AN ESTIMATION OF CHANGE IN FOREST AREA IN CENTRAL SIBERIA USING MULTI TEMPORAL SAR DATA

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ABSTRACT

The objective of this study is forest cover change quantification in Central Siberia, using ALOS-PALSAR data and forest/biomass map product of SIBERIA project. Two sites (Irkutsk and Krasnoyarsk), covering around 50,000 km^2 each are studied. The classification algorithm is developed in the Irkutsk site and applied without further modification to the Krasnoyarsk site. Classification accuracy is assessed for the Krasnoyarsk site using as reference data from the Russian forest inventory. Over the studied period, a net forest cover loss of 9 to 11.5 % is estimated, depending on the site. Deforestation affects 12.2% to 16% of the area while forest regrowth is registered for only 3.2 to 4.5% of the studied area. Among the different causes that could explain forest area loss (e.g. natural disasters, clear cuts etc.) the geometric shape of the detected forest cover changes suggests an active deforestation process.

1. INTRODUCTION

Russian boreal woodlands represent the largest unbroken tracts of forests containing roughly half of the growing stock volume of coniferous species and playing a significant role as carbon pool. These forests are very vulnerable to natural hazards (e.g. forest fires) and human impacts (e.g. over exploitation) especially while considering their slow recovery rate and the increasing interest of wood industry. Analysis of forest cover changes in boreal regions is of major interest for many agencies dealing with environmental (e.g. global carbon budget), economic (e.g. wood exploitation) and legal issues (e.g. illicit deforestation). Assessing biomass loss is not an easy task, particularly when using remotely sensed data and change detection techniques. Growth is a slow process in boreal ecosystems and could be easily overlooked when large biomass intervals are used in the classification scheme. Change detection records only variations from one category to another and due to the slow growing process time may be insufficient for forests to cross class limits. Thus, the use of large biomass intervals underestimates growth for forests which do not change classification category within the time interval considered. On the other hand more classes imply higher uncertainty levels which directly influence estimation accuracy. Narrower biomass intervals will result in frequent category changes which often correspond to classifications disagreement due external factors and not to a real change. In addition clear cuts or natural disasters occur much faster often within days, transforming large areas of forests in bare land. These changes are easily recognizable and therefore will be accounted for by the change detection algorithms and thus overestimation of loss rates may take place. Further issues of primary importance in regional to global cover change studies based on Earth Observation data are data availability, the consistency of the sensor(s) used, spatial resolution and data processing.

The objective of this study was the quantification of forest surface change occurred during the last ten years in two selected sites located in central Siberia. This has been achieved by comparing recently acquired ALOS PALSAR (Advanced Land Observing Satellite, Phased Array type L-band Synthetic Aperture Radar) data and the biomass/land-cover map obtained in the SIBERIA (SAR Imaging for Boreal Ecology and Radar Interferometry Applications) Project. The SIBERIA Project was an international effort to map Siberian boreal vegetation using synthetic aperture radar (SAR) backscatter and interferometric data acquired by the European Remote Sensing (ERS) 1&2 satellites, and the Japanese Earth Resources Satellite (JERS). Data were classified in four growing stock volume classes (0-20, 20-50, 50-8- and > 80 m^3/ha), a smooth area class and a water body class [1]. The SIBERIA map represents a snapshot of the forest cover for a 1,000,000 km^2 area of Central Siberia (Fig. 1) for the years 1997-1998.

2. STUDY AREA AND DATASETS

Site selection was conditioned by the availability of PALSAR data and the extent of unclassified areas in SIBERIA product. Two sites covering around 50,000 km^2 each were selected. The first one, Irkutsk site, is situated about 250 km north of the city of Bratsk. The second one, Krasnoyarsk site, is located westwards at around 190 km north of the city of Kansk (Fig.1). The relief is represented mainly by plateaus and hills, almost 90% of the surface lying below 500 meters a.s.l. More

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than 95% of the slopes are below 8^0, the whole territory being within the typical boreal forest zone.

