K&C Science Report – Phase 1
Law Enforcement Deforestation Assessment

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***Abstract*— Deforestation monitoring for the Brazilian Amazon has been carried on by INPE since 1988, under the PRODES program, and recently, the DETER, both have been used by IBAMA for operational purposes and law enforcement. However, optical sensors are limited by the presence of clouds. The ALOS was launched in 2006, and its data became available to IBAMA thought the JAXA's ALOS Kyoto and Carbon Initiative project. The study site is an area of forest facing a growing pressure of deforestation. The first approach was developed with ScanSAR strip mode image was geo-rectified and DN image values were converted to the normalized radar cross section (σo), in dB, with a calibration factor of -83 dB. In the second approach we have also used five Fine Bean Single Mode Strips Slant Range data for visual interpretation and 738 were identified and it represents 15% of *posteriori* deforestation detections of DETER. The mean σ value for recent deforested area was -5.315dB and the mean so value for preserved native forest was – 7.569dB. From five fine bean strips The executed methodology, using a threshold to classify new deforested areas, has a good potential to be the base of a semiautomatic detection system for operational purposes, using ScanSAR images. The third approach was developed using a temporal RGB composition to identify possible changes in the detained areas object of a fine. This system has potential to produce data that could complement the information already available from well established optical sensor satellites monitoring systems of Brazil..**

***Index Terms*—ALOS PALSAR, K&C Initiative, Forest Theme, Law-enforcement, Monitoring, Amazon.**

I. INTRODUCTION

A. Project Purpose

The main idea of this project is to develop operational methodology to generate deforestation information for law enforcement action in the field based on SAR orbital images.

To develop this project ALOS-PALSAR images [1] provided by Kyoto and Carbon Initiative of Advanced Land Observation Satellite were proposed to be used for operational monitoring of tropical forests in Brazil. In

On the development of this project are expected to achieve some specific goals:

- Decrease de average time between the act of deforestation and the deforestation recognition by satellite images.
- Develop methodologies for detection changes applied to forest monitoring on the specialized Remote Sensing Centre on the headquarter office.
- Build-up SAR capacity to develop SAR temporal analysis by training the staff of regional offices;
- Build up a SAR image catalogue on image server data base to share satellite information to regional offices to be use on temporal series analysis;

B. The overview

Deforestation monitoring for the Brazilian Amazon has been carried on annually by INPE (National Institute for Space Research) since 1988, under the PRODES (Brazilian Amazonian Forest Monitoring by Satellite) program. More recently, the DETER (Real Time Deforestation Detection System) program was launched to give a faster response (twice a month). PRODES uses Landsat TM and Brazilian-Chinese CBERS data, while DETER is fed by the MODIS sensors on board NASA's Aqua and Terra satellites. The data from both programs have been used by IBAMA (Brazilian Institute of Environment and Renewable Natural Resources) and the Brazilian Federal Police to detect deforestation areas for operational purposes and law enforcement. However, the use of orbital optical sensors to detect deforestation in the tropical rainforest on the Amazon region is limited by the presence of clouds. Some areas remain covered for more than a year. This problem affects critically affects the time spend by the authorities mentioned above to react against the ongoing deforestation processes.

Past research has pointed out that data from SAR satellite sensors can be used to detect land cover changes in tropical forests. The Advanced Land Observing Satellite was launched in 2006, and from August 2007 its data became available to IBAMA through the JAXA's ALOS Kyoto and Carbon Initiative project (K&C). The ScanSAR-ALOS is one of the products available under the K&C. With L band and HH polarization, it is suitable for vegetation analysis.

C. The achivements

The team that proposed activity on the law enforcement deforestation assessment by PALSAR images starts became part of K&C science team on august 2007. The achievements obtained represent partially what are the expected for the the end of the project implementation.

The results presented here will show the importance of SAR images to the tropical forests monitoring (e.i. how the can contribute to anticipate the law enforcement activity and how effective ALOS-PALSAR are to identify new deforestation polygons).

Another point that should be stressed here is one of the main goals of this project, to build-up capacity to use and analyse SAR imagery. The results are scalable presented as the knowledge and the availability of SAR images were increasing along the development of the project. As mentioned before it is part result of the heuristic pyramid of knowledge that will be achieved on the end of this project. These beginning results denote that an institutional and operation use orbital SAR images for vegetation monitoring are viable.

