K&C Science Report – Phase II

Forest biomass assessment in Vietnam using ALOS/PALSAR

Thuy Le Toan
Centre d'Etudes Spatiales de la Biosphère
18 Avenue Edouard Belin, 31401 Toulouse Cedex 9, France
Email: Thuy.Letoan@cesbio.cnes.fr

Collaboration
Tran Tuan Ngoc, Nguyen Thanh Nga
National Remote Sensing Centre,
108, Chualang, Dongda, Hanoi, Vietnam
Email : trantuanngoc@rsc.gov.vn

Lam Dao Nguyen
GIS & Remote Sensing Research Center (GIRS)
Vietnam Academy of Science and Technology (VAST)
1 Mac Dinh Chi St., Dist. 1, Ho Chi Minh City, Vietnam
Email: ldnguyen@vast-hcm.ac.vn

Ludovic Villard, Alexandre Bouvet*,
Centre d'Etudes Spatiales de la Biosphère
18 Avenue Edouard Belin, 31401 Toulouse Cedex 9, France
(* Now at JRC, Ispra, Italy)
Email: Ludovic .Villard@cesbio.cnes.fr

Ake Rosenqvist
soloEO
TTT Mid-Tower 1708, Kachidoki 6-3-2, Chuo-ku, Tokyo 104-0054, Japan.
Email: "Ake Rosenqvist" <ake.rosenqvist@gmail.com>

***Abstract*— This paper presents a preliminary assessment of ALOS/PALSAR data from the Kyoto and Carbon Initiative program for monitoring of forest status and mapping of biomass in Vietnam. The changes in forest status (deforestation, reforestation, growth) occurred during three years (2007-2008-2009) were detected in a region of intensive rubber plantation program. Biomass estimation has been estimated in a province of active tree planting. Optical data (SPOT 5) have been used for mapping of forest types and in-situ biomass measurements have been used to analyse PALSAR data. The resulting biomass map of the Hoa Binh province has been validated using forest inventory data. The results obtained indicate that the forest biomass is relatively low (average values less than 40 ton/ha). This is due to the shortened exploitation cycle of the forest plantation (harvest of *acacia mangium* species after 4-5 years instead of 6-8 years). This change in the forest exploitation practices effects the carbon stock of the region, and will need to be accounted for in the carbon budget calculations. ALOS PALSAR data proved particularly useful for providing information relevant to carbon budget calculation and to the assessment of forest states, from logging to regrowth during the first decades after disturbances in Vietnam. Future works will consist of applying the methods developed to the entire Vietnam, for the present period starting from 2007.**

***Index Terms:* ALOS PALSAR, K&C Initiative, forest biomass, reforestation, afforestation, tree plantation, Vietnam.**

INTRODUCTION

Estimates made for FRA 2010 [1] show that the world's forests store 289 Gigatonnes (Gt) of carbon in their biomass alone. While sustainable management, planting and rehabilitation of forests can conserve or increase them, deforestation and degradation and poor forest management reduce forest carbon stocks. Globally, carbon stocks in forest biomass decreased by an estimated 0.5 Gt annually during the period 2005-2010, and this loss has significant implications for the Earth system

Increased awareness of these impacts has led to a number of international conventions including the UN Framework Convention on Climate Change (UNFCCC), its Kyoto Protocol contributing to the preservation, enhancement and long-term sustainability of global forest carbon stocks. For this reason, there is a need to continue the mapping of forests on a regular basis and to assess the changes in extent and in status (in terms of structure and biomass), so that processes and drivers of change can be better quantified. For reporting to international agreements, there is also a requirement to retrieve specific data relating to the carbon budgets associated with these forests. Although considerable advances have been made in these areas in recent years, significant obstacles still remain in terms of collecting and collating relevant and timely data.

