OBJECT BASED CLASSIFICATION OF L-BAND SAR DATA FOR THE DELINEATION OF FOREST COVER MAPS AND THE DETECTION OF DEFORESTATION

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KEY WORDS: JERS, ALOS, L-band, Forest Cover, Forest Cover Change, Kyoto, ARD, Object Based Classification

ABSTRACT:

This paper assesses the feasibility of forest cover mapping and the delineation of deforestation using Japanese Earth Resource Satellite (JERS-1) Synthetic Aperture Radar (SAR) data. The assessment is carried out at five test sites in Germany (Thuringia), the UK (Kielder), Sweden (Remningstorp and Brattåker) and Russia (Chunsky). These temperate and boreal sites all have high forest cover, but with different forestry management practices. The stands at the Swedish, Russian and UK sites are harvested by clear-cutting, while in Thuringia, thinning is the predominant practice.
Man-made deforestation is characterised in SAR imagery by regular geometric patterns which can be segmented and classified for data analysis. This reduces the statistical effects of SAR speckle. The procedure for mapping deforested areas exploits time series of SAR images, taken from the period 1992-1998 during which JERS was operational. Two different approaches were developed. The first detects forest cover separately for each JERS scene, while the second takes all scenes into account simultaneously. Images are classified into forest, non-forest and deforested areas. The overall accuracy of the derived forest cover map is about 90% in acreage, and about 90% for logging.
Two different approaches to detect forest cover changes have been applied. The post-classification detection of changes in forest cover is based on the analysis of the delineated forest cover maps. The forest cover maps are derived for each chosen JERS scene. A temporal change of the classified forest cover can be interpreted as ARD activity. Knowledge based rules were used for this analysis. The pre-classification detection of changes in forest cover utilises all chosen JERS images at once. By means of a multitemporal composite the changes of the forest cover are detected and classified. Both approaches are characterised by certain strengths and weaknesses as will be discussed in the paper.
The segmentation of the SAR data was based on sigma nought values of the complete SAR data time series and was conducted with the eCognition software.

1. INTRODUCTION

1.1 General Instructions

Current Synthetic Aperture Radar (SAR) missions of the European Space Agency (ESA) are operated at C-band (5.3 GHz, 5.7 cm wavelength). However, new imaging radar mission at L-band (1.3 GHz) such as PALSAR at ALOS are going to provide new L-band data soon.

Despite the Japanese Earth Resource Satellite (JERS) program and NASA Shuttle Imaging Radar (SIR) missions, the experience with L-band applications especially in Europe is not as well developed as for C-band.

The scope of the project "Demonstration of L-Band Capabilities using JERS SAR data" (ESTEC Contract No. 18311/04/NL/CB), carried out from May to October 2004 by an international consortium led by Gamma Remote Sensing (Switzerland) with two other partners - the Institute of Geography of the Friedrich-Schiller-University of Jena (Germany) and the Alfred Wegener Institute Foundation for Polar and Marine Research of Bremerhaven (Germany) - was to illustrate the capabilities of an L-Band SAR mission (JERS satellite) in three specific applications, i.e. Kyoto protocol monitoring (this paper), landslide deformation monitoring, and sea ice classification. The provided examples on L-band monitoring potentials were to serve for the TerraSAR-L capability demonstration. JERS SAR data analysis was supported by a comparison with ground truth information and C-Band SAR data.

Over a period of seven years (October 1992 - October 1998) JERS SAR data have been archived by ESRIN and JAXA. Level 0 products were been considered for the four test sites of this study. For every test site a specific set of SAR images was selected out of the SAR data pool. The selection accounted for temporal, spatial and quality issues.

1.2 Testsites

To identify suitable sites for demonstrating the capabilities of L-band SAR in forest mapping applications, the following selection criteria were adopted:

- Coverage of different European climate and vegetation zones,
- Access to a time-series of JERS-1 data,
- Availability of ground data.

The following European sites were chosen: Kielder (England), Thuringia (Germany), Remningstorp (South-Sweden), and Brattåker (North-Sweden), together with the Chunsky site in Siberia (Figure 1).

