and longitude 107˚29'30'' - 107˚48'30'' (**Figure 1**).

Topography: The whole area is divided into two main geographical terrain forms: fairly smooth pen plain, and being lower towards the Mekong River. The other terrain form, low hills, and mountains is lying along the north riverbank. The topography of this park contains relatively plain topography and is located at an altitude of 200 - 300 m above sea level. Most of the terrain with an average slope from 7˚ - 10˚ (Nguyen, 2009).

Climate: This region is a tropical monsoon that has well-defined and distinct dry and rainy seasons. The rainy season runs from May to November. The average rainfall obviously changes among months of the rainy season and the dry season. It is very low in the dry season from October to April; the average value is less than 50 mm. In contrast, it is very high from April to August and then quickly decreases in September and October at the end of the rainy season. The average annual rainfall about 1530 mm, while the average annual evaporation is 1470 mm, and the mean monthly temperature is around 25˚C (Nguyen, 2009).

Compared to rainfall and humidity, the monthly change of air temperature is very high. April and May are months whose average air temperature is highest, about 27˚C, while the average temperature in December and January is lowest, about 14˚C.

Biodiversity: This park is very rich in biodiversity: 854 species, belonging to 478 vascular plant species and 129 families of 4 phyla have been recorded (Canh et al., 2009; Nguyen, 2015). This park has two major types of forest: deciduous broadleaf forest and evergreen broadleaf forest. The dominant tree species in the deciduous broadleaf forest are *Dipterocarpus tuberculatus*, *Dipterocarpus obtusifolius*, *Terminalia tomentosa*, and *Shorea obtuse*. The evergreen broadleaf forest mainly comprises of *Michelia mediocris*, *Cinamomum iners*, *Syzygium zeylanicum*, *Syzygium wightianum*, *Garruga pierrei*, *Gonocaryum lobbianum*, *Schima superba*, *Camellia assamica*, and *Lithocarpus fenestratus*. This park has 21 tree species in the list of the Red Data Book of Vietnam (Nguyen, 2015). A total of 89 species of mammals, 250 species of birds, 48 species of reptiles, 16 species of amphibians, 31 species of fish, and 437 species of butterflies were recorded (Canh et al., 2009; Nguyen, 2015). This park is one of the most important protected areas and provides a suitable habitat for conservation of globally endangered species in Southeast Asia such as wild elephants, wild cow, deer and a lot of birds such as peacocks and several species of birds of prey and large water birds (Nguyen, 2015).

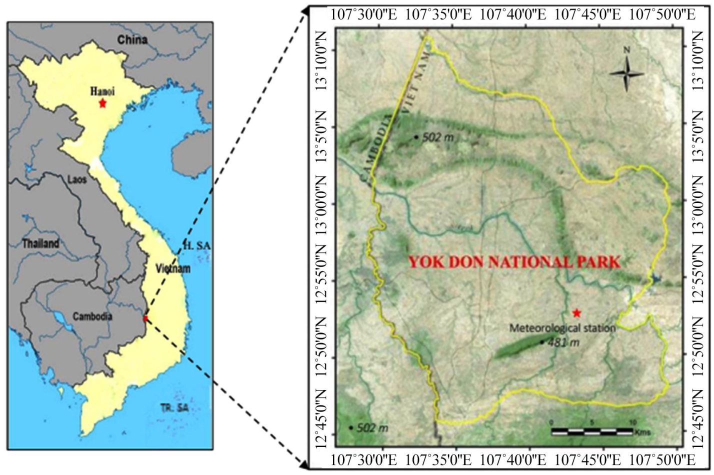


Figure 1. Location of the study area Yok Don National Park in Vietnam (boundary is the yellow polygon).

