Forest carbon stock estimation using ALOS/PRISM in Myanmar

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ABSTRACT

Forest carbon stock estimation is very important for the REDD+. Forest carbon stock estimation by overstory height method has been studies using ALOS/PRISM imagery.
Forest inventory of 28 plots was conducted in Shan state, Myanmar. The coefficient of determination between biomass and overstory height was 0.73. The forest carbon stock estimation model by overstory height was derived from this result.
Tree height can be measured by stereo pair satellite imagery by aerial reconnaissance technology. Tree height measurement was conducted at each Forest inventory plots using ALOS/PRISM imagery. Accuracy of tree height measurement by ALOS/PRISM was RMSE 1.61. The coefficient of determination between tree height measurement by ALOS/PRISM and tree height by field result as truth was 0.96.
2km interval grid was set in the study area of Shan state. Tree height of each grid was measured by ALOS/PRISM imagery using ortho-photographic software 'AZUKA'. And then, forest carbon stock of each grid estimated by applying tree height to the forest carbon stock estimation model.
It could be verified that overstory height method is effective for forest carbon stock estimation.

1. INTRODUCTION

In REDD+, it is need to adopt a method for setting the reference level based on actual examples, and the challenge is to estimate forest carbon stock efficiently.
This study was conducted on carbon stock estimation in pilot study area.
A method for estimating forest carbon stocks is to establish a number of fixed inventory plots within the forest and to directly measure carbon stock based on the types, sizes and numbers of trees inside those plots. Whereas the method and tools are simple and would allow to be obtained more accurate data, a lot of labor is needed to establish and maintain the fixed plots and it is only possible to inventory areas that are accessible to the surveyors.
Accordingly, it was decided to examine a method (method utilizing the estimation model) for indirectly measuring carbon stock in the target area from image analysis of satellite or aerial photographs. With this approach, there is a trade-off between the cost of the data and equipment required for image analysis and the accuracy of the analysis, however, because it doesn't require as much forest inventory work as the aforementioned direct measuring method, an advantage is that labor can be saved .
There is reported to be an exponential relationship between tree height (height of trees in forest stands or community), which is an important physical quantity of forests, and biomass. The overstory height method is a method for estimating the carbon stock per unit area from the tree height.
Forest inventory was conducted in the pilot study area and relational analysis with the physical volume of stands was carried out. As a result, the relational expression between tree height and biomass, i.e. the model for estimating carbon stock from tree height, was compiled.
Also, examination was conducted on the method for simplifying tree height measurements and measuring tree height using satellite data with the purpose of estimating carbon stock over a wide area. Possible methods for estimating the overstory height by remote sensing are aircraft, satellite LiDAR, ALOS/PRISM stereo satellite images and so on, and it was decided to use data from the Japanese ALOS/PRISM satellite that is cheap and covers almost the entire globe.
Accuracy verification of tree height measurement using ALOS/PRISM was conducted by comparing with the result of forest inventory in sample plots.
Next, the 2km grid was set over the pilot study area. And tree heights at the grid intersection points were measured using ALOS/PRISM.
Finally, the carbon stock in each grid square was estimated by applying the tree heights into the carbon stock estimation model. Figure 1 shows the flow chart of Overstory height method.

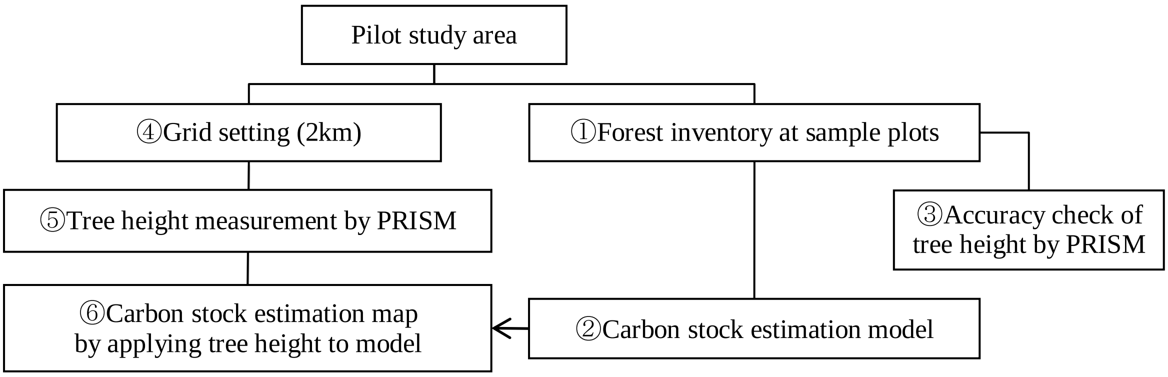

Figure 1 Flow chart of Overstory height method

2. PILOT STUDY AREA

Carbon stock estimation was implemented upon setting the pilot study area. Five townships encompassing almost the entire watershed of Inle Lake in Shan State (south) and Taunggyi District were selected. This area is located approximately 150 kilometers as the crow flies northeast of the capital Naypyitaw; it includes the famous tourist resort of Inle Lake and also has relatively abundant data. Figure 2 shows the map of the pilot study area.