Kielder forest is located in northern England and is managed by the state funded Forest Enterprise agency. This area covers about 86 km², of which more than 50% is forested. Productive coniferous species are predominant in these forests and a harvesting yield of some 400,000 tonnes of timber per year is sustained. The main tree species are Sitka spruce (75%), Norway spruce (12%) and lodgepole pine (9%), with a small proportion of Scots pine, larch and broadleaf. It is an area of relatively low relief, with minimal affect on SAR backscatter. Information on forestry activities is provided by means of a GIS inventory, which includes time and location of clear cutting for the period 1996-2003. Clear cutting between 1993 and 1996 can only be approximately inferred from the GIS information using the reforestation information held in the database. To the North-west of Kielder Forest lies the Scottish border, over which the forest continues, but GIS format felling data for this region are unavailable.

The Thuringia test site is part of the middle mountain range Thuringian Forest. Here high relief causes significant variations in backscattering intensity. The test site covers ~ 1000 km². About 58% of the area is forested land, divided into more than 50,000 forest compartments. The tree species composition is approximately 86% spruce, 7.5% pine, 3.1% beech and 3.5% others. Clear-cutting is generally not practised; thinning is the more common logging technique. Extensive information on the forest stands (e.g. plant year, stock volume) is available in inventory records.

The Brattåker test site is located in the northern part of Sweden. Its elevation varies from 160 to 400 m above sea level. Brattåker is a forest research site managed by the Swedish forest company, Holmen Skog AB, managing about 60 km² of mainly coniferous forests. The prevailing tree species are Norway spruce and Scots pine, but some deciduous tree species, e.g., birch, are also present. This test site represents rather intensively managed boreal forest, compared with other areas in the northern part of Sweden. Thinning is exercised during the growing phase. This is recommended for all forest that is later going to be harvested. Two types of thinning are used in Sweden. The first (called *röjning* in Swedish) refers to the removal of small trees from a young forest. This is usually done to eliminate unwanted tree species and to allow selected trees more space to grow. The second type (called *gallring*) is practiced in older stands to remove damaged or "low quality" trees and again allows more space for the remaining trees to grow before clear-cut harvesting.

The other Swedish site, Remningstorp, is located in south-west Sweden and covers about 12 km² of forested land, which is divided into 340 compartments. About 10% of the area is forested peatland. The main tree species are Norway spruce, Scots pine and birch. A few stands are dominated by oak and beech. The topography is fairly flat with a ground elevation varying between 120 and 145 m above sea level. For both the Swedish test sites a GIS based clear-cutting map is available.

The Chunsky forest territory is located 280 km northeast of Krasnoyarsk, south of the river Angara. The test area covers almost 400 km² and includes more than 1,200 forest compartments, of which about 90% can be denoted as natural stands. Birch and aspen are the major broad-leaved species, while pine and larch are the dominant coniferous species. Fir, spruce and cedar are also present but less common. The elevation varies between 300 and 400 m above sea level. The available GIS database contains information on forest stand characteristics and clear-cutting activities. Deforestation information originates from a Russian forest inventory data base (Schmullius et al. 2001). Forest loss due to fire events is also embedded in these data.

Figure 1. Location of testsites

2. METHODOLOGY

The SAR data pre-processing involved, inter alia, the reduction of topographic distortions in backscattering intensity (see van Zyl et al. 1993) using SAR processing software for relief calibration and angular backscatter correction developed by Stussi et al. (1995). As forestry activities are largely characterised by regular geometric patterns, the data analysis and classification were based on image polygons (segments). This process is also helpful in averaging out the noise effect of SAR speckle. Figure 2 shows an example of a segmented image. Bright segments are forested and dark segments unforested. Coloured regions indicate deforestation. Image segmentation was based on all JERS scenes utilised for the site.

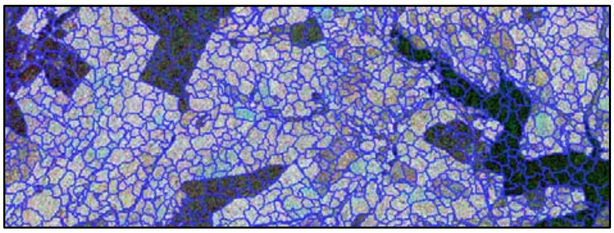

Figure2: Example for segmented SAR-image

For the delineation of forest cover maps and the detection of forest cover changes, two different approaches were considered. Both are based on segmented image data, where segments are identified using a multiresolution segmentation algorithm (Baatz & Schäpe 2000). The multi-image segmentation was conducted comprising all chosen SAR images of each test site. Consequently the segments are the same in all images. Each image segment is characterised by its mean SAR backscattering coefficient. The borders of the segments do not necessarily represent the forest compartments, but typically identify homogeneous pieces of land.