Forests act both as sources and sinks of CO_2 as deforestation depletes carbon stocks and releases CO_2 to the atmosphere, while on the other hand, forest regrowth can result in large absorptions of carbon. Quantifying forest carbon stocks and their changes is therefore critical. However, the magnitude, stability, and regional and temporal variability of these sinks and sources are poorly known and are the subject of heated debate, particularly because of its relevance to the Kyoto Protocol.

According to available data, in 1943 Vietnam had 14.3 million ha of natural forests, accounting for 43% of the country's area. Since that time, forest cover has decreased dramatically, especially during the 1976–1990 period. During that period, about 98,000 ha were annually contracted for logging. Forest cover declined to 27.2% in 1990, but increased again to 28% in 1995, as a result of forest protection and rehabilitation programs. This changing trend, however, still meant that from 1991 onward the area of natural forests continued to decline, although at a slower pace than in previous years. The establishment of plantations increased fast. Vietnam is currently carrying out a large-scale "reforestation" programmes. Much of the planting taking place today is of fast-growing tree species aimed at producing raw materials for the pulp and paper industry or manufacturing of woodchips for export. Selection and breeding of new tree species with high productivity and adaptability make a significant contribution to the implementation of the national planting program. Hybrids of *Acacia mangium* and *A. auriculiformis* are among the species selected for reforestation work, together with various *Eucalyptus* and *Pinus* species. Also, the area of rubber (*Hevea brasiliensis*) plantations increases very fast to produce more natural rubber. According to Vietnam's agriculture ministry, the area of rubber has increased from about 75,000 ha of rubber in 1975, to about 700,000 ha in 2010. In 2009 alone, some 37,000 ha of new plantations were created. Despite a decreasing density of biomass due to the degradation of forests and the increasing proportion of young trees, the total carbon stock in forests also followed a pattern of transition. Forests in Vietnam represented a net carbon sink of around 36TgC per year since the beginning of the 1990s. Forests in some regions became more fragmented and subjected to edge effects, while the opposite occurred in other regions [2].

Currently, forest area and resource in Vietnam are surveyed every 5 years. Earth Observation data have been introduced since the 1990-1995 period, based on Landsat data; and SPOT data have been used since 1995-2000.

For the recent period 2005-2010, SPOT 5 (5 m x 5 m and 2.5 x 2.5 m resolution) data have been used to establish forest maps at scales of 1/25,000 (commune), 1/50,000 (district), 1/100,000 (province), 1/ 250,000 (region) and 1/1,000,000 (nation). Remote sensing digital processing and interpretation units have been set up at 39 out of 40 provinces with significant forest cover [3]. Systematic in-situ survey provides data for forest inventory. They are also used as training data for forest mapping using SPOT data. The biomass and carbon stock accounting for every 5-year period are based on forest maps and on biomass in-situ sampling.

OBJECTIVE

In this context, the objective of this study is to assess the use of ALOS-PALSAR data to provide information that can be used to replace or to extend the in situ sampling measurements in the carbon stock estimates in Vietnam. Moreover, it is expected that the changes in forest status and in biomass following tree harvesting, deforestation and regrowth can be effectively detected on an annual basis using time series of ALOS PALSAR data. ALOS is programmed by JAXA to cover all of Vietnam at least 2 times every year

In the phase 2 of the project, a feasibility study has been performed at two forestry development areas in Vietnam.

DESCRIPTION OF THE PROJECT

Relevance to the K&C drivers

The use of ALOS data to quantify changes in forest status is in accordance with the Carbon driver outlined in the K&C Science Plan [4]. The ALOS PALSAR is expected to facilitate estimation of changes in biomass associated with deforestation and degradation (clearing, felling of timber) and to monitor (re)growth through temporal comparison of SAR backscatter data. Relating such changes to fluxes of carbon is difficult given uncertainties in the processes of decomposition and

regeneration and the rates of change [5]. Nevertheless, by integrating models and observations of carbon dynamics with forest cover or change information generated using PALSAR data (either singularly or in combination with other remote sensing data), improved estimates of carbon flux may be obtained [6].

