Detection of forest degradation caused by fires in Amazonia from time series of MODIS fraction images

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Abstract. A new method is presented to detect and assess the extent of burned forests in a tropical ecosystem. Our study area is located in Mato Grosso state southern flank of the Brazilian Amazon region. MODIS images are used over the dry season of year 2010. The proposed method is based on (i) linear spectral mixing model applied to MODIS imagery to derive soil and shade fraction images and (ii) image segmentation and classification applied to a multi-temporal dataset of MODIS-derived images. In a first step, deforested areas are identified and mapped from the soil

fraction images while burned areas are identified and mapped from the shade fraction images. Then, burned forest areas are mapped by combining a forest/non forest mask with the resulting burned area map. Our results show that 14,220 km^2 of forests were degraded by fire in Mato Grosso during year 2010. Our approach can be potentially used operationally for detecting forest degradation due to fires. The proposed method can also be applied to time series of medium and high spatial resolution images for regional and local analysis.

Keywords: Remote Sensing, Image Processing, Forest Degradation, Forest Fires, Fraction Images, MODIS.

1. Introduction

A large part of the gross carbon emissions into the atmosphere due to land cover changes is attributable to deforestation in the tropics (Achard *et al*., 2014). Forest degradation, defined as long-term disturbance in forested areas (Simula, 2009), is considered to represent up to 40% of the gross emissions from deforestation in the Brazilian Amazon (Aragão *et al*., 2014, Berenguer *et al*., 2014). In this region deforestation is defined as forest clear cut with conversion to other land uses (INPE, 2008), while forest degradation is related to a combination of selective logging and forest fires (Souza *et al*., 2009, Asner *et al*., 2009, Eva *et al*., 2012). Forest degradation can be a precursor of deforestation especially in the Amazon basin (Asner *et al.,* 2006, Numata *et al.,* 2010,).

Fraction images derived from Moderate Resolution Imaging Spectroradiometer (MODIS) images have been used for many tropical forest applications, especially in the Brazilian Amazon. Such applications include the near real time detection of deforestation in the Brazilian Amazon from soil fraction images (Anderson *et al.,* 2005, Shimabukuro *et al.,* 2006, 2012) and the mapping of burned areas from shade fraction images (Anderson *et al.*, 2005, Shimabukuro *et al*., 2009). Fraction images derived from different remote sensing sensors can be used for mapping areas of deforested and 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 vegetation indices such as the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI); b) shade fraction images highlight areas with low reflectance values such as water, shadow and burned areas; and c) soil fraction images highlight areas with high reflectance values such as bare soil and clear-cuts.

In this context the main purpose of this study is to present a semi-automated procedure based on a multi-temporal dataset of fraction images derived from MODIS sensor for mapping the extent of degraded forest through fires in the Brazilian Amazon.

2. Material and Method

The study area corresponds to Mato Grosso State located in the Brazilian Amazon region (Figure 1). This region is experiencing high deforestation rates and therefore has high probability of forest degradation activities due to fire and selective logging activities. For this work, we selected MODIS images at 250 m resolution acquired during the dry season of year 2010 (from June to October) to adapt a methodology developed on Landsat imagery (Shimabukuro *et al*., 2014). First a forest/non forest mask is created using MODIS imagery from year 2009 (Figure 1) similarly to the method used by INPE in the DETER project to create a forest map (INPE, 2008). Secondly, we generate vegetation, soil and shade fraction images (Shimabukuro and Smith, 1991) for the MODIS images of year 2010. Deforested and burned areas are then analyzed by applying

an image segmentation process to a multi-temporal dataset composed of soil and shade fraction images. This dataset is used to delineate the changes which occurred during year 2010. The polygons are then classified through an interactive and sequential process which starts with the identification of deforested and burned areas in the most recent data. Finally, forest degradation areas due to forest fires are mapped by combining the resulting maps of forest/non forest areas with the burned area maps, i.e. the forested areas that were burned without clear cut during the analyzed year (in our study the year 2010).

