K&C Science Report – Phase 2
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 more recent DETER program. Both have been used by IBAMA for operational purposes and law enforcement activities. However, optical sensors are limited whenever there is cloud cover. The ALOS was launched in 2006, and its data became available to IBAMA through the JAXA's ALOS Kyoto and Carbon Initiative project. The study site is all the Brazilian Amazonian Tropical Rain Forest, concerning all areas facing growing pressure of deforestation. The main objective was to implement an operational satellite monitoring system based on ALOS-SCANSAR images. The wide acquisition mode of ALOS PALSAR sensor are providing repeated images that are used to complement the short time response of optical monitoring system. The images are a valuable resource to the early deforestation identification when the study area presents cloud cover. For each new change in the vegetation the polygon area is delimited to generate a deforestation detection individualized document. Three experimental approaches were conducted before the implementation of the operation methodology. The operational system was adopted using multi-temporal color composite images to detect new deforestation areas in the Amazonian Tropical Rain Forest and to complement the well-established optical sensor satellites monitoring systems of Brazil, when clouds are limiting factor.**

***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.

The motivation goals were:

- Decrease the average time between the deforestation starting time and the deforestation recognition by satellite images.
- Develop SAR change detection methodologies that can be operational and be applied to forest monitoring on the specialized Remote Sensing Centre of Brazilian Institute of Environment and Natural Renewable Resources (IBAMA) of Brazilian Government.
- Build-up SAR capacity to develop SAR temporal analysis and training the regional offices staff to use it;

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. 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 enforcements. 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 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 ALOS-ScanSAR is one of the products available under the K&C. With L band and HH polarization, it is suitable for vegetation analysis.

C. Achievements

The IBAMA's team that proposed the activity to implement an operational system for the law enforcement deforestation assessment by PALSAR images became a member of K&C science team on August 2007. The achievements presented until June 2011 represent mostly of what was expected at the beginning of this project. Many efforts are expected from now on to consolidate an operational system. The challenge to the future is to keep the actual low level of deforestation in the Amazonia and to become a traditional SAR monitoring system.

The results presented here will show the importance of ALOS-PALSAR images to the tropical forest monitoring by satellites. It will be clear how this kind of images contributes to anticipate the law enforcement activities. Another import achievement is, beside the real capability to detect forested and non-forested areas (clear cutting), the capability of ALOS to detect initial deforestation process. Even not in all the cases of recent deforestation, in some cases it will be certainly effective (in the point of view of detecting illegal activities, one effective result, even not the totality of illegal deforestations, is better than despite it in the proposition of the absolute totality). ALOS-PALSAR proved to be effective to detect recent deforestation activities in several cases.

Another point that should be stressed here is one of the main goals of this project, that is, to build-up capacity to use and analyse SAR imagery. The increasing results obtained during the development of the project, as well as, the increasing number of the availability of SAR images and the knowledge that was acquired from the joint group of K&C and transferred to other IBAMA's staff was a important motivation factor for IBAMA´s Remote Sensing activities. These results showed that an institutional and operational use of orbital SAR images for vegetation monitoring is feasible, as well as, the IBAMA became an reference in the monitoring environmental systems, in Brazil and outside Brazil.

II. Project Description

A. Relevance to the K&C drivers

III. IBAMA is the most important institution related to environmental protection in Brazil. The institution have about four thousand staff people and part is working on the law enforcement activities to combat illegal deforestation. The Remote Sensing Centre of IBAMA plays an important hole on training people on the use of remote sensing data and GIS capabilities to increase the effectiveness of the environmental protection action in the office and in the field. With the support of National Institute for Space Research (INPE), that has been 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.

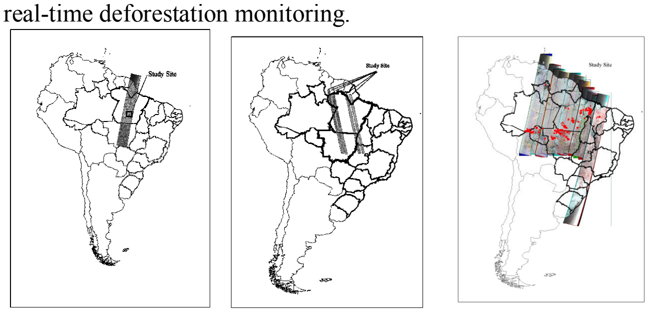
IV. The advances of SAR methodologies used to build-up operational systems to improve the monitoring of tropical vegetation was an important approach to contribute to the reduction of the carbon emissions as well as to the conservation of the tropical rain forests in Brazil. These forests play important hole on carbon and water cycles and are considered hotspots for biodiversity conservation. The achievements confirm the hole of the SAR for forest monitoring systems to complement the actual well-established but limited optical monitoring systems. The K&C science advisory panel [2] will contribute to the development of SAR methodologies that can potentially be used for other countries that want to establish SAR operational system to protect their tropical rainforests. On that purpose, in 2009, IBAMA started a joint effort with INPE, supported by Brazilian and Japanese Cooperation Agencies

(ABC and JICA), to promote a third countries training for African, South Asian, and South American countries.

