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A CASE STUDY OF A FOREST CARBON STOCK MONITORING SYSTEM FOR REDD+ IN LAO P.D.R.

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ABSTRACT:

Various technical studies for building forest monitoring system for MRV system of REDD+ has been implemented utilizing satellite remote sensing technology and ground survey upon configuring two pilot study areas, at whole Louangphabang (LPB) province (approximately 20,000 km^2) and in Bolikhmxai(BLK) province (approximately 4,400 km^2) in Lao PDR. Multi-temporal land use/cover data were prepared for making analyses of deforestation and forest degradation caused by various driving factors, and to establish reference scenario for REDD+. In addition to ordinary method of forest carbon stock estimation based on the forest plot surveys, land use/cover maps and IPCC's emission factors (GOFC-GOLD, 2010), improved methods were studied introducing a concept of biomass classing derived from multispectral data and tree height measurement utilizing ALOS/PRIS stereo images, in order to reduce difficulty of field surveys at high altitude and steep mountain forest, especially in natural forest areas. First, multi-temporal land use/cover maps were prepared for two pilot study areas for analyzing deforestation and forest degradation of the subjected area. Then, the biomass level of "Current Forest" area of the land use/cover maps were classified into three classes as high, medium, and low applying spectral analyses of LANDSAT/TM and SPOT images, and based on visual interpretation results of pan-sharpened ALOS/AVNIR2 images in addition to limited number of field surveys as references. Matching accuracies were around 60% at this stage of study (This number improved to 85% at the later stage). Based on the field survey data, the forest carbon stock vs. tree height model was established, and furthermore it was related to the forest biomass classes. ALOS/PRISM images were used to measure heights at about 1,500 forest stands selected at 2 - 4 km grid intervals. Accuracy analyses showed that the standard deviation of the tree height measurement errors was approximately 4 - 5 m, but the mean value of the measured data were within 1- 2 m comparing to the field survey data. Finally, wall-to-wall, above-ground forest carbon stock estimation maps which would be useful for forest management and REDD+ were prepared. As a conclusion, it can be said that 3D measurement, in addition to multi-spectral information, of the forest provides useful information for monitoring forest carbon stock for REDD+ although further refinement of technologies is to be needed. And, the results and experiences obtained from the studies will provide useful data for establishing actual MRVsystem.

1. INTRPDUCTION

REDD+ refer to efforts and initiatives for the reduction of greenhouse gas (GHG) emission through vigorously increasing forest carbon stocks based on reducing the deforestation and forest degradation and implementing afforestation programs and forest conservation in developing countries. It is anticipated that the reduction of GHG emissions enabled by such efforts can be treated as carbon credits in the same way as carbon credits from use of renewable energies and improvement of energy efficiency, and consequently be used for carbon offsetting, etc.

A case study (Study) entitled "Study on the Strengthening of Methodological and Technological Approaches for Reducing Deforestation and Forest Degradation within the REDD imple mentation Framework" was carried out in order to contribute to the early realization of the REED mechanism with cooperation of the Forest Inventory and Planning Division, Department of Forestry, Ministry of Agriculture and Forestry, Lao P.D.R., and Asia Air Survey Co. Ltd. (Japan), with a support of the Forest Agency, Ministry of Agriculture, Forestry and Fishery, Japan, from 2009 to 2011.

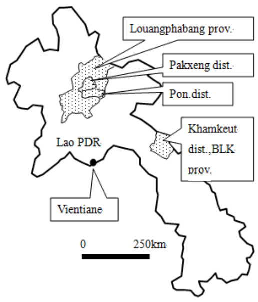
Objectives of the MRV(Measurement, Reporting and Verification) system in REDD+ are to measure and provide forest carbon stock data arising from REDD+ activities and valid enough for credit trading, etc. Outline and outcomes of the three year's study project are shown in Table 1. The scope of MRV in REDD+ mechanism is broad and complex. In this paper, results of remote sensing and photogrammetric analyses are mainly discussed. More detailed reports are given by Asia Air Survey (2011) and Kamusoko et al.(2011), etc.