PALSAR data acquired during summer 2007 (cycles 12 and 13) in Fine Beam Dual polarization (FBD) mode (polarizations HH and HV) were provided in the framework of the Kyoto & Carbon (KC) Initiative. Russian forest inventory data were used for backscatter analysis (Primorsky test area) and accuracy assessment (Bolshe-Murtinsky & Chunsky test areas) (Fig.1).

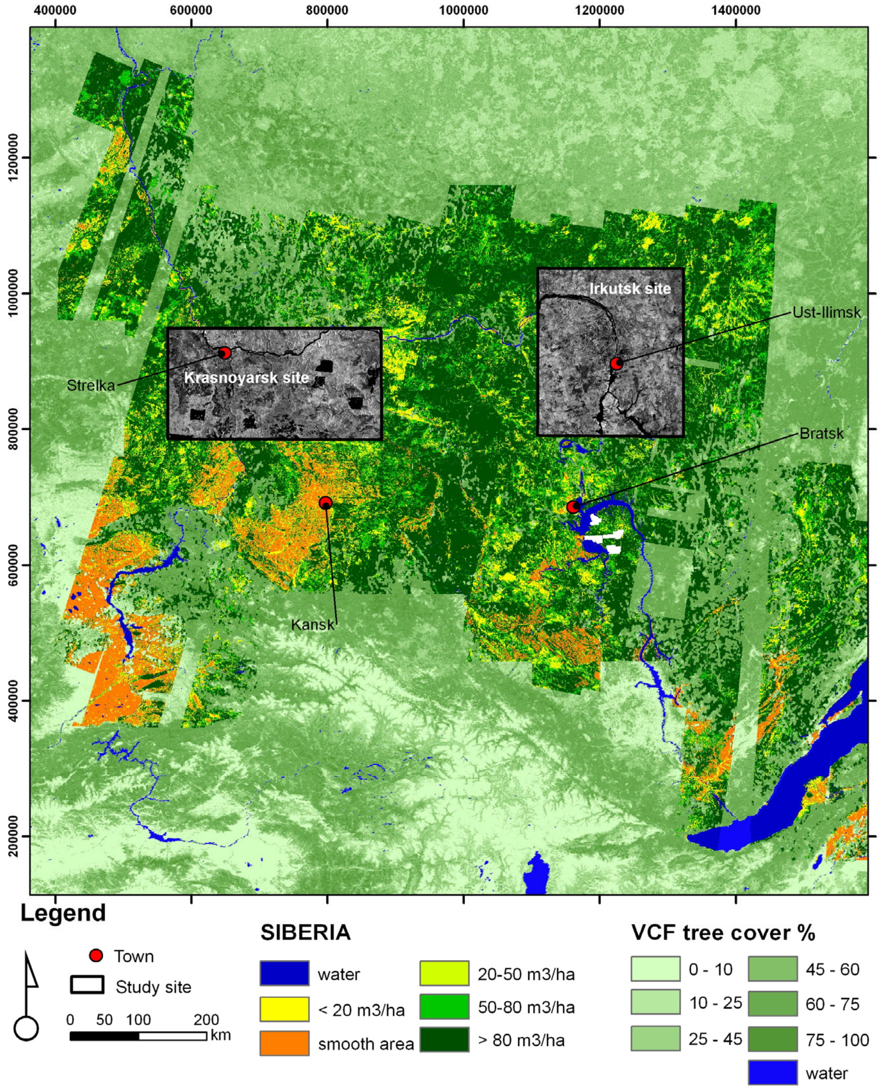

Figure 1. Irkutsk and Krasnoyarsk study sites over SIBERIA product. White colored parcels corresponds to Primorsky test area, black colored to Bolshe-Murtinsky & Chunsky test areas.

3. METHODS

The work was divided into preparation of the SAR dataset, image classification and accuracy assessment, and estimation of forest cover change. The first part was carried out using specific SAR data software while the others were realized using common remote sensing and geographic information systems (GIS) software. A flowchart of the workflow is presented in Fig. 2.

