DETECTION OF FOREST CHANGES OVER FRENCH GUIANA USING ERS-1 AND ASAR IMAGERY

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ABSTRACT

ERS-1 and ASAR imagery were used for mapping and monitoring the forest area of French Guiana for 1992/1993, 2003/2004, and 2006/2007. Imagery was ortho-rectified using the SRTM DEM. A least square algorithm was used to improve the residual geometric inaccuracies. For the ERS data, significantly better geometric performance could be achieved using the PGS processor (the so called Envisat processor) data than with the standard VMP processor. The image analysis used three SAR based features, which were computed of two to five acquisitions from the same location. The most effective feature in change detection is annual average amplitude. The planned future operative system uses annual SAR data acquisitions and sample point inventory using high-resolution optical data twice in decade. The study was part of the GMES (Global Monitoring for the Environment and Security) Service Element Forest Monitoring.

***Keywords*—Forest; Change detection; French Guiana; ERS;ASAR; GMES.**

1. INTRODUCTION

Implementation of the Kyoto Protocol of the United Nations Framework Convention on Climate Change requires estimation of the forest area and monitoring its development. The area information is further utilized to evaluate the carbon that is assimilated by forest.

National forest inventory that is based on field sample plots can be used to define and monitor forest area, but this expensive approach is only feasible in few countries. Plot inventory does not either produce wall-to-wall maps that would be useful in the area monitoring. Earth observation offers a good possibility to frequently acquire information about forest resources with reasonable costs and with a complete coverage of the area of interest. However, satellite imagery cannot exclusively provide statistically representative information on forest cover but reference data are needed in addition to the image data.

In many regions such as in the tropics and northern regions, cloud coverage hampers acquisition of optical images that are traditionally used for forest inventory purposes. Synthetic Aperture Radar (SAR) instruments onboard ESA's ERS and Envisat satellites offer an opportunity to acquire frequently information on forest irrespective of the weather conditions [1, 2, 3].

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 ASAR satellites. The user of the results is Ministère de l'Agriculture et de la Pêche of France that uses the information to support the implementation of the Kyoto Protocol in the French overseas province of Guiana. Forest resource inventory in Guiana has not been very detailed thus far. Comprehensive field inventory is not a feasible alternative due to poor accessibility in the most part of the territory. However, the French government has to apply the same nomenclature in forest resource mapping in Guiana as in mainland France. Thus, there is a clear need and financial interest to improve forest resource information. In our approach, the mapping using SAR data is combined with a sampling point inventory using optical data. The project focuses on the whole territory of French Guiana of approximately 90 000 km^2.

Until May 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 1993 using ERS data

Proc. 'Envisat Symposium 2007', Montreux, Switzerland
23–27 April 2007 (ESA SP-636, July 2007)

- forest area map and statistical data 2004 using ERS data
- forest area change map 1993-2004 and statistical data using ERS and ASAR data
- preliminary forest area change map 2004 – 2007 using ASAR data
- forest area estimation applying statistical stratified point sample and visual interpretation to Geocover data of Landsat 5 for 1990
- forest area estimation applying statistical stratified point sample and visual interpretation to Geocover data of Landsat 7 for 2000
- forest area change statistics using the point sample data 1990-2000
- SAR based forest maps were validated using the independent point sample data not utilized in the training of SAR image analysis

The approach in SAR image analysis is based on collection of several acquisitions form the same location during a year. Several observations make it possible to reduce effects of changes of weather such as rain showers. They also can be used to reduce the speckle noise because images are filtered using the temporal dimension. On the other hand, the variability of backscatter within the yearly time-series can be utilized as an important source of information. Five images from the same location were attempted but this did not succeed at all locations with ERS data.

The (repeat pass) interferometry has not been considered feasible in the tropical forest using C-band SAR and has thus not been applied in the mapping.

The project has been earlier reported in [4, 5].

2. MATERIALS

2.1. SAR imagery

For the 1992-1993 image mosaic, 60 ERS-1 images were reprocessed at ESA in 2006, using PGS ASAR processor (v. 4.02), and delivered in E1 ASAR format. This particular processing was chosen because of ERS geo-location information appeared to be truncated when processed with ERS VMP processor and provided in the CEOS format. Four to five images of the same location were attempted within one year in order to enable the use of method based on the seasonal change of the backscattering characteristics of ground cover types [6].