A. Study sites

In the begging of this project two prototypes areas were analyze in the Brazilian Amazonian Rain Forest. Both areas were used to test primary methodology viability studies. On the Amazonian region four approaches were developed in scalable increasing on area and complexity. Finally the system were implemented for all the Amazonian region.

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*.

B. The hypothesis

Seasat, launched on 1978, was the first Earth-orbiting satellite that had the space borne synthetic aperture radar (SAR), L-band system onboard. The use of L-band orbital SAR images for vegetation analysis started with SeaSat data developed to the SIR-A,B and C missions that were followed by JERS-1 and more recent ALOS PALSAR systems.

The L-band SAR images have been related to the canopies, biomass estimation, and structure modeling. Luckman et 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 et al. [4] developed a model for the tropical forest stand structure using SAR data.

Sgrenzaroli et al. [5] have shown that on the published remote sensing literature, there are several Amazon forest mapping experiments actually dealing with single SAR satellite images (i.e. JERS-1 or European Remote Sensing – ERS-1/2), with focus on local-scale mapping. In this category, approaches based on visual inspection or automatic classification was investigated.

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

More recently, Almeida-Filho et al. [7] evaluated the potential use of orbital L-band JERS-1 SAR images 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. 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 georeferenced multitemporal 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 in 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. 2). 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 cloud-free images. ALOS-ScanSAR can be used to identify recent deforested areas and to reduce the interval between two observations.

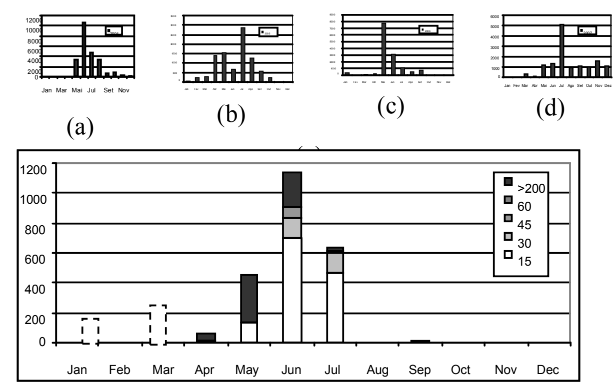


Figure 2 - Monthly distribution of DETER deforestation detection in area (km2). (a) 2004, (b) 2005, (c) 2006, (d) 2007, and (e) 2007 with the proportion of the each age per month in the beginning of the dry season. Dashed columns means hypothetic scenario of PALSAR complementary data, showing some deforestation that may be not able to detect during the rainy season.

C. Approaches

On the first approach, one strip of 2,730 km of length by 380 km of swath width, on wide bean mode 1 of ScanSAR images, with 100 per 100 meters resolution and HH polarization, of August 23^{rd}, 2007 was analyzed. In order to validate the ALOS detection, we selected the following scenes: Landsat-TM images (path 226, rows 64 and 65, overpass in September $2^{nd,}$, 2007 and path 225, rows 64 and 65, overpass in September 27^{th}, 2007) and CBERS images (path 164, rows 106 and 107, overpass in September 11^{th}, 2006). The purpose was 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 appear in PALSAR imagery. Then, the ScanSAR strip mode image was georectified and subset. DN image values were converted to the normalized radar cross section (σ^o), units 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 backscatter values were 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 σ^o values 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. 3).

(a) (b) (c)

Figure 3. The yellow lines are the DETER detection polygons, the red lines are the ALOS detection polygons while the pink areas corresponded to the PRODES polygons. (a) ALOS ScanSAR image ALOS K&C © *JAXA/METI* used with the defined threshold value and to identify the possible recent deforestation, (b) CBERS image from 2006 before the characterization of 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 from the first approach. Some of the highlighted areas (i.e., square shaped deforestation) were identified over fine bean images overlaid by PRODES 2007 and DETER from August to December of 2007 (Fig. 4).

