Revista Brasileira de Cartografia (2014) N⁰ 66/3: 451-462
Sociedade Brasileira de Cartografia, Geodésia, Fotogrametria e Sensoriamento Remoto
ISSN: 1808-0936

# ASSESSMENT OF DEFORESTATION DETECTION BY REMOTE SENSING METHODS IN TOCANTINS STATE, BRAZIL, FROM 2006/2007 TO 2010/2011

*Avaliação da Detecção de Desmatamento por Métodos de Sensoriamento Remoto no Estado do Tocantins, Brasil, entre 2006/2007 e 2010/2011*

**Gustavo Maximiano Junqueira Lazzarini[1], Gudmar Regino Dias Magalhães[1], Flávia Imaculada da Silva[1], Edivaldo Dias Barbosa[1] & Emerson Figueiredo Leite[2]**

**[1]Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis – IBAMA**
**Superintendência no Tocantins**
402 Sul, conjunto 01, lote, 6-A, CEP 77021-622, Palmas – TO, Brasil
gmjlazzarini@bol.com.br; gudmar.dias@gmail.com; flaviaimaculada@yahoo.com.br;
aestiva2@hotmail.com

**[2]Universidade Federal do Mato Grosso do Sul - UFMS**
**Departamento de Geografia**
Rua Oscar Trindade de Barros, nº 740, Aquidauana – MS, Brasil
emerson.leite@ufms.br

***Recebido em 03 de Junho, 2013/ Aceito em 05 de Fevereiro, 2014***
***Received on June 03, 2013/ Accepted on February 05, 2014***

## ABSTRACT

Amazonia and Cerrado are the largest Brazilian biomes that have been affected by the clear-cutting of native vegetation. This study analyzed the deforestation in Tocantins state in Brazil from 2006/2007 to 2010/2011. Deforestation was measured using the DETER system (conducted by National Institute of Spatial Research, INPE) which uses data from Moderate Resolution Imaging Spectroradiometer sensor (MODIS; 250-m spatial resolution) and the results were compared with detections pointed out by visual interpretation of medium spatial resolution images (CBERS 2, Landsat 5 and Resourcesat). Out of the 4,278,372 ha area visually monitored by interpretation of images (places prevailed by the Cerrado's biome), we demarcated 842 indicatives of deforestation totaling 60,098 ha. Out of the 3,963,037 ha area monitored by the DETER system (places prevailed by the Cerrado's biome), we found 114 alerts accounting for 12,489 ha. From those detections, 20.9% were inspected in field, agreeing to deforestation as pointed out by 72.8% of the indicatives by visual interpretation and 81.5% of the DETER alerts. The remaining indicatives and alerts were commission errors by confusion with old deforestation, native vegetation, and burnt area. We estimated a real deforestations of 0.92 ha/km² in the region of the Cerrado biome predominance (monitored by visual interpretation of images) and 0.27 ha/km² in the area of Amazonia biome predominance (covered by the DETER monitoring). Features of each monitoring method highlighted the higher vulnerability of Cerrado in relation to Amazônia with respect to deforestation.

**Keywords:** Deforestation, Cerrado, Amazonia, DETER, Visual Interpretation, Remote Sensing, Monitoring.

## RESUMO

Amazônia e Cerrado são os maiores biomas brasileiros e têm sido afetados pela remoção da vegetação nativa. Este trabalho analisou a detecção de desmatamento no Estado do Tocantins, Brasil, entre 2006/2007 e 2010/2011. O desmatamento foi mensurado usando dados do sistema DETER (conduzido pelo Instituto Nacional de Pesquisas Espaciais, INPE), que utiliza imagens do sensor MODIS (Moderate Resolution Imaging Spectroradiometer, resolução espacial de 250 m). Esses dados foram comparados com as detecções oriundas de interpretação visual de imagens de satélites de média resolução espacial (CBERS 2, Landsat 5 e Resourcesat). Em 4.278.372 ha monitorados por interpretação visual das imagens (locais com predomínio do bioma Cerrado), foram demarcados 842 indicativos de desmatamento que totalizaram 60.098 ha. Nos 3.963.037 ha monitorados pelo DETER (locais com predomínio do bioma Amazônia), ocorreram 114 alertas de desmatamento que somaram 12.489 ha. Dessas detecções, 20,9% foram vistoriadas em campo, confirmando-se desmatamento em 72,8% dos indicativos detectados por interpretação visual, bem como em 81,5% dos alertas DETER. As demais áreas corresponderam a erros de comissão, por confusão com desmatamentos antigos, vegetação nativa e queimadas. Estimou-se desmatamento real de 0,92 ha/km² na área predominantemente bioma Cerrado (monitorada por interpretação visual de imagens) e de 0,27 ha/km² na área predominantemente bioma Amazônia (abrangida pelo monitoramento DETER). Apesar das peculiaridades de cada método, foi clara a maior vulnerabilidade do Cerrado em relação à Amazônia.


**Palavras chave:** Desmatamento, Cerrado, Amazônia, DETER, Interpretação Visual, Sensoriamento Remoto, Monitoramento.

## 1. INTRODUCTION

Amazonia and Cerrado are the first and second largest Brazilian biomes, respectively. They have faced high level of destruction of native vegetation, mostly to introduce crops and pastures (NEPSTAD *et al.*, 1997; FEARNSIDE, 2001). The Amazonia biome includes Acre, Amapá, Amazonas, Mato Grosso, Maranhão, Pará, Rondônia, Roraima, and Tocantins States. The biome hosts a rich but not well-known biodiversity (KIER *et al.*, 2005; PERES, 2005) and a hydric supply of global significance (MULLER-KARGER *et al.*, 1988). It plays an essential role in the weather balance (SILVA *et al.*, 2008); however, it suffers from dilemmas with respect to its conservation (FEARNSIDE, 2003). Cerrado, the Brazilian neotropical moist savanna is the second Brazilian biome in length, with 204,7 millions of hectares encompassing Bahia, Goiás, Maranhão, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Paraná, Piauí, São Paulo, and Tocantins States (SANO *et al.*, 2010); it covers about 24% of the Brazilian territory (IBGE, 2011). Cerrado is considered hotspot for conservation of biodiversity because of the exceptional concentrations of endemic species and exceptional loss of habitat therein (MYERS *et al.*, 2000). In addition, it offers significant biodiversity by highlighting that six out of the eight largest Brazilian watersheds (Amazonic, Araguaia-Tocantins, North-Northeast Atlantic, São Francisco, East Atlantic, and Paraná-Paraguay) have their sources in Cerrado (LIMA, 2011; WANTZEN, 2006). Furthermore, similar to the fate of Amazonia, deforestation in Cerrado can cause increase of frequency and duration of the dry season. Such a weather change can compromise the local weather and ecosystem (COSTA & PIRES, 2010).

