MONITORING DEFORESTATION AND FOREST DEGRADATION USING MULTI-TEMPORAL FRACTION IMAGES DERIVED FROM LANDSAT SENSOR DATA IN THE BRAZILIAN AMAZON

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ABSTRACT

This work presents a semi-automated procedure for monitoring deforestation and forest degradation in the Brazilian Amazon using a multi-temporal dataset of satellite imagery. Degradation in forest cover in the Brazilian Amazon region is mainly due to selective logging of intact/un-managed forests and to uncontrolled fires. For this study, part of a Landsat TM scene located in the State of Mato Grosso, in the “deforestation arc” of the Brazilian Amazon was selected. Landsat TM images acquired in years 2005, 2006, 2007, 2008, 2009, 2010 and 2011 and one RapidEye image acquired in 2013 was used in this study. The proposed approach can be used for monitoring deforestation and forest degradation activities by selective logging and fires. The current availability of high spatial resolution data such as Sentinel-2 is expected to allow improving the assessment of deforestation and forest degradation processes using the proposed method and, consequently, facilitating the implementation of actions of forest protection.

Index Terms— *Forest degradation, Fire, Selective logging, Brazilian Amazon, Mato Grosso State*

1. INTRODUCTION

Forest degradation in the Brazilian Amazon has impacted vast areas of forest due to selective logging and forest fires. The DEGRAD project from the Brazilian Institute for Space Research (INPE) has been mapping degraded forest areas using Landsat TM and ETM+ images through visual interpretation of enhanced color composite images [1]. On the other hand fraction images derived from Landsat TM and ETM+ sensors have been used for many tropical forest applications, especially in the Brazilian Amazon: for mapping deforested areas from soil fraction images and for mapping burned areas from shade fraction images ([2]; [3]). Then fraction images can be used for mapping areas of disturbed or degraded forests due to the following characteristics: a) vegetation fraction images highlight the forest cover conditions and allow differentiating between forest and non-forest areas similarly to existing vegetation indices (NDVI, EVI); b) shade fraction images highlight areas with low reflectance values such as water, shadow and burned areas and, consequently, allow identifying forest degradation caused by fires; and c) soil fraction images highlight areas with high reflectance values such as bare soil and clear-cuts and, also highlight areas smaller than the pixel size (selective logging), consequently, allow identifying forest degradation caused by selective logging. In this context the main purpose of this work is to develop and demonstrate the usability of a semi-automated procedure based on fraction images for the assessment and monitoring of deforestation and forest degradation by fire and selective logging in the Brazilian Amazon using a Landsat multi-temporal dataset.

2. MATERIALS AND METHOD

Study area

The study area corresponds to part of one Landsat TM scene (path/row 226/068) located in the State of Mato Grosso, in the region named as “Deforestation Arc” of the Brazilian Amazon (Fig.1). This region is presenting high deforestation rates and therefore has high probability of forest degradation activities due to fire and selective logging [4].

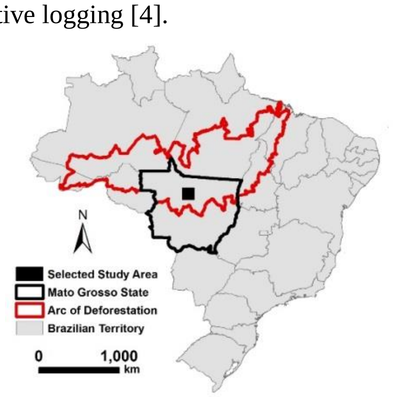


Figure 1. Location of the study area.

Landsat TM and RapidEye images

For this work, we selected 21 cloud-free Landsat TM images acquired in 2005, 2006, 2007, 2008, 2009, 2010 and 2011, and one RapidEye image acquired in 2013 that was used for validation purposes (Table 1).

