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Evaluation of multi-temporal JERS-1 SAR images as an operational mean to monitor deforestation in the Amazônia

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Abstract. Using a test-site located within the "Arc of Deforestation", this article discusses the potential use of JERS-1 SAR images as a basis for an operational program to monitor deforestation in the Amazônia. For the purpose of indicating only new deforested areas, we masked out deforestation previously mapped by PRODES Project at INPE. Normalized Difference Index (NDI) and false-color composites derived from multitemporal radar images were analyzed. Results were compared with information derived from the interpretation of corresponding multitemporal Landsat-5 TM images. Unambiguous detection and mapping of new deforested areas using JERS-1 SAR multitemporal data proved to be possible only when the entire deforestation process (slash, burning and clearing) had been concluded. This limitation strongly claims for the necessity of additional investigation on the real effectiveness of SAR data as basis for a regional-scale operational program to monitor deforestation in the Amazônia.

Key-word: Deforestation, Radar imagery

1. Introduction

Over the past two decades the Instituto Nacional de Pesquisas Espaciais-INPE has been monitoring annual gross deforestation in the Brazilian Amazônia, through the "Monitoring the Amazon Gross Deforestation" (PRODES) Project. According to PRODES data (INPE, 2001; 2002), gross deforestation in the region reached approximately 630,000km^2 up to 2002. The "cycle of deforestation" starts with the implantation of the cattle farms, which are gradually replaced by soybean plantations, thus pushing deforestation for new areas of primary forests.

Up to now, the study conducted by INPE has been based only on images provided by the family of the Landsat satellites. At the 16-day revisit frequency of Landsat, at least one free-cloud scene has been annually obtained along the 'arch of deforestation", the most critical region of deforestation, in parts of the Maranhão, Tocantins, Pará, Mato Grosso and Rondônia states. However, according to study by Asner (2001), it is highly improbable to obtain annual Landsat scenes (or equivalents) with 10% or less of cloud covers for the northern half of the Amazônia. This means that annual monitoring based on optical images will be increasingly constrained as the occupation moves toward Central Amazônia.

These data show that cloud cover highly challenges the requirements for an operational deforestation surveillance program at an Amazonian scale based only on optical images. Synthetic Aperture Radar (SAR) images seem to be a suitable tool to cope with these requirements, as SAR data can be acquired consistently on a repetitive basis regardless weather conditions. To ensure sensitivity to the vegetation structure, L-band SAR is preferred (Saatchi et al., 1977; Rosenqvist et al., 2000; Angelis et al., 2002).

New opportunities to use this kind of data will be open with the 2005 launch of the Japanese Advanced Land Observing Satellite (ALOS), which will carry PALSAR (Phased Array-type L-band Synthetic Aperture Radar) system, a multi-polarization radar system that will be the successor of the first Japanese Earth Resources Satellite (JERS-1).

As a contribution to this relevant theme, this study presents a perspective of using radar imagery as a basis for an operational surveillance program to monitor deforestation in the Amazônia, in the context of a project like PRODES.

2. Materials and Methods

The study area, with approximately 5,300 km^2, is located in the border of the states of Mato Grosso and Pará (Figure 1), one of the most critical regions of deforestation in the Amazônia.

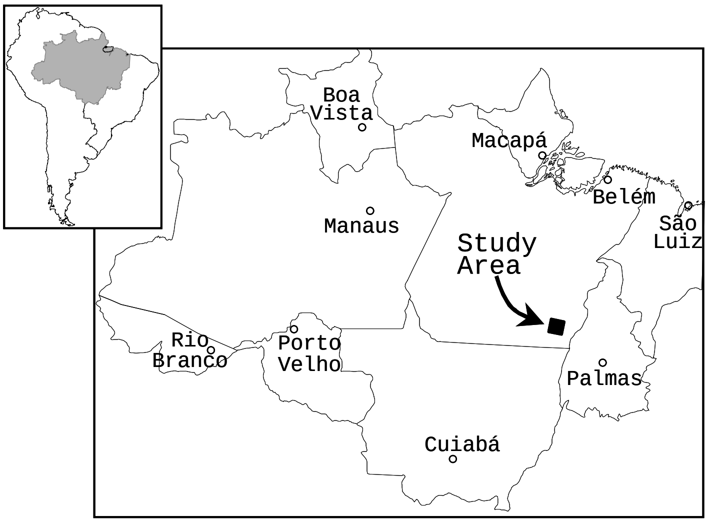

Figure 1. Location of the study area in the Amazônia.