Tocantins state is located in the central part of Brazil, and it was originally covered by Cerrado (92%) and Amazonia (8%) biomes (IBGE, 2011). A survey in 2002 showed that 79% of the original land in Tocantins state is still preserved (SANO *et al.*, 2010), making it one of the largest remainders of that biome. The rest of the native vegetation of Tocantins belongs to the Amazonia biome (IBGE, 2011). More recently, Tocantins native vegetation has faced deforestation for the purpose of grain production (FINCO & DOPPLER, 2010).

Remote sensing is one of the most recommended techniques to perform regional monitoring of a land cover (ACHARD *et al.*, 2010), including to assess deforestation. Programs like PRODES (Amazonia Deforestation Monitoring Program) and SIAD (Integrated System of Deforestation Alert) were developed to systematically monitor the Brazilian land cover using optical remote sensing data (CÂMARA *et al.*, 2006; FERREIRA *et al.*, 2008). Another project, the DETER, is conducted by National Spatial Research Institute (INPE) and uses data from MODIS sensor to quickly and near-precisely detect deforested areas in real-time (SHIMABUKURO *et al.*, 2006). Synthetic aperture radar (SAR) data have also been incorporated as they are unaffected by the presence of clouds during their data acquisition process (INPE, 2008). The three abovementioned programs monitor Amazonia only. Unlike others Brazilian biomes like Amazonia, Mata Atlântica and Pantanal, Cerrado is not acknowledged by the Brazilian Constitution (ALVARENGA, 2010; JURAS, 2013; RATTER *et al.*, 1997).

This study analyzed the detection of deforestation in places from Tocantins state issued by the visual interpretation of remote sensing images and by the DETER alerts. The features of the results issued by both the methods have been compared among them and among the studied regions.

## 2. METHODS

The study have employed data and resources from Brazilian Institute for Environment and Renewable Natural Resources (IBAMA) in Tocantins State's.

### 2.1 Search for deforestation by visual interpretation

Deforestation polygons were detected by Geoprocessing Bureau from Brazilian Institute for Environment and Renewable Natural Resources (IBAMA) in Tocantins State's Department to schedule inspection operations. They were used images from CBERS 2 and 2B, Landsat 5, and Resourcesat P6 satellites, available at INPE website (http://www.dgi.inpe.br/CDSR). The images were composed in RGB color bands (342 or 234 to CBERS and 543 to Landsat and Resourcesat) and were georeferenced based on tracking files acquired by GPS during the IBAMA's surveillance activities. The deforestation detection was performed by visual interpretation using a 1:50,000 scale. The images were examined with the "swipe layer" tool from the ArcGIS™ 9.1 geographical information system software package. The said tool allows dragging to make observation underneath the selected images. The places visually interpreted as removal of native vegetation were delimited using the editor toolbar from the same software and were classified as deforestation indicatives polygons.

Deforestations occurred between 2007 and 2011 (corresponding start and finish dates are shown in Table 1) were detected in 8 search regions encompassing 4,278,372 ha (Figure 1). These regions were defined by the Control and Surveillance Division from the Tocantins state IBAMA's that employed the data in surveillance activities during 2010 and 2011. The institution regarded factors like annual work planning, availability of images, knowledge of the field, infrastructure, access, and others for selection of the regions.

### 2.2 DETER alerts

The DETER alerts are forwarded from INPE to IBAMA to verify possible environmental infractions *in loco*. The features of alerts sent between 2006 and 2010 were analyzed.

### 2.3 Confirmation of the deforestation

The deforestation indicatives and the DETER alerts were inspected in the field by surveillance teams during 2010 and 2011. After field inspection, the areas were reclassified in four classes: 1. deforestation, when the native vegetation had been clarified during the analyzed period; 2. old deforestation, when there was no deforestation evidence and the place features were from anthropic consolidated use; 3. native vegetation; and, 4. burnt area, when the native vegetation was not suppressed, but there were forest fire features.

In the cases in which the original polygon contained more than one reclassification category, the category were subdivided and resized according to the limits detected in the field.

The two detection methods were assessed by the overall accuracy (G), which is the ratio of the true and total inspected area, where deforestation was considered true (Equation 1). The others classification (old deforestation, native vegetation, and burnt area) were accounted as commission errors. The confidence interval was estimated at G to 95% of probability, and was employed to calculate the estimated total deforestation in each monitored area (Equation 2) (CONGALTON *et al.*, 1983; MORISETTE & KHORRAM, 1998; FOODY, 2008; FOODY,

Table 1: Satellites overpasses features utilized for the deforestation search by image's visual interpretation

| Region | Sensor | Paths/rows | Date | |
|---|---|---|---|---|
| | | | Start land cover | Final land cover |
| I | Landsat 5 TM | 221/66 | 23/05/2006 | 23/09/2010 |
| II | Landsat 5 TM | 222/68 | 15/06/2006 | |
| | Resourcesat LISS3 | 326/85 | | 07/02/2011 |
| III | Landsat 5 TM | 222/65 | 15/06/2006 | 01/11/2010 |
| IV | Landsat 5 TM | 223/64; 223/65 | 09/08/2006 | 21/09/2010 |
| | | 222/65 | 18/08/2006 | 13/08/2010 |
| | | 222/64 | 17/07/2006 | 14/09/2010 |
| V | Landsat 5 TM | 222/67 | | 12/05/2011 |
| | CBERS 2 CCD | 159/112 | 10/07/2006 | |
| VI | Landsat 5 TM | 222/67 | 21/08/2007 | 28/05/2011 |
| VII | Landsat 5 TM | 223/67 | 12/10/2006 | 17/04/2011 |
| VIII | Resourcesat LISS3 | 326/86 | | 07/02/2011 |
| | Landsat 5 TM | 223/69 | 06/06/2006 | |

2009).

$$G = \frac{t}{n} \quad (1)$$

where:
G = overall accuracy
t = field true
n = total inspected

And

$$G - 1.96\sqrt{G\frac{(1-G)}{n}} < G < G + 1.96\sqrt{G\frac{(1-G)}{n}} \quad (2)$$

where:
G = overall accuracy
n = total inspected

## 2.4 Analyzed features

The potential and the confirmed deforestation data were analyzed and faced by extention and by number of polygons. Their relative incidence, or concentration, was studied regarding their number or area on each 1,000 km² of searched area. Thereby, they could be done comparisons among the different regions and methods with proportional units.