Table 1: Landsat TM and RapidEye data acquisition

Landsat TM	05 Jun 2005	26 Jul 2005	27 Aug 2005
Landsat TM	27 Jun 2006	14 Aug 2006	15 Sep 2006
Landsat TM	14 Jun 2007	16 Jul 2007	17 Aug 2007
Landsat TM	16 Jun 2008	18 Jul 2008	19 Aug 2008
Landsat TM	19-Jun-2009	21 Jul 2009	22 Aug 2009
Landsat TM	22 Jun 2010	24 Jul 2010	10 Sep 2010
Landsat TM	09 Jun 2011	12 Aug 2011	13 Sep 2011
RapidEye	23 Sep 2013		

Linear spectral mixing model

Linear Spectral Mixing Analysis (LSMA) assumes that pixel values are linear combinations of reflectance from a number of components, called endmembers. Mathematically, this statement is expressed for each pixel of the image according to the linear system equations. The aim of spectral unmixing is to solve these equations for each pixel of the image, obtaining the proportion knowing the reflectance of the endmembers. In this way, a fraction image is obtained for each endmember considered which represents the proportion of that endmember in the original data.

It is very important to adequately select the endmembers and their spectral signatures, as their definition has a considerable influence on the accuracy of the final result. If the number of endmembers defined together with their spectral signatures has been correctly characterized, the proportion will conform to the following conditions: (1) all its elements are greater than or equal to zero and less than or equal to one; (2) the sum of all of them is the unit; and (3) the error term will be negligible. There are different methods for solving equation (1). Approximation using least squares techniques is one of the most common and that used in this study [5]. The soil, vegetation and shade fraction images are generated for all TM RapidEye images applying the LSMA.

Methodological approach

The proposed method is performed according to the following steps: 1) to generate a forest mask to prevent mapping areas already deforested before the analyzed year; 2) to generate fraction images for all images selected for this study; 3) to apply the image segmentation process to a multi-temporal dataset composed of soil and shade fraction images for the analyzed year; 4) to generate map of new deforested areas using the soil fraction images; 5) to generate map of burned areas using the shade fraction images; and 6) to combine the resulting two maps to generate a map with four classes: old deforestation (areas deforested up to the analyzed year, 2005 in this case), new deforestation (areas deforested during the analyzed year, 2006 to 2011), degradation forest areas due to forest fire (areas of forest that has been burned but not clear cut), and forested areas (intact forest and forest selected logged) according to [6]. Although the soil fraction images highlight selective logging areas, there is not an available approach for extracting such information from the images. In this work we propose to use a pixel based classification of fraction images. We use the hypothesis that selective logging pixel presents a low proportion of soil fraction and medium vegetation and shade fractions. In order to perform the steps listed above, several different study sites were selected over the Landsat TM (orbit 226/path 068) as showed in figure 2.

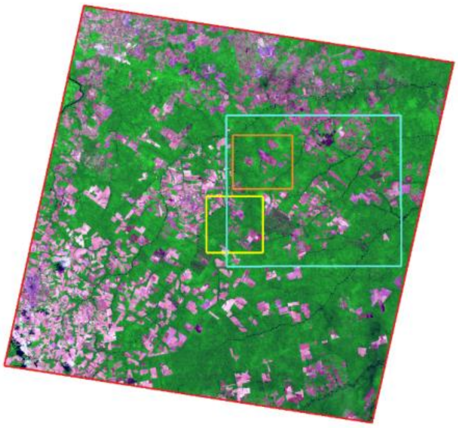


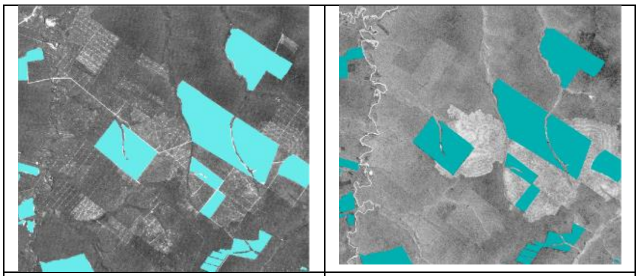
Figure 2. Location of the study sites used to perform the work: the sample site for annual monitoring in blue; the experiment site for defining the thresholding values for selective logging mapping in orange; and the test site covered by RapidEye image used for comparison with Landsat TM data in yellow.