Table 1 summarizes the JERS-1 SAR and Landsat-5 Thematic Mapper (TM) scenes used in this study. SAR data were processed to standard level 2.1, i.e. 16 bits ground range, 3 looks and a pixel spacing of 12.5 x 12.5 m. Based on satellite ephemeris, the 1993 TM scene was geometrically rectified to the Universal Transverse Mercator (UTM) coordinate system. The other TM images were subsequently co-registered relative to this scene. In all cases the co-registration accuracies were better than 0.8 pixels. After this, SAR images were co-registered relative to the TM images and resampled to a same spatial resolution (pixel 30 x 30 m).

Table 1. JERS-1 SAR and Landsat-5 TM images used in this study.

JERS-1 SAR Images (path395/row315)	Landsat-TM Images (path224/row66)
20-March-1993	27-July-1993
07-March-1994	15-August-1994
13-October-1994	01-July-1995
30-October-1996	03-July-1996

Due to the complexity of the radar return that sometimes made difficult the discrimination between disturbed and non-disturbed areas, a Normalized Difference Index (NDI) technique involving scenes acquired at different dates was utilized as an attempt to enhance areas of incremental change in deforestation from one year to another (*e.g.* from 1993 to 1994). The following equation expresses the adopted procedure:

$$NDI = \frac{(DATE1 - DATE2)}{(DATE1 + DATE2)},$$

where,

NDI = normalized difference index;

*DATE*1 and *DATE*2 = multi-temporal JERS-1 SAR imagery.

In this procedure, DATE1 always indicates a SAR image acquired earlier than DATE2. For display purposes, NDI values (-1 to +1) were re-scaled to the interval between 0 (black) and 255 (white). Assuming that backscattering from a deforested area is expected to be lower than from a forested terrain, NDI values between zero and +1 indicate deforested areas, while values from zero to –1, indicate regrowth process. Values close to zero mean no changes have occurred over the time of acquisition of both images.

To complement the NDI SAR analysis, detection of land cover changes using SAR standard (level 2.1) backscatter data was also undertaken. Two-date false-color composite images were then generated for the 1993(March)-1994(October) and 1994(October)-1996(October) periods.

Corresponding multitemporal TM images were used to evaluate the performance of the JERS-1 SAR images to map new deforested areas. They were processed using region segmentation, followed by non-supervised classification and image edition techniques (Almeida-Filho and Shimabukuro, 2002). Additionally, spectral mixing modeling techniques (Adams et al., 1995) were used to generate vegetation, soil, and shade fraction images, used to estimate the percentage of these scene components in the deforested areas. Such information allowed inferring the dynamic of the deforestation process over time.

Considering that our study is focused only on the detection and mapping of new areas of deforestation, a mask was superimposed to the images to eliminate areas deforested up to July 1993, since our interest was to map increment in deforestation from 1993 on. This procedure was necessary because NDI SAR images capture land use changes (*e.g.* new slash in areas of vegetation regrowth) which otherwise could be misinterpreted as new deforestation over the period covered by the images. These effects showed to be more severe when NDI SAR involved images acquired in different seasons (rainy and dry seasons, March and October, respectively), due to the combined effect of soil moistures and different stages of the vegetation regrowth.

3. Results and Discussion

Landsat TM time-series showed that up to July 1993 approximately 1,667km^2 of primary forest had already been destroyed in the study area. An increase of approximately 68km^2 was detected from July 1993 to August 1994, and approximately 53km^2 from August 1994 to July 1996, indicating that about 90% of the deforestation over this period occurred between 1994 and 1995. Figure 2 is a TM color composite [TM5(R)+TM4(G)+TM3(B)] of the scene acquired in August 1994. New deforested areas are indicated in A, B, C, D, E, F, and G. By the time of the image acquisition, areas A, B, C, and D were still burning, as denoted by the dark blue shades in the color composite. Meanwhile, in the areas E, F, and G, the entire process of deforestation (slash, burning, and clearing) had already been completed, as indicated by significant soil exposures (shades of magenta in the color composite). Fraction images of the 1994 scene indicated that these areas comprised approximately 65% of bare soils and 30% of green vegetation cover, with minor quantities of shading.