## 3. RESULTS

There were presented results of 956 polygons detected by remote sensing and the results of the 200 from those that were inspected in field.

## 3.1 Deforestation by visual interpretation

A total of 842 deforestation indicatives (60,098 ha) were detected (Table 2), meaning 19.68 indicatives/1,000 km², performing 1.40 ha/km² potentially deforested, with an average of 71.38 ha size. The region II presented the smallest and the most homogeneous indicatives, while the regions I and IV presented the largest deforested areas.

The regions VII and VIII presented the highest proportions of potentially deforested areas at 3.09 and 2.36 ha/km², respectively, while the regions V, VI, and IV showed the smallest proportional quantities at 0.63, 0.69, and 0.94 ha/km², respectively; all regions showed up to 30% of the values from the most potentially deforested region.

Region VIII showed the highest fragmentation with 61.11 indicatives/1,000 km². This is almost the double of the observation for region VII (38.68 indicatives/1,000 km²) and almost nine times the observation for region V, which was the least fragmented of all regions (6.91 indicatives/1,000 km²).

## 3.2 DETER alerts in Tocantins state, Brazil

Brazil is considered a worldwide reference in the forest monitoring with regards to use of remote sensing (FULLER, 2006; KINTISCH, 2007). In Tocantins state, the PRODES encompasses the Amazonia biome (2,485,056 ha) and a little (1,477,981 ha) of the Cerrado biome (IBGE, 2011). Otherwise, a large remnant

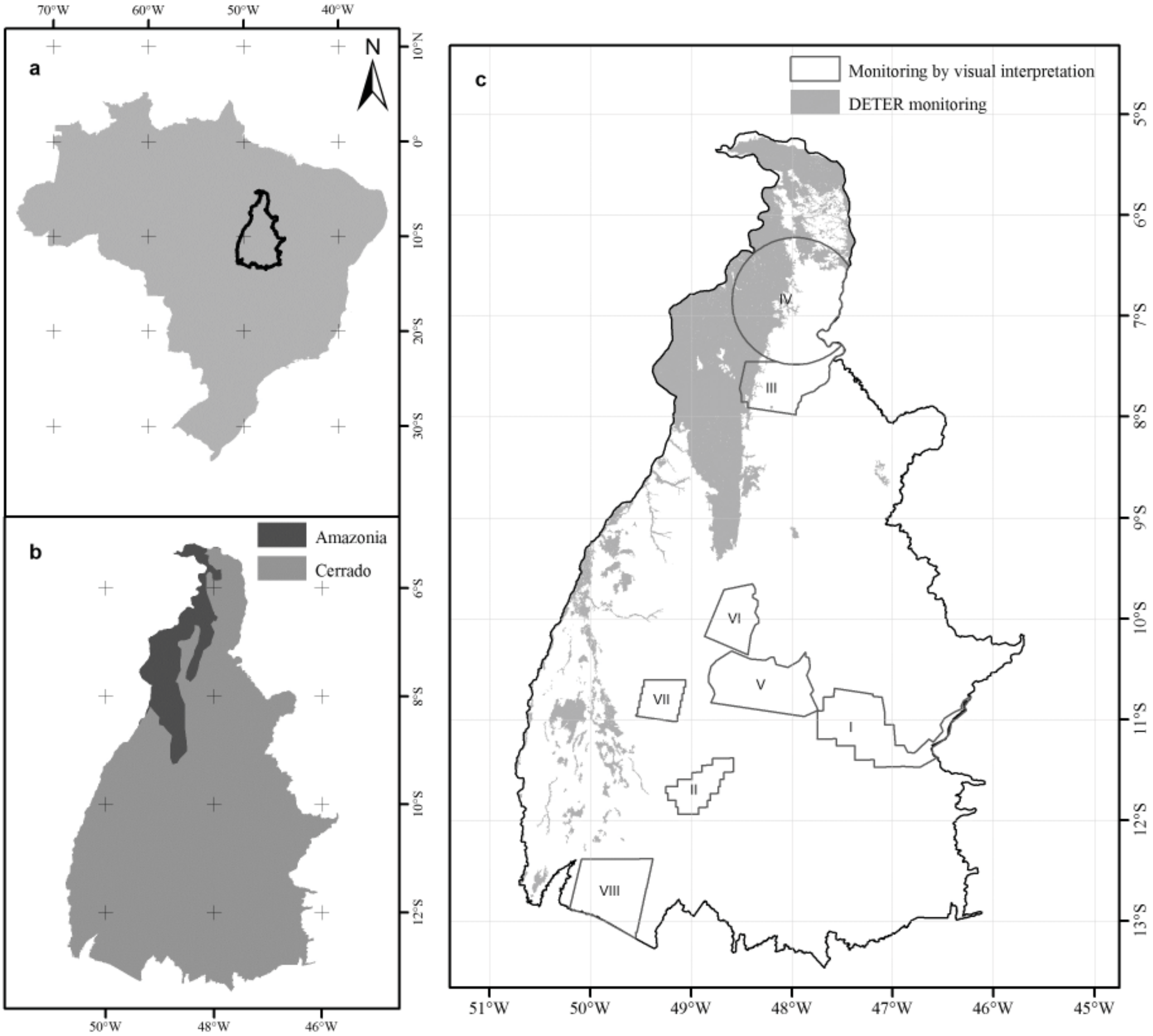


Fig. 1 - Map of the study area. a) Tocantins state in central Brazil. b) Amazonia and Cerrado in Tocantins state. c) Deter monitored area and analogically monitored area.

of 23,874,569 ha of Cerrado has not been officially monitored.