3.1. Preparation of the SAR dataset

Spatial accuracy plays an important role when analyzing geographical data available from different sources. PALSAR data were provided by Japan Aerospace Exploration Agency (JAXA) in form of long strips as multi-looked intensity images in slant range geometry. The data have been calibrated to sigma nought and geocoded (50m pixel spacing) to Albers Equal Area Conic (AEAC) projection using the Shuttle Radar Topography Mission (SRTM) 90-m digital elevation model (DEM). The geocoding algorithm consists in the generation of a lookup table describing the relationship between pixels in radar and map geometry. Refinement of the lookup table is implemented in the form of offsets estimation between the SAR image and a reference image (e.g. simulated SAR image) transformed to the radar geometry. Offsets are estimated using a cross-correlation algorithm [2].

Typically the root mean square error of the offset estimates was less than one pixel which indicates satisfactory geocoding accuracy.

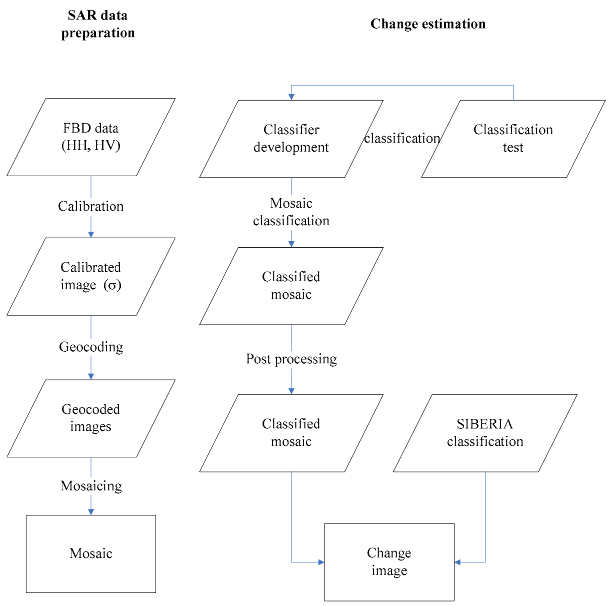

Figure 2. Methodology flowchart

The relatively small number of strips processed, the narrow acquisition period and the small range of incidence angles (~5^0) ensured a certain degree of radiometric homogeneity between adjacent data strips.

Efforts have been put to compensate some of the error sources that might have influenced the outcome of the study, i.e. radiometric anomalies, different environmental conditions and mis-registration of the overlapping data strips. To ensure the highest possible radiometric homogeneity required by the classification algorithm, the images were normalized with respect to the local incidence angle. The remaining inter-strip radiometric variation, changing weather effects and speckle were reduced using averaging while mosaicking individual data strips. Since adjacent PALSAR strips overlap more than 50% in range each pixel combined at least two backscatter values. It was considered that inter-strip registration errors were minimal since blurring effects were not observed after mosaicking.

Even though the SIBERIA Project dataset was processed with the identical procedure as the PALSAR data, unfortunately the DEM for geocoding was different. SRTM data were not available at the time of the SIBERIA project so that 60% of the SAR image frames were geocoded based on the Global 30 Arc-Second Elevation Data Set (GTOPO30). The rest was geocoded using digital elevation models derived from the ERS1/2 interferometric data [3]. Since the SIBERIA products were obtained in Universal Transverse Mercator (UTM) system resampling to AEAC projection was necessary to allow a comparison with the PALSAR dataset. The comparison revealed mismatches of up to two pixels which was primarily due to the use of different digital elevation models for geocoding the SIBERIA project (ERS 1/2 and JERS) data and the PALSAR data.

3.2. Classification

The classification scheme exploited the properties of the PALSAR data while taking into account the need of matching SIBERIA`s classes. As a result a classifier was developed that implements backscatter thresholds and class relations by means of an iterative process (building/assessing) for the Irkutsk test site using HH and HV backscatter intensities and their ratio. To determine the thresholds, the level of backscatter in several types of forest was investigated. Sample polygons were digitized using very high resolution 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.