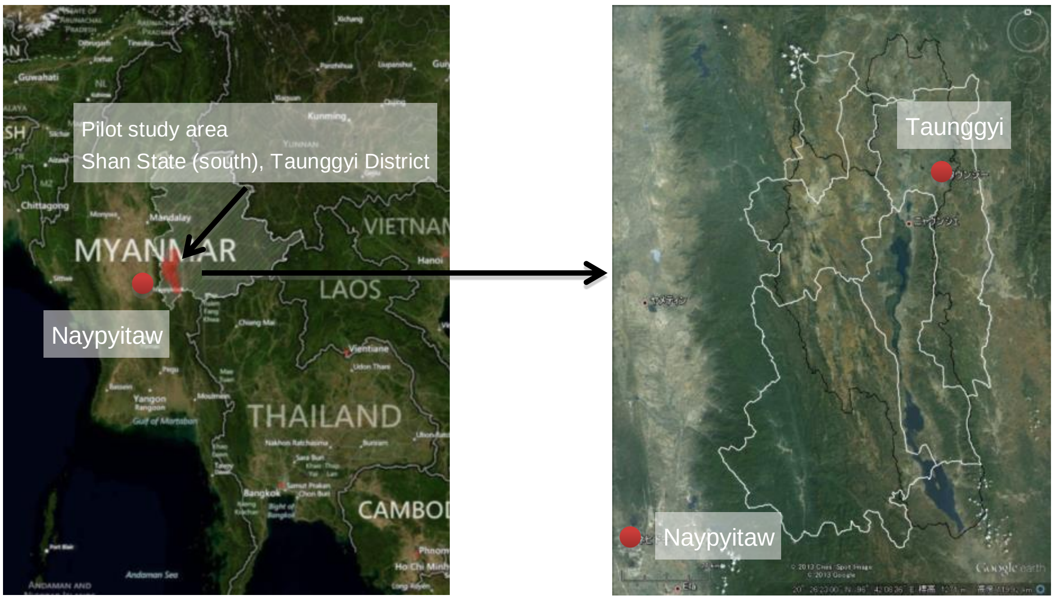

Figure 2 Pilot study area

3. METHOD AND RESULT

3.1 Developing carbon stock estimation model by forest inventory

The sample plot method was adopted on square plots of 25m x 25m. The following nine measurement items were targeted.

A) Upper story tree height (using VERTEX to measure a few upper level trees in 10 cm units)
B) Diameter breast height (measurement in centimeter units using a diameter tape)
C) Crown density (measurement in units of 10%)
D) Undergrowth (3-stage judgment based on visual inspection as sparse, medium and dense)
E) Dominant species (identification by the counterparts)
F) Inclined orientation (measurement in 8 orientations)
G) Incline (measurement of the degree of incline in the inclined orientation)
H) Current situation photographs (photography of 4 items, i.e. overview, crown, undergrowth and surface)
I) Others (state items meriting special mention, for example, intrusion of bamboos and so on)

First, the forest inventory candidate plots were selected from topographical map and satellite image, and the inventory was implemented upon confirming the local road access and condition of forests. Inventory was implemented in a total of 28 plots.

The results of the forest inventory are compiled in Table 1. Concerning the carbon stock in each plot, the allometry formula (1) that is stated in the IPCC "Good Practice Guidance for Land Use and Land Use Change Forestry" and is applicable to tropical forests in general was used. This formula can be applied to all tropical forest types with a diameter breast height of between 5~148 centimeters in tropical lowlands with annual rainfall of between 2,000~4,000 millimeters.

$$Ya = \exp[-2.289 + 2.649 \bullet \ln(DBH) - 0.021 \bullet (\ln(DBH))2] \quad (1)$$

Ya: Above ground Biomass (kg dry matter / tree)

$$BGB = \exp[-1.0587 + 0.8836 \bullet \ln(AGB)] \quad (2)$$

BGB: Below ground Biomass (T dry matter / ha)
AGB: Above ground Biomass (T dry matter / ha)

$$C = B \times 0.47 \quad (3)$$

B: AGB+BGB Living Biomass (T dry matter / ha)
C: Living Biomass Carbon (tC / ha)
0.47: Carbon Fraction (kg C / kg d.m.)