From 2006 to 2010, a total of 114 DETER alerts were sent, totaling 12,489 ha of probable deforestation (Table 2). This indicates 2.88 alerts/1,000 km², performing 0.32 ha/km² potentially deforested average size of 109.56 ha (range 6.40–2,468 ha).

### 3.3 Visual interpretation versus DETER monitoring

The DETER alerts-monitored area ratio (2.88 alerts/1,000km²) was smaller than the visually interpreted area ratio as deforestation indicatives (19.73 indicatives/1,000 km²). The area monitored with DETER (0.32 ha/km²) was smaller than that detected by visual interpretation (1.40 ha/km²). The minimum area pointed out by DETER was 6.40 ha, amounting to 18 times the size of the smallest indicative. On an average, the detected region was DETER was 109.56 ha and the analogical was 71.38 ha.

The DETER monitoring and monitoring by visual interpretation intersected at nearly 714,153 ha in the regions III and IV (Figure 1). The intersected area held 12 DETER alerts (3,771 ha) and 82 indicatives (8,860 ha).

The deforestation areas detected by both the methods overlapped only with 209 ha from 3 alerts inserted on 2 indicatives, encompassing 789 ha. Thus, 3,561 ha area classified under potential deforestation by DETER were visually interpreted as being no deforestation area, while 8,638 ha from area visually classified as deforestation was not pointed by DETER.

### 3.4 Validation data

The detections of deforestation were

Table 2: Features of potential deforestation detected in each region monitored by visual interpretation and pointed by deter in Tocantins state

| Region | Monitored area (km²) | Potential deforestation number | Total area (ha) | Average area (ha) | Highest area (ha) | Smallest area (ha) | Fragmentation (number/1,000 km²) | Concentration (ha/km²) |
|---|---|---|---|---|---|---|---|---|
| I | 6,305.88 | 80 | 14,065 | 175.81 | 1,267 | 5.12 | 12.69 | 2.23 |
| II | 2,265.16 | 77 | 2,429 | 31.55 | 223 | 0.34 | 33.99 | 1.07 |
| III | 4,433.45 | 110 | 6,552 | 59.57 | 676 | 3.05 | 24.81 | 1.48 |
| IV | 13,576.17 | 113 | 12,778 | 113.08 | 1,631 | 3.52 | 8.32 | 0.94 |
| V | 6,075.23 | 43 | 3,827 | 89.01 | 698 | 5.62 | 7.08 | 0.63 |
| VI | 2,896.11 | 20 | 1,996 | 99.83 | 744 | 4.55 | 6.91 | 0.69 |
| VII | 1,913.29 | 74 | 5,903 | 79.78 | 896 | 4.53 | 38.68 | 3.09 |
| VIII | 5,318.42 | 325 | 12,545 | 38.60 | 534 | 1.21 | 61.11 | 2.36 |
| Visual interpretation total | 42,783.72 | 842 | 60,098 | 71.38 | 1,631 | 0.34 | 19.68 | 1.40 |
| DETER | 39,630.37 | 114 | 12,489 | 109.56 | 2,468 | 6.40 | 2.88 | 0.32 |

validated regarding the visual interpretation, the DETER and their intersection region.

### 3.4.1 Detections by visual interpretation

A set of 173 indicatives were analyzed. The field results of regions II and V were not found due to lack of reports.

The subdivision and resizing of those areas resulted in 202 reclassified polygons (Table 3): 147 deforestations, 40 old deforestations, 12 native vegetations, and 3 burnt areas. The G value was 72.77% for the number of polygons. The highest misinterpretation (Figure 2) was for old deforestation (19.80%). It was verified in the field that most of those places where hoeing operation had been performed were pasturelands. The less intensive pasture management affords arising of weeds, thereby transforming the land cover to a scrub. In the remote sensing analysis, the aspect of those places resembles sparse native vegetation and the hoeing weeds take after suppressed native vegetation. However, in the field inspection, no deforestation evidence was found; this misinterpretation was quite relevant in the region IV (52.17%).

Other misinterpretations occurred for native vegetation (5.94%) and burnt areas (1.49%). This result highlights the high degree of confusion between deforestation and native vegetation in region I (10.34%).

Finally, regarding the polygons size, G value was 65.57%, being 15,569 from 23,742 ha, and it was rightly interpreted as deforestation.

### 3.4.2 DETER

From the 114 alerts issued, 27 were analyzed (Table 3). The highest misinterpretation occurred for old deforestation (14.81%) and there was only one case of confusion for burn area and none for native vegetation. The DETER's G value was 81.48%, which was better than that by the visual interpretation method.

Furthermore, regarding the polygons size, G value was 85.07%, being 2,549 from 2,996 ha, and it was rightly interpreted as deforestation.

### 3.4.3 Intersection region

A total of 20 out of the 82 indicatives were inspected in the intersection region to obtain 4 deforestation and 16 ancient deforestation (G = 20%). From the 12 DETER alerts issued in the same region, 3 agreed to the indicatives and they were inspected. However, the 3 alerts were for ancient deforestation. We observed that G value was outlier regarding the total studied area.

### 3.5 Total deforestation estimation

The confirmed deforestation polygons averaged 105.91 ha, ranging from 1.54 to 1,111 ha in the area monitored by visual interpretation and from 30.46 to 404 ha in the DETER-monitored region. However, we noticed high variability in the features from each monitored region. The average deforestation for region VIII (64.09 ha) was below that for the others regions. The highest average was found for regions VI and VIII.

