K&C Science Report – Phase 1
Change in forest cover in Central Siberia using ALOS/PALSAR

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

Collaborators
Mihai Tanase, Juan de la Riva
University of Zaragoza, Pedro Cerbuna 12, 50009, Zaragoza (Spain),
Email: mihai.tanase@tma.ro, delariva@unizar.es
Alexandre Bouvet
Centre d'Etudes Spatiales de la Biosphère
18 Avenue Edouard Belin, 31401 Toulouse Cedex 9, France
Alexandre.Bouvet@cesbio.cnes.fr
Maurizio Santoro
Gamma Remote Sensing AG, Worbstr. 225, CH-3073 Gümligen (Switzerland),
Email: santoro@gamma-rs.ch
Christiane Schmullius
Friedrich-Schiller-Universität (FSU), Jena, Germany
c.schmullius@uni-jena.de

***Abstract*— This paper presents a preliminary assessment of ALOS/PALSAR data from the Kyoto and Carbon Initiative program for monitoring changes in forest in terms of biomass loss and gain in central Siberia. The changes in forest area occurred during the last ten years were estimated using PALSAR data acquired in 2007 as compared to the forest map in 1997 using data from ERS1-ERS2 combined with JERS satellites (the SIBERIA-I project).**

The results obtained for the two study regions of Irkutsk and Krasnoyark which cover each about 5 millions of hectare indicate that the forest areas where biomass is lost (logging and fires) in 10 years are 12.2% of the area in Irkutsk and 16% in Krasknoyarsk, whereas the areas with increase in biomass account for 3.2 and 4.5% respectively in these two regions. This high rate of net loss (9% and 11.5% in 10 year) , around 1% per year, if validated, could be a concern for future development of the Siberian forests.

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 Siberia.

***Index Terms*—ALOS PALSAR, K&C Initiative, forest biomass, SIBERIA-I.**

I. INTRODUCTION

The loss and degradation of forests worldwide has significant implications for the Earth system. The burning of forest biomass and removal or felling of timber have contributed to the additional burden of CO_2 in the atmosphere and the associated changes in climate. Clearance, degradation and fragmentation of forests have also resulted in significant losses of biodiversity and resources of social and economic importance.

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. Large areas of forest are also regenerating naturally and these forests play a key role in the recovery of the carbon lost.

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 condition (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.

In this context, the objective of this study is to assess the contribution of ALOS PALSAR data to provide better estimates of biomass losses and gains associated with the clearance and growth of regenerating forests. The focus is put on the boreal forests in central Siberia where forest, and which retains much less attention of the scientific community as compared to tropical and temperate forests.

The forests of Siberia constitute about 20% of the total world forested area and nearly 50% of the total world coniferous-forested areas. The Siberian forests have recently become an important topic of debate. The first reason of interest is that Siberian forests are considered in recent studies only as a weak carbon sink, however the studies show large uncertainties in the sink estimates. The second reason for this interest is concerned with the ongoing exploitation of forest resources. When combined with natural hazards, over exploitation may cause deterioration of the environment, especially when considering the boreal forest low recovery rate.

I. OBJECTIVE

The objective of this study was to quantify the change in forest cover and biomass occurred during the last ten years in two selected sites located in central Siberia. This has been achieved by comparing ALOS PALSAR data acquired in 2007 and the biomass/land-cover map obtained in the SIBERIA-I (SAR Imaging for Boreal Ecology and Radar Interferometry Applications) Project based on data acquired in 1997.

II. DESCRIPTION OF THE PROJECT

A. *Relevance to the K&C drivers*

The use of ALOS data to quantify changes in forest condition, is in accordance with the Carbon driver outlined in the K&C Science Plan [1]. The ALOS PALSAR is expected to facilitate estimation of changes in biomass associated with deforestation and degradation (clearing, felling of timber) and to monitor regeneration through temporal comparison of SAR backscatter data up to the levels of saturation. Relating such changes to fluxes of carbon is difficult given uncertainties in the processes of decomposition and regeneration and the rates of change [2]. For example, Schulze *et al*. (1999) [3] suggest that several decades may pass before the Net Primary Productivity (NPP) of regenerating forests on cleared land in Siberia exceeds heterotrophic respiration, largely because of the decomposition of dead biomass. 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 [4], [5] .