Work approach

ALOS PALSAR K&C data have been assessed for mapping of forest cover and biomass in prototype regions of Vietnam. Changes in forest status (clearfelling, plantation and growth) are tested in a region of active plantation of rubber in the South of Vietnam. Forest biomass mapping is assessed in one province of forestry development area in the Red River watershed in the North of Vietnam. For biomass mapping, in situ forest biomass measurements have been used to establish the relationship between the backscatter coefficient and biomass. Optical data (SPOT 5) have been used for the mapping of land cover, forest/ non forest and forest types. The inversion of PALSAR data into biomass has been applied to the forest maps derived from SPOT 5. The resulting biomass map is validated using independent forest inventory data

Satellite and ground data

PALSAR data used in the study were acquired during summer 2007 (cycles 12 and 13) in fine beam dual polarization (FBD) mode (polarizations HH and HV). Data from paths 460 to 468 and 473 to 484 were processed and geocoded using a Shuttle Radar Topography Mission (SRTM) derived digital elevation model (DEM) [7]. Moreover, data from 2008 and 2009 have been used for change detection.

Figure 1 shows the location of the two test regions in Vietnam studied using PALSAR data.

Processing and results

1. Change in forest cover:

PALSAR images of 2007, 2008 and 2009 have been analysed for change mapping in the prototype area 1. Figure 2 shows the changes observed during this 3-year period in the region of Dau Tieng, Binh Duong province. The plantation cycle, previously of 30 years, is at present much shortened, to 20 years or less. Old plantations have been clearfelled and replaced by new plantations and the possibility to monitor the process is assessed with ALOS- PALSAR data.

Figure 3 shows a comparison between the forest map of the area of Dau Tieng reservoir in 1989, based on classification of Landsat data and the forest map provided by HH and HV ALOS PALSAR data.in 2007. Significant changes can be observed. While most close forests in 1989 (e.g. north of the reservoir) have been transformed to non forest area (e.g. agriculture land), new forests set up on previously bare land are found in 2007 (e.g. South East of the reservoir), most of them are rubber plantations.

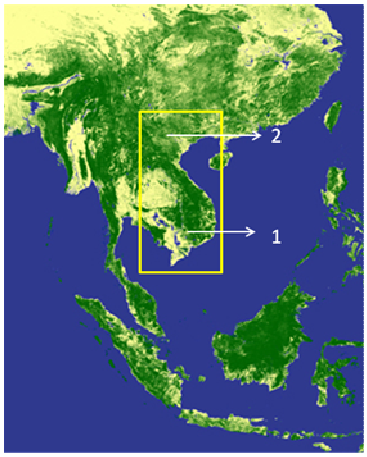

Figure 1. JAXA Forest/non forest map of South East Asia. 1 and 2 are the two prototype areas studied during phase 2. Area 1 is an region of active rubber plantation in South West Vietnam, and area 2 is a region of dynamic forest development in North Vietnam.