The first segment classification approach discussed here is referred to "post-classification detection". Thresholds on segmented σ^0 values are used to divide each scene into forest and non-forest (see Figure 3.). This threshold varies between acquisitions as a result of different tree properties, weather conditions and acquisition system parameters, and it must be adapted for each scene individually to achieve optimum classification. Forest cover maps and GIS data are used to guide this process. Changes in forest cover can then be mapped by comparing classified images.

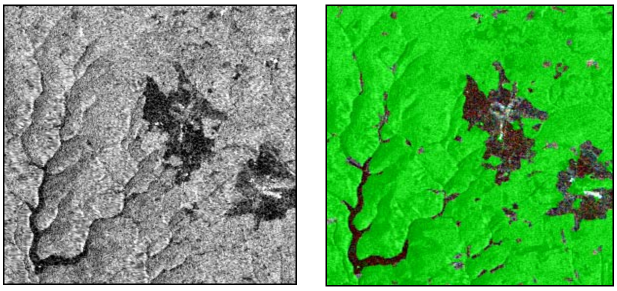

Figure 3: Left: original σ^0 image, Right: Example of delineated forest cover map (subsection of the Thuringia test site, 11.11.1998, image size: ca. 7 x 8 kilometres).

Time series of classified images are used to delineate forest cover changes. The delineation was accomplished by means of GIS procedures with integration of expert knowledge. Each image polygon (segment) was analysed temporally with respect to its membership to forest or non-forest respectively. To reduce the impact of misclassifications for each particular time of recording a expert knowledge was integrated into the change analysis. For example, if the class of one image object was fluctuating over the whole time series like 1992: forest, 1994: non-forest, 1996: forest, 1998: non-forest etc. it is not interpreted as change. This decision is basing on the fact, that it takes a much longer time span to grow and to harvest a forest. Based on those assumptions the time series of classified images was translated into a forest cover change map.

One example for the delineation of forest cover changes is given in Figure 4. The first five images represent the derived forest cover maps for the years 1992, 1993, 1994, 1995 and 1998 respectively. The last image is the result of the combination of the forest cover maps. A variation of the classification of one image object was interpreted as change, if it was assigned stable to one class for the consecutive years before the change (e.g. 1992 – forest, 1993 – forest, 1994 – forest) and to the opposing class past the change (1995 – non-forest, 1998 – non-forest).

The second approach used here considers all the scenes simultaneously before classification is attempted. The classification incorporates forest, non-forest and diverse deforestation classes. This method is referred to as "pre-classification detection" because changes are detected before extracting forest maps from each SAR image.

In the multitemporal composite (Figure 5, left), forest cover changes appear in more intensive colours. Permanent forested areas are characterised by bright colours and un-forested sections are dark. Areas covered by young forest can be identified due to a reduced brightness in comparison with older forest stands. Supervised classification (Figure 5, right) is based on σ^0 values and uses the "nearest neighbour" algorithm to identify features for classification. To create class signatures, a set of training areas (image segments) are selected for each class. During the classification process each image segment is then assigned to the appropriate class signature. From these classification results, forest cover maps for each of the utilised SAR scenes can be created.