Components Of the Study	Results of the Study
1. Deforestation and forest degradation analyses using remote sensing technology	-Land use/cover maps of 1993, 2000, and 2007 (Sub-national, LPB province, Khamkeut district, BLK province by LANDSAT and SPOT) -Land use/cover maps of 1993, 1997, 2000, 2004, and 2007 (Pakxen district, LPB) -Land use/cover map (JICA PAREDD project area, Phongxai district, ALOS/AVNIR2) -Forest/Non-forest cover maps of Lao PDR (National level, 2001, 2004, 2007, 2010 by MODIS) -Forest degradation map (Khamkeut district, BLK) -Tree height measurement (LPB) and Khamkeut district (BLK) by ALOS/PRISM -Accuracy verification of various maps -Ray (slash-and-burnt cultivation field) analysis -Biomass classification map (LPB,BLK by LANDSAT, ALOS/AVNIR2) -UAV aerial photography and analysis of digital canopy model
2. Forest GIS database	-Base map from ALOS/PRISM images -DEM/DSM(SRTM, GDEM, ALOS/PRISM) -Orthoimage(ALOS/PRISM) -Forest compartment map -Forest management parcel -Maps prepared by remote sensing analyses -Updating methodology of forest GIS database -MRV system design and analysis
3. Forest carbon stock estimation	-Tier 1 estimation of forest carbon stock (LPB) -Tier 2 estimation (LPB, BLK) -Tier 3 estimation (Test areas) -Carbon stock estimation model based on tree height -Wall-to-wall carbon stock estimation based on biomass classes
4. Deforestat-ion trend analysis and future forecasting simulation analysis	-Analysis of driving factors of deforestation and forest degradation -Village surveys (Socio-economic surveys) -Reference scenario analyses -Simulation analyses of future forest cover changes using the Marcov-Cellular Automata model (Village, district, provincial, and national levels)
5.Technology transfers	-Technical trainings -On-the-job trainings -Workshops and seminars -Training in Japan

Table 1 Outline and outcomes of the Study

2. PILOT STUDY AREAS

Study activities were implemented upon configuring two pilot study areas, namely entire Louangphabang (LPB) province and Khamkeut district in Bolikhamxai (BLK) province (Figure 1). LPB province is experiencing extreme deforestation and forest degradation as a result of extensive human activities such as slash and burnt shifting cultivation.



Study Areas	Characteristics
LPB province	Area: 20,000 km^2 Altitude: 200-2,300m
Pakxeng district (LPB)	Area: 1,600 km^2 10x10km test area
Pongxai district (LPB)	JICA PAREDD project site
Khamkeut district (BLK)	Area: 4,400 km^2 Altitude:400-2,000 m 10x10km test area
Drivers: Populatiom increase, slash and burnt shifting cultivation, natural forest, pasturage, dams, mines, legal/illegal loggings, etc.	

Figure 1. Locations and characteristics of the pilot study areas in Louangphabang (LPB) and Bolikhmxai(BLK) provinces in Lao PDR

Khamkeut district (BLK) contains abundant forest resources including natural forests, and human activities here include paddies, slash and burnt cultivation, pasturage, dams and mines. There is a risk that the district suffers from deforestation and forest degradation, both legal and illegal.

3. FOREST MONITORING SYSTEM UTILIZING REMOTE SENSING

3.1 Land Use/Cover Mapping for Forest Monitoring

3.1.1 Satellite Images Used for Sub-national Level: Multitemporal land use/cover maps provide the basis for (1) analysing deforestation and forest degradation, (2)estimating wall-to-wall forest carbon stocks, (3)obtaining base data for simulation analysis of future deforestation, and (4)setting the reference level of REDD+ credit, etc.

Medium resolution satellite images (LANDSAT and SPOT) obtained from 1990 to 2010 were selected to prepare land use/cover maps for sub-national level (provincial level) monitoring of forest through combining digital image processing with visual interpretation and field survey. In selecting the images, search was conducted during the period immediately after the rainy season (October-December) before the start of defoliation and slash and burnt when the impact of moisture vapour and smoke in the atmosphere is small in the pilot study areas, and images from the same period were selected to reduce the occurrence of classification error arising from different timing of images for conducting multitemporal comparisons. However, in cases where images from the period in question were not available, the most recent images were selected. As the results, many multi-dated images were subjected to various image analyses and interpretations.