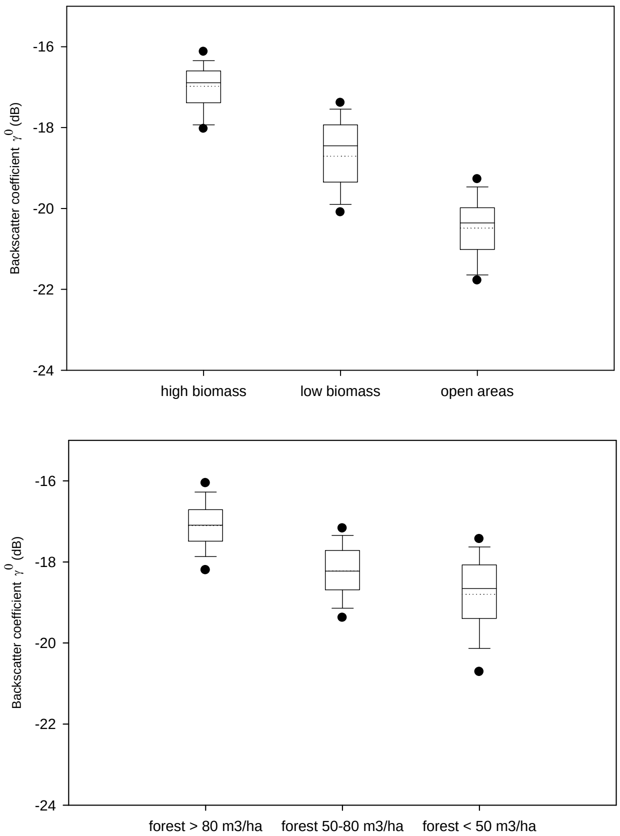

Figure 3. Box plot of digitized samples (top) and forest inventory parcels (bottom) – HV polarization

Using the backscatter properties of the sample polygons (Fig. 3) the classification algorithm was adjusted for extraction of the three provisional classes. 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 within the, Primorsky test area located south of the Irkutsk site [3]. The analysis revealed some differences to the variation boundaries (i.e. of the provisional classes) (see Fig. 3) which were incorporated into the classification algorithm. The upper threshold of the *forests <50 m^3/ha* class was increased by approximately 0.5 dB while for the intermediate forest class a shift of about 0.2 dB was necessary for both the upper and the lower thresholds. A scheme with five classes was implemented into the classification model (Tab. 1) and applied to the Irkutsk site. The PALSAR classification results were post-processed to remove small area (i.e. <2.5 ha) polygons. At first, contiguous pixels of same category were clustered. Then, the classification of the small clusters (i.e. less than ten pixels) was changed to the class category of the clusters sharing the largest border. To verify its consistency the model was applied without any further modification to the Krasnoyarsk site.

Table 1. Classification schemes: SIBERIA & PALSAR

SIBERIA →	*Reduced number of classes*	*← PALSAR*
unclassified	unclassified	unclassified
missing image data		
water	water	water
smooth areas	smooth areas	smooth areas
forest <20 m^3/ha	forest <50 m^3/ha	forest <50 m^3/ha
forest 20-50 m^3/ha		
forest 50-80 m^3/ha	forest >50 m^3/ha	forest 50-80 m^3/ha
forest >80 m^3/ha		forest >80 m^3/ha

3.3. Classification accuracy assessment

For an effective use of remote sensing data both information on accuracy and method are needed. Accuracy information is especially important when comparing multiple datasets since errors tend to combine. The error matrix analysis is a well-established accuracy assessment method in the field of remote sensing and was therefore employed. This method gives the correspondence of the classified map to the reference data set and is used to calculate a posteriori coefficients of agreement like Cohen`s kappa (*k*). To avoid biases associated with training and testing on the same area the accuracy assessment was carried out at pixel level in Krasnoyarsk site using as reference data from the Russian forest inventory (test areas of Bolshe-Murtinsky and Chunsky).

