Estimating Natural Forest Above-ground Biomass using ALOS-PALSAR: A Case Study in Thua Thien, Hue Province, Vietnam

ALOS-PALSARを用いた森林地上部バイオマスの推定 :ベトナム・フエ省トゥアティエンにおける事例

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In this paper, ALOS/PALSAR FBD L-band level 1.5 data were used to estimate the above-ground biomass of natural forest in Thua Thien Hue province. The radar backscatter at relatively long wavelengths can penetrate through the canopy and leaves in natural forestry, thus it is suitable for estimating biomass. The methodology was using the regression model to analysis the sensitivity of backscatter to above-ground biomass in natural forest. In-situ data were collected at 60 sites in 4 forest types of volume (rich, medium, poor and non-volume) with cutting 30 trees for measuring and sampling. Mean error and Mean square error were calculated for comparison between the estimated AGB and in-situ AGB. The rich forest displayed a large difference whereas there was a small difference in AGB value in estimated result and in-situ data.

1. INTRODUCTION

In Vietnam, forests are one of the major factors in socio-economy development and vice versa, the socio-economy strategy has a great influence on forestry management. The forestry development strategy in 2006-2020 has marked a new cycle of development policy. The period of 2006-2020 also informs the high awareness of Vietnam government in problems of climate change by increasing active participation in the international climate change arena. The country signed the UNFCCC in 1994 and the Kyoto In 2009, Vietnam was selected as the first in the world to pilot the United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (UN-REDD) funded by the Government of Norway. REDD+ has also been integrated into several key legal frameworks, including the National Target Programme on Climate Change Response for the period 2009–2015; the Action Plan Framework to Respond to Climate Change for Agriculture; and the National Forest Development Strategy [Thuy, 2011].

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Biomass is one of the important biophysical parameters for determining the function of the ecosystem environment. Biomass also directly represents the mass of carbon stored in living plants, which can be divided into two types: above-ground biomass (stored in branches, trunks, leaves of plants) and underground biomass (stored in soil and roots). Above-ground biomass can be observed by remote sensing technology due to the sensitivity of vegetation to the incident light. Above-ground biomass (AGB) and some forest structure parameters can be estimated by optical images indirectly through vegetation indices, such as Landsat, MODIS, SPOT by the statistics regression with satellite-observed vegetation [Zheng et al, 2004]. But this method tends to underestimate AGB in tropical forests beyond the dense canopy closure [Toan *et al.*, 2011, Gibbs *et al.*, 2007].

In a study of terrestrial biomass in urban areas, Azizi and Hashim (2002) applied SPOT-4 and Quickbird with resolution respectively is 10 meters and 4 meters.

Recent years, the synthetic aperture radar have created an additional opportunity for research required a high resolution. ALOS is one of the Earth Observation Satellite launched on January 24 in 2006, at the Tanegashima Space Center in Japan. The purpose is that providing a useful information on terrain and landuse/landcover to produce a 1: 25,000 scale thematic map. The advantage of the PALSAR data is that it can penetrate cloud due to the long wavelengths (23 cm, L-band), so it is highly applicable in the tropical humid forest.

2. STUDY AREA

The study area comprises al the natural forest in Thua Thien Hue province which is from 15⁰59'30" to 16⁰44'30" in the North and from 107⁰00'56" to 108⁰12'57" in the East (Figure 1). The forestry areas take account for 70% of total area and coverage reach 43%. Thua Thien, Hue belongs to the tropical monsoon climate with high temperature and solar radiation as well as the abundant rainfall. The annual average temperature is 25⁰C with the yearly sunshine hours is around 2000. The hot and dry season are from April to July and the rainy season usually falls from September to December. The terrain is characterized by a hierarchical structure, in which high mountains account for ¼ of total area, midlands are ½ areas with under 500 meters altitude and plain is 1,400 km2. The main type of ecosystem is an evergreen humid tropical forest with high biodiversity level. In this paper, the study area is focused on the detailed analysis in natural forest sites in Nam Dong and A Luoi. These regions are distributed by forest areas of Thua Thien in Hue province and the main type of ecosystem is evergreen humid tropical forest.

3. DATA AND METHODS

3-1. SAR data and pre-processing

In this study, we used the ALOS PALSAR L-band level 1.5 products with HH and HV polarization options and 12.5 meters pixel spacing which were acquired on 10 July 2010. The incidence angle (θ) 38.7° at the center of the frame. The azimuth spacing is 3.2 meters and the range spacing is 9.4 meters.

The preprocessing steps included geometry and radiometry calibration. The data in the scenes were converted to σ° values using the following equation:

$$\sigma° = 10 * Log(DN^2) + CF$$

In which DN is digital number value of image pixel and the calibration factor CF is −83.2. The function Log denotes natural logarithm (base *e*). After that, a Lee sigma filter was used to eliminate the noise speckle of SAR data.

