MONITORING FOREST COVER IN FRENCH GUIANA USING SPACE-BORNE RADAR DATA

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ABSTRACT

As part of the GMES Service Element project Forest Monitoring, a service that utilizes space-borne synthetic aperture radar (SAR) data supported by a sample of optical satellite was established. Three SAR ortho-rectified mosaics using C band radar data from 1992/1993, 2003/2004, and 2006/2007 were compiled. Three features, average amplitude, temporal variability and average texture, were computed using overlapping radar imagery. Land cover / Land cover change map was produced and the result was compared with a sample point set that was selected from optical satellite data by the IFN. The overall accuracy was 95.6 % but per-point accuracy of change detection was poor.

Keywords: SAR, forestry, change detection, tropical forest

1 INTRODUCTION

French Guiana has almost 90 000 km^2 land area of which more than 90 percent is forested. Since the region is an overseas department of France its forest area has to be reported as part of the French forests in the implementation of the Kyoto Protocol of the UNFCCC. Forest inventory information in Guiana has been limited due to poor accessibility to most of the forest area.

This paper reports a work that has been conducted in the GSE Forest Monitoring project of the ESA in French Guiana. The aim of the activity is to map and monitor forest area using SAR data of ERS and Envisat satellites. The user of the results is Centre Interprofessionnel Technique d'Etudes de la Pollution Atmosphérique (CITEPA) of France, which uses the information to support the implementation of the Kyoto Protocol. Thus, there is a clear need and financial interest to improve forest resource information.

The motivation of using SAR comes from the penetration capability of the microwave signal through the clouds which is very important in tropics where frequent cloud cover makes the acquisition of optical data difficult.

However, the C-band SAR data, the most widely acquired space-borne radar data type in French Guiana, are not optimal for forest mapping purposes. To reduce the shortages due to frequency, a specific approach in image analysis was applied.

Until September 2007, the following phases of the project have been completed:

- ortho-rectified ERS-1 mosaic using data from 1992-1993

- ortho-rectified ASAR mosaic using data from 2003-2004
- ortho-rectified ASAR mosaic using data from 2006-2007
- forest area map and statistical data 1992/1993 using ERS data
- forest area map and statistical data 2003/2004 using ASAR data
- forest area change map 1992/1993-2003/2004 and statistical data using ERS and ASAR data
- comparison of the above-listed forest area / forest area change maps with the IFN (Inventaire Forestier National in France) sample points from optical satellite data
- preliminary forest area change map 2003/2004 – 2006/2007 using ASAR data

2 MATERIALS AND METHODS

2.1 SAR DATA ACQUISITION

The target area for the forest monitoring was the entire territory of French Guiana.

The image analysis approach was based on collection of several SAR image acquisitions from the same location during a year to reduce effects by weather and the speckle noise. Five acquisitions from the same location were attempted but this objective could not always be met because ESA could not provide all the requested images. The acquired numbers of the VV polarized images with approximately 25 meter spatial resolution for the three points of time were:

for 1992/1993 60 ERS AMI images; PGS ASAR processor, incidence angle 23 degrees

for 2003/2004 107 Envisat ASAR images; IS4 – incidence angle 33 degrees

for 2006/2007 122 Envisat ASAR images; IS4 – incidence angle 33 degrees

Different incidence angles in the ERS/ASAR data sets introduced additional challenges in the image analysis. The ASAR angle was selected to improve accuracies in the future forest monitoring activities.

The surface elevation model of the Shuttle Radar Topography Mission (SRTM) was downloaded from http://www2.jpl.nasa.gov/srtm/cbanddataproducts.html. The model of 90 meter pixel size was used to remove the geometric distortion in the SAR images and to reduce the radiometric effect due topography.

2.2 OPTICAL DATA

The optical satellite data to evaluate the sample points of the IFN for circa 1990 were from the Geocover Landsat 4/5 data set https://zulu.ssc.nasa.gov/mrsid/. The resolution of the Landsat data was 30 meters.