B. *Work approach*

ALOS PALSAR K&C data have been first assessed for mapping of forest cover and biomass classes, using high resolution optical data and forest inventory database. In order to compare the mapping results with the map provided by SIBERIA-I, the biomass class definition is based on the SIBERIA-I classification scheme. Detection of changes is conducted in the second phase, where areas of biomass loss and gain are highlighted.

C. *Satellite and ground data*

Site selection was conditioned by the availability of PALSAR data and the extent of SIBERIA-I product. The SIBERIA-I Project was an international effort to map Siberian boreal vegetation using SAR backscatter and interferometric data acquired by the ERS-1/2, and JERS satellites [6]. Data were classified in four growing stock volume classes (0-20, 20-50, 50-8- and > 80 m3/ha), a smooth area class and a water body class [7]. This SIBERIA map represents a snapshot of the forest cover for a 1,000,000 km2 area of Central Siberia (see also Fig. 1) for the years 1997-1998.

Two sites covering about 50.000 km^2 each were selected. The first is the Irkutsk site situated about 250 km north of Bratsk. The second is the Krasnoyarsk site, located westwards at about 190 km north of Kansk city. The relief is represented mainly by plateaus and hills, almost 90% of the surface lying below 500 meters a.s.l. More than 95% of the slopes are below 8^0, the whole territory being within the typical boreal forest zone.

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).

Figure 1 shows the SIBERI-I map and the location of the two testregions analysed using PALSAR data.

Very high resolution optical data (available in Google Earth) are used for analysis and qualitative validation, whereas forest database provided by IIASA (ref) are used in the analysis.

D. *Processing and results*

PALSAR data were provided as long strips multi-looked intensity images in slant range geometry [8]. The processing steps described in [9] includes transformation to backscattering coefficient and geocoding, strip mosaicking, and co registration to SIBERIA-I map.

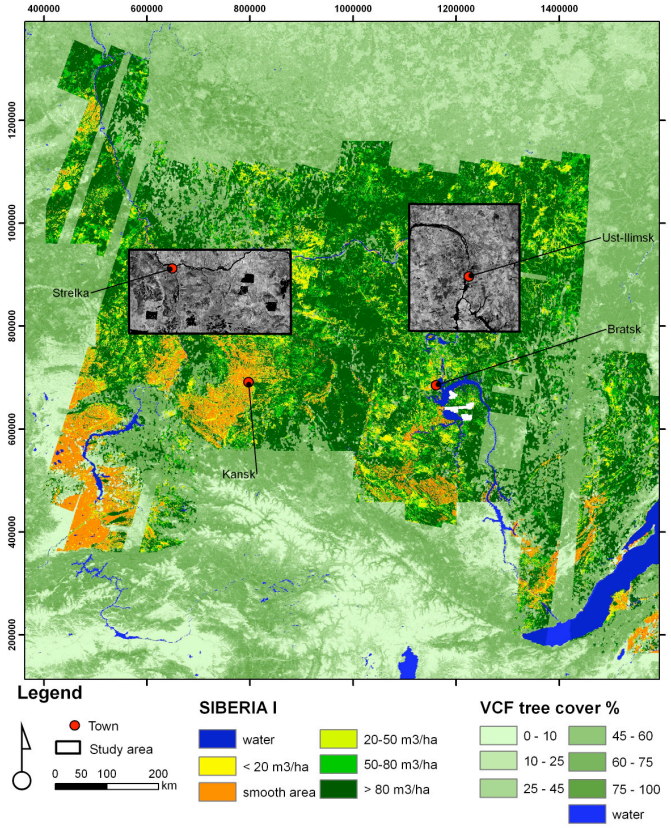

Figure 1: Map of Central Siberia (Baikal lake in the bottom right), where SIBERIA-I and the two PALSAR study regions are localized.