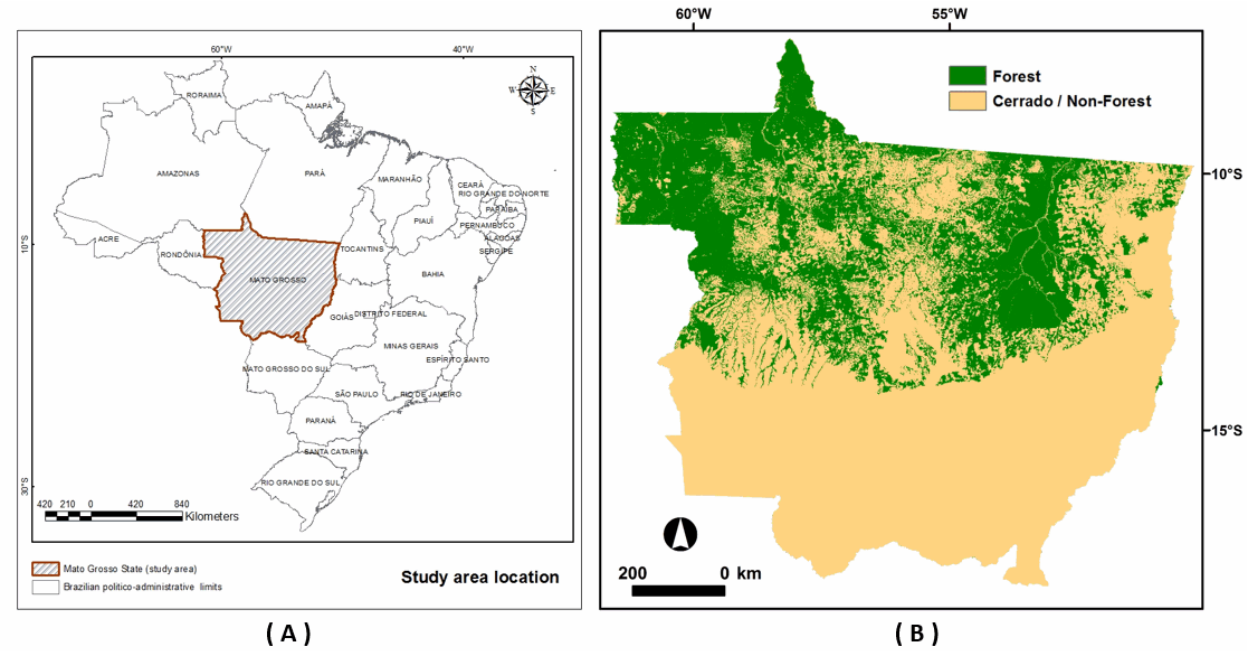

Figure 1. (A) Location of the study area and (B) forest/non forest map derived from MODIS images from year 2009. Non forest areas (in brown) correspond to cerrado or deforested areas and forest areas are displayed in green.

3. Results and discussion

The depicted burned areas in Amazonia are either related to deforestation or to a degradation process: in the case of deforestation the forest cover is first clear cut and then the remaining vegetation is burned to allow using the land for agriculture (cropland or grassland). In the case of degradation, the forest cover is burned through an uncontrolled fire without removal of wood nor conversion to another land use. This makes the use of a multi-temporal dataset essential for differentiating between deforestation and degradation processes. Deforested areas will appear as non-forest areas (cropland or grassland) in the successive months or years after the initial deforestation event while burned forests (degraded forest) will recover as forest regrowth (Shimabukuro *et al.*, 2014).

The comparison (Figure 2) of our estimates of degraded forest areas by fires with the estimates of degraded areas mapped by the DEGRAD project (Forest Degradation Mapping in the Brazilian Amazonia) project (INPE, 2008) showed that while our method detects 14,220 km^2 burned forests during the dry season in 2010, the DEGRAD estimated only 2,496 km^2, about 83% less than our estimate. This difference is due to the characteristics of the datasets used in the two studies. DEGRAD project uses medium spatial resolution data (Landsat TM with 30 m resolution) to map

degraded forest from selective logging and fires (Figure 3). However, due to the timing of the imagery used by the DEGRAD project, which is around August – at the beginning of the burning season - as selected in the PRODES project (Deforestation Assessment in the Brazilian Legal Amazonia), the mapped areas of degradation are mostly related to selective logging and only few areas correspond to forest fires. On the other hand, our method uses MODIS data acquired over the full dry period (June to October) during which a large number of burned forest areas occurred (Figure 4). Figure 5 shows the forest degraded areas by fires mapped by our method.

The results of these two methods (DEGRAD and ours) are complementary. Our method does not detects areas affected by selective logging, due to the coarser spatial resolution of MODIS imagery (250 m), while the DEGRAD results underestimate the degraded areas due to forest fires, by using satellite imagery acquired before the end of the fire season.