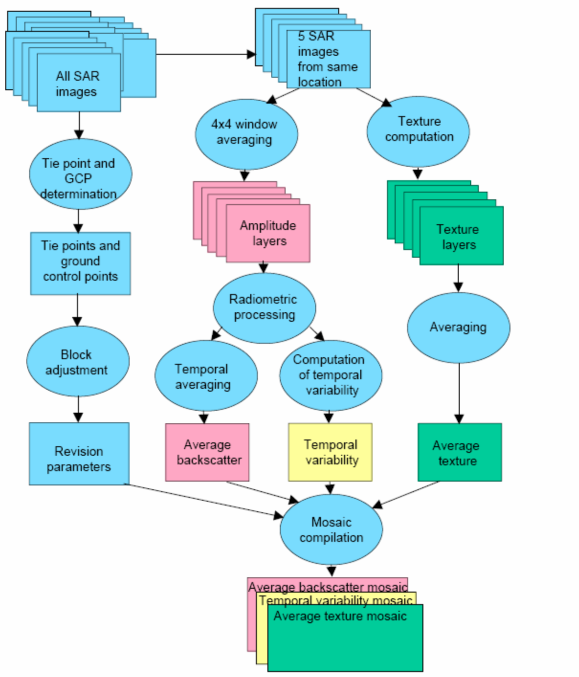

Figure 1. Computation of SAR features and SAR image mosaics.

A Spot 2, 4 and 5 data coverage was acquired in 2006 at the new receiving station in Guiana.

The resolution of Spot data was 10 to 20 meters in multi-spectral mode.

1.1.1 Sample point data

During 2007 the IFN evaluated a sample of 16787 points using the optical satellite data from *circa* 1990 and from 2006. Of the total sample, 15727 points could be evaluated. The 1070 points were rejected due to clouds in either or both of the optical data sets.

Of the accepted sample, 870 points belonged to a stratum that represented inland forests, in which the forest area percentage was assumed to be close to 100 %. In this stratum the point distance of the systematic sampling was 8388 meters and the area of the stratum was 7 022 150 ha. A stratum of 2450 points represented a region of a water reservoir that was built in the 1990’s. The largest sample size of 12407 points was selected in the coastal region and close to the river valleys. This stratum included the agricultural and residential areas. In the two latter strata the sampling density was 81 times denser than in the inland stratum since the sample distance was 932 meters. The areas of the “reservoir” and coastal strata were 212 641 ha and 1 161 435 ha, respectively.

2.3 SAR DATA PROCESSING

The deliverables to the user included radar data image mosaics and classification results. The image mosaics were input to the classification.

The SAR data were pre-processed and the features were computed with in-house software using the overlapping ortho-rectified images that had been acquired within one year (Figure 1):

average amplitude;

average spatial texture;

temporal variability.

For details about the procedure to compute the features see (Häme *et al*. 2005, Rauste *et al*. 2007, Henry *et al*. 2007). The coordinate system was WGS-84 projected onto the UTM zone 22 grid.

2.4 SAR IMAGE CLASSIFICATION

1.1.2 Classification of ASAR image mosaic 2003/2004

Preliminary examination of the forest and non-forest classifications using the sample that became available in 2007 showed that the forest area was somewhat overestimated and the change underestimated in a previous classification (Häme *et al.* 2005). Therefore the forest cover and forest cover change classifications were re-done in 2007.

An unsupervised k-means clustering (in-house software Autochange, Häme *et al.* 1998) was applied to make a forest cover classification with the ASAR mosaic 2003/2004. The input data were the three SAR image features: average amplitude, average texture and temporal variability. Forty (40) classes were separated. During the clustering process, the software normalized the features to the same standard deviation and mean. The classes were labeled using the IFN sample points with some exceptions.

The classes of the unsupervised clustering were applied only to the region in which the elevation was less than 80 meters from sea surface. This stratification was done using the SRTM elevation model. The area that had an altitude higher than 80 meters was assumed to be forested.

The numerical image classification could not be applied in the more inland regions since the radar mosaic was too noisy. The radiometric correction of SAR imagery was not completely successful due to too coarse elevation model compared to the level of details in the terrain.

1.1.3 Classification of changes between 1992/1993 and 2003/2004

To separate the changes, two change candidate classifications were combined. The first classification was from an earlier phase of GSE Forest monitoring and it was done applying the Autochange to the average amplitude and temporal variability features of mosaics ERS 1992/1993 and ASAR 2003/2004 (Henry *et al.*2007). The third feature, texture, was mainly effective to separate built-up areas only and it was not effective in change classification.

Another change candidate classification was the thresholded difference of the average amplitude in ERS 1992/1993 mosaic and ASAR 2003/2004 mosaic.

The reason to combine two different change classification approaches was that although the temporal variability was effective in some cases to separate the changes, its inclusion sometimes hampered detection of an apparent change. Thus the additional use of amplitude difference could separate changes that otherwise would have remained undetected.

The change pixels in the two change classifications were merged so that a change in either of the change classifications was accepted as an actual change. In both change detection approaches the change was detected directly by analyzing combined bi-temporal image datasets to avoid accumulation of errors compared to evaluating two individual classifications.