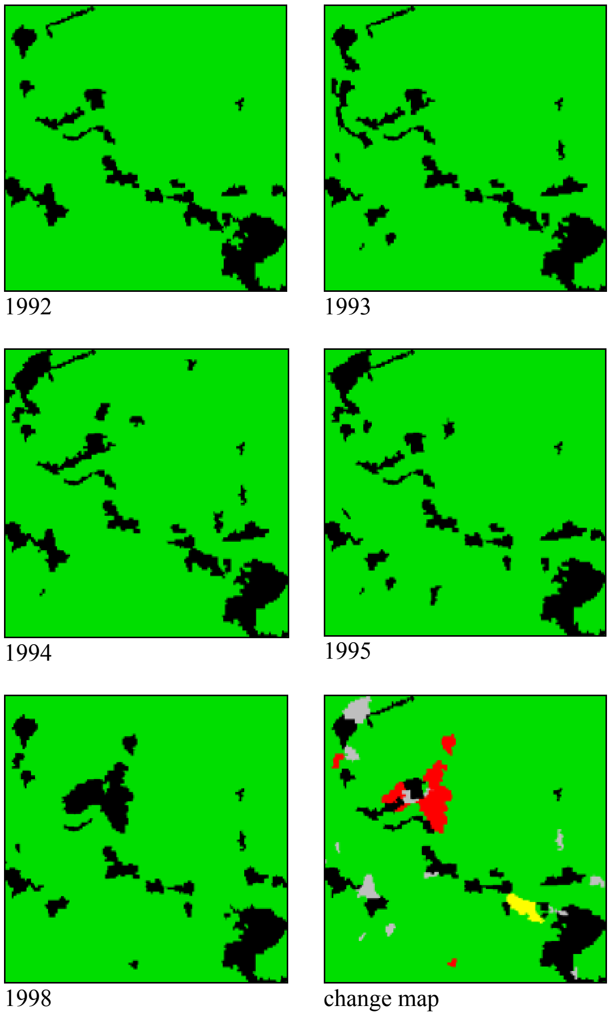

Figure 4: Forest cover time series and delineated forest cover change map (subsection of the test site Thuringia, image size: ca. 5 x 4 kilometres). Colours: green = permanent forest, black = permanent non-forest, red = deforestation, yellow = afforestation, grey = no change (real land cover ambiguous)

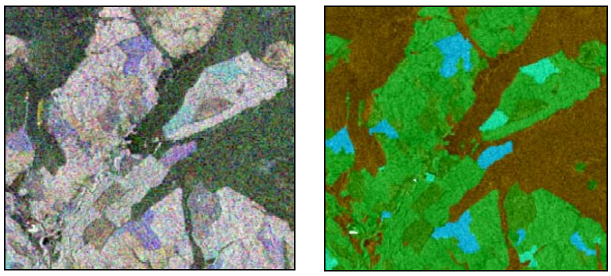

Figure 5: Left: Example of a multitemporal σ^0 RGB-composite (subsection of the Kielder test site, selected years: 1998, 1996, and 1993. Image size: ca. 7 x 8 km); Right: classification of forest cover changes: brown = non-forest, green = forest, blue = deforested 1993-1996, cyan = deforested 1996-1998.

3. RESULTS

3.1 Kielder (UK)

The results presented in this section are obtained with the "pre-classification detection approach" (see methodology), while the "pre-classification" results are summarised in the discussion section. SAR images acquired on the dates 11.07.1993, 16.07.1996 and 02.08.1998 were chosen as input for the nearest neighbour classification. In accordance with the available ground data, the validation of the clear cut detection map was carried out only for the 1996-1998 period.

To evaluate the separability of the classes, a signature analysis for the training area set was conducted (Figure 6). For the second and the third acquisitions the clear-cut class experienced a decrease in backscattering intensity. Although the mean σ^0 values of the clear-cut classes lie in the range of the standard deviation of the forest class, the separability was found to be sufficient to detect most deforestation. Figure 7 shows the results for the entire time-span (1993-1998).

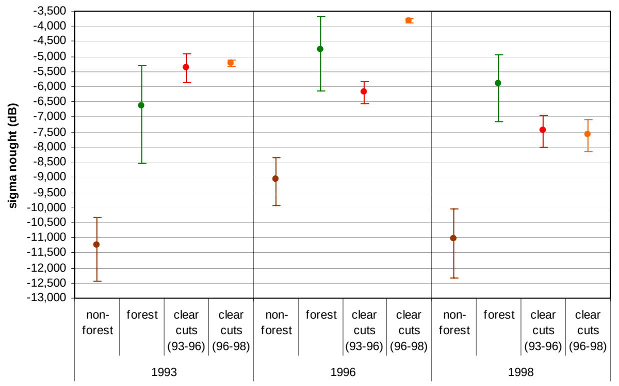

Figure 6: Signature analysis for Kielder Forest. Note the shift of the σ^0 values for the clear-cuts as time proceeds. In 1993 all of these forest sections were still covered by forest. After deforestation the backscatter diminishes.