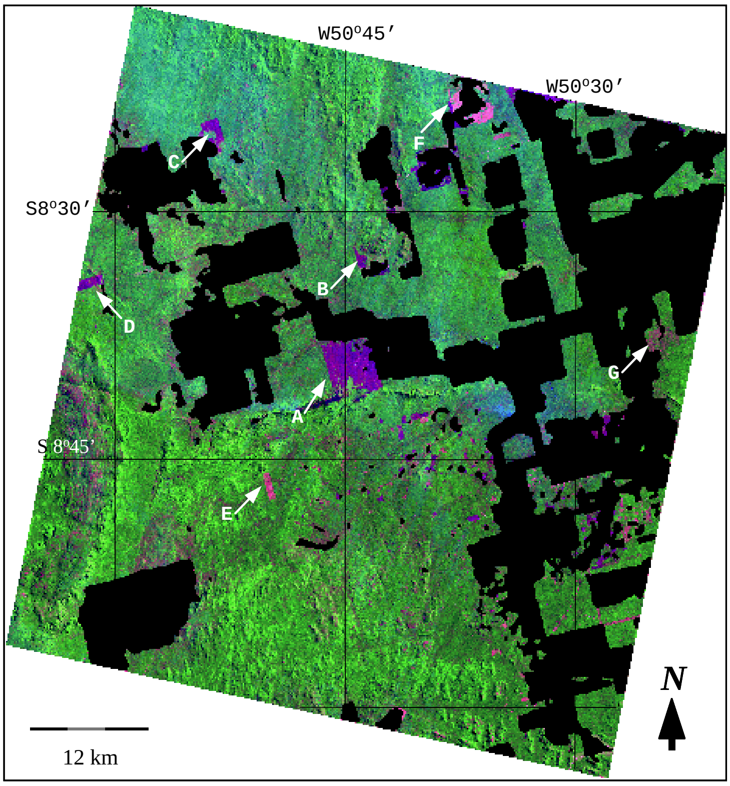

Figure 2. Deforested areas (arrows) indicated in the Landsat-5 TM color composite (TM3B+TM4G+TM5R) acquired in August 1994. Black mask covers areas deforested up to July 1993. Letters refer to areas discussed in the text.

Figure 3 is the NDI 1993(March)-1994(October) SAR image. Comparative visual analysis indicated that only the areas where the deforestation process had already been completed (areas E, F, and G) were highlighted as bright gray shades. On the other hand, although slash and burning had already been occurred in the areas A, B, C, and D by the time of acquisition of the SAR in October 1994, these areas were not identified in the 1993-1994 NDI SAR image. Our interpretation is that, by the time of the SAR image acquisition in October 1994, cleaning of these slashed areas had not been completed yet, with stems and branches still remaining on the ground, so producing enough radar return to cause these deforested areas to be missed in the NDI image.

In the particular case of the area A, analysis of the TM scene acquired in 1995 showed a significant vegetation regrowth in that area (approximately 75% of the vegetation cover in fraction image), indicating that it had been abandoned after first slash and burn. However, TM scene acquired in 1996 showed that it had been cleared up again, now showing about 75% of soil exposure.

Areas deforested in 1994 were detected in the 1994(October)–1996(October) NDI SAR image (Figure 4), i.e. two years after slashing. This occurred because the entire clearing process had already been concluded in these areas by the time of the 1996 image acquisition. New areas deforested and cleared during this period are highlighted in the southeast part of this scene.

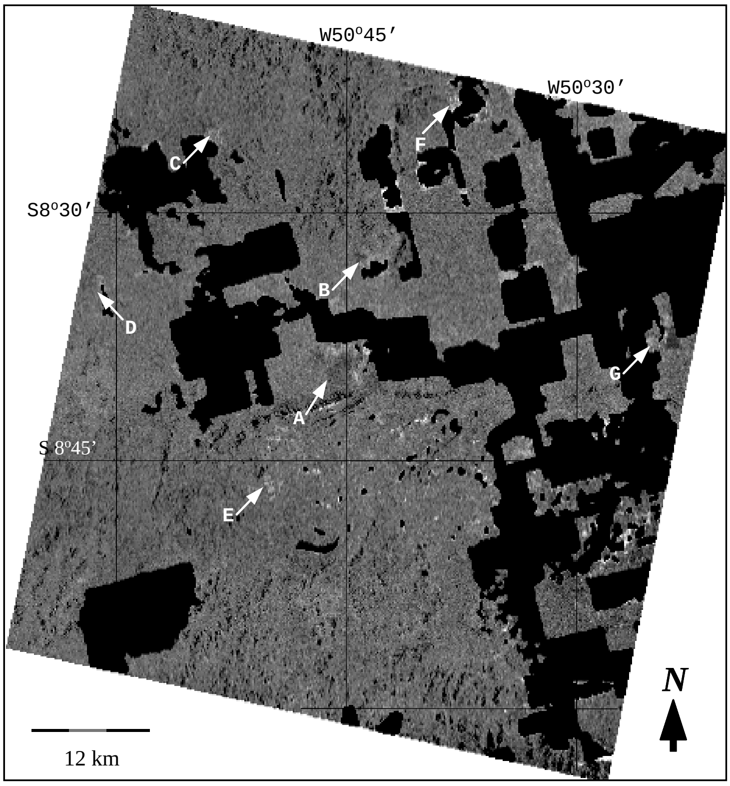

Figure 3. JERS-1 SAR NDI image [1993(March) – 1994(October)] indicating in bright shades areas deforested over the period. Black mask covers areas deforested up to July 1993. Letters refer to areas discussed in the text.