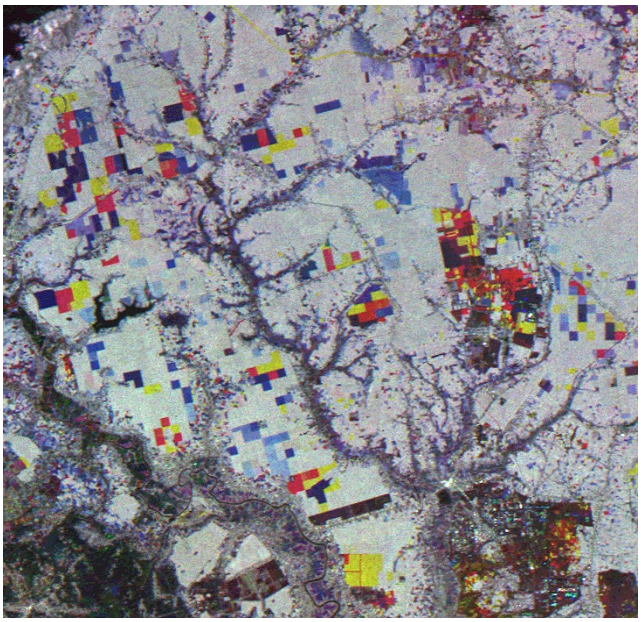

Figure 2: Multi-temporal HV PALSAR image over Dau Tieng, province of Binh Duong, Vietnam (R: 2007; G: 2008; B: 2009). The area is part of the extensive rubber plantation program. Red: forest cleared 2007-2008, Yellow: clearings between 2008-2009, Blue: young growing rubber.

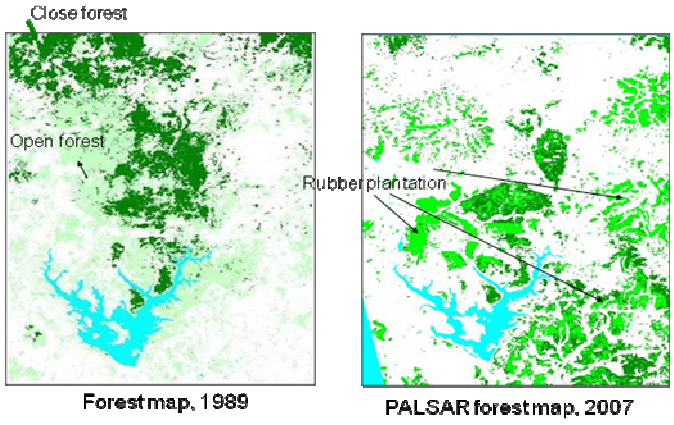

Figure 3: Forest map of the region of Dau Tieng Reservoir, 11.379°N, 106.345 E. Left: map of forest in 1989 based on Landsat data, dark green: close forest, light green: open forest. Right: Forest map using PALSAR 2007 data. Dark green: forest, light green: rubber plantation.

The result shows that ALOS-PALSAR can be used for monitoring changes in forest cover and status. To apply the method to the whole extent of Vietnam, PALSAR data will be used to detect changes in the forest cover provided by existing forest maps obtained using SPOT 5 data (e.g. for the period of 2005-2010). A study will be needed to assess the used of forest maps at different scales, from local to national. It is expected that regional (or national) maps will be used for masking of non forest area, whereas local maps (ward or district) will be used for training.

2. Biomass estimates

The biomass mapping has been tested in the province of Hoa Binh, North Vietnam. Hòa Bình has an area of 469,912 ha, about 44% of it is covered by forest (208,922 ha). The topography is complex, ranging from moderate to high mountainous areas.

Ground data

Ground data consist of measurements in sampled plots. Each plot has an area of 400 m2. All the trees with diameter at breast height (DBH) > 5 cm are measured and recorded. (species, diameter, total height, crown height, crown diameter). Biomass has been estimated following IPCC guidelines [8]. Allometric equations established by destructive sampling have been used for the same species in similar growth conditions. The following relations have been used:

- Tree volume= Stem volume*1,3736
- Tree Fresh biomass=Tree volume* 0,9 (wood density)
- Tree Dry biomass= Tree Fresh biomass *0.53
- Dry forest above ground biomass= Dry above ground biomabioof all the trees in 1 ha.

In this study, 20 sampling plots have been used to establish the relationship between the backscatter and biomass. whereas 52 inventory plots are used to validate the result.

Land cover and forest map

SPOT 5 images have been used for land cover and forest mapping. The network of reference plots are used for supervised classification. Forest is classified into 5 classes: afforestation (plantation on non forest land), reforestation (plantation after forest clearfelling or disturbances), evergreen deciduous forest, montane forests and other natural forests. Figure 4 shows the resulting forest map of the province.