3.1.2 Land Use/Cover Categories for Forest Monitoring: In the survey of deforestation, forest degradation, forest carbon stock, etc. necessary for REDD+, first the approach that entails grasping forest state based on survey of land use/cover and monitoring of changes is adopted (IPCC(2003, 2006)). In this Project too, based on similar approach, it was decided to prepare land use/cover maps upon combining remote sensing technology with field surveys.

In Lao PDR, so far the FIPD has implemented National Forest Inventory Surveys once every five years. Definition of forest had changed recent year to (1) Tree height: 5m or higher, (2) Crown density: 20% or more, and (3) Area: 0.5ha or greater. In this Project, bearing in mind the land use categories (six main headings) required for gauging forest carbon stock based on land use models in the IPCC guidelines, etc., 11definitions and classification (level II forest classification categories) suited to estimating of carbon stock due to deforestation and forest degradation were established as shown in Table 2, while taking consistency with existing forest survey maps prepared by the FIPD in Lao PDR into account.

Land Use/Cover Category	
1. Current Forest	7. Plantation 2
2. Plantation 1	8. Grassland
3. Unstocked Forest	9. Others
4. Bamboo	10. Water
5. Ray	11. Cloud
6. Crop Land	

Table 2 Land use/cover category

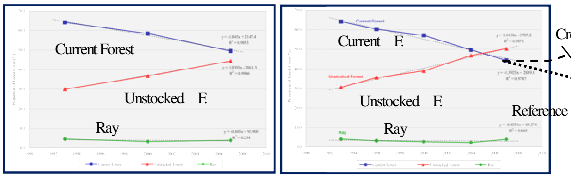
3.1.3 Satellite Image Analyses for Land Use/Cover Mapping: The necessary technical system was constructed out of the following components: geometric correction and georeferencing, pre-processing, multispectral analyses based on the ISODATA method, classification and labelling of land use/cover categories, integration into land use/cover maps, correction of classification results considering change over time patterns and topographic information, supplementation based on field survey and visual interpretation of images and so on.

LPB province was covered by two or more satellite imagery scenes. Thus, land use/cover maps classified from individual scenes were mosaiced to form a land use/cover map that covers the whole province. A post-classification analysis was also performed to minimize misclassifications due to seasonal changes or radiometric noises. Finally, results from image interpretation and corrected land use/ cover maps were merged into a final classification. Masked areas representing cloud/cloud shadows from one time period were replaced by land use/cover from another time period. Table 3 shows a list of land use/cover maps in this study.

	1993	1996	2000	2004	2007	2010
LPB	○		○		○	
Pakxen	○	○	○	○	○	
Khamk	○		○		○	
Phongx	○: LANDSAT/TM,SPOT, ◎:AVNIR2					◎

Table 3 Land use/cover maps prepared in the Study

3.1.4 Forest Cover Changes and Reference Scenarios: Figure 2 show historical trends of forest cover changes of LPB province and Pakxeng district. Forest cover changes in LPB indicate that "Current Forest" areas decreased, while "Unstocked Forest" increased. A similar historical trend is observed for Pakxeng district (LPB). However, Current Forest and Unstocked Forest changes were greater from 2004 to 2007 in Pakxeng. Reference scenarios (REL) can be set up in order to estimate the potential REDD+ credits.



(LPB province) (Pakxeng district)

Figure 5 Historical trends of forest cover changes and REL

3.1.5 Accuracy Analysis of Land Use/Cover Maps: Accuracy analyses of the land use/cover maps were carried out three ways by field survey, image interpretation higher resolution images (pan-sharpened ALOS/AVNIR2 image), and interpretation and measurement of tree heights using ALOS/PRISM stereo images in a digital photogrammetric stereo plotter.