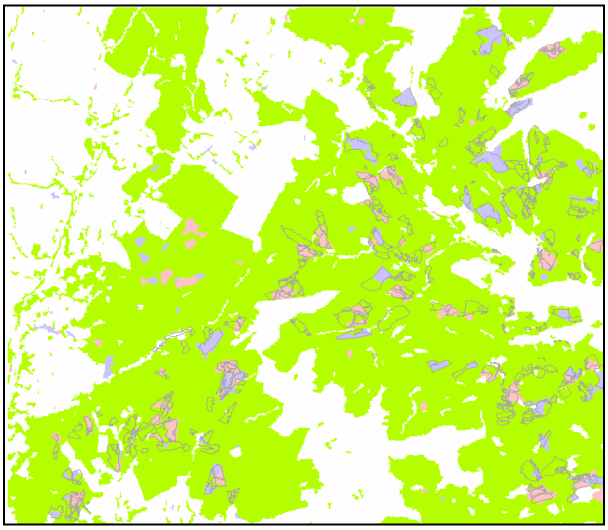

Figure 7: Detected logging at Kielder Forest; Colours: green = permanent forest, white = permanent non-forest, blue = deforestation 1993-1996, blue = deforestation 1996-1998

The spatial and temporal correspondence of the SAR and GIS data between 1996 and 1998 allows direct comparison of the results. Out of the 42 clear-cuts within the test site, 37 could be recognised by means of the radar data. Seven SAR-detected clear-cuts could not be confirmed by the GIS data, which may be because of incomplete clear cut information in the ground data. It should be noted that clear-cut was considered correctly detected if the centres of the SAR polygons were located within the ground data GIS polygon, even if the borders were somewhat different. In some cases discrepancies can be attributed to the different geometric properties (resolution, geometric distortions). However, inspection of Figure 7 indicates that the size of SAR detected clear-cut polygons is often underestimated. One reason for this could be that ground based felling data may include areas of cleared shrubs, dead forest, or failed (unestablished) forest, in addition to mature forest that has been cleared in preparation for replanting. The change from these types of forest to clear-cut is hardly detectable with JERS SAR data, and is also not necessarily classifiable as deforestation. In addition some cases the SAR-detected deforestation that could not be confirmed by the ground data could be a consequence of wind damage, which in the case of Kielder Forest is a frequent occurrence that is not embodied in the ground clear-cut GIS data.

3.2 Thuringia (Germany)

For the creation of the forest cover change map of Thuringia the post-classification detection approach was applied. Five JERS SAR images, from 1992, 1993, 1994, 1995 and 1998, were selected. The forest cover maps were formed by thresholding σ^0 for each particular SAR image. A subsection of the classification for 1992 is shown as Figure 8. To evaluate the separability of the classes, signature analysis was performed similarly to Figure 6. The class means and the standard deviations of the training areas indicate a distinct separability of forest and non-forest.

Figure 8: Forest cover map Thuringia for 1992 (green: classified forest, polygons taken from forest inventory data)

The forest cover map based on the JERS SAR data of 1992 was validated by means of the inventory data. The overall accuracy (for the whole test site) of the delineated forest cover map is 90%. Image segments (compare to Fig. 2) where forest was incorrectly detected amount to 7.5% (of total area). These misclassifications mainly occur at small settlements and some agricultural areas with crops such as maize. Both these land cover types can produce very high backscatter that extends into the range of the forest signatures (see discussion section). Converse misclassifications (detection of non-forest instead of forest) amount to 2.7% of total area and occur mainly for young forest stands with low backscatter. The verification of the SAR based forest cover maps for acquisitions after 1992 was not possible because of the lack of forest inventory data for this period, but similar accuracy would be expected for these maps.

The SAR-based forest cover change map combines the information from the temporal sequence of forest cover maps as described above. Even though clear-cutting is not officially exercised in Thuringia, deforestation is evident in Figure 9. Clear-cutting may be applied as an exception to remove diseased (e.g. bark beetle) or damaged (e.g. storm damage) forest, but such activities cannot be inferred from the inventory data.