Source: IPCC Good Practice Guidance for LULUCF p.4.114-116
Brown & Schroeder et al., 1999, Caims et al., 1997

Table 1 Results of Forest Inventory

Inventory Year	No.	Township	Tree Height (m)	Number of tree /ha	DBH/ Plot (cm)	TBA/ha (cm2)	Carbon tC/ha
2014	1	Tigit	18.4	997	19.0	40.7	217.8
2014	2	Pin Laung	17.6	821	14.5	24.1	133.0
2014	3	Pin Laung	18.2	586	20.2	28.4	157.0
2014	4	Pyindayan	17.1	479	27.1	28.1	88.5
2014	5	Pindaya	17.2	883	13.9	17.0	71.8
2014	6	Pindaya	22.9	352	32.1	39.3	253.8
2014	7	Nyaung Shwe	7.5	1,358	7.9	7.4	21.6
2014	8	Nyaung Shwe	5.7	3,039	6.2	7.9	22.5
2014	9	Nyaung Shwe	7.9	2,222	7.3	10.2	27.8
2014	10	Taunggyi	24.7	522	23.1	54.0	442.9
2014	11	Taunggyi	13.2	2,553	10.0	26.8	108.2
2014	12	Nyaung Shwe	29.6	715	20.1	46.0	322.7
2014	13	Taunggyi	18.2	1,090	15.9	30.0	148.5
2014	14	Taunggyi	33.2	900	21.5	142.6	1,669.1
2014	15	Taunggyi	22.9	898	25.1	56.0	310.1
2013	16	Kalaw	5.7	2125	8.9	15.3	48.9
2013	17	Kalaw	17.2	175	37.1	19.1	74.4
2013	18	Kalaw	17.5	775	21.8	30.3	84.6
2013	19	Kalaw	10.1	1400	13.1	25.9	125.5
2013	20	Nyaung Shwe	5.9	1325	12.2	17.5	65.1
2013	21	Nyaung Shwe	9.5	950	15.8	20.2	86.3
2013	22	Nyaung Shwe	20.9	425	48.1	50.8	415.0
2013	23	Nyaung Shwe	33.2	125	86.8	97.3	1300.0
2013	24	Taunggyi	23.4	275	45.5	57.2	507.5
2013	25	Taunggyi	10.6	2275	12.7	32.9	125.5
2013	26	Nyaung Shwe	6.7	2325	7.9	13.8	44.6
2013	27	Kalaw	12.8	275	26.3	15.2	47.2
2013	28	Kalaw	16.3	380	31.1	36.5	291.8

Based on this result, the physical quantity of each forest stand was analyzed. Table 2 shows the correlations between each forest stand physical quantity and carbon stock. The coefficient of determination of the tree height and carbon stock was based on power approximation. Other coefficients of determination were based on linear approximation.
The coefficient of determination of the tree height and carbon stock was 0.723. The results backed up the research on the existing overstory height method which purports that carbon stock can be estimated from tree height. The regression formula of tree height and carbon stock was calculated and used as the model for estimating carbon stock in the pilot study area (figure 3).

Table 2 Correlation between Forest Stand Physical Volume and Carbon Stock

Coefficient of Determination	Number of tree /ha	DBH/Plot (cm)	TBA/ha (cm2)	Carbon tC/ha
Tree Height (m)	0.445	0.441	0.693	0.723
Number of tree /ha		0.451	0.151	0.120
DBH/Plot (cm)			0.306	0.346
TBA/ha (cm2)				0.943