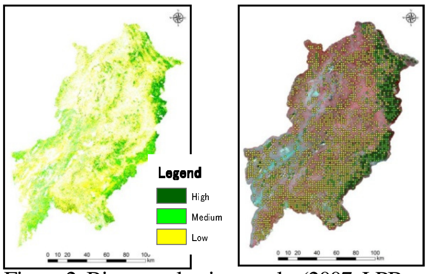
Overall accuracy of the land use/cover map of 2007 is 86 % at 4804 grid points for LPB province and 88 percent at 975 grid points for Khamkeut district in BLK province. In terms of each individual classification category, accuracy is generally between 80~90 percent. As the third method of accuracy checking, ALOS/PRISM data was used to assess the land use/cover maps. A total of 150 check points (100 points for LPB province and 50 points for Khamkeut district (BLK) were checked and the accuracy were 90% and 86%, respectively, which is within the range of accuracies that can be achieved with mid-resolution imagery (GOFC-GOLD, 2009). Since the satellite images from 1993 and 2000 were also classified using this method, it is thought that the land use/cover maps for LPB povince and Khamkeut ditrict (BLK) are accurate too for the study.

3.2 Forest Biomass Classing

3.2.1 Objective and Method of Forest Biomass Classing: Forest biomass classes (High, Medium, and Low) were devised for evaluating in detail the distribution and changes of forest carbon stocks. Forest biomass classing based on visual interpretation of ALOS/AVNIR2 images was carried out on 2 km and 1802 grid points that were deemed to be Current Forest in the said images. In classing biomass, the interpretation criteria indicated focusing on tree crown size, texture and colour, etc. in the ALOS/AVNIR2 were configured based on the ground truth data obtained from the field survey.

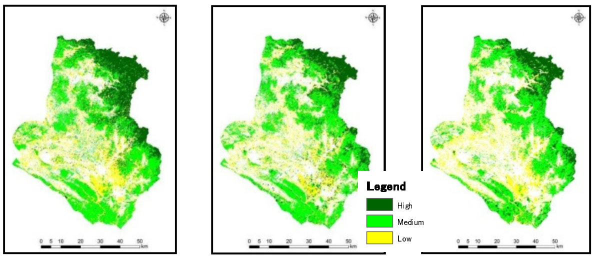
Then, biomass classing based on satellite image analysis was conducted according to objects. This is done to conform with the results of biomass class visual interpretation classified according to objects (zones). For classifying objects, eCognition Developer was use. Targeting the 2007SPOT and LANDSAT images of Current Forest areas used to make the land use/cover maps of LPB province and Khamkeut district (BLK) , segmentation (SP=10) by eCognition

Developer was carried out. Next, training data for each biomass class were prepared in reference to the results of visual interpretation, and the biomass classes were classified by the maximum-likelihood method based on the training data. The results of LPB and BLK are shown in Figure 2 and 3, respectively.



Biomass Classes	
High	10%
Med	24%
Low	65%
Total: points	1802

Figure 2. Biomass classing results (2007, LPB province)



Year (Area)		1993 (ha)	2000(ha)	2007(ha)
Bio-mass class	H	76,414	58,196	49,541
	M	136,412	142,817	132,875
	L	76,820	65,963	71,074
Total		289,646	266,976	253,490

Figure 3. Biomass classing results (1993,2000, and 2007, Khamkeut district(BLK)) based on 491 visual interpretation data

Overall accuracy of matching of biomass classification was approximately 60% in both LPB province and Khamkeut district. Targeting Khamkeut district where the accuracy of each biomass class was relatively high, biomass classing was implemented on Current Forest from two past periods (1993 and 2000) utilizing same method that was used in 2007. The results of biomass classing in 2007 were referred to as training data for the maximum-likelihood method. Figure 3 shows the results of Current Forest biomass classing from three periods, and statistics of forest covers and biomass changes over time. The high biomass area decreased (including transition to the lower class) due deforestation and forest degradation.

The results of the biomass classing were used to evaluate wall-to-wall above-ground forest carbon stocks as discussed in Section 4.

4. ESTIMATION OF FOREST CARBON STOCK

4.1 Tier Levels for Forest Carbon Stock Estimation

Tier levels have been defined according to the IPCC tier requirements stated in the GOFC-GOLD SOURCE BOOK (COP17 Version). According to the definitions, data availability is an important item to consider when selecting the appropriate tier. In the study, Tier 1 (basic), Tier 2 and Tier 3 level estimations of forest carbon stock were carried out for test and pilot study areas. However, only results of Tier 2 are shown hereafter.