In 7,527,256 ha monitored area, 20.9% of the potentially deforested were checked, ratifying 18,118 ha. We estimated that the total deforestation from 2006/2007 to 2010/2011 ranged from 49,025 to 49,836 ha (Table 4), representing around 0.66 ha/km². Nevertheless, regarding each method, monitoring by visual

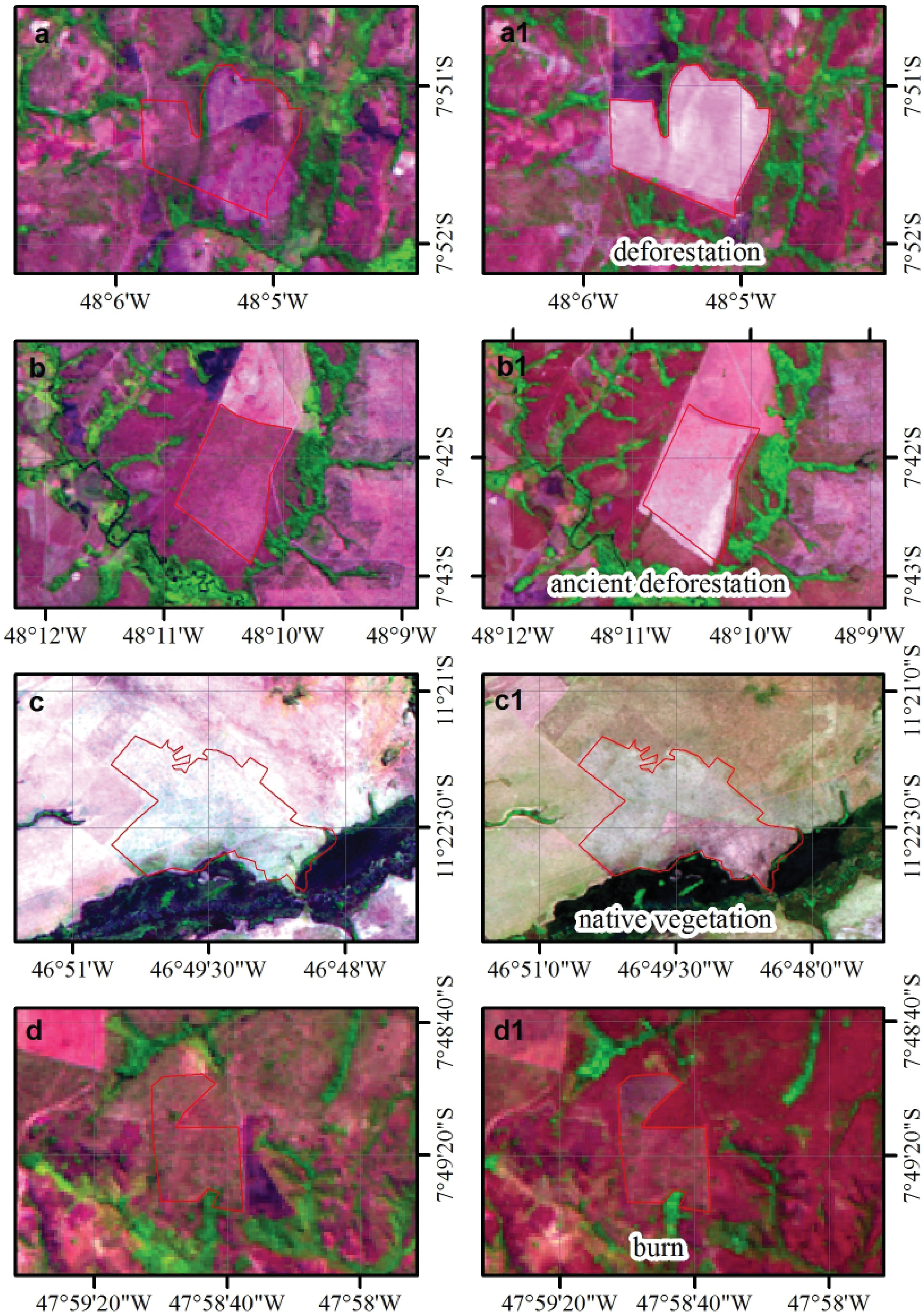


Fig. 2 - Potential deforestation detected (left) and their field true (right): a/a1) deforestation, b/b1) ancient deforestation, c/c1) native vegetation, d/d1) burn.

Table 3: Features of the checked places from each region monitored

| Region | Checked area (ha) | Checked polygons | True field | | | | | Confirmed deforestation | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Deforestation | Ancient deforestation | Native vegetation | Burn | Commission error (%) | Total area (ha) | Average size (ha) | Highest (ha) | Smallest (ha) | Standard deviation |
| I | 9,951 | 58 | 38 | 12 | 6 | 2 | 34.48 | 4,995 | 131.46 | 1,111 | 2.45 | 235.96 |
| III | 4,822 | 42 | 30 | 10 | 1 | 1 | 28.57 | 3,406 | 113.55 | 676 | 6.30 | 131.55 |
| IV | 2,500 | 23 | 8 | 12 | 3 | 0 | 65.22 | 1,033 | 129.14 | 418 | 8.12 | 131.71 |
| VI | 314 | 2 | 2 | 0 | 0 | 0 | 0.00 | 314 | 157.39 | 305 | 8.98 | 209.88 |
| VII | 2,358 | 15 | 15 | 0 | 0 | 0 | 0.00 | 2,358 | 157.23 | 667 | 43.04 | 159.42 |
| VIII | 3,794 | 62 | 54 | 6 | 2 | 0 | 12.90 | 3,460 | 64.09 | 516 | 1.54 | 110.44 |
| Visual interpretation | 23,742 | 202 | 147 | 40 | 12 | 3 | 27.23 | 15,569 | 105,91 | 1,111 | 1.54 | 163.44 |
| DETER | 2,996 | 27 | 22 | 4 | 0 | 1 | 18.52 | 2,549 | 115.87 | 404 | 30.46 | 101.25 |

Table 4: Estimation of the total deforestation at the monitored regions

| Region | Monitored area (km²) | Area indicated as deforestation (ha) | Confidence interval of G% | Estimated deforestation | |
|---|---|---|---|---|---|
| | | | 95% | Total (ha) | Proportional (ha/km²) |
| Visual interpretation | 42,783 | 60,098 | 65.57±0.60 | 39,046 to 39,772 | 0.92 |
| DETER | 39,630 | 12,489 | 85.07±1.27 | 10,465 to 10,784 | 0.27 |
| Total | 75,272 | 72,378 | 68.30±2.86 | 49,025 to 49,836 | 0.66 |

interpretation estimated 0.92 ha/km² deforested and the DETER estimated 0.27 ha/km² deforestation.