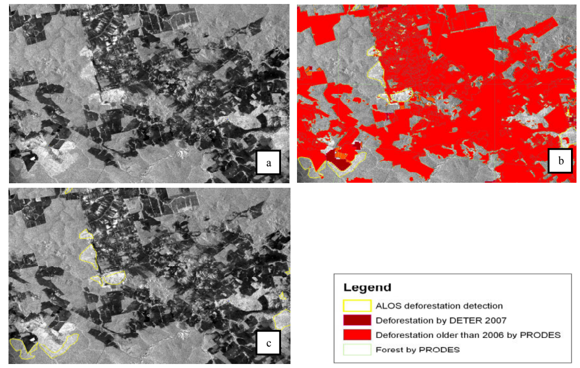
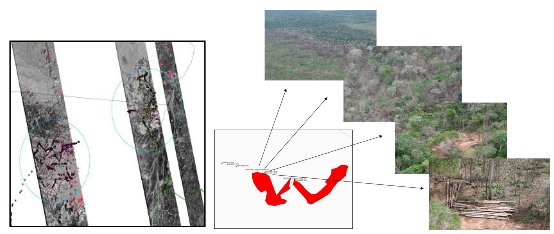


Figure 4. (a) ALOS PALSAR Fine Beam Single Mode (FBS) HH ALOS K&C © *JAXA/METI* with 50m resolution of December 2007, (b) ALOS PALSAR FBS overlaid by PRODES 2007 and accumulated DETER until December 2007, (c) ALOS PALSAR fine mode overlaid by the drawn polygons detected using PALSAR image.

Field activities were developed to check the identified polygons and two data collection on helicopters were done (Fig. 5). The increase in the intensity of the PALSAR images were confirmed was areas of disturbance of the forest structure and some failed trees were found.



(a) (b)

Figure 5. (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, the Amazonian region ALOS-ScanSAR images were used to build-up temporal color composites. This methodology was used together with visual interpretation inside of the detained areas were a fine were applied because of the illegal deforestation by the enforced law agents of IBAMA. Figure 6 shows an example of temporal color composite applied in one of the eleven strips that cover all the detained areas.

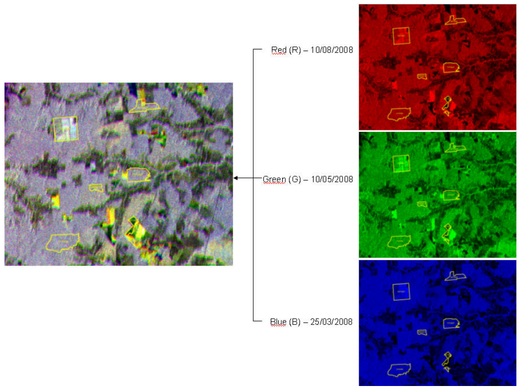


Figure 6. Temporal RGB composition using three ScanSAR strip images of three different dates were DN of images show changes with different colors ALOS K&C © *JAXA/METI.*

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

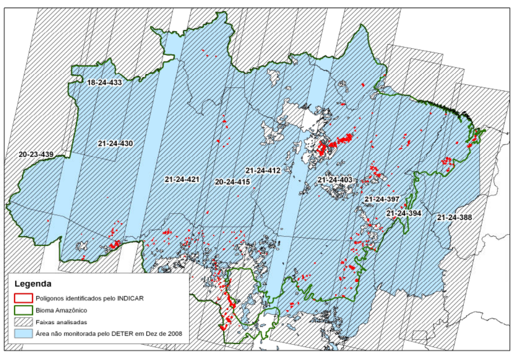


Figure 7. (a) ALOS-ScanSAR strips. Blue color = cloud cover on December by DETER monitoring system; red color = new deforestation detections by ALOS.

As shown on Fig. 7, the temporal composites were used to detect new deforestation where the optical system DETER cannot detect due to the presence of clouds from October to December. Few white areas represents the areas where optical monitoring systems were possible. Light blue areas represent the most of the Amazonian areas covered by clouds. Figure corresponds to the first ALOS cycle 24 covering whole Amazonia. Following the cycle 24, we obtained coverage from cycles 27 and 30 in order to obtain non-stop operational procedure. The system was named as INDICAR (*Indicador de Desmatamentos por Imagens de Radar*) which means Deforestation Indicator by Radar Images.