Tier 2 (intermediate, called Tier 2-1 hereafter) level forest carbon stock estimation was implemented through combining these results with the land use/cover maps and forest survey data. This method is adopted as the common technique of Tier 2. However, this technique does require a lot of plot surveys.

Thus, Tier 2-2 level method was also studied here based on forest biomass classes, forest survey, the IPCC recommended forest carbon stock model and the forest carbon stock vs. tree height model that applies stereo satellite image analysis, and will be discussed hereafter.

4.2 Forest Survey for Obtaining Basic Data for Forest Carbon Stock Estimation

Forest survey was carried out several times with the aims of analyzing the relationship between forest carbon stock and tree height, accuracy of tree height measurements based on ALOS/PRISM, the correlation between ALOS/AVNIR2 biomass classes and LANDSAT/TM images, and so on.

The widely adopted standard forest survey method was used to conduct forest survey at the pilot study areas. Squares of 20 m x 20 m were adopted as the standard plots, while 30 m x 30 m was used in the areas where the mean tree height was higher than 30 m. The forest surveys were implemented over seven weeks at a total of 21 locations, specifically 10 in LPB province and 11 in Khamkeut district in BLK province. Apart from one deciduous broad-leaved tree forest, all the tree species that were confirmed locally comprised evergreen broad-leaved forest. The upper tree height was 5.2 m minimum and 48.0 m maximum, DBH was 3 cm minimum and 148 cm maximum, and the number of standing trees per hectare range from 450 to 1,600. Moreover, elevation of the survey locations ranged from 452 m to 1,319 m and the slope ranged from 0 to 35 degrees.

4.3 Relationship between Forest Carbon Stock and Tree Height

From the results of the forest survey, the forest carbon stock at each survey plot was calculated, and the correlation of this with the actually measured mean upper tree heights was sought in order to construct the forest carbon stock vs. tree height model. As the allometry equation for calculating forest carbon stock, the equations stated in the IPCC GPG-LULUCF were used (IPCC, 2010). The equations were assumed being applicable to all the tropical tree species with diameter at DBH of 5-148 cm in tropical lowland area with annual rainfall of 2,000-4,000 mm. From the diameter at breast height (DBH), first the above-ground biomass and then the below-ground biomass (BBD) are calculated, and the combined total gives the living biomass stock. Using these equations, the forest carbon stock for all the forest survey plots was calculated. Then, relationship between the forest carbon stock and upper tree height was analyzed as shown in Figure 4. Applying this model, it is possible to estimate forest carbon stock from upper tree height obtained from satellite images, aerial photos, etc.

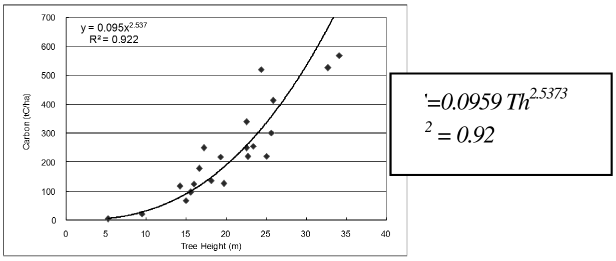


Figure 4. Relationship between forest carbon stock and upper tree height obtained from forest survey data

4.4 Tree Height Measurement based on ALOS/PRISM Images

4.4.1 Stereo Photogrammetry for PRISM Tree Height Measurement: A total of 74 ALOS/PRISM scenes with RPC model data covering LPB province and Khamkuet district (BLK) were prepared for making the measurements of tree height and forest compartments, preparation of basic map for forest GIS, and to produce orthophoto maps, etc. using a gidital stereo plotter. Average tree heights (PRISM tree height) of small areas of Current Forest at the 4 km and 2 km grid intersection points (as discussed in Section 3.1.4) for LPB and BLK provinces, respectively, were obtained by operators. As the results, 1042 points of 4 km grid points and 529 points of 2 km grid points were measured for the PRISM tree heights. Figure 5 shows the results of PRISM tree heights. In LPB province, the most frequent tree height level was 15 - 20 m, whereas in Khamkeut district (BLK) the most frequent level was 30 - 35 m.