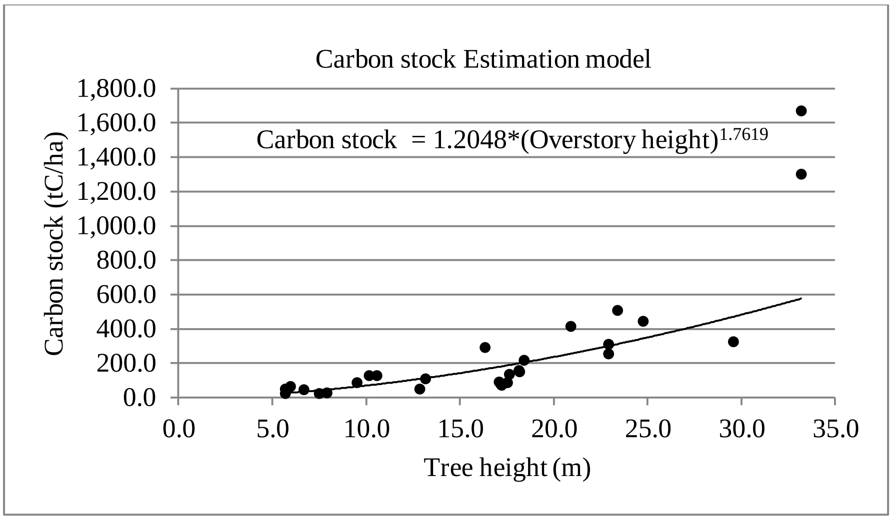

Figure 3 Carbon stock estimation model in pilot study area

3.2 Accuracy evaluation of tree height based on satellite image data

The tree height measurement method utilizing satellite image data was examined with a view to efficiently measuring tree heights.
Concerning the method for measuring tree height, operator decipherment measurement based on ALOS/PRISM three-dimensional view was adopted. Between three and five upper story trees were selected from the forest inventory plots, the visible disparity between ground and tree tops was measured , and the disparity was assumed to be the tree height. The mean of the three measured trees was assumed to be the tree stand height (equal to overstory height). As reference information, Figure 4 shows the concept of tree height measurement using ALOS/PRISM.

- Used data :ALOS/PRISM (Nadir and Back), 2.5 m ground resolution
- Data observation year :2009~2011
- Measurement software :AZUKA(three-dimensional digital mapping system, Asia Air Survey)
- Measurement points :28 points (same locations as the forest inventory)

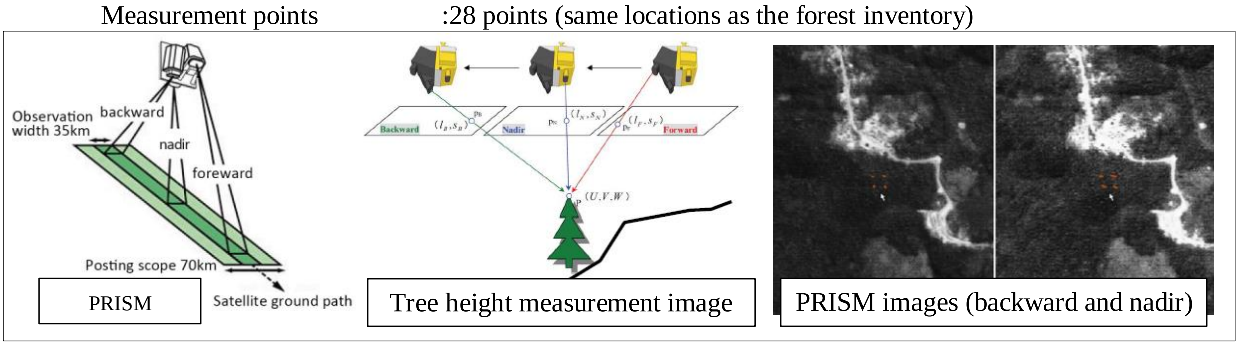

Figure 4 concept of tree height measurement by ALOS/PRISM

Figure 5 shows distribution and correlation of tree height measurements by ALOS/PRISM and the result of forest inventory as a truth. Coefficient x was 0.0813, indicating a slope of almost 1. The coefficient of correlation R^2 was very high at 0.9633. Based on this result, the accuracy of ALOS/PRISM tree height measurements is extremely high and this method can be put to actual use.