II. PROJECT DESCRIPTION

A. Relevance to the K&C drivers

The Brazilian Institute of Environment and Natural Renewable Resources (IBAMA) is the main important institution related to environmental protection in Brazil. The institution have about 4 thousand staff people and part of that working on the law enforcement to combat the illegal deforestation. The Remote Sensing Centre of IBAMA play an important hole on training people on the use of Remote

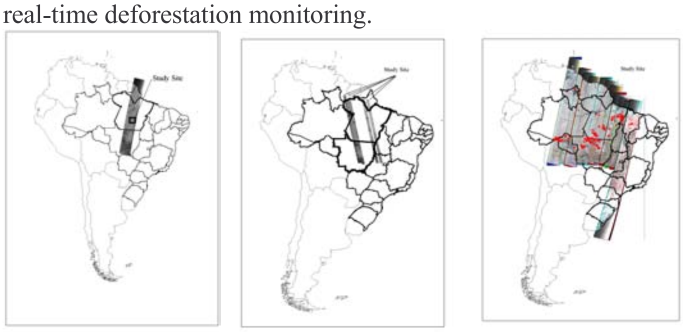
Sensing and GIS to increase the effectiveness of the environmental protection action on the office and on the field. With the support of National Institute for Space Research (INPE), that made available optical images and promote the development of new methodologies for vegetation monitoring with satellite images, Brazilian government had improve the monitoring systems for vegetation protection.

These advances of SAR methodologies to be used to build-up operational systems to improve to monitoring of the tropical vegetation is an important approach to contribute to the reduction of the Carbon emissions as well as to the Conservation of the tropical rain forests in Brazil. These forests are playing important hole on carbon and water cycles and are considered hot spots of biodiversity conservation. The achievements already obtained confirm that we still have more to improve in the operational satellite monitoring systems using ALOS-PALSAR. The K&C science advisory panel [2] will contribute of develop SAR methodologies that can potentially be used for other countries that want establish SAR operational system to protect their tropical rainforests.

B. Study sites

The two prototypes areas on the proposed project are the Amazonian Rain Forest and the tropical rain forest, close to the Brazilian east cost hereafter called Atlantic Forest. Both areas were used to test primary methodology viability studies. On the Amazonian region four approaches were developed in scaleable increasing on area and complexity.

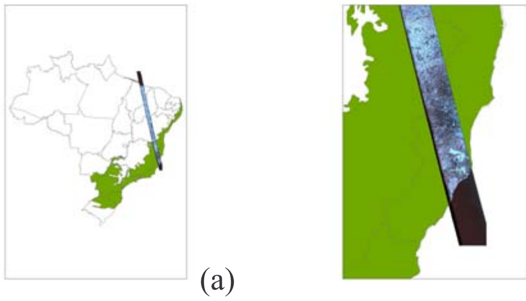
On the Amazonian region the study area related to the first approach is defined by a rectangle (180km by 200km) centrally located in the state of Pará, Brazil, centred coordinates of 52o 47’ 44” W and 6o 34’ 03” S (fig. 1). The second approach was conduct in some parts of Pará and Mato Grosso States (fig. 1). The third approach was conduct on the entire Amazon region. These corresponds to areas of forest that has been facing a growing pressure of deforestation, with a good amount of recent deforested areas detected by DETER. The area was selected to be used as pilot area to test new methodologies on real-time deforestation monitoring.



(a) (b) (c)

Figure 1. (a) Study site location in the Para State, (b) five fine bean strips in the Para and Mato Grosso States, (c) all the detained areas in the Brazilian Amazon Region ALOS K&C © *JAXA/METI*.

For the Atlantic Forest, one area on the south of Bahia and north of Minas Gerais States (fig. 2) were chosen for to test to the PALSAR ability to detect new deforestation. These areas are recognized in Brazil as an area with high pressure of deforestation and still have large size polygons of remnant natural vegetation.



(a) (b)

Figure 2. (a) In green the old spatial distribution of Atlantic Forest biome and the position of the PALSAR strip ALOS K&C © *JAXA/METI*, (b) the zoomed area on the south of Bahia and north of Minas Gerais States.