It should be noted that because of the time lag of approximately 10 years between the last forest inventory collection and the acquisition of the PALSAR images some of the reference data might have become obsolete. Furthermore, depending on location of the test sites the accuracy of the in situ data can change significantly. Three methods were implemented to compensate for such errors. Firstly, the number of classes used in SIBERIA project was diminished from four to three. Secondly, only polygons covering at least 35 hectares were selected. Finally a validation procedure was performed to assess whether polygons were affected by clear cuts or natural hazards since the last update of the forest inventory (1998). Polygons presenting high growing stock volumes in the forest inventory database and low SAR backscatter levels in the PALSAR dataset were eliminated since it was considered they had been affected by clear cuts or natural disasters in between. Since the forest inventory database does not include information on all classes, sample polygons were digitized with the help of VHR imagery for *water* and *smooth areas*. Around 2% of the Krasnoyarsk study site was used for accuracy assessment. Due to ground truth data availability the area sampled in each class was not perfectly proportional with the total classified surface of the respective class, some differences being unavoidable (Tab. 2).

Table 2. Distribution of sampled area for accuracy assessment – Krasnoyarsk site

Class	*Classified area % from total classified*	*Sampled area % from total sampled*
water	1.7	1.4
smooth areas	7.2	4.9
forest <50 m^3/ha	20.0	19.0
forest 50-80 m^3/ha	22.8	15.4
forest >80 m^3/ha	48.0	59.3

3.4. Change detection analysis

Change detection analysis was carried out at general level (comparing class area statistics) and at detail level (generating change maps at pixel level). To analyze general changes maps have to contain similar information. Since, the classification schemes were slightly different common classes were generated (Tab. 1) and their statistics were then compared.

At detail level two analyses were carried out. In the first case the full set of classes (i.e. SIBERIA and PALSAR) was used. In the second case a reduced number of classes were used. For the change map generated using the full set of classes variations of one volume class upwards or downwards were interpreted as classification disagreements due to different properties of SAR data and/or of the classification methods used in the SIBERIA project and for the classification of PALSAR data. For this reason they were not taken into account. A change in forest cover was considered when the two classification differed by more than one class (e.g. *forest >80 m^3/ha* to *forest <50 m^3/ha*). This criterion implies certain underestimation of *deforestation/afforestation* but still it was considered since results should be more robust (only severe changes will be recorded). Pixels not classified in at least one of the two datasets were grouped as *unclassified* areas. A pixel was classified as *water* if both classifications agreed on this class. Forest and smooth areas were classified as unchanged if both datasets agreed on the class value or the pixel registered a change of only one class to the immediately superior/inferior corresponding class. The class *other changes* contains the remaining pixels, after discarding the not classified ones, and corresponds to erroneous changes (e.g. water to forest, open to water, etc.). This class contains pixels affected by mis-registration between the datasets and, to a certain extent, by classification errors in one or the other map.

Since the accuracy assessment revealed high confusion levels for intermediate forest classes a change map was generated using a reduced number of classes after collapsing forest categories in both SIBERIA and PALSAR products (Tab. 1). With the exception of impossible status changes (e.g. water to forest) all other changes were taken into account.

4. RESULTS AND DISCUSSIONS

4.1. Accuracy assessment

The overall accuracy at the Krasnoyarsk site was 75.3% with individual classes' accuracy ranging from 35% to 96%. The lowest accuracy was registered for the forest 50-80 m3/ha class due to its frequent confusion especially with the *forest >80 m^3/ha* class (Tab. 3). The kappa coefficient (*k*), expressing the proportionate reduction in error generated by the classification process compared with the error of a completely random classification is 0.57. According to [4] this can be interpreted as a moderate classification agreement. If class *water* and *smooth areas* are not accounted for, *k* decreases to 0.53 while the overall accuracy remains almost the same. The high omission and commission errors of class *forest 50-80 m^3/ha* could be partially explained by the higher variability of the forest structure compared to other growing stock levels and the uncertainty of forest inventory data used for the model training which translates into lower discrimination capability.