For the 2003-2004 ASAR mosaic, 107 images were purchased. For the 2006-2007 mosaic, the number of images was 122. ASAR data were VV polarization images of swath IS4 (incidence angle 33 degrees). Thus, the polarization was the same as with the ERS but the incidence angle was shallower (23 degrees with ERS). A higher incidence angle for ASAR was chosen to maximize the difference between forest and open areas. Thirty three (33) degrees was the highest angle that still enabled a complete overlap between orbits.

2.2. Optical data

The Landsat image mosaics were purchased from Geocover (http://www.geocover.com/). The first mosaic was for 1990 and it was done using Landsat 5 imagery (acquisition 1986-1997). The second mosaic was made using pan-sharpened Landsat ETM+ data (acquisition 1999-2003). In addition, for the 1990 mosaic two Landsat 5 images from 1992 were separately purchased and added to the mosaic.

During 2006, a coverage of Spot 5 data has been collected over the whole territory of Guiana, thanks to the new Spot/Envisat receiving station installed in French Guyana in 2006 in the framework of the SEAS Program. These data will be used to define forest area with a very dense sample and to evaluate the performance of SAR based classifications.

2.3. Digital Elevation Model

The final version of the SRTM (Shuttle Radar Topographic Mission) was downloaded from the seamless distribution site. (http://seamless.usgs.gov/Website/Seamless/). Still in some places data were missing, with zero as elevation value. The DEM also had pixels with negative elevations. The anomalies had to be reduced because ortho-rectification needs elevation for all pixels in the area of interest. The area where zero is a valid elevation value (sea and lower reaches of major rivers) was delineated manually, and a mask was made for these areas. Then a version of the DEM was made where 0-pixels were mapped to value one (giving sea an elevation of 1 m, which does not produce major errors for the ortho-rectification) and negative pixels were set to zero. Outside the coastal area all pixels with zero or negative elevation were filled by linear interpolation from the neighbouring pixels.

3. METHODOLOGY

3.1. Importing and averaging

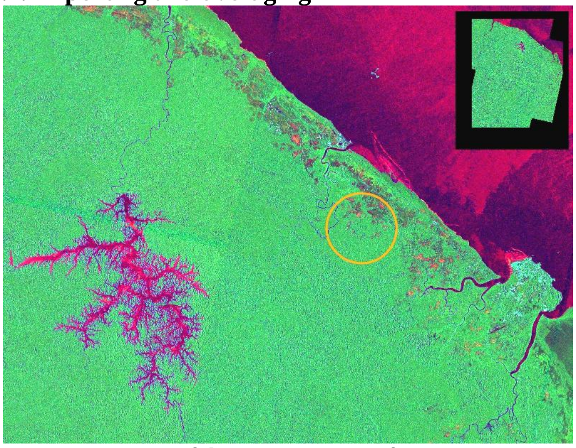

Figure 1. Extract of the ASAR mosaic from 2006-2007. The capital city Cayenne can be seen close to the lower right corner. The orange circle refers to Fig 3. Red: temporal variability, Green: Average amplitude, Blue: Average texture Area size approximately 115 x 90 km^2.

Images were first filtered using a 4x4 pixel block averaging and then calibrated to σ^o. This resulted in the pixel size of 50 m by 50 m. Average texture, average amplitude, and temporal variability were computed over each image stack of overlapping images from the same location. Ortho-rectification was performed using the updated version of SRTM DEM.

Topographic effects on image radiometry were corrected in connection with ortho-rectification:

$$r_c = \mathrm{sqrt}(\tan(\theta_r)/\tan(\theta_n))*(r_o - N) + N$$

where r_c = corrected amplitude, r_o = original amplitude, θ_r = incidence angle in range direction, θ_n = nominal incidence angle, and N = noise-equivalent σ^o of the SAR system.

The texture feature was computed scene by scene as the standard deviation of backscatter amplitude (within the 4 by 4 window) divided by average amplitude. Average texture and average amplitude were computed over all individual texture and amplitude observations in the time-series of scenes. Temporal variability was computed as the standard deviation of the logarithms of amplitude observations.

3.2. Ground control and tie point generation

The PGS-processed ERS-1 data seemed to have good within-image geometry but the absolute location of images was unsatisfactory. The geometric performance of the ERS images was clearly poorer than that of the ASAR imagery from the same processor. To ensure the best image co-registration within each stack and between stacks, methods that had been developed in the GRFM (Global Rain Forest Mapping) and GBFM (Global Boreal Forest Mapping) projects were used to generate tie points between images [7, 8]. Tie points were generated by a semi-automatic method that utilizes image correlation. Least squares block adjustment was used in the so-called TaigaMosaic algorithm to minimize residuals [9]. Residual Mean Square Error (RMSE) in tie points were 14.9 m in northing and 17.7 m in easting with some outliers up to 100 meters with ERS data. For ASAR 2006-2007, the RMSE in tie points were 14.1 in northing and 13.6 m in easting. The corresponding values for GCPs (relative to the used DEM) were 23.2 m and 33.1 m. Finally, country-wide SAR image mosaics of the three features were compiled (Fig. 1). The coordinate system was WGS-84 projected onto the UTM zone 22 grid, which is widely used in Franch Guina.