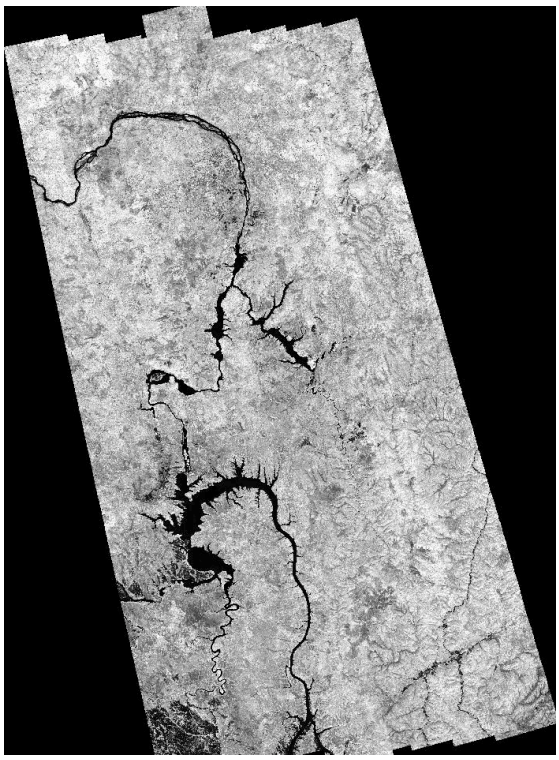

Figure 2: Mosaic of the PALSAR strip images of the Krasknoyarsk region.

Efforts have been put to compensate some of the error sources in strip mosaicking (i.e. errors related to data acquisition - radiometric accuracy, changing weather, and errors related to SAR processing - inter-strip co-registration).

Figure 2 shows the resulting mosaic covering the region of Krasknoyarsk.

E. Classification

The classification scheme was developed based on the data analysis results and the need of matching SIBERIA`s classes. A classifier based on HH and HV backscatter and their ratio was used. The analysis of the backscatter values was done based on sample polygons digitized using very high resolution optical satellite imagery (VHR). More than two hundred samples, equally distributed between three provisional classes (*open areas, low biomass forests* and *high biomass forests*) were selected for the Irkutsk site. These classes were preferred because their visual discrimination was possible on VHR optical imagery.

To fine tune these classes into SIBERIA like classes (*i.e. forests <50 m^3/ha, forests 50-80 m^3/ha and forests >80 m^3/ha)* a second backscatter analysis was carried out in 1067 polygons of Russian forest inventory parcels [10]

The classification method based on the data analysis has been described in [9] and applied to the two test regions. Figure 3 shows a subset of classification result for the region of Krasknoyarsk, where the percentage cover was found to be 59% of forests > 80 *m^3/ha, 15% for class 50-80 m^3/ha, 19% for forests <50 m^3/ha, 5% of smooth area, and 1.5% of water.* This is interesting to note that only 60% of the pixel area are forests of more than *80 m^3/ha (or about 50 ton/ha).*

F. Change detection

To evaluate the percentage of area with forest biomass loss and gain, the classification scheme of both SIBERIA and PALSAR data are compared on a pixel basis. Due to the high confusion errors for the intermediate forest classes (50-80 m3/ha) a reduced number of classes was implemented, where classes 50-80 m^3/ha and > 80 m^3/ha are merged to a class of > 50 m^3/ha. Reducing the number of classes greatly diminishes classification uncertainties, assessed using validation data even though it reduces the sensibility of the change detection algorithm to small biomass changes. In Siberia small changes (for the considered time interval) represent mostly growing processes.