In the SIBERIA project, the classification accuracy was estimated using as a basic unit the polygons of Russian forest inventory. All polygons were used for the accuracy assessment of the SIBERIA product, the confusion matrix being calculated just for the forest classes (Tab. 4). Confusion matrix analysis of SIBERIA data reveals high user`s and producer`s accuracies for the classes *forest <20 m^3/ha* and *forest >80 m^3/ha* and much higher omission and commission errors for the two intermediate classes (*forest 20-50 m^3/ha* and *forest 50-80 m^3/ha*). In the test areas of Bolshe-Murtinsky and Chunsky *k* reached 0.6 and 0.38 respectively, values comparable with that obtained for PALSAR data (*k*=0.57) where the two test areas were used jointly. To decrease uncertainty, forests were grouped in only two classes (forest >50 m3/ha and forests <50 m3/ha). The overall accuracy obtained after reducing the number of classes reached 87.6% and *k* value increased to 0.71. The omission and commission errors of the classes decreased remarkably, with some confusion remaining between the two forest classes (Tab. 5). The overall accuracy of the SIBERIA product after class grouping increased to a similar value 90% (*k*=0.64). Both forest maps were affected by similar confusion problems especially at the level of the intermediate forest classes. Despite of some differences in the implementation of the accuracy assessment (i.e. polygon vs. pixel based) for the two datasets (SIBERIA and PALSAR) the results were comparable and the two products were used jointly for the detection of changes.

Table 3. Pooled confusion matrix for the complete classification scheme. Numbers are pixel counts. k=0.57

Reference data →	*>80 m^3/ha*	*50-80 m^3/ha*	*<50 m^3/ha*	*smooth areas*	*water*	*Total*	*user's acc.*
forest >80 m^3/ha	213832	15267	17478	0	8	246585	87 %
forest 50-80 m^3/ha	35750	11647	16513	0	0	63910	18 %
forest <50 m^3/ha	4568	5850	68561	2	1	78982	87 %
smooth areas	170	59	6240	13817	269	20555	67 %
water	4	0	24	523	5439	5990	91 %
Total	254324	32823	108816	14342	5717	416022	
prod. accuracy	84%	36 %	63 %	96 %	95 %		75.3%

Table 4. Pooled confusion matrix for all test sites – SIBERIA dataset. Numbers are polygons counts. k=0.43

Reference data →	*>80 m^3/ha*	*50-80 m^3/ha*	*20-50 m^3/ha*	*<20 m^3/ha*	*Total*	*user's acc.*
>80 [m^3/ha]	5327	223	96	31	5677	94 %
50-80 [m^3/ha]	1023	297	237	135	1692	18 %
20-50 [m^3/ha]	117	52	110	144	423	26 %
<20 [m^3/ha]	136	21	104	589	850	69 %
Total	6603	593	547	899	8642	
prod. accuracy	81%	50%	20 %	66%		73.1%

(source: SIBERIA project final report [3])

.*Table 5. Pooled confusion matrix for the reduced classification scheme. Numbers are pixel counts. k=0.71*

Reference data →	*>50 m³/ha*	*<50 m³/ha*	*smooth areas*	*water*	*Total*	*user's acc.*
forest >50 m³/ha	276496	33991	0	8	310495	89.1 %
forest <50 m³/ha	10418	68561	2	1	78982	86.8 %
smooth areas	229	6240	13817	269	20555	67.2 %
water	4	24	523	5439	5990	90.8 %
Total	287147	108816	14342	5717	416022	
prod. accuracy	96.3 %	63.0 %	96.3 %	95.1 %		87.6 %

Table 6. Percentages of surface changes – overall statistics analysis (1997 vs. 2007)

	Irkutsk site			*Krasnoyarsk site*		
Class	*SIBERIA*	*Palsar FBD*	*Change*	*SIBERIA*	*Palsar FBD*	*Change*
not classified	4.0	0.1	-	10.1	0.3	-
water	2.8	3.2	0.4	1.3	1.7	0.4
smooth areas	0.6	3.2	2.6	2.6	7.2	4.6
open areas	12.6	18.1	5.5	14.5	20.0	5.5
forest	80	75.5	-4.5	71.5	70.8	-0.7
forest 50-80 m³/ha	*15.7*	*18.1*		*18.8*	*22.8*	
forest >80 m³/ha	*64.3*	*57.4*		*52.7*	*48.0*	