According to the area distribution of the 5 forest classes in figure 5, reforestation and afforestation account for 70% of the forest area in the province.

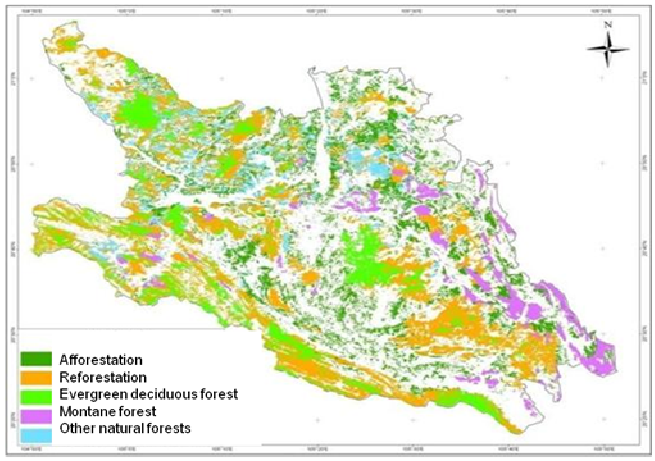

Figure 4: Forest map of the province of Hoa Binh based on SPOT 5 data.

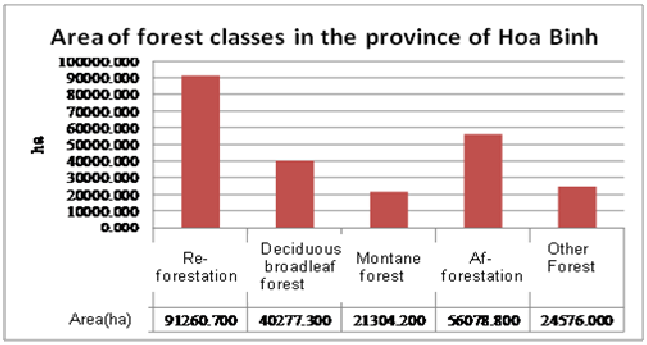

Figure 5: Area (in ha) of the 5 forest classes in the province of Hoa Binh.

Relationships between PALSAR backscatter and biomass

Because of the highly dynamic forest plantation and exploitation program, and because of the small size of exploitation units, forest classes as found in figure 4 form a mosaic of backscatter levels, depending upon the status and history of the exploitation. In order to reduce the errors due to localisation, reference plots located well inside a homogeneous units are selected for the analysis of the backscatter coefficient as a function of biomass

As expected, the HV and HH backscatter coefficients show increasing trend with biomass. The increase is about 4 dB for

biomass from 10 to 80 ton/ha and about 2 dB for biomass varying from 80 to 160 ton/ha. The topographic effect is present in HH, and reduced in HV. HV is thus retained for biomass inversion. The following equation is used, corresponding to a correlation coefficient R^2= 0.7907 with the data.

$$\ln(B) = 0.4167\sigma_{hv} + 11.5055$$

Where B is the above ground biomass in ton/ha, and is the backscattering coefficient HV in dB.

Figure 6 shows the biomass map of the province of Hoa Binh, after inversion of PALSAR HV data and masking of non forest area using the forest map obtained with SPOT 5 data. The image displays biomass classes of < 10 ton/ha, 10-25, 25-50, 50-75, 75-100, 100-120 ton/ha.

The map appears to be made of inhomogeneous plots of different biomass density, as illustrated in figure 7.

The result has been validated by using 52 independent plots. The RMS Difference is 3.26 ton/ha (11.11% of the mean values of biomass in the reference plots), with a Pearson coefficient r_s = 0.94 (figure 8). However, because most of the plots (44 out of 52) are in reforested and afforested areas having biomass values in the range of 6 to 40 ton/ha, the validation is biased towards these two types of forest of low biomass values.