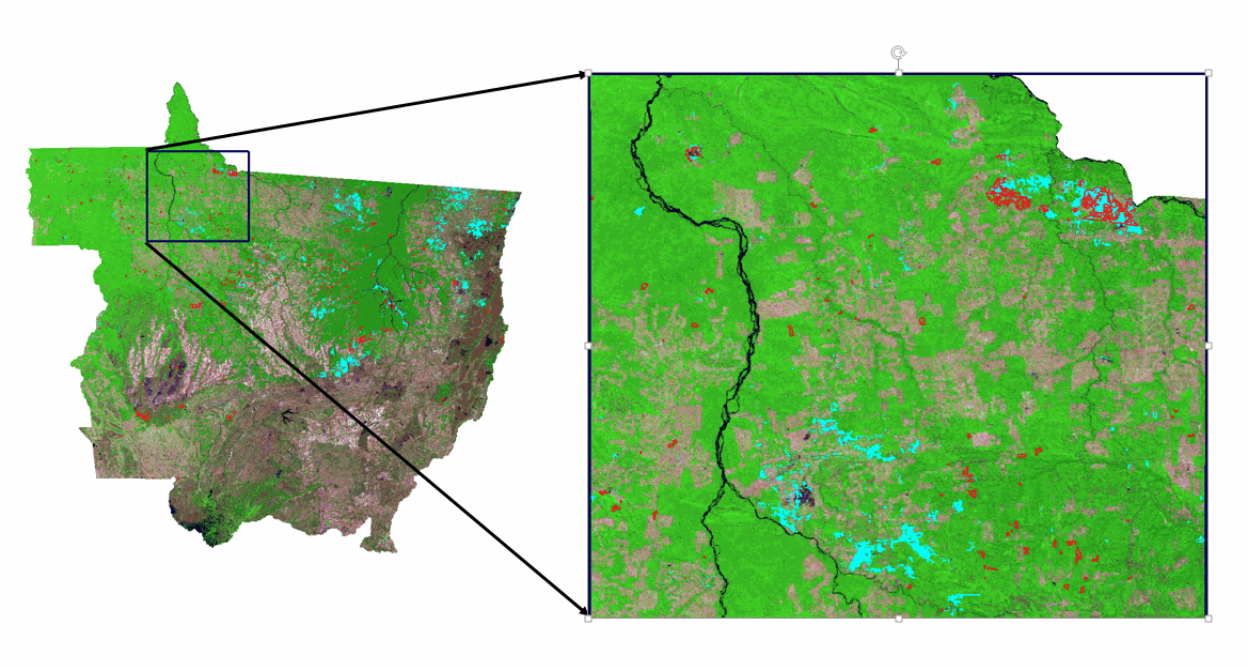

Figure 2. Burned forest areas (in light blue) and degraded areas mapped by DEGRAD project (in red) over the MODIS image (Channels 6, 2, and 1 in RGB) acquired on 03 July 2010.

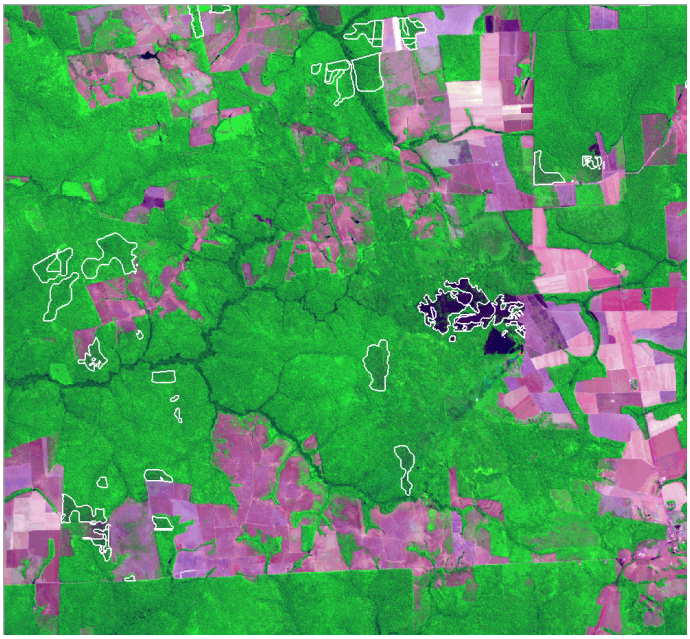

Figure 3. Degraded forest areas delineated by DEGRAD project (white polygons) over a subset of the Landsat TM image (path/row 227/068; bands 5, 4, and 3 in RGB) acquired on 31 July 2010. These degraded areas include selective logging and burned forests.