4.2. Change detection

4.2.1. Overall statistics analysis

At general level the assessment of land cover change with respect to the years 1997-1998 was possible after classification. Forests were grouped into a common class (Tab. 1) and statistics were calculated for Irkutsk and Krasnoyarsk sites (Tab. 6). Since changes between forest >80 m3/ha and forest 50-80 m3/ha classes could be the effect of the confusion errors, the two forest classes were analyzed as one. Total forest surface did not seem to suffer significant changes (-4.5% and -0.7% respectively) between the 1997 and 2007 considering the overall statistics. However, the SIBERIA product presents unclassified surfaces in both study areas, the percentage of forest surface being consequently underestimated. To account for these areas the unclassified surfaces were divided among the four land use/land cover classes based on the percentage cover of each class. As a result, in 1997 forests should have covered around 83.2% of the Irkutsk site and 78.7% of Krasnoyarsk site, thus being 8.1% and 7.9% higher than the levels registered in 2007.

4.2.2. 4.2.2 Pixel level analysis

Since repartition of not classified surfaces of SIBERIA project among the remaining classes is somehow arbitrary the change detection analysis at pixel level was carried out only for areas where classification was available for both dates (1997 and 2007). Two methods were used to evaluate the percentage of forest surface loss. The first method used the complete classification scheme of both SIBERIA and PALSAR data set, taking into account only changes of at least two classes for both deforestation and afforestation processes. Due to the high confusion errors for the intermediate forest classes a second method based on the reduced number of classes was implemented. All changes were considered while estimating deforestation and afforestation within the study areas with the second approach. The implementation of the two methods allows certain balancing between the loss of sensitivity to changes induced by the smaller number of classes and the higher confusion of a more detailed classification.

4.2.2.1. Full set of classes

The change analysis using the all classes reveals deforestation processes on approximately 6.2 % of the surface in Irkutsk study area and 7.0% at Krasnoyarsk study site. Forest surface loss corresponds almost entirely to deforestation of high growing stock areas (due to clear cuts, fires etc.) while a small part corresponds to further degradation of areas with medium growing stock volumes. Forest growth is generally a continuous process when natural disasters or human interferences are not involved. Volume increase has been unquestionably registered in all Siberian forests but due to confusion errors of the intermediate forest classes its quantitative estimation is difficult. In this study it has been possible to detect low biomass surfaces with sustained growth rates. Such areas, classified as afforestation were recorded on 2.3% of the Irkutsk site and 3.4% of the Krasnoyarsk site. It should be noted that these areas could partly correspond to volume underestimation in the SIBERIA map coupled to an overestimation in the PALSAR map. The net surface forest loss estimated using the complete classification scheme and considering only changes of at least two classes was 2.9% for the Irkutsk site and 3.6 % for the Krasnoyarsk site. These values represent a rather conservative estimation of deforestation process mainly due to omission of the previously exploited areas cleared/degraded during the last years (*forest 50-80 m^3/ha* to *forest <50 m^3/ha* changes). Detailed information is given in Tab. 7

Table 7. Change detection - class correspondence SIBERIA ←→ PALSAR (full set of classes)