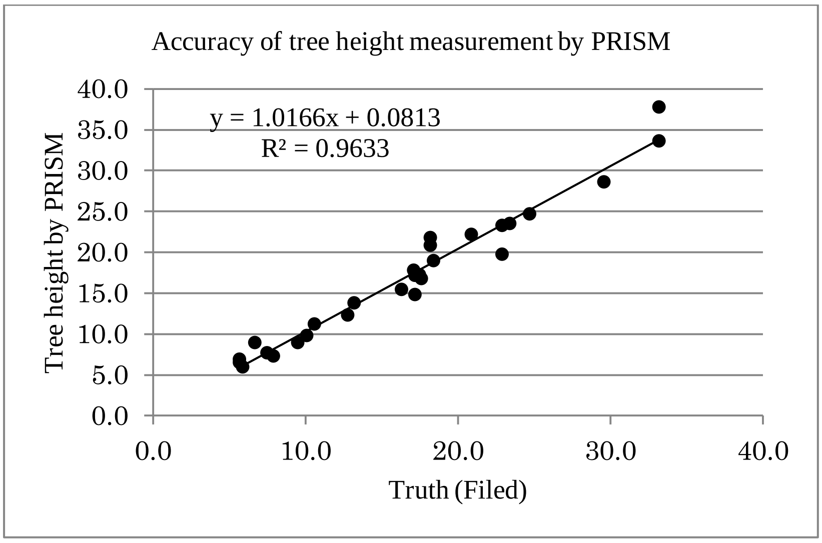

Figure 5 Accuracy of tree height measurement by PRISM

3. 3 Carbon stock estimation at grid points

After setting a 2-kilometer grid over the study target area, stand heights at each intersection were measured by ALOS/PRISM. The measured stand heights were fitted in to the carbon stock estimation model to calculate carbon stock at each intersection, and a forest carbon stock estimation map for the pilot study area was prepared (Figure 6). It can be seen that carbon stock is high in the area to the east of Inle Lake and in the mountainous region to the southwest.
Moreover, Figure 7 shows the frequency distribution of stand height and carbon stock. The most common stand height was 10~15 meters, followed next by 15~20 meters and then 5~10 meters. The mean stand height was 15.3 meters, and the maximum was 45.3 meters. In terms of carbon stock frequency distribution, 100~200tC/ha is the most common, followed in order by 50~100 and 0~50. The mean carbon stock per hectare was 245.04tC.

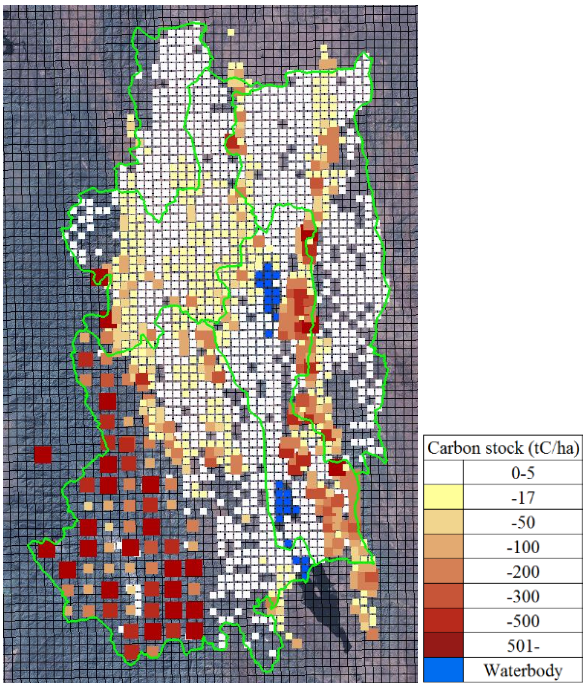

Figure 6 Carbon stock estimation map in pilot study area

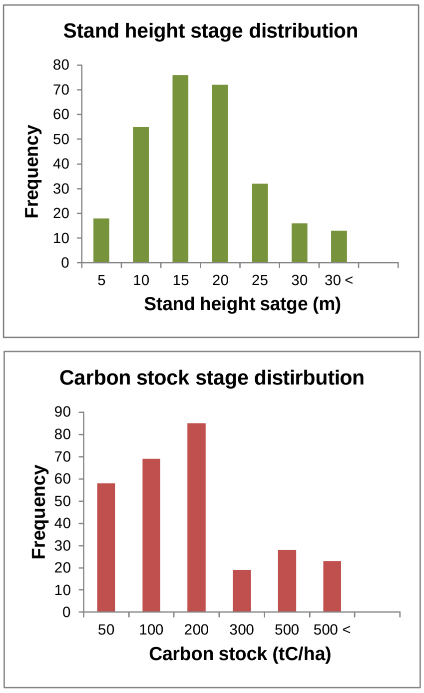

Figure 7 Stand Height and Carbon Stock Distributions

4. CONCLUSION

By the results of the field inventory, high correlations were found between carbon stock stand height, indicating the possibility that carbon stock can be estimated from stand height. The model for estimating carbon stock from stand height was prepared by this correlation.

As a result of conducting stand height measurement based on ALOS/PRISM and verifying accuracy, a high degree of accuracy was obtained. Accordingly, the stand height measurement technology of using three-dimensional satellite image data including aerial photography is deemed to be fit for practical application.

In conclusion, the overstory height method based on satellite images is useful for estimating of forest carbon stock.

It was reconfirmed that selection of sample locations is important for estimating the carbon stock. Moreover, although only one carbon stock estimation model was used, since there is thought to be a difference depending on crown density and climate zone, the future challenge will be to prepare a carbon stock estimation model formula for each of forest types.

In future, it will be important to grasp changes over time and set reference levels for deforestation and forest degradation and carbon stock.

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