2.2. ALOS-2 PALSAR-2 Data

In this study, we used the Advanced Land Observing Satellite-2 Synthetic Aperture Radar (ALOS-2 SAR), provided by Japan Aerospace Exploration Agency (JAXA), a Japanese satellite launched in 2014, which operates in L-band radar and collects very high spatial resolution data. ALOS-2 SAR data with level 2.1, which has 6.25 m pixel resolution was selected from October 2014 (rainy season) to February 2015 (dry season). The digital number (DN) values of the SAR images in both the HH and HV polarizations were calibrated by calculating the backscattering intensity using Equation (1) (JAXA, 2014).

$$\sigma^{o} = 10 \times \log_{10}\left(\mathrm{DN}^{2}\right) + \mathrm{CF} \quad (1)$$

In Equation (1), the σ^o is the sigma-naught backscattering intensity in the units of decibels (dB), and CF is the calibration factor which is currently set as −83 (JAXA, 2014).

The details on the ALOS-2 SAR images used in this research are described in Table 1. Both dry and rainy season SAR images were used, acquired with the same off-nadir angle (32.9˚) in descending modes in order to avoid bias related to observation angles.

3. Methodology

3.1. Field Work

The in situ measurements were conducted by establishing the sample plots according to the inventory guideline available for the Central Highlands region (Van Vo et al., 2006; Vu Tan et al., 2012). All sample plots were established by meeting the criteria of representativeness of different forest types across the study areas such as 1) Evenly distributed in the study area; 2) Representativeness of the forest types in the study area; 3) Representativeness for topographic conditions; 4) At least 100-m apart from trains, roads, streams, and rivers. We carefully designed the sample plots in such a way that they were at least 100-m apart

Table 1. The ALOS-2 PALSAR-2 data used in this research.

No.	Obs. date	Scene ID	Polar.	Obs. angle	Seasons
1	5 Oct. 2014	ALOS2019900240-141005-FBDR2.1GUA	HH, HV	32.9˚	Rainy
2	5 Oct. 2014	ALOS2019900250-141005-FBDR2.1GUA	HH, HV	32.9˚	Rainy
3	22 Feb. 2015	ALOS2040600240-150222-FBDR2.1GUA	HH, HV	32.9˚	Dry
4	22 Feb. 2015	ALOS2040600250-150222-FBDR2.1GUA	HH, HV	32.9˚	Dry

from trails, roads, streams, and rivers to avoid the signals from unwanted surface types for sensitivity analysis.

Each sample plot established during the forest inventory was (50 m × 50 m) with an area of 0.25 ha. Measurement of the diameter at breast height (D) and total tree height (H) of all the trees larger than 5 cm diameter at breast height located inside the sample plots. The tree diameter and height were measured by using laser diameter (Criterion RD1000 Laser) and laser height (Trupulse 360B Laser) instruments. The central geo-location (latitude and longitude) of each sample plot was recorded by using GPS instruments.

The RGB color composite image was created by using the HH channel for red (R), HV channel for green (G), and the ratio HH/HV for blue (B). The distribution of sample plots used in this research is shown in Figure 2 and Figure 3 using RGB color composite of the SAR color composite images. Distinct variation between the rainy season and dry season RGB images in Yok Don National Park were observed as shown in Figure 2 and Figure 3.

3.2. Estimation of Forest Biomass

This research converted the individual tree biometry data: diameter at breast height (D) and total tree height (H) measured during the forest inventory into above ground biomass (AGB) using the allometric equations. The research used separate allometric equations for calculating the AGB of the deciduous and evergreen forests (Vu Tan et al., 2012). The allometric equations used for calculating the AGB of deciduous and evergreen forest types are given in Equation (2) and Equation (3) respectively.

$$\mathrm{AGB} = 0.14 \times \mathrm{D}^{2.31} \quad (2)$$

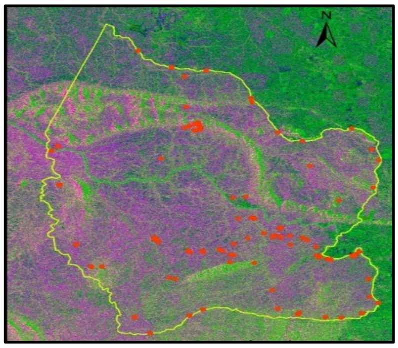
$$\mathrm{AGB} = 0.098 * \exp\left(2.08 * \mathrm{Ln}(\mathrm{D}) + 0.71 * \mathrm{Ln}(\mathrm{H}) + 1.12 * \mathrm{Ln}(\mathrm{WD})\right) \quad (3)$$

In Equation (2) and Equation (3), where: AGB is the above ground biomass of a tree in kilograms (kg); D is the diameter at breast height measured at 1.3-m above the ground level; H is the total height of tree in meters (m); WD is the wood density of tree in tones dry matter per fresh cubic meters ($\mathrm{Mg} \cdot \mathrm{m}^{-3}$).