4. RESULTS

4.1. Geometric quality improvement

Data reprocessing at ESA with the PGS processor (implemented for ENVISAT ASAR instrument) improved the geometric quality of the ERS mosaic significantly. Because orbit data are included with a higher accuracy, image co-registration within stacks and ortho-rectification efficiency (including radiometric corrections) were both improved, especially by the use of GBFM optimization strategy. The improvement was crucial for the further image analysis because already slight displacements between images greatly decreased the intensity difference between forest and open areas.

The problem with the geographic registration of ERS-1 images processed with the “old” ERS VMP processor was caused by a truncation in the number of decimals of the provided geo-coordinates. PGS-reprocessed images, with the additional least-square optimization, showed better quality after ortho-rectification and radiometric calibration.

Even though no independent control points were used to estimate the geo-location accuracy of the mosaics, it can be expected that in most of the mosaic area the geo-location error is within 81 m, relative to the DEM used as the source of GCPs.

4.2. Change detection quality improvement

A visual examination of the ERS SAR features already showed the improvements due to the reprocessing using the PGS processor. The change classification between 1993-2004 confirmed the result of the visual inspection. The classification was done using the AutoChange method [10] to the three SAR features (Fig. 2). The change was extracted by merging the SAR feature data from two different mosaics directly instead of extracting the change by comparing two individual classifications. The post-classification approach was presented in the previous Envisat symposium and resulted in overestimation of the change. It used a previous ERS mosaic using data from the VMP processor. The overestimation was also observed when change classification was validated with sample points from 1990 and 2000 Landsat mosaics [4].

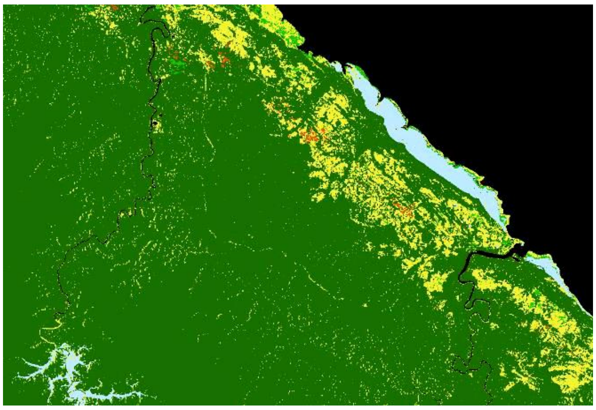

Figure 2. Autochange result of change classification 1993-2004. Input ERS data processed with the PGS (Envisat) processor. Red: from forest to non-forest, Dark green: forest in both years, Light green: from non-forest to forest, Yellow: non-forest in both years, Light blue: from forest (or mangrove) to water. Scattered yellow dots are due to the residual intensity variation, which is caused by inaccuracies of the DEM in the topographic normalization

The changes 1993-2004 in the forest cover were small, the largest change being construction of the water reservoir in late 1990's. In the change map, the reservoir area was 0.4 percent of the area of Guiana. The coastal zone had changes that covered a significant size of area but they are not considered changes from forest to non forest or *vice versa* because the wooded vegetation consisted of mangrove. Mangrove vegetation is not considered in the reporting required by the Kyoto Protocol.

The accuracy, as measured using visually interpreted Landsat points was 90 % in forest and non-forest classification using ERS data 1992-1993 and 94 % using ASAR data 2003-2004 in forest and non-forest classification, as reported in [4]. The number of points was 1136. The ERS SAR classification was done using an earlier mosaic that was based on the data from the ERS processor (VMP). The forest area from the new ERS mosaic, compiled in 2006 has not yet been evaluated.

Using the point data evaluation only, with this sample size the 95 % confidence intervals for 1990 and 2000 for forest area did overlap. Thus, statistically valid forest area definition more precisely requires a higher sample size. Presently a very dense new sample of 15000 points has been defined. This sample will be visually evaluated during summer 2007 using Landsat data for 1990 and Spot data for the present (2006). The sample result will also be used to evaluate the performance of SAR based classifications.