C. The hypothesis

Seasat was launched on 1978, and was the first Earth-orbiting satellite that had the space borne synthetic aperture radar (SAR), L-band, on board. The use of L-band orbital SAR images for vegetation analysis starts with SeaSat data, developing to the SIR-A,B and C data, followed by JERS-1 and recently with ALOS PALSAR data.

The L-band SAR images have been related with the canopies and have been related with biomass estimation and structure modeling. Luckman & al. [1] developed a semi empirical model for the retrieval of above-ground biomass density on the tropical forests. Several papers were developed on this matter to understand this relationship. Neeffa & al. [4] developed a model for the tropical forest stand structure using SAR data.

Sgrenzaroli & al. [5] have shown that on the published remote sensing literature, there are several Amazon forest-mapping experiments actually deal with single SAR satellite images (i.e. JERS or European Remote Sensing – ERS), with focus on local-scale mapping. In this category, approaches based on visual inspection or automatic classification, were investigated.

Saatchi & al. [6] have studied the radar characteristics of the training sites on the State of Rondônia for land cover-type classes identification using L-band SIR-C data.

More recently, Almeida-Filho & al. [7] evaluated the potential use of orbital L-Band SAR images of JERS-1, to test a multitemporal monitoring methodology. They found that for the initial deforestation process the proposed methodology is not able to unequivocally detect areas in initial phase of deforestation, and the unambiguous detection of deforested areas is only possible if the entire clearing process has already been concluded. They also mentioned that for an operational program to monitor deforestation, based on SAR data, it is very important to have a properly geo-referenced multi-temporal database to integrate different sources of data.

The use of orbital optical sensors to detect deforestation in the tropical rainforest is usually delayed due to presence of clouds. The age of a certain deforested area is defined by the period that starts when original forest was last observed and ends when deforestation was first observed with satellite images. Recent deforested areas are considered priority for law enforcement agents because they can indicate the ongoing deforestation processes. DETER's data provides deforestation polygons with an age that can vary from 15 days up to more than a year long (fig. 3). By the beginning of the dry season most of the deforested areas detected by DETER are old (more than 90 days) due to a long period without clear images. ALOS-ScanSAR can be used to identify recent deforested areas and to reduce the interval between two observations.

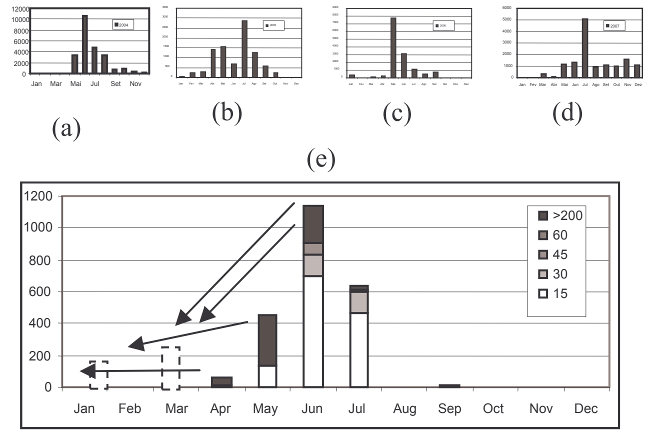


Figure 3. Monthly distribution of DETER deforestation detection in area (km2). (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) 2007 with the proportion of the each age per month in the beginning of the dry season. Dashed columns means hypothetic scenario of PALSAR complementary data, showing some deforestation that may be able to detect during the rainy season.

D. The aproaches

On the first approach the strip of 2730km of length by 380km of swath, on wide bean mode 1 of ScanSAR images, with 100 per 100 meters resolution and HH polarization, of august 23rd, 2007. In order to validate the ALOS detection Landsat-TM images path 226 row 64 and 65 of September 2sd, 2007 and path 225 row 64 and 65 of September 27th, 2007. CBERS images path 164 row 106 and 107 of September 11th, 2006 were used to verify the forest condition one year before the ALOS image acquisition. Images were registered using orthorectified images from Geocover Landsat Facilities project (GLCF orthorectified data).

This study was conducted to test operational capability of ScanSAR images as complementary resource to the optical sensors already used in Brazil. First, an analysis was carried out in order to understand how deforested areas would show up on PALSAR sensor imagery. Than the ScanSAR strip mode image was geo-rectified and subset. DN image values were converted to the normalized radar cross section (σo), in dB, with a calibration factor of -83 dB.