4. Results and Discussions

4.1. Field Survey Results

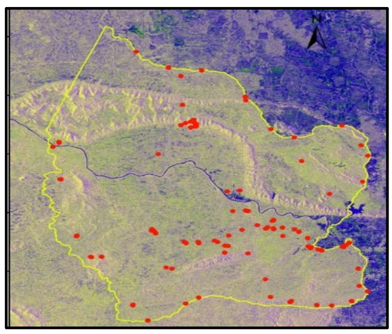
The plot wise distribution of forest structural variation shows that: In total, 110 sample plots were established in the study area. Of which, 10 sample plots were from the evergreen forest and 100 sample plots were from the dipterocarp forest, the sample plots represent larger variation of the diameter at breast height (8.14 - 48.74 cm), tree height (6.13 - 18.23 m), tree density (220 - 2800 trees·ha^{-1}) and biomass (42 - 450 Mg·ha^{-1}).



(a)

(b)

Figure 2. Distribution of sample plots. (a) Dry season RGB color composite images; (b) Forest in rainy season.



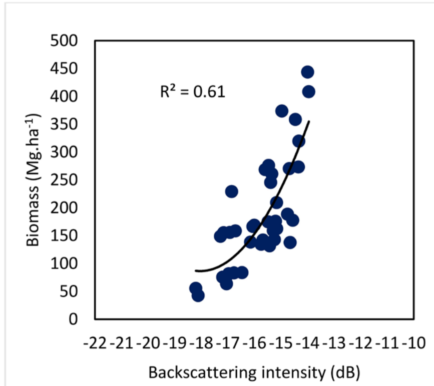
(a)

(b)

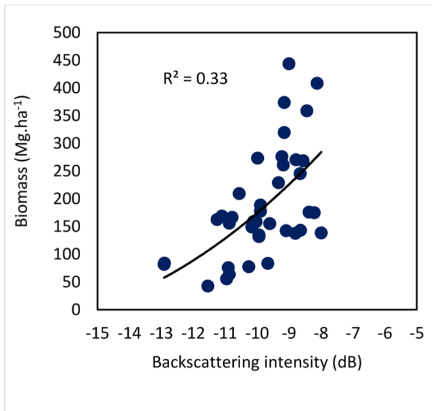
Figure 3. Distribution of sample plots. (a) Rainy season RGB color composite images; (b) Forest in rainy season.

4.2. The Polarizing Difference of L-Band SAR to the Retrieval Forest Biomass

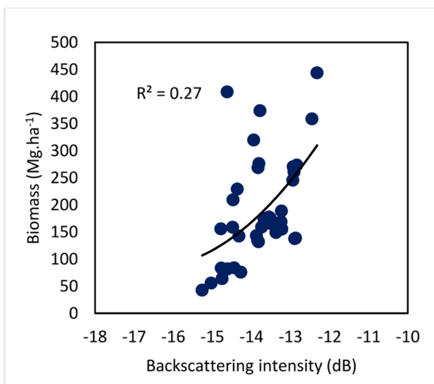
The sensitivity of biomass with the backscattering intensity of the HH and HV polarizations for the dry season was analyzed using the coefficient of determination (R^2) and Root Mean Square Error (RMSE). As shown in Figure 4(a) and Figure 4(b), the HV polarization was highly related to both the biomass (R^2 = 0.61, RMSE = 38.28 Mg·ha^{-1}); whereas the HH polarization did not show a significant relationship with the above ground biomass (R^2 = 0.33, RMSE = 65.87 Mg·ha^{-1}).