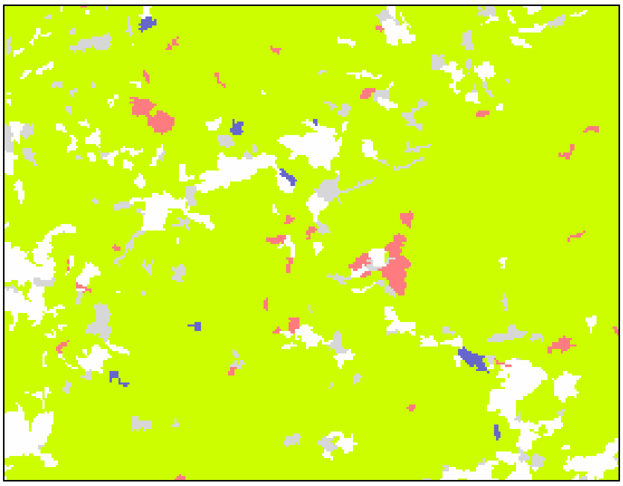

Figure 9: Forest cover change map for Thuringia; Colours: green = permanent forest, white = permanent non-forest, red = logging, blue = replanting, grey = ambiguous

3.3 Remningstorp (South-Sweden), Brattåker (North-Sweden), Chunsky (Russia)

The procedure for the remaining sites was identical to that for Kielder and Thuringia. For the Swedish sites the pre-classification approach was applied, while the post-classification approach was chosen for Chunsky. Again, separable classes could be identified by means of signature analysis.

Unfortunately, for Remningstorp, Brattåker and Chunsky, the in situ information was insufficient for proper accuracy assessment. Therefore this assessment was conducted based on the SAR images, using the confusion matrix method proposed by the IPCC (2003). Forest cover changes were detected by means of a visual interpretation of all considered SAR images. Coloured areas represent changes; stable sections appear in shades of grey. Validation areas were selected for each class based on the visual interpretation. These areas are taken as the actual 'truth' data in the confusion matrix. For each class, the numbers of correctly classified pixels and confused pixels resulted in an overall accuracy of ~90% for the three sites. This figure is comparable to Kielder and Thuringia.

4. DISCUSSION

This investigation indicates that JERS images can be used to create reasonably accurate forest cover and forest cover change maps in the temperate and boreal regions studied. The overall accuracy of the derived forest cover maps is about 90% by area. Moreover, about 90% of the logged area could be detected. An approach based on image segmentation was shown to be suitable.

For the detection of forest cover changes and the delineation of forest maps, two methods were applied. The pre-classification method uses a multi-parameter set of SAR data and delivers more precise results than the post classification method. The multi-dimensional parameter set requires classification algorithms such as "Nearest Neighbour" or "Maximum Likelihood" to optimise classifications.

Post-classification detection is a simple method for separating forest from non-forest by a single threshold value. It is more transferable to other sites, and only a single JERS SAR image is required to create a forest cover map with an accuracy of about 90%. On the other hand, change analysis requires more than one image and the classification errors in each individual forest cover map can propagate into the forest cover change map, which will be affected by the errors in each scene. These errors can be reduced by applying knowledge based rules to the analysis, for example by detecting fluctuations in classification during the time-series which cannot occur in real forests. The accuracy of post-classification detection was found to be far below the pre-classification approach. At the Kielder testsite, only 65% of the detected clear cuts agree with the in situ data (65% of the centres of the SAR polygons were found within the GIS polygon). In addition, the number and area of felled areas is overestimated with this technique. The reason for these contradicting results can be explained by the limited number of SAR images available for Kielder. For the rule based post-classification method, the potential to detect fluctuations which are uncharacteristic of forest change increases with the number of images available. With only three images nearly every fluctuation must be interpreted as change. Five or more SAR images would be more likely to detect fluctuations inconsistent with forest cover changes.

For operational purposes, the choice of method must take account of practical issues, such as the level of dependence on ground data. The pre-classification method is more accurate when only a small number of SAR images are available, but requires ground data classifying forest, non-forest, and change classes for each acquisition. The time periods for the ground data must be in accordance with the SAR data acquisition dates (and vice versa). With progressive forest cover monitoring in mind (Kyoto protocol monitoring) the post-classification method has the advantage that classification of each acquisition is not necessary. This is an advantage because ground based records for the entire time sequence of images is not required. This weaker requirement for ground data and SAR image processing is a significant advantage for operational applications.

5. CONCLUSIONS AND OUTLOOK

In summary, JERS images provide sufficient information for the detection of deforestation or clear-cutting. Although the time span of only seven years (1992 - 1998) of JERS data permitted neither afforestation nor reforestation activities (in the sense of the Kyoto Protocol, see IPCC 2003) to be detected, some forest stands with recently planted trees are apparent at most of the sites. As their backscatter lies close to the threshold that separates forest from non-forest, these stands cannot be clearly assigned to either class by means of JERS data. This results in reduced accuracy in mapping reforestation. The availability of polarimetric L-band SAR data (or at least of more than HH polarisation) is expected to allow higher accuracy (Israelsson et al. 1994, Rignot et al. 1997) for this application.

