Anais do XVIII Simpósio Brasileiro de Sensoriamento Remoto -SBSR
ISBN: 978-85-17-00088-1
28 a 31 de Maio de 2017
INPE Santos - SP, Brasil

# Monitoring deforestation and forest degradation in the Amazon basin using multi-temporal fraction images derived from Sentinel-2 sensor data

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**Abstract.** In this work we present a semi-automated procedure for monitoring deforestation and forest degradation in the Brazilian Amazon using a multi-temporal dataset of Sentinel-2 sensor. Forest cover degradation in the Brazilian Amazon region is mainly due to selective logging of intact/un-managed forests and to wildfires. The study area covers part of a Sentinel-2 sensor scene located in the State of Mato Grosso, in the "deforestation arc" of the Brazilian Legal Amazon. We selected three cloud-free Sentinel-2 images acquired on 21st June, 1st August and 10th September 2016. We generated soil, vegetation and shade fraction images for highlighting the deforested, burned and selectively logged areas. Our analysis shows that deforestation and forest degradation by fire can be mapped using object based analysis. On the other hand, forest degradation by selective logging can be mapped using a pixel based classification of fraction images. Our results allowed the estimative of recent deforestation processes in old growth forests: 1,000 ha between 21st June and 1st August and 900 ha between 1st August and 10th September 2016. The burned forest areas corresponded to 10,700 ha between 21st June and 1st August and to 22,800 ha between 1st August and 10th September 2016. Degraded forest areas due to selective logging added to 135,000 ha as mapped in the image dated 1st August 2016 with 17,300 ha of new areas mapped in the image dated 10th September 2016. The proposed approach shows great potential for monitoring deforestation and forest degradation activities by selective logging and fires using the Sentinel-2 multi-temporal dataset, facilitating the implementation of actions of forest protection in Amazon region.

## 1. Introduction

Forest degradation in the Brazilian Amazon has impacted vast areas of forest due to selective logging and forest fires (Souza, 2012). The DEGRAD project from the Brazilian National Institute for Space Research (INPE) has been mapping degraded forest areas using Landsat (E)TM images through visual interpretation of enhanced color composite images since 2007 (INPE, 2008). 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, e.g. for mapping deforested areas from soil fraction images and for mapping burned areas from shade fraction images (Souza et al., 2005; Shimabukuro et al., 2009; Shimabukuro et al., 2012). 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. The current availability of Sentinel-2, with better spatial and temporal resolutions compared to the Landsat sensors, can improve the deforestation and forest degradation estimates.

In this context the main purpose of this work is to develop and evaluate the usability of a semi-automated procedure based on fraction images for the assessment and monitoring of deforestation and forest degradation by fires and selective logging in the Brazilian Amazon using a Sentinel-2 multi-temporal dataset. The method to be used is adapted from previous initiatives developed for Landsat TM images (Shimabukuro et al., 2014).

## 2. Materials and methods

### Study area

The study area corresponds to part of one Sentinel-2 scene located in the State of Mato Grosso, in a region named as “Deforestation Arc” of the Brazilian Amazon (Fig.1). This region is presenting high deforestation rates and has high probability of forest degradation activities due to fire and selective logging (Eva et al., 2012).