Mapping new deforested areas

Initially the TM images acquired in 2005 are used to generate a forest/non forest mask based on INPE's PRODES deforestation map for year 2005 [1]. Then the incremental deforestation is mapped for every study year using a semi-automated procedure implemented by PRODES project of Brazilian Institute for Space Research [1].

This approach is applied successively for each year from 2006 to 2011 and the annual results are analyzed for monitoring the deforestation changes which occurred during 2005 to 2011 time period.

Once deforested areas are mapped and masked out in the images, the soil and shade fraction images highlight degraded forest areas (bright) due to selective logging (Fig. 3a) and fire (Fig. 3b) respectively.



(a)	(b)

Figure 3: (Panel a) Soil fraction image derived from Landsat TM imagery (24 July 2010) highlighting the selective logging; selectively logged areas stand out as brighter patches of forest. (Panel b) Shade fraction image derived from Landsat TM imagery (19 August 2008) highlighting burned areas. Forest areas degraded by fire stand out as brighter patches of forest. The deforested areas are masked out in the images to better highlight the degraded forest areas.

Mapping degraded forest due to fires

After the deforested areas have been masked out, the degraded forest areas due to fire are classified by combining the burned areas mapped using shade fraction images (Figure 3b) and the forested areas (forest / non forest mask) as described in [6].

The fire induced forest degradation was mapped using the segment based approach described in detail in [6]. The method is based on multistage image segmentation to create spatially and spectrally consistent mapping units (polygons) and subsequent assigning the burned areas. The depicted burned areas are related either to a deforestation process (i.e. the forest is totally logged and the remaining vegetation and biomass is cleared through burning) or to a degradation process (i.e. the forest is burned through an uncontrolled fire). It is also possible to estimate the burned areas occurred in the areas already deforested (e.g. pastureland). This makes the use of an annual multi-temporal dataset essential for differentiating between deforestation and degradation processes [6]. Deforested area will remain as non-forest area (e.g. for agricultural use) while burned forest will remain as forest.

This approach is applied successively for each year from 2006 to 2011 and the annual results are analyzed for monitoring the forest degradation by fires changes which occurred during 2005 to 2011 time period.

Mapping degraded forest due to selective logging

For the degraded forest area, it is more complicated to provide quantitative estimates than for deforestation, most particularly in the case of selective logging.

The stocking areas and exploration roads can be identified in the soil fraction images, but the geographical extent to which the logging has affected the surrounding forest area is difficult to define. Here we propose a method based pixel level identification of selective logging indicators (i.e. tracks and stocking areas) developed within this work.

The threshold approach using soil and vegetation fraction images was developed by observing that selective logging activities only affect partially the pixel of TM image, i.e., the soil component that represents the selective logging presents low proportion compared with clear cut TM pixel with very high proportion of soil component. Therefore these threshold values were searched in the forested pixels (represented by medium vegetation and shade proportions and no soil component) and disturbed forested pixels (represented by medium vegetation and low soil proportions).

The threshold values for classifying the selective logging indicators were defined in a sample area analysis following the assumptions: forest areas present very low soil fraction and medium vegetation fraction; deforested areas present high soil fraction and low vegetation fraction; and degraded forests by selective logging present low soil fraction and medium vegetation fraction. Table 2 shows the results of the experiment. Then we decided to use the threshold - vegetation fraction greater than 40% and soil fraction around 10% for classifying the selective logging in all soil fraction images analyzed.

Table 2: Threshold values and corresponding selective logging areas generated.

Threshold	**Selective Logging (km^2)**
Veg > 40 x Soil = 05	58.27
Veg > 40 x Soil = 06	43.22
Veg > 40 x Soil = 07	32.78
Veg > 40 x Soil = 08	22.02
Veg > 40 x Soil = 09	14.35
Veg > 40 x Soil = 10	9.34
Veg > 40 x Soil = 11	10.96
Veg > 40 x Soil = 12	3.5
Veg > 40 x Soil = 13	2.12
Veg > 40 x Soil = 14	1.52
Veg > 40 x Soil = 15	1.04

3. RESULTS

The forest / non forest mask was performed using the 2005 TM dataset. We used the INPE´s PRODES data available for the year 2005 as an ancillary information. In order to have a more precise forested areas we performed a pos-classification image edition by visually interpretation. Then the new deforested areas are easy to detect and map from Landsat TM images. We mapped the incremental deforested areas throughout the study period: 99 km^2 (2006), 71 km^2 (2007), 71 km^2 (2008), 33 km^2 (2009), 52 km^2 (2010), and 46 km^2 (2011). Figure 4 shows the deforested areas mapped during the study, overlaid on a Landsat TM color composite (R5G4B3) of the study area.