The first change classification results between the two ASAR mosaics 2004-2007 indicate very few changes. One likely change is shown in Fig. 3. The early results suggest also that the changes were only apparent in the amplitude channel whereas no intensity change could be observed in the temporal variability or spatial texture channels. This result is somewhat surprising since in forest and non-forest classification and in change classification over a longer period of ten years (1993-2004) the temporal variability feature was significant in addition to the amplitude channel.

5. CONCLUSIONS

The results of forest area monitoring in French Guiana thus far have shown the potential of C-band SAR data in forest and non-forest area estimation although the C-band is far from being an optimal frequency for the forest applications. Use of several overlapping images from the same location over the year has appeared to be a feasible approach. Temporal filtering was an effective mean to reduce the speckle noise and effect of weather.

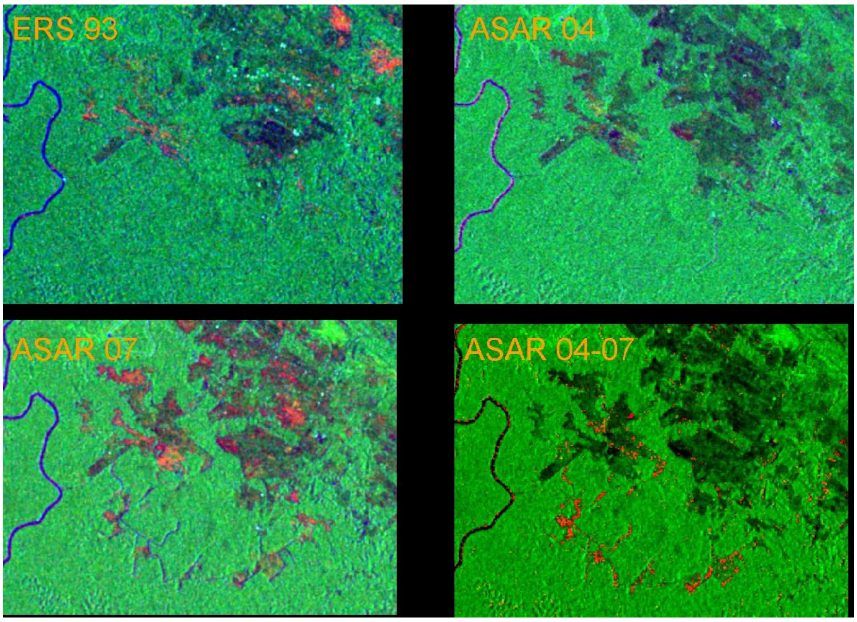

Figure 3. Details of the ERS 1992-1993, ASAR 2003-2004 and ASAR 2006-2007 mosaics. Red: temporal variability, Green: Average amplitude, Blue: Average texture. The look-up table for the colors of the SAR features is exactly the same in the three images. Lower right corner image, Red: Likely forest clearance between 2004 and 2007 from change analysis.

Repeat-pass interferometry was not considered as a realistic alternative for tropical forests because the lack of coherence.

Overlapping images make it possible to benefit from the larger variability of the back-scattering in non-forested areas than in the forested areas. The temporal variability feature has proven to be effective in general forest and non-forest classification as well as in change classification when the monitoring period is long. Preliminary results using two recent ASAR mosaics (2003/2004 and 2006/2007) and thus a short period for change suggest however, that only the amplitude channel was effective to detect forest clearing. If the change is classified using a method that is based on the Euclidean distance, as in the case of our experiments, use of non-informative features is harmful for the result. It is therefore important to select only the effective features to the change detection process.

The use of temporal variability and time-series imagery in general poses tight requirements on co-registration and absolute geo-location accuracy. These requirements were fulfilled by using (automatic) tie points and ground control points. If very accurate orbit data area used in connection with imagery from future sensors, the use of tie points and ground control points can possibly be dropped in future operative scenarios.

The future scenario for an operative monitoring system includes annual monitoring or monitoring every second year of forest area using SAR data. SAR data classification gives a wall-to-wall overview on forest area development and reveals possible dramatic changes in forest area. Approximately every fifth year the forest is monitored using a dense point sample from high-resolution optical data. The optical sample provides reliable statistical data on forest area and can be used to validate and calibrate the SAR based results.

6. ACKNOWLEDGMENT

This work is currently undertaken within the second phase of the GSE Forest Monitoring project (http://www.gmesforest.info/). SAR data were obtained under the Category 1 project 1519. The programs used in tie-point correlation and geometry revision were developed during the GRFM project in JRC and in the GBFM project under a contract (No. 15455-1999-11 F1SC ISP FI) to the Joint Research Centre of the European Commission.

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