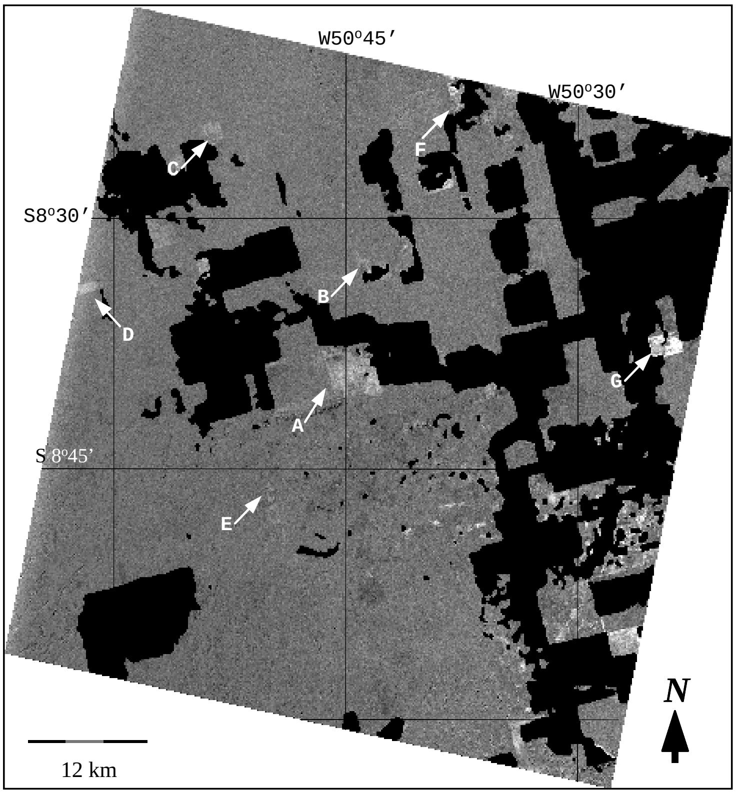

Figure 4. JERS-1 SAR NDI image [1994(October) – 1996(October)] indicating in bright shades areas deforested over the period. Black mask covers areas deforested up to July 1993. Letters refer to areas discussed in the text.

Figure 5 shows the 1993(March)/1994(October) false-color composite, where the 1993 image is displayed in red and 1994 in green and blue. In this scene, areas subject to a decrease in backscatter between the two dates – generally deforestation – consequently appear in red color, while areas of increased backscatter levels show up in cyan, indicating some kind of change in these areas. Increased backscatter levels may be related to deforested areas not completely cleared yet (*e.g.* area A), to seasonal soil moisture variation, or to regrowth in areas previously deforested.

In analogy with the NDI SAR results, some plots in the study area, which are indicated as deforested between 1993-1994 in the TM image (Figure 2), do not – as would be expected – show up in red color in Figure 6 (areas A, B, C, and D). Rather, they appear in cyan, which thus indicates an increase in backscatter. As previously discussed, by the time of the acquisition of the SAR image in October 1994, the entire clearing process in this area was not completed yet. Branches and stems lying on the ground were the probable cause for the strong radar return for this area. On the other hand, plots where the entire deforestation process was completed (areas E and F) appear in red, in accordance with the Landsat-5 TM interpretation and with NDI enhanced information.

In the 1994(October)/1996(October) false-color composite (Figure 6), all the deforested areas over this period are indicated by decrease in radar return (red shades), because the entire deforestation process (slash, burn, and clearing) had already been completed.

Results show that multitemporal false-color composites images indicate land cover changes associated with deforestation either as a backscatter decrease or increase, depending on the terrain characteristic of the deforested plots. In the used color composites, decrease in backscatter always represents deforested areas over the period embraced by the images. Changes represented by increased backscatter on the other hand, proved to be more complex and could in certain cases be associated with deforestation, and in other cases by regrowth in previously deforested areas. Multi-temporal composite images nevertheless proved useful for visual detection of changes, whether the changes resulted in a backscatter increase, or decrease, and it can thus be used as a tool to support manual interpretation techniques.