Figure 9 shows the amount of biomass distributed in the 5 forest classes. The figure shows that reforestation and afforestation contain the major part of biomass in the province.

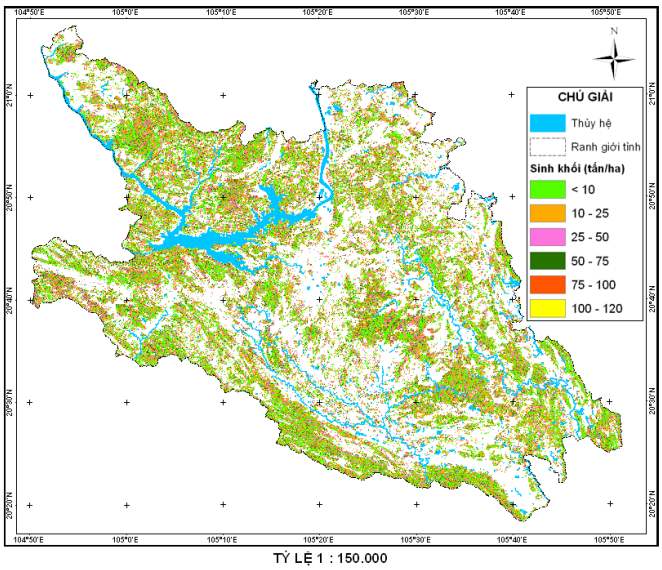

Figure 6: Forest biomass map of the province of Hoa Binh derived from PALSAR data.

Figure 10 shows the area distribution (in ha) of the different classes of biomass. The result is rather surprising. For a majority of forest area the above ground biomass is less than 50 ton/ha, with the highest percentage of the area occupied by

Figure 7: Plantations of acacia mangium in the province of Hoa Binh. Left: plot before harvest, Right: recently clearfelled plots adjacent to a plot ready for harvest.

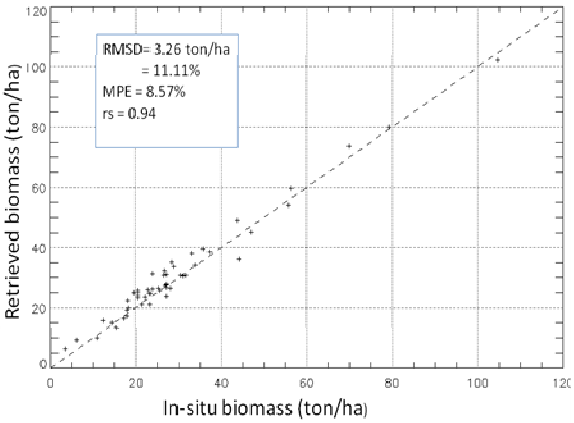

Figure 8: Comparison between retrieved biomass and in situ biomass. RMSD = Root Mean Squared Difference, MPE= mean percentage error, rs= Spearson coefficient.

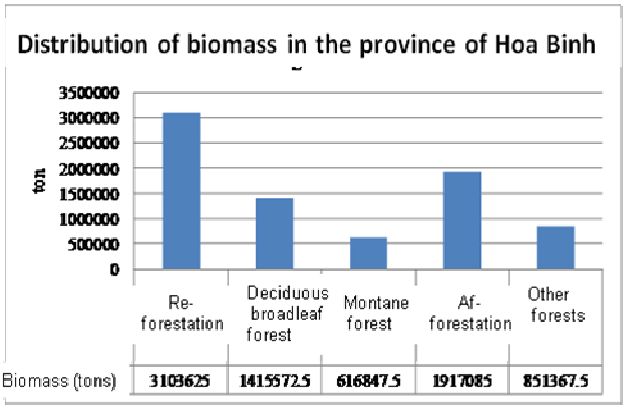

Figure 9: Distribution of biomass (in tons) by forest classes in the province of Hoa Binh.