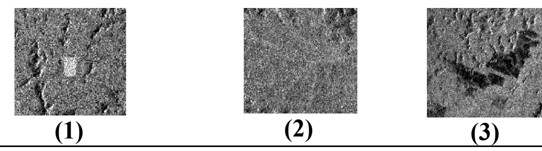
For the operational system, ALOS ScanSAR images are orthorectified using a calculated orbit in order to obtain faster image processing and to provide near real time data for law enforcement agents. They have been used to produce multitemporal color composition made with 2 images: an actual image and the same overpass of the previous cycle, using a software PALSAR Viewer developed by Dr. Makoto Ono. They are registered using an image correlation for best spatial matching. Next, polygons larger than 40ha are delimited using visual interpretation of the composites over a mask of old deforestation (PRODES, DETER, and old INDICAR).

V. RESULTS

On the first approach, DETER polygons were used to extract average values inside these areas. It was possible to recognize that most of older deforestations in the same year present low values compared with the very recent detections. Fig. 8 shows the average backscattering values obtained for old deforestations (maybe 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.

Figure 8. Comparison between very recent deforestation from DETER of the

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



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^o value for recent deforested areas was -5.315dB and the mean σ^o 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 from hilly 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 as 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 were 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 months of December 2007 and January 2008 were used to detect possible recent deforestation by visual interpretation based on the knowledge acquired on the first approach. Overlaying 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 following detection made by DETER from January to September of 2008. A set of 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 (Table 1).

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 (Fig. 9). As DETER is based on MODIS optical sensor, several detections cannot be detected when the specific region are covered by clouds. The increase of the coincidences from March to September of 2008 is old detections that occur before ALOS detections.

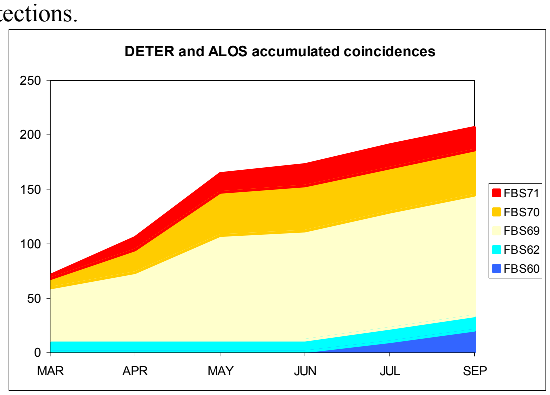


Figure 9. The accumulated coincidences between ALOS December 2007 and following DETER detection along 2008 year.

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 breakdown in a detained areas after received a fine by the IBAMA´s enforced law agent. Fig. 10 presents an example of change detection. This methodology still needs many field activities to determine the level of changes that ALOS PALSAR identifies and how it can be used by the law enforcement agents to return in the detained areas.

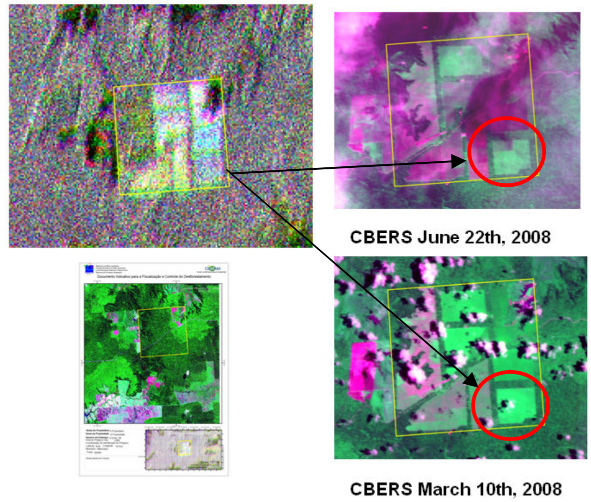


Figure 10. Upper left = ALOS ScanSAR temporal composites. Upper right = CBERS images used to confirm the changes detected by ALOS and an indicative of temporal changes in detained areas.

The beginning of operational results is 9 observations of all Amazonian region. The latest 6 cycles were consecutive and without temporal gap, which continues until now. It represents the beginning of the implementation of INDICAR system with the use of PALSAR data to identify new polygons of deforestation.

Table 2 presents the amount of polygons detected and corresponding area (km^2), considering that always we delete the polygons already detected by optical systems before SAR analysis. This means that all PALSAR detected polygons were not seen by optical data.

Table 2 – Amount of polygons detected by ALOS cycle and their respective area.

Cycle	Area km2	Number of Polygons
24	273	262
26-27	1251	430
28	38	32
30	226	137
31	87	77
32	114	88
33	125	113
34	84	65
35	28	46

Figure 11 shows the occurrence of INDICAR polygons over unmonitored area by optical systems, due to the presence of clouds. The cycle of acquisition of PALSAR images in each column and the cloud cover situation at the same time and on the months before (from the top to the bottom), the colored areas were covered by clouds and white areas were monitored by optical monitoring systems (minority).