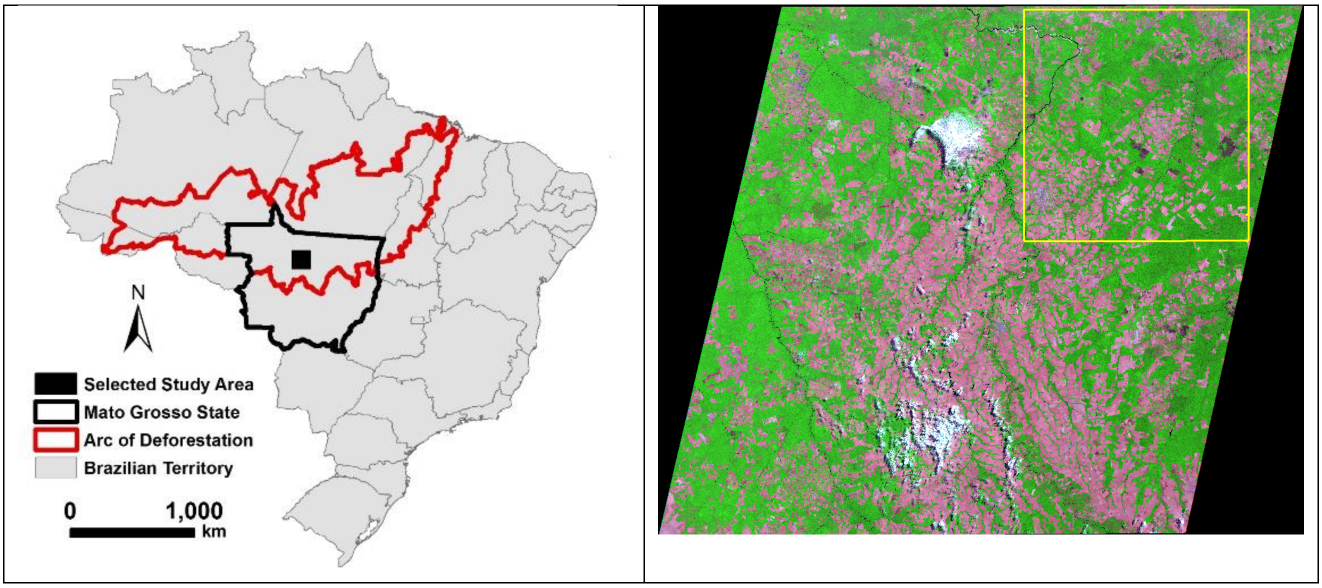


Figure 1. Location of the study area in Brazil (a) and over the sentinel-2 image acquired on 10th September 2016. The study area is part of one Sentinel-2 image (highlighted in yellow).

## Sentinel-2 images

The Sentinel-2A satellite was launched by European Space Agency (ESA) on 23 June 2015 and carries one main instrument: the MultiSpectral Instrument (MSI) sensor with 13 spectral bands, including 4 bands at 10 m resolution, 6 bands at 20 m resolution and 3 bands at 60 m resolution (Table 1). The radiometric resolution is 12 bits, swath width of 290 km and the revisit frequency is 10 days. An identical satellite (Sentinel-2B) is planned to be launch in April 2017 in opposite sides of the orbit (ESA, 2015) which will allow a revisit frequency of 5 days.

Table 1 - Spectral and spatial resolution of the MSI sensor

| **Band** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 8b | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Central Wavelength (nm)** | 443 | 490 | 560 | 665 | 705 | 740 | 783 | 842 | 865 | 945 | 1380 | 1610 | 2190 |
| **Bandwidth (nm)** | 20 | 65 | 35 | 30 | 15 | 15 | 20 | 115 | 20 | 20 | 30 | 90 | 180 |
| **Spatial resolution (m)** | 60 | 10 | 10 | 10 | 20 | 20 | 20 | 10 | 20 | 60 | 60 | 20 | 20 |

Source: https://sentinel.esa.int/web/sentinel/missions/sentinel-2/instrument-payload/resolution-and-swath

For this work, we selected 3 cloud-free Sentinel-2 images acquired on 21 June, 01 August and 10 September 2016.

## Linear Spectral Mixing Model

Linear Spectral Mixing Model (LSMM) assumes that pixel values are linear combinations of reflectance from a number of components, called endmembers. The aim of spectral un-mixing is to solve the mixture 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 sub-pixel proportion of that endmember in the original data.

It is very important to adequately select the endmembers and their spectral signature, 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 system of linear equations. Approximation using least squares techniques is one of the most common and that used in this study (Shimabukuro and Smith, 1991). The soil, vegetation and shade fraction images are generated for all Sentinel-2 images applying the LSMM to the following spectral bands of the Sentinel-2 images: band 4 (red), band 8 (NIR) and band 11 (MIR). The MIR band was rescaled from 20 m to 10 m spatial resolution before performing the un-mixing procedure.

## Methodological approach

*Overall description of the proposed method*

The proposed method is performed according to the following steps: 1) generation of a forest mask to prevent mapping areas already deforested previously to the first image acquired for this study (June 2016 in this case); 2) generation of fraction images for the other images (August and September 2016); 3) image segmentation applied to a multi-temporal dataset composed of soil and shade fraction images; 4) mapping of new deforested areas using the soil fraction images; 5) mapping of burned areas using the shade fraction images; 6) mapping logging areas using the soil fraction images; and 7) combination of the results to generate a map with four classes: old deforestation (areas deforested until 21st June 2016), new deforestation (areas deforested between 21st June and 10th September 2016), degradation forest areas due to wildfire (areas of forest that has been burned but not clear cut), and due to selective logging according to Shimabukuro et al. (2014). In this work we propose to use a pixel based classification of soil fraction images to extract characteristics of selective logging areas.

*Mapping new deforested areas*

First, the Sentinel-2 image acquired in June 2016 is used to generate a forest/non forest mask using INPE's PRODES deforestation map for year 2015 as reference / training dataset. Then the incremental deforestation is mapped for the following images (August and September) using a semi-automated procedure implemented by the PRODES project of the Brazilian Institute for Space Research (INPE, 2008).

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. 2a, 2b) or fire (Fig. 2c, 2d) respectively.