very low biomass (< 10 ton/ha). The reason of these low biomass distributions is understood as due to a very active forest exploitation. The main species used in reforestation and afforestation are hybrids of *Acacia mangium* and *A. auriculiformis* used in paper industry. The usual turn over cycle for such species was 6-8 years, when the trees reached 100-120 ton/ha at harvest. In the last few years, because of the strong demand in paper pulp, the cycle is shortened to 4-5

years, yielding 40-50 ton/ha at harvest. The landscape appears as a mosaic of small exploitation units having various status from clearcut to young (re) growth (Cf. figure 7). The mean biomass value of the reforested and afforested areas is about 30 ton/ha. Forests of biomass higher than 100 ton/ha occupy only about 5% of the province area.

Potential use of the result in carbon stock estimates

Above ground biomass retrieved from PALSAR can contribute effectively to the carbon stock estimates, at least by complementing the in situ inventory results with the highly dynamic part of the biomass of reforested, afforested and regrowth areas . For the below ground biomass and dead wood biomass, default values recommended by IPCC can be used [8]. However, for the managed forest in Vietnam, the amount of dead wood left after harvest is not significant. To apply the method to the whole country will require more work to valídate the results various ecosystems. To improve the mapping accuracy, the biomass mapping method can be fine tuned to regional forest characteristics (natural forest, plantation..), soil and climatic conditions.

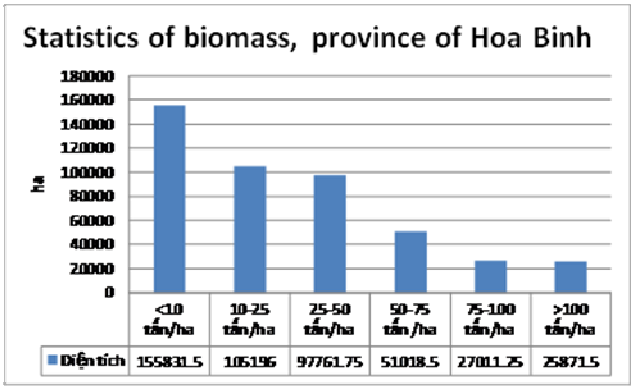

Figure 10: Statistics of area (in ha) in ranges of biomass in the province of Hoa Binh.Biomass is in classes of < 10 ton/ha, 10-25, 25-50, 50-75, 75-100 and > 100 ton/ha.

CONCLUSIONS

This paper presents an assessment of the use of ALOS PALSAR data to map changes in forest status, and to estimate forest biomass in Vietnam. The change in forest status has been tested in a region of active rubber plantation in the South of Vietnam. The study shows clearly that clearfelling, reforestation and young regrowth could be monitored using time series PALSAR data (here, 3-year data in 2007, 2008, 2009). The biomass estimation methodology is developed and applied to a prototype province in the North of Vietnam. The biomass results and their uncertainties still need further assessment. However, the study already shows that biomass and consequently the carbon stocks of the forests can be estimated with the help of PALSAR data, in particular in Vietnam where the forest biomass density is low because of the degradation of natural forests and the increasing proportion of young trees. The study needs to be pursued using multi-year ALOS PALSAR data for the whole of Vietnam. ALOS K&C Initiative provides the opportunity for such assessment during its timelife, and hopefully, during the ALOS follow-on mission.

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P.I. BIOGRAPHY

Thuy Le Toan has a PhD in atomic and nuclear physics from the University of Toulouse, France. She has been the Head of the Remote Sensing research team in the Centre d'Etudes Spatiales de la Biosphère (CESBIO).

Her research activity has been in the area of microwave remote sensing for land applications. Her present interest is the use of remote sensing to characterize land processes and their impacts on the carbon cycle.

She is member of the Kyoto and Carbon Initiative Science team. She is the co-chair of the Mission Advisory Group of BIOMASS P-band SAR mission, candidate for the 7th ESA Earth Explorer Core Mission, in phase A since 2009.