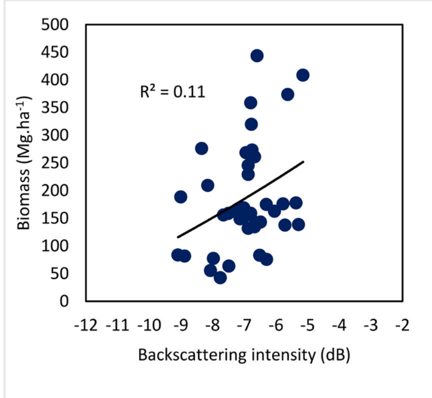
(a)



(b)



(c)



(d)

Figure 4. The relationship between the biomass, and backscattering intensity. (a) HV in dry season; (b) HH in dry season; (c) HV in rainy season; and (d) HH rainy season.

The high sensitivity of the HV polarization towards biomass was found for both the dry and rainy season SAR data. This result highlights the importance of HV polarization for the estimates of biomass.

The saturation of the radar signal was clearly observed at high biomass level (250 - 300 Mg·ha^{-1} biomass). None of the biomass data correlated with the rainy season HV polarization data as highly as the dry season HV polarization data.

4.3. The Seasonal Difference of L-Band SAR to the Retrieval Forest Biomass

The sensitivity of the ALOS-2 PALSAR-2 data (HV and HH polarizations) acquired during dry season and rainy season on biomass was analyzed. The relationship between biomass and dry season SAR data is shown in Figure 4(a) and Figure 4(b); and the relationship between biomass and rainy season SAR data is shown in Figure 4(c) and Figure 4(d). The dry season backscattering intensity of the HH and HV polarizations was highly sensitive to the biomass than the rainy season backscattering intensity. The higher relationship between the dry season HV polarization and biomass (R^2 = 0.61, RMSE = 38.28 Mg·ha^{-1}) was obtained. However, the relationship between the rainy season HV polarization and biomass was relatively lower (R^2 = 0.27, RMSE = 71.60 Mg·ha^{-1}) than the dry season. The relationship between rainy season HV polarization. This analysis suggests that dry season SAR data is more important for estimating the biomass than the rainy season data. The effect of seasonality for the SAR data was clearly observed in this research.

4.4. Validation Result

In this research used 38 sample plots data were used to test the validity of the fitted linear regression models for the prediction of biomass. In Figure 5 shown, our model could explain 59% variation of the biomass (R^2 = 0.59, RMSE = 40.28 Mg·ha^{-1}).

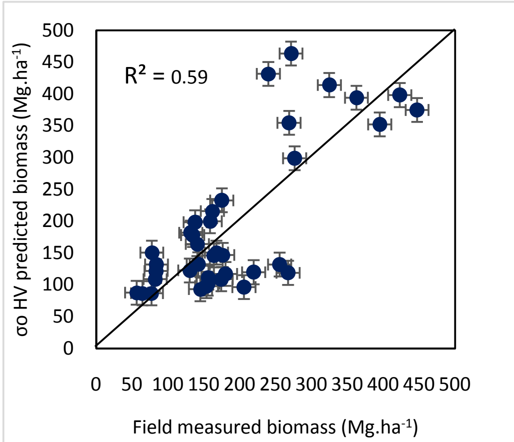


Figure 5. Validation of the SAR data based predicted results of above ground biomass. The 1:1 plot between the predicted and field data are shown.

5. Conclusion

In this research, the sensitivity of the biomass to the polarizations of ALOS-2 PALSAR-2 data (SAR data), and the season of acquisition of SAR data were analyzed. The relationship between the ALOS-2 PALSAR-2 based HV polarization backscattering intensity and field measured biomass since 59% variation in forest biomass could be explained by the HV polarization data.

This study found out that dry season SAR data is more important for estimating the biomass than the rainy season data. The effect of seasonality for the SAR data was clearly observed in this research. This result confirmed that: the importance of SAR data mainly from the dry season.

Therefore, the choice of season in which SAR data is acquired is very important for satellite based estimates of the biomass.

We expect that the results obtained in this research would be useful for promoting emission reduction programs in the forestry sector, and to achieve sustainable forest management goals in Vietnam and other tropical countries.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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