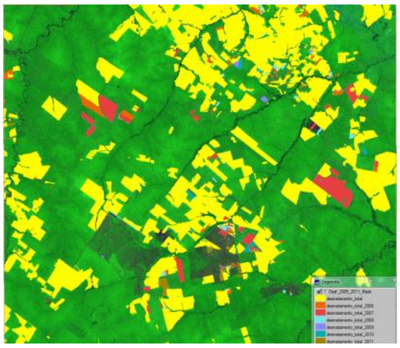


Figure 4: Deforested areas mapped during 2005 to 2011 time period.

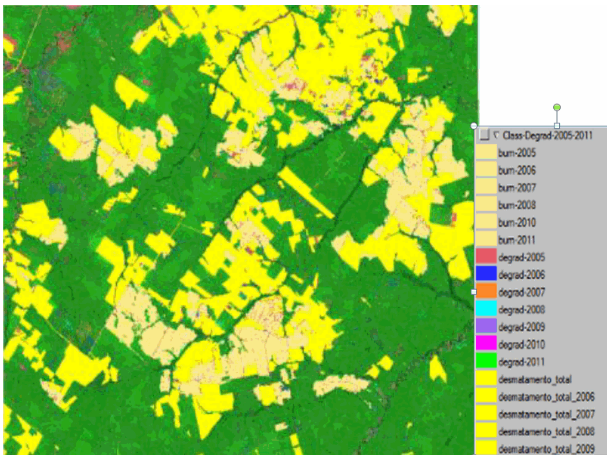


Figure 5: Selective logging areas mapped during 2005 to 2011period (classification over the TM 2011).

Table 3: Deforestation and forest degradation areas for the 2005 to 2011 time period. In parenthesis, the new deforested, selective logged and burned forest areas for the corresponding analyzed year.

Landsat TM	**Deforestation**	**Selective logging (km^2)**
2005	1146.00	131.85 (131.85)
2006	1182.35 (36.35)	83.34 (40.92)
2007	1249.22 (66.87)	53.90 (18.96)
2008	1257.90 (8.68)	61.11 (26.79)
2009	1264.93 (7.03)	60.55 (11.50)
2010	1276.63 (11.70)	55.82 (11.31)
2011	1294.63 (18.00)	55.82 (28.98)

It is also possible to estimate the areas that remains in the selective logging and burned forest classes in the following years (e.g., (83.34 – 40.92) km^2 of selective logged and (90.68 – 49.23) km^2 in 2006).
The direct comparison of our results and the available data from INPEs PRODES and Matt Hansen product is not possible due to the methodological purpose. PRODES does not consider the regrowth areas as Hansen data. We can also note that Hansen data includes areas of burned forest and selective logging areas as annual deforestation.

4. CONCLUSIONS

A forest mask is essential for developing a procedure for detecting and mapping forest degradation areas. Then changes induced by selective logging and forest fires can be identified in the soil and shade fraction images.
The results indicate the feasibility to monitor deforestation as well as degradation by selective logging and fires in a time series of multi-temporal medium resolution Landsat TM images. In addition the proposed approach shows the potential to discriminate selective logging from forest fires within degraded forests. This is very important for estimation of carbon emissions. Therefore the current availability of high frequency (5 days image interval) of 10-20 m spatial resolution data such as Sentinel-2 is expected allow great improvement in the assessment of deforestation and forest degradation processes and consequently facilitate the implementation of actions to protect the forests.

5. ACKNOWLEDGMENTS

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