The ancillary deforestation areas previously detected by PRODES were masked to eliminate old deforestation areas. An analysis was done using all DETER data sets of the year 2007. The mean sigma value was extracted for all sets of DETER deforestation detections along the year 2007 and also for the rain forest. A Lee-sigma speckle reduction filter was applied to the ScanSAR image. This image was then classified using the mean sigma value of the recent deforested areas as threshold to identify other deforested areas not detected by DETER. The CBERS 2b optical images before and after the deforestation detection by ALOS-PALSAR images were used to check the forest state (fig.4).

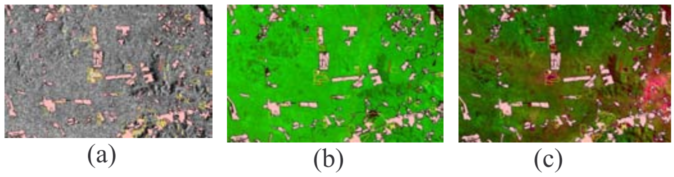


Figure 4. The yellow lines are the DETER detection polygons, the red lines are de ALOS detection polygons while the pink areas correspond the PRODES polygons. (a) ALOS ScanSAR image ALOS K&C © *JAXA/METI* used with the defined threshold value and the to identify the possible recent deforestation, (b) CBERS Image from 2006 before to characterize the situation before ALOS image acquisition, (c) Landsat image after ALOS image acquisition.

An illuminated topographic image based on the position of the PALSAR sensor was generated from the SRTM data. The simulated image was used to exclude the classified areas that could present relief related response on the ScanSAR image.

In the second approach the visual interpretation was conducted using the knowledge obtained on the first approach were some of the highlighted areas (e.i. square shape deforestation) were identified over Fine bean images overlaid by PRODES 2007 + DETER from August to December of 2007 (fig. 5).

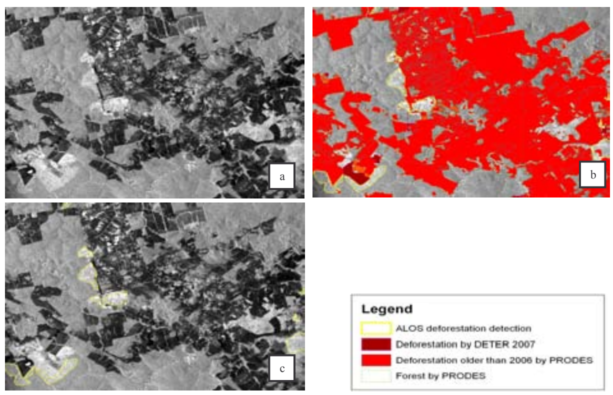
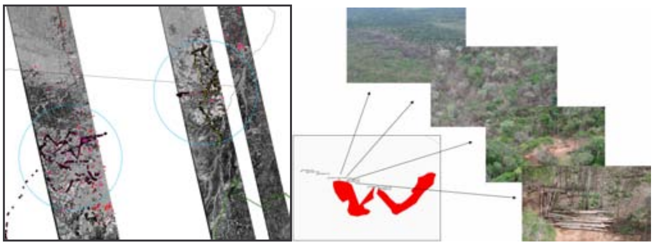


Figure 5. (a) ALOS PALSAR Fine Beam Single Mode (FBS) HH ALOS K&C © *JAXA/METI* with 50m resolution of December 2007, (b) ALOS PALSAR FBS overlaid by PRODES 2007 and accumulated DETER until December 2007, (c) ALOS PALSAR Fine overlaid by the drawn polygons detected using PALSAR image.

Field activities were developed to check the identified polygons and two data collection on helicopters were done (fig. 6). The increase in the intensity of the PALSAR images were confirmed was areas of disturbance of the forest structure and some fail trees were found.



(a) (b)

Figure 6. (a) ALOS PALSAR Fine Beam Single Mode (FBS) HH strip ALOS K&C © *JAXA/METI* and the helicopter autonomy 150miles in blue and dots showing the GPS tracks, (b) ALOS PALSAR HH deforestation detection polygon and the time synchronized pictures taken by the helicopter.