Finally, the change candidate classifications were merged with the ASAR 2003/2004 based land cover classification as follows:

if non-forest in ASAR land cover, then change candidate from forest to non-forest was accepted

if forest in ASAR land cover, then change candidate from non-forest to forest was accepted

other change candidates were rejected

However, the change from forest to water was accepted without considering the ASAR land cover classification result.

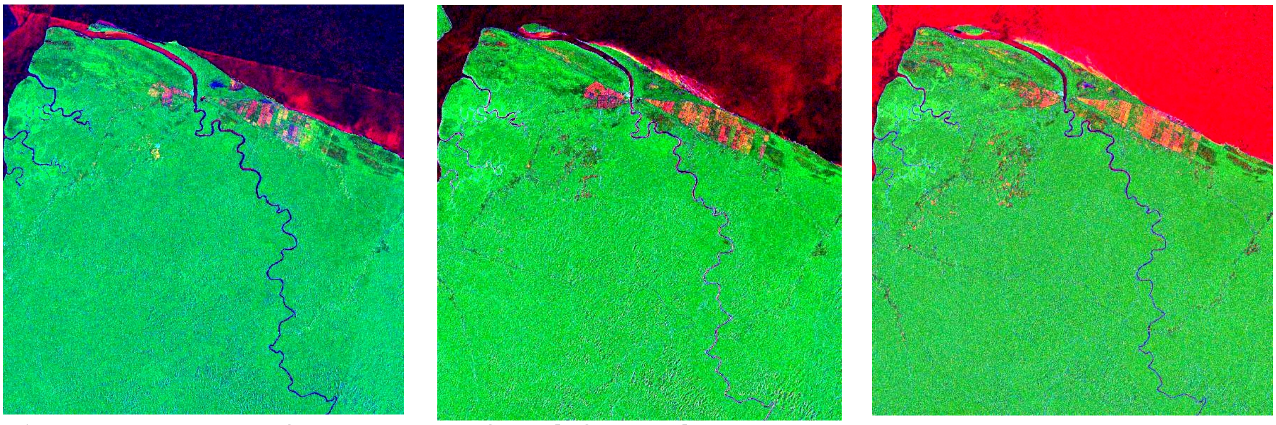

Figure 2. Extract of SAR mosaics from left to right: ERS 1992/2993, ASAR 2003/2004, ASAR 2006/2007. Colors: red – temporal variability, green – average amplitude, blue – average texture.

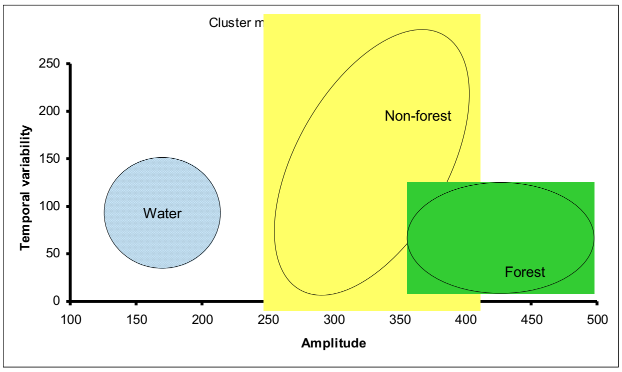

Figure 3. Location of water, non-forest and forest in ASAR 2003/2004 feature space. The land cover types have been defined using the sample points of the IFN.

3 RESULTS

The unsupervised clustering result with the ASAR mosaic data showed that if the temporal variability of the SAR back-scattering within a year is high, the region is likely non-forest. A low variability may also indicate non-forest but then the amplitude is usually lower (Figure 3). However, in such cases the forest and non-forest border is gradual. In the result of the numerical classification, part of the non-forest output class is due to the residual radiometric variation in the SAR mosaic (Figure 2).

The IFN sample points were selected from the change classification result. The classes, applied by IFN were combined to match with the agreed target classes of the GSE service (Figure 4).

Table 1 shows the comparison of optical points and radar-mapped changes, taking into account the areas of various strata. The overall accuracy in the comparison of the point evaluation results is good but the change classifications of the points by IFN and of radar data do not match particularly well. Also, the area of change is smaller in radar image based classifications than in the evaluation of the points of the optical data (Table 1).

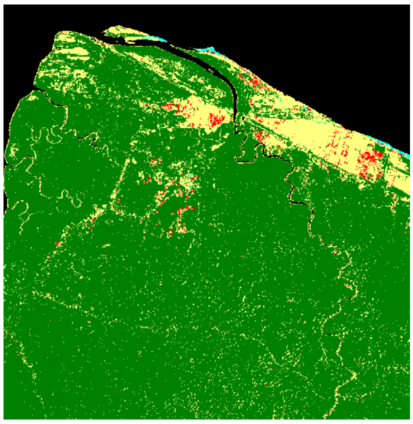

Figure 4. Land cover/land cover change classification 1992/1993-2003/2004. Colors: green – forest, forest; yellow – non-forest, non-forest, red – forest, non-forest; light blue – vegetation, water; black – water, water or outside region.