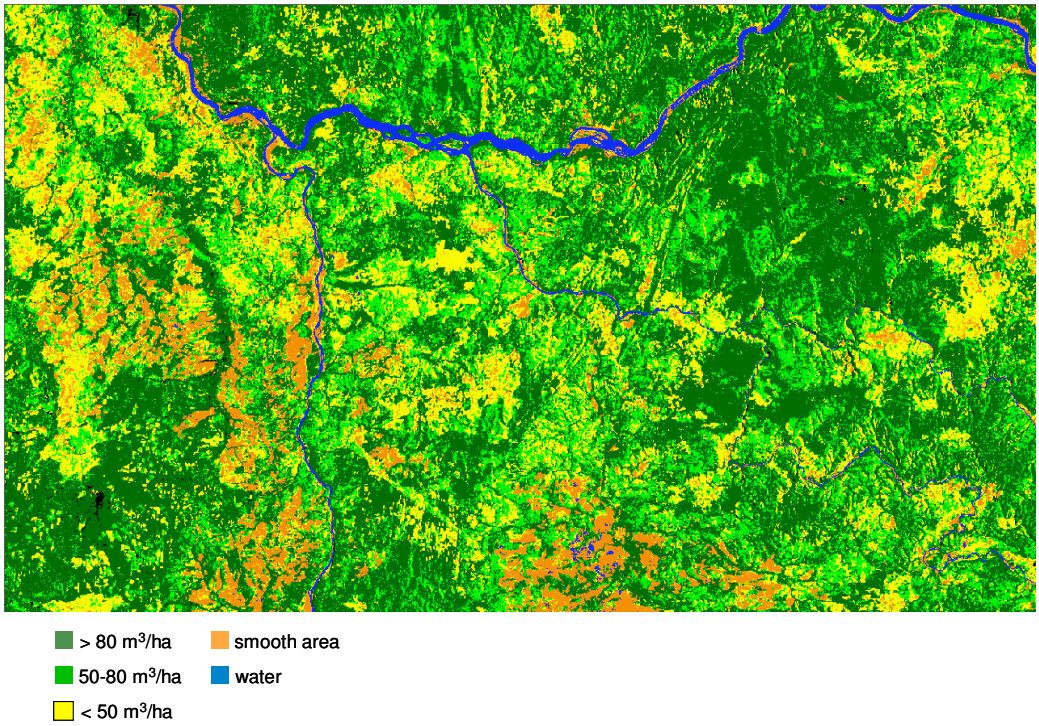

Figure 3: Map of land cover in the region North of Krasknoyarsk, central Siberia, using ALOS PALSAR FBD data acquired in 2007. The forests are mapped in three classes of growing stock volume (< 50 m^3/ha, 50-80 m^3/ha and > 80 m^3/ha) and smooth areas including agriculture and grassland. The map covers an area of 314 km x 163 km, crossed by the large Angara river in the North.

Due to slow growth ten years are not always sufficient for forests to pass from 0 m^3/ha to the 50 m^3/ha, and thus only some of the areas classified as less than 50 m^3/ha will be recorded by the change detection algorithm as surface with biomass gain. Consequently areas presenting biomass gains will be to a certain degree underestimated. On the other side clear cuts and fires will be certainly recorded since changes from forest to open area take place much faster and there are less chances of confusion. Therefore, a certain overestimation of the net forest surface loss is unavoidable when considering this method. In addition, the values registered by area with biomass loss and gain could be partially resulted from misclassification especially between classes *forest <50 m^3/ha* and *forests >50 m^3*

Class	*SIBERIA*	→	*PALSAR FBD*	*Irkutsk (%)*	*Krasnoyarsk (%)*
Biomass loss	forest >50 m^3/ha	→	forest <50 m^3/ha	9.6	11.4
	forest >50 m^3/ha	→	smooth areas	1.1 **12.2**	1.2 **16.0**
	forest <50 m^3/ha	→	smooth areas	1.5	3.4
Biomass gain	smooth areas	→	forest <50 m^3/ha	0.1	0.1
	smooth areas	→	forest >50 m^3/ha	0.02 **3.22**	0.04 **4.54**
	forest <50 m^3/ha	→	forest >50 m^3/ha	3.1	4.4
Stable forest	forest >50 m^3/ha	←→	forest >50 m^3/ha	69.1	58.5
Stable smooth fields & open areas	smooth areas	←→	smooth areas	0.5	2.3
	forest <50 m^3/ha	←→	forest <50 m^3/ha	7.9	6.7
Water	water	→	water	2.7	1.2
	not classified	→	water	0.3	0.3
Other changes	all other changes			0.4	0.4
Not classified	not classified Siberia or Palsar			3.8	10.1

Table 1. Change detection - class correspondence SIBERIA ←→ PALSAR FBD of the two test regions.

Figure 4 shows a part of the map of changes in the Krasknoyarsk region. The subset PALSAR image shows clearly areas of forest exploitation of geometrical shape. The over all dynamics of biomass loss and gain in the 10 year interval can be thus materialized.