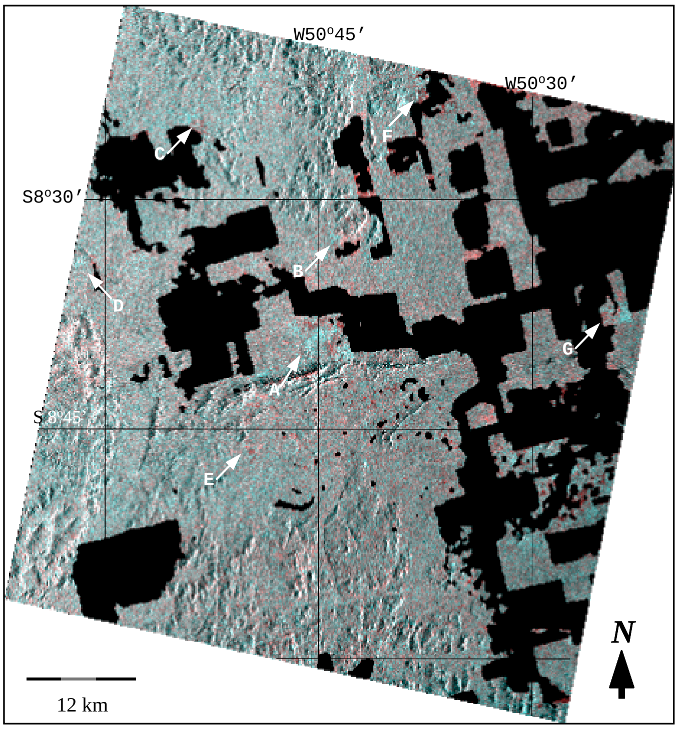

Figure 5. JERS-1 SAR false-color composite [March 1993(R)+October 1994(GB)]. Black mask covers areas deforested up to July 1993. Letters refer to areas discussed in the text.

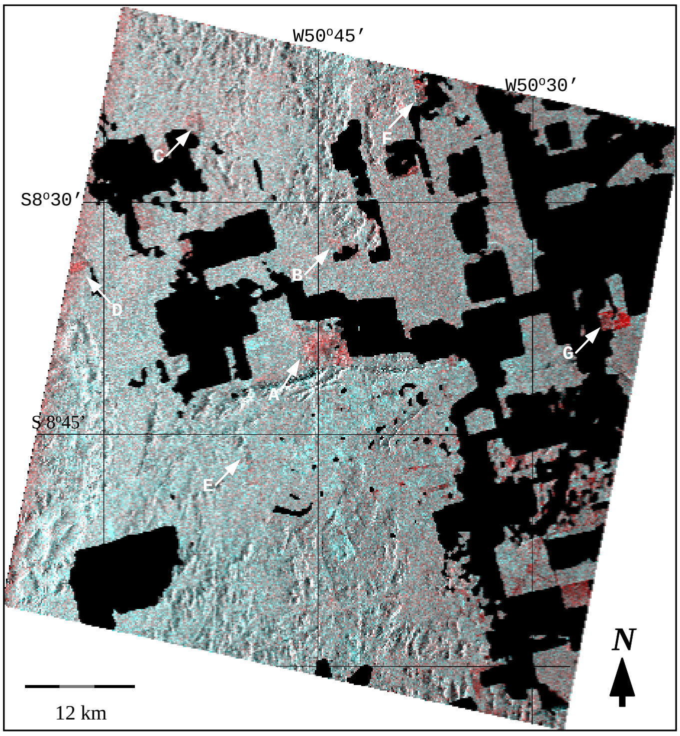

Figure 6. JERS-1 SAR false-color composite [October 1994(R)+October 1996(GB)]. Black mask covers areas deforested up to July 1993. Letters refer to areas discussed in the text.

4. Conclusions

The performance of both approaches showed to be dependent on the stage of deforestation process. Unambiguous detection of deforested areas using SAR multitemporal images enhanced by NDI techniques showed to be possible only if the entire clearing process, which involves slash, burn and removal of trunks and branches, had already been concluded. Multi-temporal SAR composite images proved useful for visual detection of changes, and it can thus be used as a tool to support visual interpretation.

These results indicate the need of additional investigation to clearly define the real effectiveness of using SAR data as the basis for a regional-scale operational program to monitor deforestation in the Amazônia. Additionally, the development of reliable algorithm for SAR image automatic classification is still an essential requirement if radar is to be used as the basis for an operational program to monitor land use in a region of continental dimensions like the Amazônia.

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