Table 1. Comparison of the point evaluations of the optical data and radar data based maps. Percentages considering the strata areas. Overall accuracy 95.6 %.

Reference optical data \ Radar image classification	1 For / For	2 Nfor / NFor	3 For / NFor	4 For / Water	5 Nfor / For	Total	Producer's accuracy %
1 For / For	94.69	1.84	0.06	0.01	0.00	**96.60**	98.02
2 Nfor / NFor	1.63	0.72	0.06	0.02	0.02	**2.46**	29.28
3 For / NFor	0.39	0.07	0.02	0.00	0.00	**0.48**	5.10
4 For / Water	0.08	0.10	0.09	0.16	0.00	**0.44**	37.43
5 Nfor / For	0.02	0.00	0.00	0.00	0.00	**0.02**	0.00
Total	**96.81**	**2.73**	**0.23**	**0.20**	**0.03**	**100.00**	
User's accuracy %	97.81	26.41	10.49	82.39	0.00		

In both cases, the proportion of the changed area is very low, less than one percent of the area of Guiana.

The time of the acquisition of the later set of optical data is about three years later than the acquisition of the ASAR mosaic of 2003/2004 that has been classified thus far. The removal of forest seems to have continued after 2004, which can be a partial reason to the lower proportion of change in the radar classification (Figure 4).

However, the main reasons are most likely associated with the radar data characteristics, the procedure to collect the optical data sample, and with the undulating terrain type.

The dimensions of the changed objects can be very small. The resolution of the SAR data was not good enough to reveal such changes particularly taken into consideration the speckle noise, the inaccuracy of the DEM, and minor shifts between the overlapping images.

The point sample approach was not optimal to validate the radar classifications because already minor geometric shifts between the data sets cause selection of the radar classification result from a wrong location. Examination of the different optical images showed that they did not completely match geometrically in the overlapping areas. Thus, there was a certain uncertainty in the coordinates of the IFN points. Although the adjustment of the geometry between the SAR data and the sample points seemed to succeed well it is obvious that geometric mismatch was not completely possible to avoid.

Visual evaluation of the points and the radar based classification shows that the SAR image classification has been able to detected changes from forest to non-forest (Figure 5).

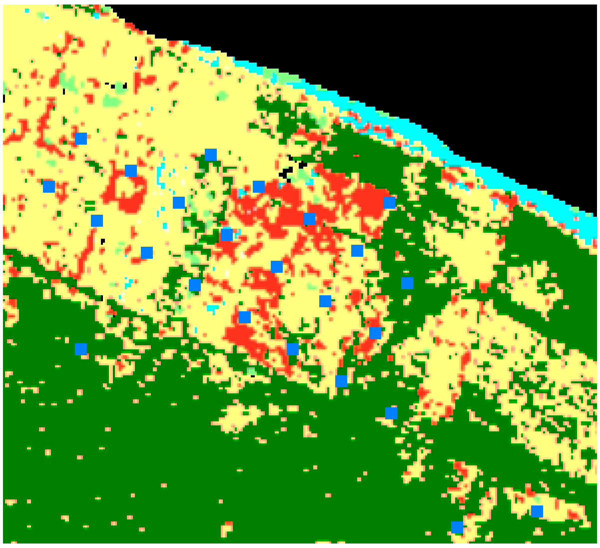

Figure 5. Forest to non-forest IFN points in blue and radar image classification. Other colors as in Figure 4. Area size 9.2 km by 9.2 km**.** Points evaluated using Landsat data from 1986 in this location.

4 CONCLUSIONS

The results indicate that forest area changes can be mapped using C-band SAR data. The main challenges are availability of accurate enough digital elevation model and the smallest size of an area of concern with respect to the resolution of the SAR data.

For French Guiana the numerical change classifications can be used to reveal the 'hot spots' of change. Estimation of the changed area may be unreliable when the required accuracy is in the order of one tenth of a percent of the total area of the territory. The classification accuracy could likely be somewhat improved using visual image interpretation of the multi-temporal radar data mosaics but this would of course be very costly.

In the next phase of GSE Forest monitoring the change classification will be done using two ASAR data sets of 2003/2004 and 2006/2007. The opportunity of using the same instrument and imaging parameters can improve the accuracy.

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