Products derived from enhanced SAR sensors like PALSAR (successfully launched this year) are expected to be more accurate than those from JERS. This is because of the availability of multiple polarisations, which can increase the contrast between forest and non-forest, and also because of improved geometric resolution, allowing detection of smaller-scale forestry activities. In addition, shorter revisit times are more suited to multi-temporal interferometric techniques. The additional benefits of enhanced L-band SAR missions over JERS suggest that such missions will be a valuable source of information for Kyoto protocol monitoring and thus for projects as GSE-FM (GMES Service Elements - Forest Monitoring), financed by ESA.

REFERENCES

Baatz, M. and Schäpe, A., 2000. Multiresolution Segmentation – an optimization approach for high quality multi-scale image segmentation. In: STROBL, J. et al. (Eds.): *Angewandte Geographische Informationsverarbeitung XII. Beiträge zum AGIT-Symposium Salzburg 2000*, Herbert Wichmann Verlag, pp. 12–23.

Intergovernmental Panel on Climate Change (IPCC), 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry, IPCC National Greenhouse Gas Inventories Programme UNEP*, Eds. Jim Penman, Michael Gytarsky, Taka Hiraishi, Thelma Krug, Dina Kruger, Riitta Pipatti, Leandro Buendia, Kyoko Miwa, Todd Ngara, Kiyoto Tanabe and Fabian Wagner, Published by the Institute for Global Environmental Strategies (IGES) for the IPCC, ISBN 4-88788-003-0.

Israelsson, H., Askne, J., and Sylvander, R., 1994. Potential of SAR for forest bole volume estimation, *International Journal of Remote Sensing*, 15 (14), pp. 2809-2826.

Rignot, E., Salas, W.A., and Skole, D.A., 1997. Mapping deforestation and secondary growth in Rondonia, Brazil, using Imaging Radar and Thematic Mapper data, *Remote Sensing Env* (59), pp. 167-179.

C. Schmullius, Ed., Baker, J., Balzter, H., Davidson, M., Eriksson, L., Gaveau, D., Gluck, M., Holz, A., LeToan, T., Luckman, A., Marschalk, U., Mc Callum, I., Nilsson, S., Orrmalm, S., Quegan, S., Rauste, Y., Roth, A., Rozhkov, V., Sokolov, V., Shvidenko, A., Sirro, L., Skuding, V., Strozzi, T., Tansey, K., Utsi, R., Vietmeier, J., Voloshuk, L., Wagner, W., Wegmüller, U., Westin, T., Wiesmann, A. and Yu, J.J., 2001. *SIBERIA - SAR Imaging for Boreal Ecology and Radar Interferometry Applications*, Friedrich-Schiller-University, Jena, Germany, Final Report, EU Contract ENV4-CT97-0743-SIBERIA.

Stussi, N., Beaudoin, A., Castel, T., and Gigord, P., 1995. Radiometric correction of multi-configuration spaceborne SAR data over hilly terrain, *Proc. CNES/IEEE Int. Symp. on the Retrieval of Bio- and Geophysical Parameters from SAR Data for Land Applications*, Toulouse, France, 10-13 October, pp. 347-467.

Zyl, J.J., Chap, 31(5), 1man, B.D., Dubois, P., and Shi, J., 1993. The effect of topography on SAR calibration, *IEEE Trans Geosc. Remote Sensing*, pp. 1036-1043.

ACKNOWLEDGEMENTS

This work formed part of the ESA financed project "Demonstration of L band Capabilities using JERS SAR data" (ESTEC Contract 18311/04/NL/CB).

All SAR data were taken from the JAXA and ESRIN archives. The ground database for Chunsky was provided by the SIBERIA project. The ground data for the Swedish test sites were available through cooperation with the Department of Forest Resource Management and Geomatics at the Swedish University of Agricultural Sciences (SLU). The ground data for the Kielder test site come from the UK Forestry Commission GIS, provided through their cooperation with the NERC Centre for Terrestrial Carbon Dynamics and the University of Sheffield. The forestry information for the Thuringian test site was purchased from the Thuringian forest management agency.