On the third approach on the Amazonian region ALOS-ScanSAR images were used to build-up temporal color composites, this methodology were used together with visual interpretation inside of the detained areas were a fine were applied by the enforced law agents of IBAMA. Figure 7 are showing one example of temporal color composite applied in one of the eleven strips that cover all the detained areas.

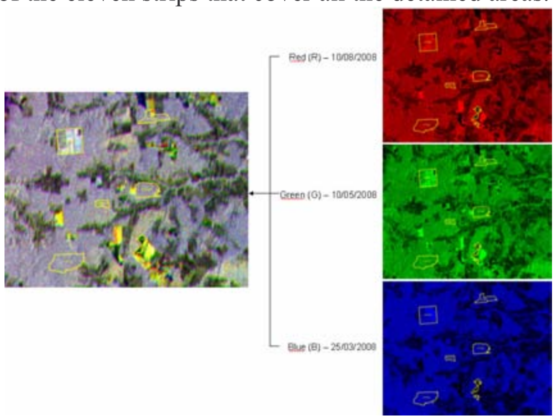


Figure 7. Temporal RGB composition using tree ScanSAR Strip images of tree different dates were DN of images show changes with different colors ALOS K&C © *JAXA/METI*.

The ALOS-ScanSAR images of December 2008 and January 2009 were used to detect new deforestations on the cloudy season on the Amazonian region.

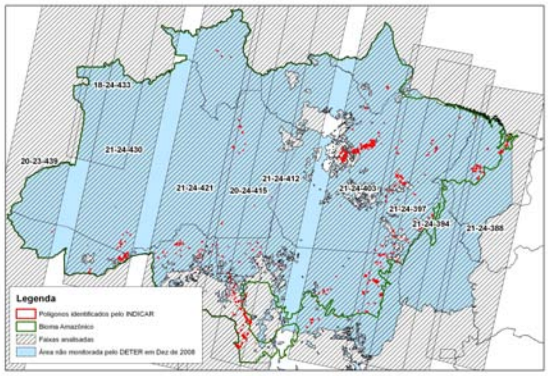


Figure 8. (a) ALOS-ScanSAR strips, in blue the cloud cover on December by DETER monitoring system, in red new deforestation detections by ALOS.

On the figure 8 the temporal composites were used to detect new deforestations where that the optical system DETER can not detect due to the presence of clouds from October to December.

III. Results

On the first approach, DETER polygons were used to extract average values inside these areas, was possible to recognize that most of older deforestations in the same year were low values compared with the very recent detections. The figure 9 shows the average sigma values obtained for old deforestations (may be crops or pasture) compared with one year old deforested areas detected by DETER system using Terra-MODIS images and the signal obtained for primary forest.

Class	Area	Min	Max	Mean	Std
DETER Recent (1)	2279	-12,330	4,204	-4,992	1,893
Forest PRODES (2)	132020769	-15,520	0,178	-7,254	1,818
Deforest PRODES (3)	162780000	-20,374	0,899	-11,020	2,505

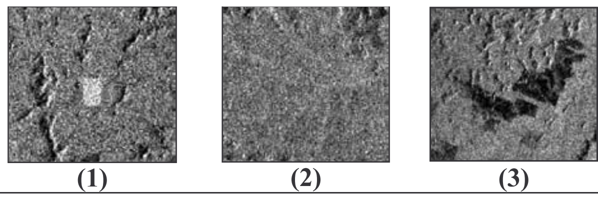


Figure 9. Comparison between very recent deforestation from DETER of the year 2007, Deforestation detected with PRODES system from 1997 to 2006 in average and the remnant primary forest identified by PRODES database.

The results showed that areas corresponding to old deforestation are related to low dB values, while recently deforested areas are related to high dB values. The mean σ_0

value for recent deforested areas was -5.315dB and the mean σo value for preserved native forests was - 7.569dB.

Based on the threshold value classified ALOS image, 1476 polygons were generated. Using the arbitrary criteria that more than 10 degrees slope can be affected with an increased brightness, 1239 polygons on slope areas were eliminated. From the resultant 237 polygons, 133 were confirmed to be over the relief but were not eliminated because they were geographically displaced, one was a false detection, and 99 were confirmed deforestations. From the 99 deforested polygons, 19 were coincident with PRODES from the year 1997 to 2006 and 55 polygons with PRODES 2007 (finished on august 2007), 4 were on areas of non forest (neither considered by PRODES nor DETER) and 17 are new detections of ALOS, not detected by any other optical system.