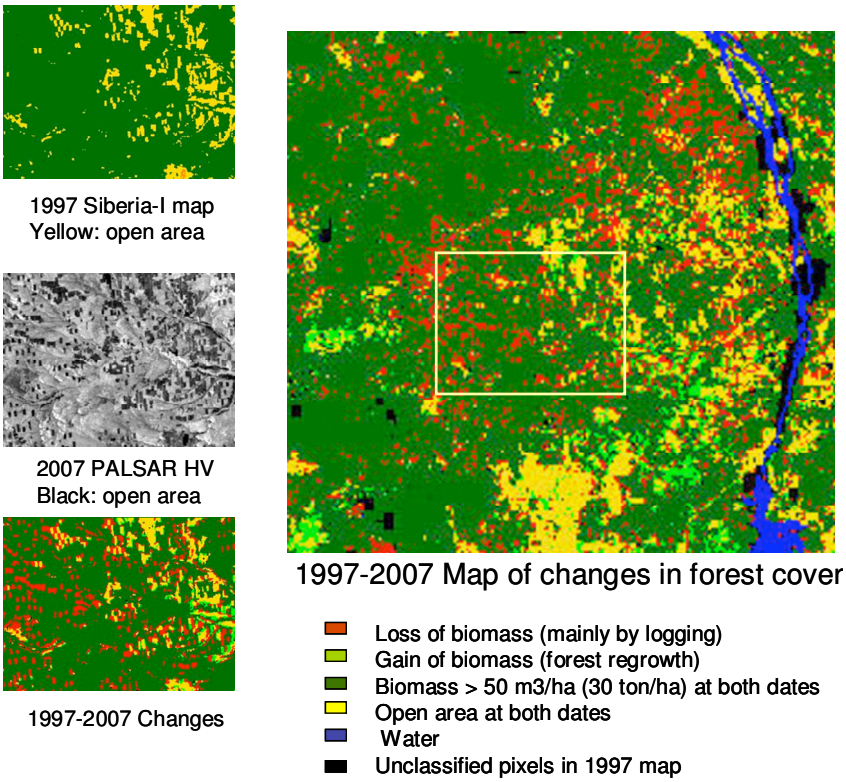

Figure 3: Right: map of changes in forest biomass in ten years (1997-2007) in the region North of Irkutsk. The map covers an area of about 120 km x 120 km, with the Angara river on the East. Left: Details of the 1997 and 2007 data and mapping result for the 40 km x 30 km subset delineated in the right figure. This includes SIBERIA-I forest map in 1997 (top), PALSAR HV image 2007 (middle) and map of changes in biomass (bottom). Note the large size of logged areas visible on the subset images.

III. CONCLUSIONS

This paper illustrates the change in forest areas associated to biomass loss and gain in Siberia as assessed using PALSAR data and the SIBERIA-I map. Two sites covering around 100.000 km^2 (or 10 Million hectares) located in the central part of Siberia have been studied.

During the last decade the percentage of the area where biomass is lost are 12.2% in Irkutsk and 16% in Krasknoyarsk, whereas the areas with increase in biomass account for 3.2 and 4.5% respectively in these two regions. The rate of net loss is thus 9% and 11.5% in 10 years, or about 1% per year. In addition, forest net loss estimates are higher for Krasnoyarsk site (11.5%) than for Irkutsk area (9%) suggesting a more active deforestation process in the eastern part of central Siberia. The similar forest net loss amount on both studied sites indicates comparable management practices at the level of the whole central Siberia.

The results and their uncertainties still need further assessment. However, the study shows clearly that area of biomass increase is much smaller than area of biomass loss. This may suggest unsustainable management policies.

The study needs to be pursued using multi year PALSAR data to detect area of forest exploitation and to evaluate the rate of exploitation. 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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VI. 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, including experimentation and modelling of microwave interaction with agricultural and forested media, and analysis of SAR images. Her current interest is on the use of remote sensing data to characterise the land processes and to quantify their impacts on the carbon cycle.

She is member of the Kyoto and Carbon Initiative Science team. She is the chairperson of the Mission Assessment Group of BIOMASS, the satellite mission candidate to the ESA Earth Explorer Core mission, retained for the pre-feasibility phase, in May 2006, and for the phase A in March 2009.