## 4. DISCUSSION

Techniques of remote sensing are helpful to monitor events that have happened at the land cover, such as changes at the vegetation cover, accompaniment of agricultural crops, and forest fires. The temporal record of the land cover features also works to support activities of supervision, monitoring, and environmental control of several Brazilian institutions such as IBAMA, Public Ministry, Chico Mendes' Institute of Conservation and Biodiversity (ICMBio), Federal Police Department and Amazonia Protection System (SIPAM) (ALVES & RUSSO, 2011; BORGES *et al.*, 2011; DUARTE *et al.*, 2007; SHIMABUKURO *et al.*, 2005; SELHORST *et al.*, 2007; TANCREDI *et al.*, 2009; TOMSHINSKI *et al.*, 2011). However, even with great utility, the remote sensing techniques need to be supported by data that allows validation of the results. Field results are among the most reliable sources of data validation; however, the costs and the time involved in their acquisition are not very attractive. Using data from institutions that undertake field incursions as routine activities is a manner of reducing expenses and enlarging the utilization of the data acquired. Monitoring by visual interpretation from the Geoprocessing Bureau from IBAMA's Superintendence in Tocantins pointed at a higher quantity of possible deforestation areas than the DETER. Even regarding distinct study regions (18.0% of the monitored area by DETER was also monitored visually) and monitoring periods not exactly equals.

There are commons discrepancies among the estimates of deforested areas (NEPSTAD *et al.*, 1997) and the differences in detection can be attributed to reasons such as spatial resolution of the products used in each method (JEPSON, 2005; SHIMABUKURO *et al.*, 2007). DETER employs 250 m of spatial resolution images, while the visual interpretation employs products of around 30 m spatial resolution. This allows minimum demarcations to 6.25 ha by DETER and to 0.09 ha by the visual method. In visually detected data, 8.8% of the 842 indicatives were below 6.25 ha and 4.8% of the 147 polygons of the confirmed deforestation, which partly explains the DETER's deficit. Areas smaller than 15 ha are hardly detected by DETER and present a low accuracy. Furthermore, its main goal is to detect deforested areas in real-time to the closest accurate estimate (SHIMABUKURO *et al.*, 2006). Thus, we consider that DETER probably leaves out deforestation by focusing on the detriment of a higher hit rate of the alerts.

Several factors that can explain the higher accuracy of the DETER system over the visual interpretation method include PRODES Project older database, the mask employment to hide areas without monitoring and the automatic methods and interpreter operator interaction (INPE, 2013; SHIMABUKURO *et al.*, 2006). The older database allows reduction of ancient deforestation misinterpretation, which were the major commission errors in the visual interpretation during this study.

About the commission errors, places with intensive pastures and agriculture are easily differentiable from the Cerrado's typologies (RATANA *et al.*, 2005). Nevertheless, the opposite occurred with areas of little intensive farming. Moreover, the great regenerative capacity of Cerrado (JEPSON, 2005) produces a secondary regrowth land cover similar to the native vegetation, thereby increasing the confusion.

There was a great disparity among the regions monitored by visual interpretation. Different regions with similar characteristics have divergent suppression patterns of native vegetation (BRANNSTROM *et al.*, 2008; ESPÍRITO SANTO *et al.*, 2009). The region I, for example, called Jalapão, characterized by sandy soils and covered by low vegetation with a small incidence of arborous individual, is highly susceptible to the rainfall variations and to the fires. This region presented higher variation in the size of deforestation indicatives and in the confirmed deforestations, but it also presented one of the highest commission errors of the study. The rate of detected area in region I was similar to that in region VIII; however, the difference in the average size of the areas both detected and confirmed was more than double. Those differences can be attributed to the discrepancy in the edaphic, topographic, hydric, economic, demographic, and infrastructure factors, which are strongly correlated to the patterns of the native vegetation conversion to areas of human use (BRANNSTROM *et al.*, 2008; CARVALHO *et al.*, 2009; DINIZ-FILHO *et al.*, 2009; FERREIRA *et al.*, 2006; FERREIRA *et al.*, 2007; MCCRACKEN *et al.*, 1999).

Even with an underestimation of the deforestation pointed by DETER, the deforestation rates were higher in the Cerrado's biome than in the forest area. The elevated conversion rate to agricultural use, allied to the weak protection system, make Cerrado a strongly threatened biome (SILVA *et al.*, 2006). Its predominantly low and sparse vegetation furthers the natural land cover clearing to install agricultural and pastoral activities. It is estimated that 41–44% of the native land cover would be converted to anthropic use. This is much higher than the estimate of 13% for the Amazonia biome (RATTER *et al.*, 1997). Similarly, at the current devastation rates, Cerrado will disappear in 2030 (MACHADO *et al.*, 2004). It subscribes to explain the lowest deforestation rate at the areas covered by forest, where the DETER monitoring happens.

## 5. CONCLUSIONS

Tocantins state is comprised of the Amazonia and Cerrado biomes. This study confirms the results from other researches that show the great vulnerability of Cerrado, both for the anthropic pressure that it suffers and the scarcity of specific actions of monitoring and protection to which it is submitted.

The validation of results obtained by remote sensing is one of the bottleneck techniques, because of the costs and associated delay in acquiring the field data. In that sense, the use of data obtained by institutions that collect and store field information can contribute to the environmental assessment as well as to the improvement of already consolidated and developing techniques. It also highlights the need to refine methods of differing Cerrado deforestation and others land cover, especially the one with little intensive growing, because of the high possibility of misinterpretation.

Finally, our results contribute to subsidize future researches on deforestation monitoring. They can be also used to head inspectional actions, plan public policies on the environment, detect areas that suffer more pressure, and others applications.

## ACKNOWLEDGEMENTS

The authors thank Lenine Barros Cruz for providing the data and Edson Eyji Sano for the constructive review of the manuscript.

## REFERENCES

ACHARD, F.; STIBIG, H.; EVA, H. D.; LINDQUIST, E. J.; BOUVET, A.; ARINO, O.; MAYAUX, P. Estimating tropical deforestation from Earth observation data. **Carbon Management**, v.1, n. 2, p. 271-287, 2010.

ALVARENGA, L. J. O tratamento jurídico-constitucional dos biomas no Brasil. MPMG Jurídico, n. 20, august 2010. Available: <https://aplicacao.mp.mg.gov.br/xmlui/handle/123456789/447>. Accessed in 04/03/2013.