3-2. Field data and analysis

Two survey routes were established along Nam Dong and A Luoi sites with 60 plots of 1000 m2 (40m x 25m). These plots were covered in the range of volume level including 16 plots for each type of rich, medium, poor and 12 plots for non-volume forest. In each plot, every tree was higher than 30 centimeters were measured. Each plot was divided into four type 1 sub-plots of 5m x 5m in the corner and one sub-plot in the center in order to measure every tree with diameter from 5 to 30 centimeters. Besides, in non-volume type, a type 2 sub-plot was established with a dimension of 0.5 m x 1.0 m in the center of the plot in order to collect the sample of shrubs.

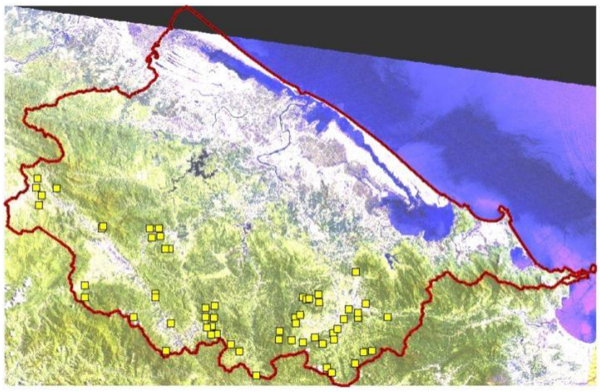

Figure 1. The study area including in-situ sites

In some selected plots, thirty trees were cut for collecting samples and estimating biomass in stems (W_{st}), branches (W_b) and leaves (W_l).

The above-ground biomass (AGB) was calculated by the formula:

$$AGB = W_{st} + W_b + W_l$$

In which, biomass in each part of stems, branches, and leaves (W_{st} , W_b , W_l) was calculated by the formula:

$$Log(W_{st}) = -0.678388+2.268982*Log(D_{1.3})$$
$$Log(W_b) = -0.581645+1.754334*Log(D_{1.3})$$
$$Log(W_l) = 0.304153+0.358045*Log(D_{1.3})$$

($D_{1.3}$ is the diameter at breast height, estimated as 1.3 meters)

4. RADAR BACKSCATTER AND ABOVE-GROUND BIOMASS REGRESSION

The sensitivity of the radar backscatter to AGB is analyzed using sigma naught value and in situ AGB data.

The biomass values in 47 plots were used for regression analyzing and 13 plots for accuracy assessment. The interrelations between biomass and backscatters were interpreted based on the linear regression with a variable and multi-variables models of y = f(x), in which y is above-ground biomass and which is dependent variable, f(x) is L-band backscatter value and is the independent variables in two polarizations HH, HV and the ratio HH/HV. The best statistical model was selected with the highest correlation. Table 1 shows HH, HV, HH/HV and AGB values in 10 of the plots.

Table 1. HH, HV, HH/HV and AGB values in 10 plots

TT	X	Y	HH	HV	HH/HV	Forest types in volume	AGB (ton/ha)
1	760027	1783405	-2.5	-7.6	5.1	Poor	175.38
2	758985	1783108	-10.4	-13.8	3.4	Medium	165.94
3	758662	1785390	-9.3	-13.9	4.6	Medium	145.19
4	758675	1787355	-12.6	-17.4	4.8	Poor	136.15
5	748672	1804581	-11.1	-15.6	4.5	Medium	154.88
6	760780	1787762	-12.1	-17.4	5.3	Non-volume	7.85
7	747075	1802591	-16.9	-21.3	4.4	Medium	170.80
8	746653	1804643	-9.1	-13.9	4.9	Poor	115.29
9	761111	1781600	-15.4	-19.9	4.6	Medium	218.10
10	747934	1790444	-12.8	-17.4	4.6	Medium	138.06

However, the results of the relationship interpretation between AGB and sigma naught value in all options was showed that the probability for statistical models P-values was higher than 0.05 and R was lower than 0.4. These denoted that the backscatter values in HH, HV and the ration HH/HV were inversely proportional to AGB. Besides, because L-band with long wavelength enables go through the canopy and reach understory objects, they are strongly affected by the humidity of soil and plants, especially in tropical humidity forest such as this study area.

Therefore, the transformation of variables was necessary to modify the type of model with logarithms such as $Log(Y) = a \times e^{bX}$ in mono-variable and multi-variables analysis. The transformed variables were described in the table 2.