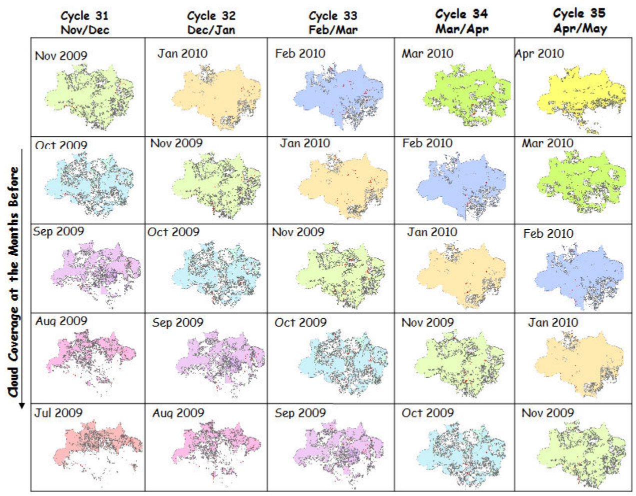


Figure 11 – Red spots represent the INDICAR polygons and the colored areas represent the cloud cover situation.

This figure gives an idea of the cloud persistence before the detection of the INDICAR new deforestation, and the understanding that clouds cause a time delay for single optical systems. Because of the persistence of the clouds, detected deforestation areas are delayed in optical systems. In some cases, there are regions that stay cloud covered by more than one year.

VI. Discussions

The mean σ^o value for recent deforested areas, preserved native forests and old deforested areas are similar to those found by other authors (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 et al. [7] noticed the importance of high quality georegistration on the several databases in order to implement an operational monitoring system.

To reach a successful operational system, JAXA provides ScanSAR images to IBAMA. This is essential for fast response system and for the comparison of two cycles images, and them with the old deforestation.

The results have shown that the deforestation detected by ScanSAR are detected by optical systems some months after.

VII. Conclusions

VIII. The beginning methodology, using a threshold to classify new deforested areas, has a very good effect to motivate IBAMA's remote sensing technicians (familiar with optical monitoring systems) that ALOS-PALSAR have a good potential to be use in satellite detection system for operational purposes. The second approach was the beginning of real use of ALOS-PALSAR data to produce indicative documents, and these documents were used and validated in the field by the law enforcement environmental agents. In the first approach, the repercussion was internally on the IBAMA's Remote Sensing Centre (CSR) and in the second approach the repercussion was on all IBAMA institution. The third approach was a director's demand.

IX. During the implementation of the INDICAR system, CSR was visited by many international missions interested on the satellite monitoring systems and its advances. This resulted on a third part training course, a joint effort of IBAMA and INPE, with support of JICA and ABC. With this initiative during this year and the next two years, countries from South Asia, South America and Africa, that have tropical rain forest, will learn about the Brazilian satellite monitoring systems. During the last year and this year, technicians from CSR were trained for the PALSAR image processing techniques and during this year the first course given in Portuguese by CSR for IBAMA people. It will become a part of the corporative courses and will appear as one of the scheduled IBAMA's courses on the next year.

X. The implemented system produces data that 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, decreases the time delays of deforestation detection by optical-based systems. As a result, the response time of the law enforcement environmental agents to combat illegal logging decreases.

XI. Two points need to be stretched here. One is that the recent deforestation detected are not totally detected in ALOS-PALSAR images. This partial detection are valuable to combat illegal deforestation because the information shows up before the conventional optical systems. To reach a maximum effectiveness of the satellite-base monitoring systems of tropical rainforests affected by clouds, the use of combined optical and SAR systems are mandatory.

XII. The second one is to increase the knowledge of the SAR images. For that purpose, training and published papers are necessary, but in practical terms, a real demand is the best way to understand SAR image interpretation. Regarding this subject, JERS-1 and ALOS play an important hole in terms of provision and accessibility of great amount of images and some products that support the use of SAR in the world. With the constant increase on the number of SAR satellites including ALOS-2, the SAR images will be used by more people.

XIII. The approaches revealed that simple methodologies can be applied to build-up robust operational system and that there are scientific knowledge to support this systems. The challenge is to turn it as popular as the optical image are for most of people.

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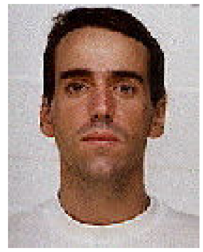

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