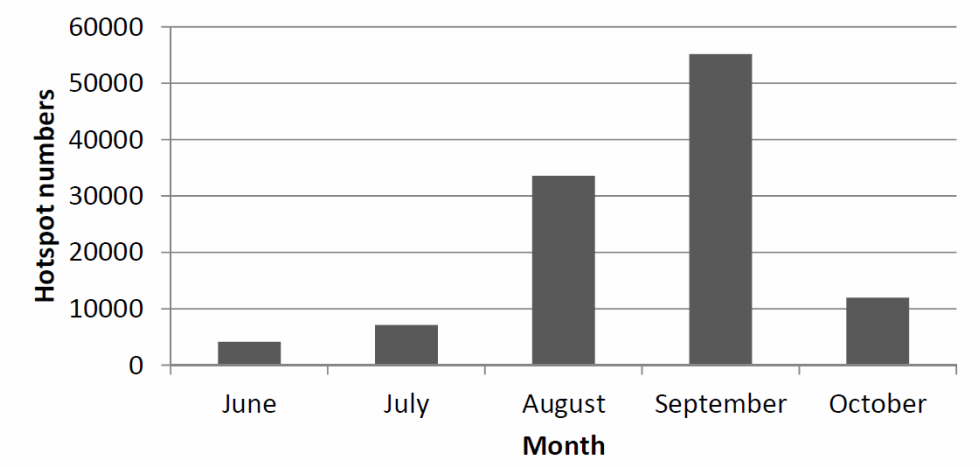

Figure 4. Number of MODIS hotspots (active fires) per months for the year 2010 from MOD/MYD14 product.