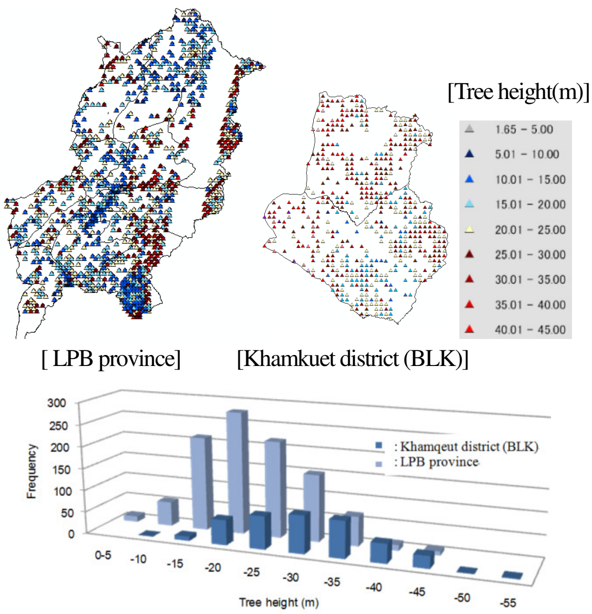


Figure 5. PRISM tree heights (LPB province and Khamkuet district)

4.5 Wall-to-wall Forest Carbon Stock Estimation using Forest Biomass Classes

4.5.1 Mean Tree Heights of Each Biomass Class: In view of high correlation between biomass and tree heights, the results of biomass classing based on ALOS/AVNIR2 and PRISM tree height measurements were aggregated in order to seek the mean tree height according to each biomass class (Figure 6). The mean values of PRISM tree height and the biomass class indicate a positive relationship.

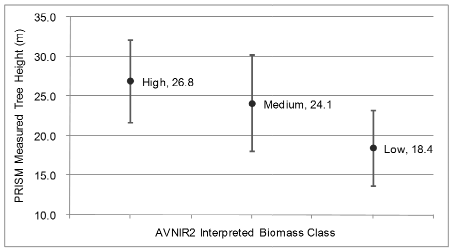


Figure 6 PRISM measured tree height and biomass class

4.5.2 Estimation of Mean Forest Carbon Stock from the Biomass Class: Finally, the mean forest carbon stock for each biomass class was configured upon applying the mean tree heights of biomass class to the model shown in Figure 4 and Table 3.

Biomass Class	PRISM Measurement		
	Mean tree height (m)	Corresponding forest carbon stock (Tc/ha)	Measured points
High	26.8	404.4	138
Medium	24.1	306.6	286
Low	18.4	155.3	588
Mean	21.2	221.1	1,012

Table 3. Biomass classes and forest carbon stocks

4.5.3 Preparation of Wall-to-wall Forest Carbon Stock Estimation Map: Through applying the biomass class vs. forest carbon stock model, forest carbon stock estimation maps of Khamkuet district (BLK) were prepared as shown in Figure 7. On visually comparing the maps, it can be seen that the area of high forest carbon stock around the border with Vietnam in the north-east declined between 1993, 2000, and 2007. The rate of decline in forest carbon stock from 1993 to 2007 (15.2%) is higher than that of the forest area (12.5%) indicating the possible forest degradation of the area. It is also shown that the forest carbon stock estimated from the biomass classing and upper tree height and IPCC's allometry equation based on DBH of forest survey are comparable. This may indicate that the forest survey data are sampled reasonably well in distribution of the forest carbon stock. It also shows that the forest carbon stock estimated from the biomass classing and upper tree height has a certain advantage if the forest survey data have some bias due to for example accessibility, etc.