ISBN: 978-85-17-00088-1

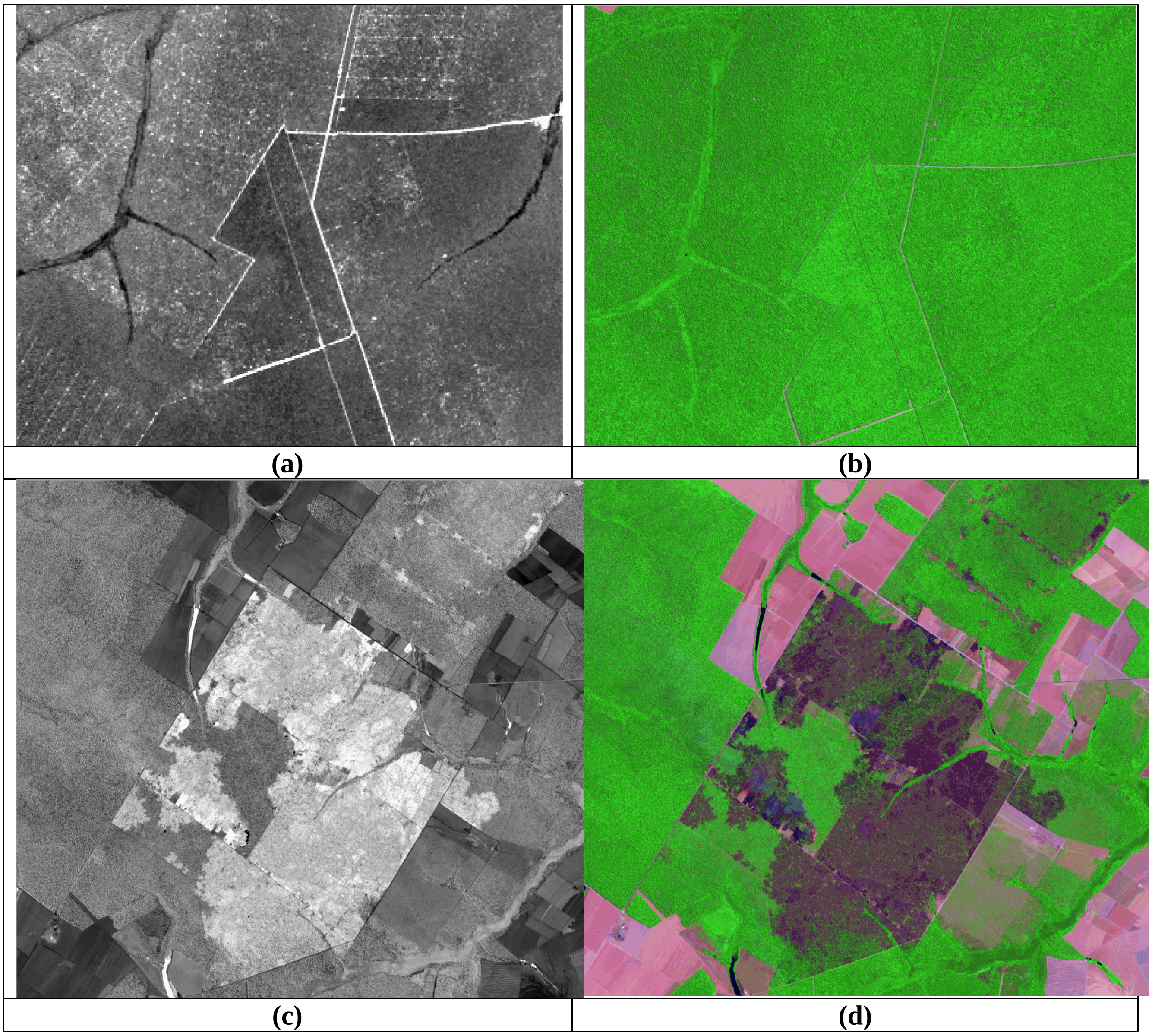


Figure 2: (Panel a) Soil fraction image derived from Sentinel-2 imagery (10 September 2016) highlighting the selective logging; selectively logged areas stand out as brighter patches of forest; (Panel b) the selective logging areas are not clear in the RGB color composite (S-2 MSI bands 4, 8 and 11); (Panel c) Shade fraction image derived from Sentinel-2 imagery (10 September 2016) highlighting burned forest areas. (Panel d) Forest areas degraded by fire stand out as darker patches in the RGB color composite.

*Mapping degraded forest due to fires*

Once 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 2c) and the forested areas (forest / non forest mask) as described in Shimabukuro et al. (2014).