The results of logarithm interpretation showed that the fixed model with R was equal to 0.53 and uncertainty is 0,000180. The regression between AGB and L-band backscatter was shown in the equation below;

$$Log(AGB) = 2.137302 - 0.00085 \times e^{HH/HV}$$

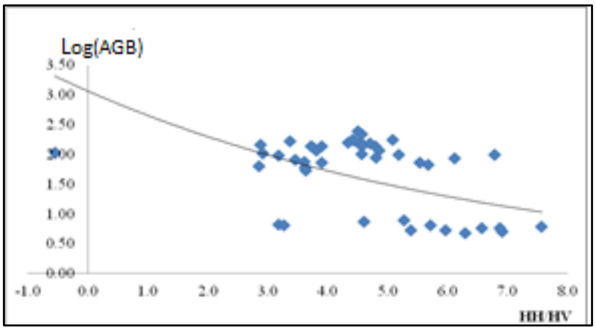

Figure 2. Regression between AGB and the ratio HH/HV

5. NATURAL FOREST BIOMASS IN THUA THIEN HUE PROVINCE

5-1. Natural forest AGB

Figure 3 shows the results of computed AGB in natural forests of Thua Thien Hue province in 2011 varying in the range from 0 to 138 ton/ha. Most of the forest types had AGB value varying from 120-138 ton/ha. Low AGB forests distributed along forest edges, nearly residential areas and transportation. The AGB values obtained from regression are lower compared to in-situ AGB values. In addition, for ratios HH/HV higher than 5, the values of Log(AGB) tend to be stable (almost unchanged).

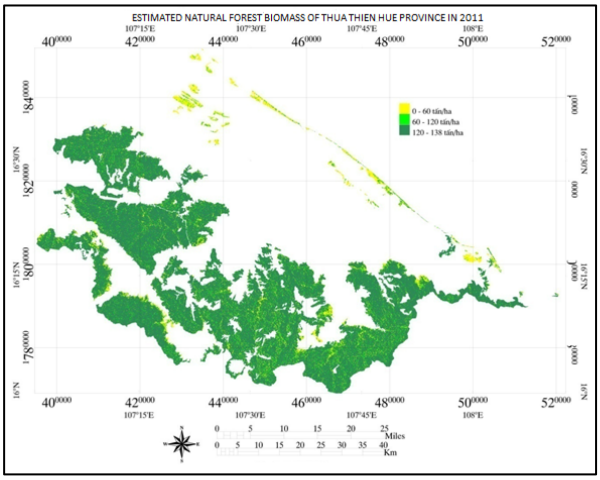

Figure 3. Estimated forest biomass for the study areas

5-2. Accuracy assessment

Based on estimated AGB values as well as in-situ AGB, the Mean Square Error were used to evaluate the accuracy. The number of independent plots is used to test one-third of the sample plots. Results are shown in Table 3.

Table 3 denoted that the difference between estimated AGB and In-situ AGB was 37.60 ton/ha and Mean square error was 31.42%. For rich forest such as sites 1, 8, 10, 12, the difference showed higher than 50 ton/ha, whereas for poor forest (sites 2, 5, 13) this difference was lower. There was a range of uncertainty sources of underestimation which affected the relationship between

L-band backscatter and natural forest AGB. They were related to forest structure, environment (soil moisture) and the saturation in PALSAR L-band data. For the natural forest, the complex layer structure and dense canopy have a strong effect on the sensitivity of backscatter and the collecting the exactly points from GSPS tool. The number of sample plots and plot size have a large impact on the representation for AGB of the entire study area. In addition, the error sources could be related to the selection of model regression and the analysis the relationship among variables.

6. SUMMARY AND CONCLUSIONS

The regression model analysis between AGB and the ratio of sigma naught value of HH and HV polarization was higher than that of AGB and HH and HV as well. However, AGB value was higher, the sensitivity of L-band backscatter reduced. For rich forest with high volume, AGB value was underestimated with the large difference compared to in-situ AGB nearly 50 ton/ha. Mean square error was 31.42% generally. For medium, poor and non-volume forest, the result showed the high accuracy with the mean error under 10 tons/ha. These denote that PALSAR L-band data is effective for AGB observation in the homogeneous forest with simple layer structure. In the future, another model should be analyzed to survey the sensitivity of backscatter and natural forest AGB. The accuracy of the results is low, however, it can be used to obtain preliminary information on the status of forest resources and can be used as a guiding reference for wide-scale management.

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Table 3. Comparison between estimated AGB and In-situ AGB in terms of Mean Error

ID	X	Y	In-situ AGB	Estimated AGB	Mean error
1	786071	1773325	255.45	101.13	-154.32
2	782353	1780881	102.20	98.48	-3.72
3	778183	1785191	116.72	106.62	-10.10
4	774568	1780442	105.87	136.03	30.16
5	774692	1782295	87.12	92.64	5.52
6	791677	1786258	105.42	131.10	25.68
7	779871	1789609	136.50	117.90	-18.60
8	798155	1785340	154.13	86.82	-67.31
9	786424	1781890	145.91	108.44	-37.47
10	779842	1779815	60.18	112.96	52.78
11	786469	1780452	73.34	88.37	15.03
12	788612	1784846	63.68	122.24	58.56
13	780595	1789115	88.23	78.72	-9.51
			Mean error		37.60
			Mean square error (%)		31.42

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