ALVES, R. A. L.; RUSSO, D. Análise multitemporal de imagens Landsat 5 no apoio a confecção de laudo pericial da Polícia Federal sobre desflorestamento. In: XV Simpósio Brasileiro de Sensoriamento Remoto, Curitiba, 2011. **Anais**. p. 2959-2966, 2011.

BORGES, R. O.; COSTA, D. P.; CAMPAGNOLI, F.; GALVÃO, W. S. Monitoramento complementar de desmatamentos e queimadas no município de Marcelândia-MT a partir de imagens do sensor ResourceSat-1. In: XV Simpósio Brasileiro de Sensoriamento Remoto, Curitiba, 2011. **Anais**. p. 6012-6018, 2011.

BRANNSTROM, C.; JEPSON, W.; FILIPPI, A. M.; REDO, D.; XU, Z.; GANESH, S. Land change in the Brasilian Savanna (Cerrado), 1986-2002: comparative analysis and implications for land-use policy. **Land Use Policy**, v.25, p. 579-595, 2008.

CÂMARA, G.; VALERIANO, D. M.; SOARES, J. V. 2006. **Metodologia para o cálculo da taxa anual de desmatamento na Amazônia Legal**. São José dos Campos, SP: INPE, 2006. Available: <http://www.obt.inpe.br/prodes/metodologia.pdf> Accessed in: 6 January 2012.

CARVALHO, F. M. V.; MARCO Jr., P.; FERREIRA, L. G. The Cerrado into-pieces: habitat fragmentation as a function of landscape use in the savannas of central Brazil. **Biological Conservation**, v.142, p. 1392-1403, 2009.

CONGALTON, R. G., ODERWALD, R.G., & MEAD, R.A. Assessing Landsat classification accuracy using discrete multivariate analysis statistical techniques. **Photogrammetric Engineering and Remote Sensing**, v.49, p. 1671-1678, 1983.

COSTA, M. H.; PIRES, G. F. Effects of Amazonia and Central Brazil deforestation scenarios on the duration of the dry season in the arc of deforestation. **International Journal of Climatology**, v.30, n. 13, p. 1970-1979, 2010.

DINIZ-FILHO J. A. F.; OLIVEIRA, G.; LOBO, F.; FERREIRA, L. G.; BINI, L. M.; RANGEL, T. F. L. V. B. Agriculture, habitat loss and spatial patterns of human occupation in a biodiversity hotspot. **Scientia Agricola**, v.66, n. 6, p. 764-771, 2009.

DUARTE, E. C.; GONÇALVES, M. C. A.; REGO, P. A. O uso de produtos de sensoriamento remoto e suas implicações para a tomada de decisões do Ministério Público do Acre. In: XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, 2007. **Anais**. p. 4457-4463, 2007.

ESPÍRITO SANTO, M. M.; SEVILHA, A, C.; ANAYA, F. C.; BARBOSA, R.; FERNANDES, G. W.; SANCHEZ-AZOFEIFA, G. A.; SCARIOT, A.; NORONHA, S. E.; SAMPAIO, C. A. Sustainability of tropical dry forests: two case studies in southeastern and central Brazil. **Forest Ecology and Management**, v.258, p. 922-930, 2009.

FEARNSIDE, P. M. Soybean cultivation as a threat to the environment in Brazil. **Environmental Conservation**, v.28, p. 23-38, 2001.

FEARNSIDE, P. M. Conservation policy in Brazilian Amazonia: understanding the dilemmas. **World Development**, v.31, n. 5, p. 757-779, 2003.

FERREIRA, N. C.; FERREIRA, L. G.; MIZIARA, F. Deforestation hotspots in the Brazilian Amazonia: Evidence and causes as assessed from remote sensing and census data. **Earth Interactions**, v.11, p. 1-16, 2006.

FERREIRA, M. E.; FERREIRA Jr., L. G.; SANO, E. E.; SHIMABUKURO, Y. E. Spectral linear mixture modelling approaches for mapping the Brazilian Cerrado physiognomies. **International Journal of Remote Sensing**, v.28, p. 413-429, 2007.

FERREIRA, L. G.; FERREIRA, N. C.; FERREIRA, M. E. Sensoriamento remoto da vegetação: Evolução e estado da arte. **Acta Scientiarum Biological Sciences**, v.30, n. 4, p. 379-390, 2008.

FINCO, M. V. A.; DOPPLER, W. Bionergy

and sustainable development: the dilemma of food security and climate change in the Brazilian savannah. **Energy for Sustainable Development**, v.14, p. 194-199, 2010.

FOODY, G. M. Harshness in image classification accuracy assessment. **International Journal of Remote Sensing**, v.29, n. 11, p. 3137-3158, 2008.

FOODY, G. M. Classification accuracy comparison: Hypothesis tests and the use of confidence intervals in evaluations of difference, equivalence and non-inferiority. **Remote Sensing of Environment**, v. 113, p. 1658-1663, 2009.

FULLER, D. O. Tropical Forest monitoring and remote sensing: A new era of transparency in forest governance? **Singapoure Journal of Tropical Geography**, v.27, p. 15-29, 2006.

IBGE. Instituto Brasileiro de Geografia e Estatística. 2011. **Mapa de Biomas do Brasil - Escala 1:5,000,000**. Available: <http://mapas.ibge.gov.br/biomas2/viewer.htm>. Accessed in: 30 September 2011.

INPE. Instituto Nacional de Pesquisas Espaciais. **Monitoramento da cobertura florestal da Amazônia por satélites**. São José dos Campos, INPE - Coordenação Geral de Observação da Terra, 2008, 16p.

INPE. Sistema DETER. 2013. Available: <http://www.obt.inpe.br/deter/>. Accessed in: 29 February 2013.

JEPSON W. A disappearing biome? Reconsidering land-cover change in the Brazilian savanna. **The Geographical Journal**, v.171, n. 2, p. 99-111, 2005.

JURAS, I. A. G. M. Breves comentários sobre a base constitucional da proteção da biodiversidade. In.: Conservação da Biodiversidade, ALEGIS, p. 131-138. Available: <http://www.aslegis.org.br/aslegisoriginal/images/stories/artigospessoais/conservacao-biodiversidade/breves-comentarios-sobre-a-base-constitucional-da-proteccao-da-biodiversidade.pdf>. Accessed in: 04/03/2013

KINTISCH, E. Carbon emissions – improved monitoring of rainforests helps pierce haze of deforestation. **Science**, v.316, p. 536-537, 2007.