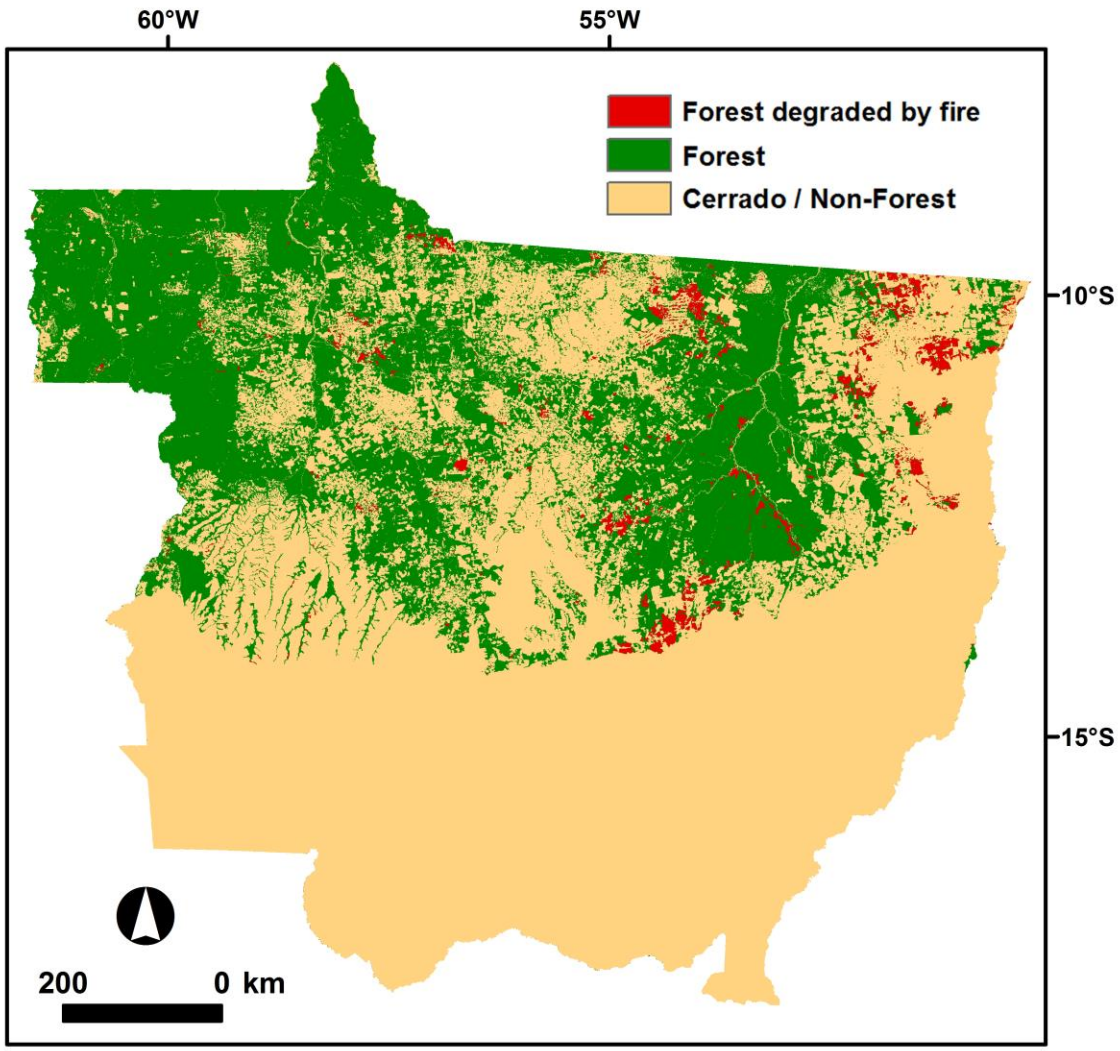

Figure 5. Burned forest areas depicted by our method (in red) over the forest/non forest map.

By looking at the multi-temporal dataset of MODIS imagery from 25 July to 6 October 2010, we can observe that DEGRAD results depict only the burned areas (dark targets) in August 2010 (figure 6). Therefore for analyzing forest degradation by fires the use of a multi-temporal dataset acquired during the full fire season is critical.

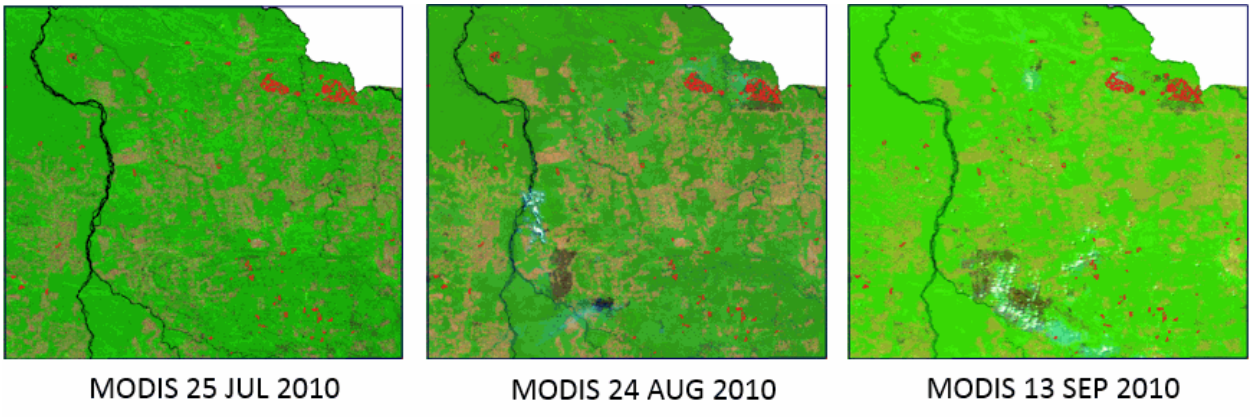

Figure 6. Degraded forests areas from DEGRAD project (in red) over MODIS images (bands 6, 2, and 1 in RGB) acquired on 25 July 2010, 24 August 2010, and 13 September 2010 for the subset highlighted in Figure 2.

4. Conclusions

The proposed method is efficient for mapping burned forest areas (degraded forest areas due to fires). The MODIS multi-temporal imagery provides the information needed for mapping of forest/non forest areas and burned areas over the Amazon basin. An initial forest/non forest map is essential for developing a procedure for mapping degradation areas due to forest fires.

The future availability of 5-days temporal resolution imagery at 10m spatial resolution from Sentinel-2 satellites is expected to allow a more accurate and detailed monitoring of forest degradation processes (selective logging and forest fires) at regional and local scales through this new proposed approach.

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