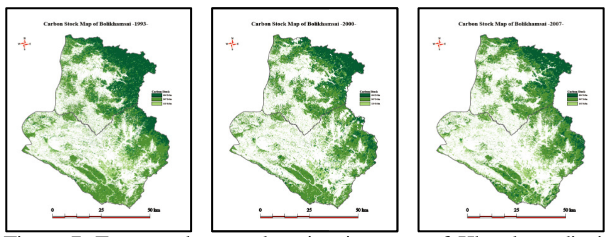


Figure 7. Forest carbon stock estimation map of Khamkuet district (BLK) based on biomass classification

5. ACCURACY ANALYSIS OF PRISM MEASUERD TREE HEIGHT

5.1 Theoretical Accuracy Analysis

In the Study, photogrammetric measurement of forest plays veryimportant role. Especially, the accuracy of the tree height measurements is the most critical technology for supporting forest carbon stock model based on the upper tree height. A theoretical analysis of the tree height measurement accuracy was first carried out. According to the researchs (Uchida et al.,2008), the theoretical accuracy of planimetry and height in measurement of stereo satellite images is generally expressed as follows:

$$\sigma_X = \sigma_Y = H/f \times \sigma_p \quad (1)$$

$$\sigma_Z = H/B \times H/f \times \sigma_p$$

where σ_X, σ_Y : Theoretical accuracy of planimetry

σ_Z : Theoretical accuracy of elevation

σ_p: Measurement accuracy of image coordinates

The value of σ_p is generally 0.2 - 0.5 pixels, but can be 1 pixel maximum. Here, value of σ_p= 0.5 pixel was assumed and $\sigma_{Z=}$ 2.5 m.

5.2 Accuracy Analysis Comparing Tree Heights from ALOS/PRISM Measurements and Forest Plot Survey

In order to verify the accuracy of tree height measurements, PRISM measured tree heights and the forest survey data were compared at 16 plots. The results are as follows:

- Standard deviation of discrepancies (errors): $\sigma_{ZTH=}$ 3.9 m
- Minimum discrepancy: 0.2 m
- Maximum discrepancy: 6.4 m
- Mean PRISM measured tree height: 20.2 m
- Mean field measured tree height: 20.1 m
- Difference of the mean values: 0.1 m

These values were very similar to the result of the previous study in Vietnam.

5.3 Accuracy Analysis using PRISM Images Before and After Forest Cutting.

In order to verify the accuracy of PRISM tree height measurements at estimated ground height, 146 locations showing conditions before- and after-forest-cutting were selected from ALOS/PRISM images acquired over LPB province in November 2007 and January 2010. Then, the estimated ground height and the height of the ground that can be visually confirmed at same location were measured on the before- and after-forest-cutting PRISM stereo images using a digital stereo plotter. The ground elevations measured on two PRISM images were compared to estimate accuracy of the estimated ground heights. As a results of verification at 146 selected points, the amount of discrepancies was σ_{Zg}=4.4 m (standard deviation) ranging from 0.0 m to 11.6 m. Furthermore, the measurement accuracy of PRISM measured tree heights σ_{ZTH} can be estimated trough applying the error propagation principle:

$$\sigma_{ZTH} = \mathrm{SQRT}\,(\sigma_Z^2 + \sigma_{Zg}^2) = 5.1 \text{ m} \quad (2)$$

where the theoretical error is assumed to be 0.5 pixel.

Various parameters affecting the accuracy of the PRISM measured tree height were examined. And, it was shown that the most important factor is slope of terrain and associated sun light illumination (aspect). From these results, it can be said that it is necessary to measure tree height with special care when the slope is steep.

6. SUMMARY

Some results of the case study on MRV system for REDD+ in Lao PDR and improved methods for reducing difficulty of forst surveys at isolated areas and for estimating forest carbon stock using biomass classing were reported in this paper. The results of accuracy analyses of tree height measurement utilizing ALOS/PRISM showed that the error of the mean value of many measurements is reasonably well even though the errors of individual observtions are relatively large. From the results of the Study, the tree height data from sreteo satellite images can be used as at least effective additional data for forest carbon stock estimation based on ordinary forest surveys on the ground. The same thing can be said to the forest biomass classing data. The scope of MRV in the REDD+ mechanism is broad and complex as forests themselves are. It is very important to do some traial studies before establishing an actual MRV system in practice as shown in this paper since it is needed to establish a sustainable MRV system for REDD+..

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