Class	*SIBERIA*	→	*PALSAR*	*Irkutsk (%)*	*Krasnoyarsk (%)*
deforestation	forest >80 m^3/ha	→	smooth areas	0.8	0.5
	forest >80 m^3/ha	→	open areas	5.1	5.8
	forest 50-80 m^3/ha	→	smooth areas	0.3	0.7
afforestation	forest <20 m^3/ha	→	forest 50-80 m^3/ha	0.8	1.2
	forest <20 m^3/ha	→	forest >80 m^3/ha	1.0	1.5
	forest 20-50 m^3/ha	→	forest >80 m^3/ha	0.5	0.7
stable forest	forest 50-80 m^3/ha	←→	forest 50-80 m^3/ha	5.6	5.6
	forest >80 m^3/ha	←→	forest >80 m^3/ha	48.1	33.8
	forest 50-80 m^3/ha	←→	forest >80 m^3/ha	5.3	6.7
	forest >80 m^3/ha	←→	forest 50-80 m^3/ha	10.0	12.5
	forest 20-50 m^3/ha	→	forest 50-80 m^3/ha	0.9	0.9
	forest 50-80 m^3/ha	→	*forest <50 m^3/ha*	*4.5*	*5.6*
stable smooth fields & open areas	smooth areas	←→	smooth areas	0.5	2.3
	smooth areas	←→	forest <50 m^3/ha	0.1	0.1
	forest <20 m^3/ha	←→	smooth areas	1.4	3.2
	forest <20 m^3/ha	←→	forest <50 m^3/ha	5.9	5.2
	forest 20-50 m^3/ha	←→	forest <50 m^3/ha	0.1	0.2
	forest 20-50 m^3/ha	←→	smooth areas	1.9	1.5
water	water	→	water	2.7	1.2
	not classified	→	water	0.3	0.3
other changes	smooth areas	→	forest 50-80 m^3/ha	0.01	0.02
	smooth areas	→	forest >80 m^3/ha	0.01	0.03
	all other changes			0.38	0.45
not classified	not classified Siberia or Palsar			3.8	10.0

Table 8. Change detection - class correspondence SIBERIA ←→ PALSAR (reduced number of classes)

Class	*SIBERIA*	→	*PALSAR*	*Irkutsk (%)*	*Krasnoyarsk (%)*
deforestation	forest >50 m^3/ha	→	forest <50 m^3/ha	9.6	11.4
	forest >50 m^3/ha	→	smooth areas	1.1	1.2
	forest <50 m^3/ha	→	smooth areas	1.5	3.4
afforestation	smooth areas	→	forest <50 m^3/ha	0.1	0.1
	smooth areas	→	forest >50 m^3/ha	0.02	0.04
	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

4.2.2.2. Reduced number of classes

Change detection at pixel level using the reduced classification scheme estimated the total surfaces affected by biomass loss or biomass gain (Tab. 8). Reducing the number of classes greatly diminished classification uncertainties reducing however the sensitivity of the change detection algorithm to less abrupt changes. In Siberia these types of changes (for the considered time interval) represent mostly growing processes. 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 forest surface loss is unavoidable when considering this method. The net forest are loss reached 9% at the Irkutsk test site, being fairly close to the value estimated using the overall statistics (8%). For the Krasnoyarsk site the difference between the two estimations (i.e. overall statistics vs. reduced classification scheme method) is quite high, the forest net loss passing from 7.9% to 12.4%. Despite higher classification accuracy obtained for the reduced classification scheme the estimation of areas affected by deforestation and afforestation processes could be in part a consequence of classification disagreements especially between classes *forest <50* m^3*/ha* and *forests >50* m^3*/ha*.

5. CONCLUSIONS

This article illustrates the decrease of forest surface in central Siberia due to deforestation using three estimation approaches based on multi temporal SAR data analysis. Two sites in the Krasnoyarsk and the Irkustk region, covering approximately 100,000 km^2, have been studied. Change maps were generated at pixel level for each site using as reference biomass and land cover product generated by the SIBERIA project.

During the last decade the loss of forest varied from 6% to 16% of the study area, depending on the assessment method (i.e using the full set of classes vs. a reduced number of classes) and site. Forest growth was registered for only 2.3 to 4.6% of the area. This translates to annual decrease rates of forest cover of 0.4 to 1.2 %. The lower limit corresponds to notable changes (e.g. clear cuts, natural disasters, etc.) of land cover while the higher value could enclose changes of smaller magnitude (e.g. degradation, etc.). In a conservative scenario a net annual loss of around 0.4% should be probable. However, even in such scenarios, where only abrupt changes are measured, forests manifest smaller biomass increase than biomass loss suggesting unsustainable management policies. In general, forest area 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.

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