On the second approach five strips of Fine Bean Single Mode, polarization HH with 50m resolution on the month December 2007 and January 2008 were used to detect possible recent deforestation by visual interpretation based on the knowledge acquired on the approach number one. Overlaid the PALSAR images with PRODES 2007 and year before and accumulated DETER from August to December 2007, 738 polygons were generated (Table 1). These polygons were compared with the posterior detection made by DETER from January to September of 2008, were 1346 polygons were identified on the same area monitored by ALOS. From the total DETER polygons 207 (15.38%) were intersected with ALOS PALSAR polygons, 878 (65.23%) were polygons that their areas were monitored month(s) before in the year 2008 and were not detected (possible these polygons occurred after ALOS PALSAR detection), and 261 (19.39%) had their areas covered by clouds until their detection by DETER, we are not able to define when it occurs in relation to ALOS PALSAR detections (tab.2).

Table 2 – Comparison between the ALOS-PALSAR and optical capabilities by DETER system with MODIS images.

	DETER	ALOS	Intersect	MAR	ABR	MAY	JUN	JUL	SEP
FBS60	139	215	21	1	0	0	0	9	11
FBS62	137	100	13	11	0	0	0	1	1
FBS69	409	290	111	48	14	34	4	7	4
FBS70	437	77	41	8	12	19	2	0	0
FBS71	224	56	21	3	9	6	2	1	0
Total	**1346**	**738**	**207**						

Without clouds month(s) before DETER detection in 2008

	JAN	FEB	MAR	APR	MAY	JUL	TOTAL
FBS60	2	23	3	0	44	16	**88**
FBS62	50	53	0	2	5	0	**110**
FBS69	0	113	19	15	1	54	**202**
FBS70	0	257	3	47	0	15	**322**
FBS71	0	117	0	37	0	2	**156**
							878

Covered by clouds until their detection by DETER

	JAN	FEB	MAR	APR	MAY	JUL	TOTAL
FBS60	0	0	26	0	0	4	**30**
FBS62	0	12	0	0	0	2	**14**
FBS69	0	0	54	5	1	36	**96**
FBS70	0	0	38	28	0	8	**74**
FBS71	0	0	24	23	0	0	**47**
							261

The new deforestation detections produced by ALOS-PALSAR.on December 2007 and January 2008 were compared with the posterior detections produced by DETER. As DETER is based on optical sensor MODIS several detections cannot be detected when the specific region were cover by clouds. The increase of the coincidences from March to September of 2008 is old detections that occur before ALOS detections.

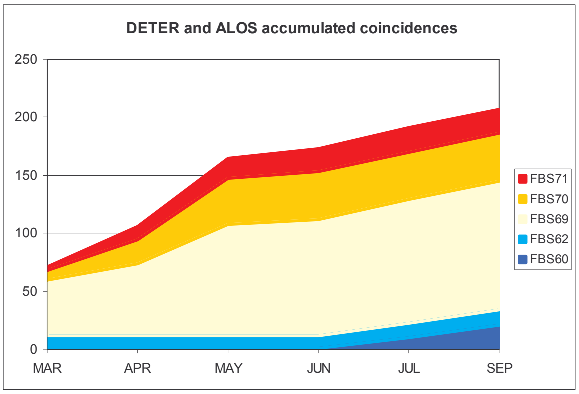


Figure 10. The accumulated coincidences between ALOS December 2007 and posterior DETER detection along 2008 year.

Seeking for changes we could find an area that were checked by optical images in other to generate an indicative of changes that may represent an break down in a detained areas after received a fine by the IBAMA´s enforced law agent. The Figure 11 is presenting an example of changing detection. This methodology still need much field activities to determine the level of changes ALOS PALSAR are identifying and how it can be used by the enforced law agents to return in the detained areas.