KIER, G.; MUTKE, J.; DINERSTEIN, E.; RICKETTS, T. H.; KÜPER, W.; KREFT, H.; BARTHLOTT, W. Global patterns of plant diversity and floristic knowledge. **Journal of Biogeography**, v.32, p. 1107-1116, 2005.

LIMA, J. E. F. W. Situação e perspectivas sobre as águas do cerrado. **Ciência e Cultura**, v.63, n. 3, 2011.

MACHADO, R. B.; RAMOS NETO, M. B.; PEREIRA, P. G.; CALDAS, E. F.; GONÇALVES D. A.; SANTOS, N. S.; TABOR, K.; STEININGER, M. **Estimativas de perda do cerrado brasileiro**. Brasília, Conservação Internacional, 2004, 23p.

MCCRACKEN, S. D.; BRONDIZIO, E. S.; NELSON, D.; MORAN, E. F.; SIQUEIRA, A. D.; RODRIGUEZ-PEDRAZA, C. Remote Sensing and GIS at farm property level: demography and deforestation in the Brazilian Amazonia. **Photogrammetric Engineering and Remote Sensing**, v.65, n. 11, p. 1311-1320, 1999.

MORISETTE, J. T.; KHORRAM, S. Exact binomial confidence interval for proportions. **Photogrammetric Engineering and Remote Sensing**, v.64, n. 4, p. 281-283, 1998.

MULLER-KARGER, F. E.; MCCLAIN, C. R.; RICHADSON, P. L. The dispersal of the Amazonia's water. **Nature**, v.333, p. 56-59, 1988.

MYERS, N.; MITTERMEYER, R. A.; MITTERMEYER, C. G.; FONSECA, G. A.; KENT, J. Biodiversity hotspots for conservation priorities. **Nature**, v.403, p. 853-858, 2000.

NEPSTAD, D. C.; KLINK, C. A.; UHL, C.; VIEIRA, I. C.; LEFEBVRE, P.; PEDLOWSKI, M.; MATRICARDI, E.; NEGREIROS, G.; BROWN, I. F.; AMARAL, E.; HOMMA, A.; WALKER, R. Land-use in Amazonia and the Cerrado of Brazil. **Ciência e Cultura**, v.49, n. 1-2, p. 73-86, 1997.

PERES, C. A. Why we need megareserves in Amazonia. **Conservation Biology**, v.19, n. 3, p. 728-733, 2005.

RATANA, P.; HUETE, A. R.; FERREIRA, L. Analysis of Cerrado physiognomies and conversion in the MODIS seasonal-temporal domain. **Earth Interactions**, v.9, p. 1-22, 2005.

RATTER, J. A.; RIBEIRO, J. F.; BRIDGEWATER, S. The Brasilian Cerrado vegetation and threats to its biodiversity. **Annals of Botany**, v.80, p. 223-230, 1997.

SANO, E. E.; ROSA, R.; BRITO, J. L. S.; FERREIRA, L. G. Land cover mapping of the tropical savanna region in Brazil. **Environmental Monitoring and Assessment**, v.166, p. 113-114, 2010.

SELHORST, D.; MARTINS, M. H. B.; SILVA, S. F. Uso de imagens CCD/CBERS para o monitoramento e fiscalização do desmatamento na Amazônia: uma experiência do IBAMA/Acre. In: XIII Simpósio Brasileiro de Sensoriamento Remoto, Florianópolis, 2007. **Anais**. p. 1117-1124, 2007.

SHIMABUKURO, Y. E.; DUARTE, V.; MOREIRA, M. A.; ARAI, E.; RUDORFF, B. F. T.; ANDERSON, L. O.; ESPÍRITO SANTO, F. D. B.; FREITAS, R. M.; AULIÇINO, L. C. M.; MAURANO, L. E. P.; ARAGÃO, J. R. L. **Detecção de áreas desflorestadas em tempo real: conceitos básicos, desenvolvimento e aplicação do Projeto DETER**. São José dos Campos, INPE, 2005, 66p.

SHIMABUKURO, Y. E.; DUARTE, V.; ANDERSON, L. O.; VALERIANO, D. M.; ARAI, E.; FREITAS, R. M. Near real time detection of deforestation in the Brazilian Amazonia using MODIS imagery. **Revista Ambi-Agua**, v.1, p. 37-47, 2006.

SHIMABUKURO, Y. E., DUARTE, V., MOREIRA, M. A., ARAI, E., RUDORFF, B. F. T., FREITAS, R. M., LIMA, A., & ARAGÃO, J. R. L. **Detecção de áreas desflorestadas em tempo real (Projeto DETER) para os anos de 2005 e 2006**. São José dos Campos, INPE, 2007, 69p.

SILVA, J. F.; FARINAS, M. R.; FELFILI, J. M.; KLINK, C. A. Spatial heterogeneity, land use and conservation in the Cerrado region of Brazil. **Journal of Biogeography,** v.33, n. 3, p. 536-548, 2006.

SILVA, R. R.; WERTH, D.; AVISSAR, R. Regional impacts of future land-covers changes on the Amazonia Basin wet-season climate. **Journal of Climate**, v.21, n. 3, p. 1153-1170, 2008.

TANCREDI, N. S. H.; SANTOS, P. M. C.; COHENCA, D. Esforço do laboratório de geoprocessamento da Gerência Executiva do IBAMA em Santarém para o monitoramento ambiental da região do Pará. In: XIV Simpósio Brasileiro de Sensoriamento Remoto, Natal, 2009. **Anais**. p. 4481-4488, 2009.

TOMZHINSKI, G. W.; COURA, P. H. F.; FERNANDES, M. C. Avaliação da detecção de focos de calor por sensoriamento remoto para o Parque Nacional de Itatiaia. **Biodiversidade Brasileira**, v.I, n. 2, p. 201-211, 2011.

WANTZEN, K. M.; SIQUEIRA, A.; NUNES, C. C.; SA, M. F. P. Stream-valley systems of the Brazilian cerrado: impact assessment and conservation scheme. **Aquatic Conservation: Marine and Freswater Ecosystems**, v.16, n. 7, p. 713-732, 2006.