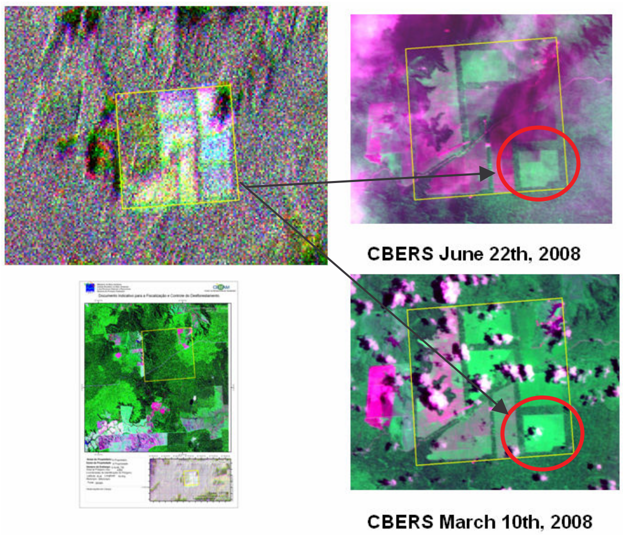
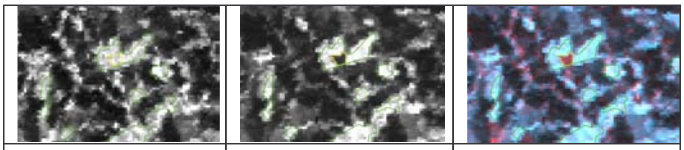


Figure 11. Up left ALOS ScanSAR temporal composites, on the right CBERS images used to confirm the changes detected by ALOS and a Indicative of temporal changes in detained areas.

An approach were also developed on the prototype area of Atlantic Forest to analyse the capability of Fine Bean Dual Mode strip mode K&C data to detect new deforestations. The area analysed on the south of Bahia shows a potential to analyse large size deforestation polygons (fig. 12).



(a) (b) (c)

Figure 12. (a) the situation at july 2007, (b) at july 2008 and (c) the temporal change in one year time change.

IV. Discussions

The mean σ_0 value for recent deforested areas, for preserved native forests and old deforested areas are similar to those found by other authors are shown on the Table 3.

Table 3 – Comparison between the sigma values obtained from different studies: (1) present study, (2) Sgrenzaroli & al. [5], (3) Saatchi & al., [6] and (4) Luckman & al. [3].

Covarage Type	1	2	3	4
Primary Forest	-7,254	-7.71dB	-9.71	-8.3 to 7.1
Recent deforestation	-4,992	----	-5.75	----
Old deforestation (may be crop or pasture)	-11,020	-1.11dB	- 14.45	-11.9 to -10.7

Almeida-Filho & al. [7] notice the importance of high quality georegistration on the several databases in order to implement an operational monitoring system. In this study the georegistration was a very limiting factor and was solved by using the recent implementation of the geocoded methodology.

V. Conclusions

The executed methodology, using a threshold to classify new deforested areas, has a good potential to be the base of a semiautomatic detection system for operational purposes, using ScanSAR images. This system has potential to produce data that could complement the information already available from optical sensor satellites (CBERS-CCD, Landsat-TM and Terra-MODIS images). The resulted monitoring system, combining optical and SAR data, would decrease the average age of the deforested areas. As a result, the response time related to law enforcement activities to combat illegal logging would decrease.

Two points need to be stressed here. One is the new detections of ALOS images which were not detected by any other optical systems. These detections are probably related to very recent deforestations that may have occurred some days before ALOS image acquisition. The second point is the number of ALOS detection coincident with PRODES 2007, these detections can be used to the enforcement law agents, because these polygons where not detected by DETER until the end of the year when the mask were changed to the PRODES 2007 database.

The DETER detections were always correct and the area not covered by clouds before DETER detections means that there was no deforestation on this areas. This presumption presumes that detection recognized after are new very recent deforestations.

In the third approach the no changes can not be necessarily defined us compliment determined in the detained areas, us well us, some cases of changes need to be studied to determine the level of change can be related to re-growth process.

The approaches reveled that there are simple methodologies that can be applied on operational systems but it still need implementation for semi-automatic processing. The improvement on software development for fast processing will be need for implementation of rapid response SAR based vegetation monitoring. Looking forward, another extension needed is to increase the number of regional offices that can use the PALSAR images as a resource for historical time series analysis.

Acknowledgements

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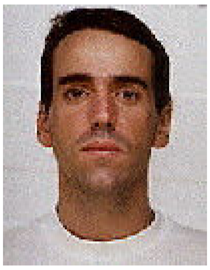

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