The fire induced forest degradation was mapped using the segment based approach described in (Shimabukuro et al., 2015). The method is based on multistage image segmentation to create spatially and spectrally consistent mapping units (polygons) and subsequent classification into burned forest areas. The depicted burned areas are related either to a slash and burn 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. pastures or agricultural fields). This makes the use of an annual multi-temporal dataset essential for differentiating between deforestation and degradation processes (Shimabukuro et al., 2014). Deforested area will remain as non-forest area (e.g. productive land) while burned forest will remain as forest.

*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.

In summary, this approach is applied successively for the August and September 2016 images and the monthly results are analyzed for monitoring the deforestation and forest degradation changes which occurred during 2016 time period.

## 3. Results

The forest / non forest mask was performed using the June Sentinel-2 image. We used the INPE´s PRODES data available for the year 2015 as an ancillary information. In order to have more precise mapping of the forested areas we performed a post-classification image edition by visual interpretation. Then the new deforested areas and burned forest are easy to detect and map from Sentinel-2 images and were classified using the segmented polygons (Figure 3a). On the other hand, the selective logging areas were more difficult to map using image segmentation techniques due to their characteristics on satellite imagery (small gaps distributed irregularly in the forest canopy). Thus, these areas were mapped using a pixel-based classification approach based on the soil fraction image. Table 2 shows the deforestation, burned forest and degraded areas due to selective logging.  We observed that some degraded areas mapped as selective logging include degraded areas due to old burned areas, since these areas lose trees forming forest gaps.  As shown in Table 2, 1,000 ha were deforested between 21st June and 1st August and 930 ha between 1st August and 10th September 2016. For the same periods, 10,750 ha and 22,800 ha of forest were burned in the study area. We could observe a total 33,500 ha of burned forest was detected in the August and September images.

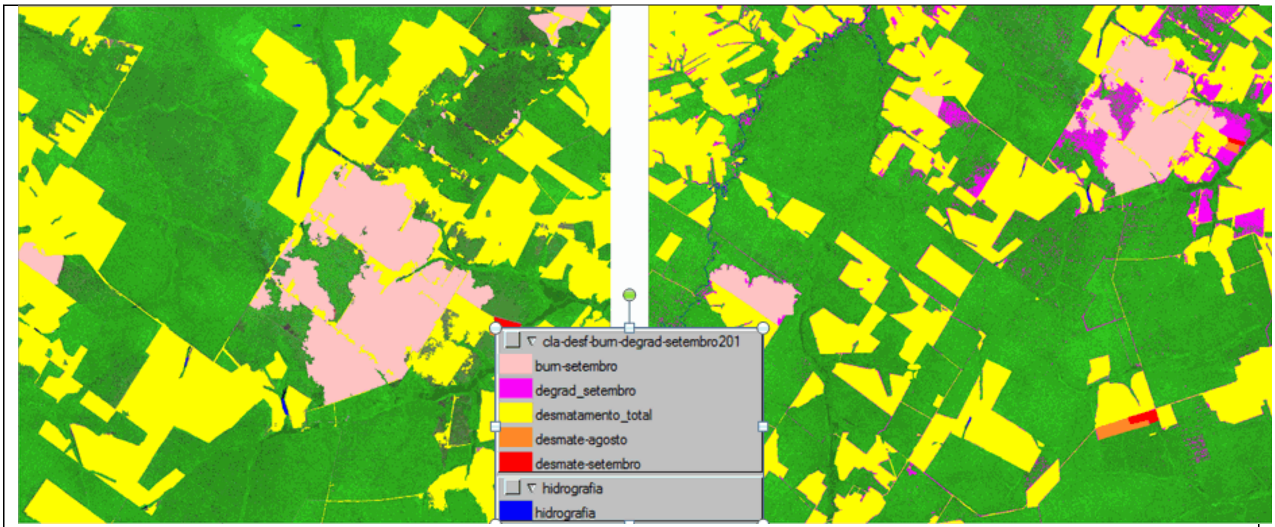


Figure 3: Deforestation and burned areas mapped in the September image (a); and deforestation and forest degradation areas mapped in the August and September images.

Table 2: Deforestation and forest degradation areas from 21 June to 10 September 2016 time period.

| Sentinel-2 | Deforestation (ha) | Selective logging (ha) | Burned forest (ha) |
|---|---|---|---|
| **Until 21st Jun 2016** | 727,450 | ---- | ------ |
| **21st June – 01st Aug 2016** | 1,000 | 135,000 | 10,750 |
| **01st August – 10th Sep 2016** | 930 | 17,300 | 22,800 (28,800-22,800) |

## 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 (Shimabukuro et al., 2014).

Our preliminary results indicate the feasibility to monitor deforestation as well as degradation by selective logging and fires in a time series of multi-temporal high resolution Sentinel-2 satellite 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 use of high frequency (5 days image interval) time series of 10-20 m spatial resolution data such as Sentinel-2 can allow great improvement in the assessment of deforestation and forest degradation processes and consequently facilitate implementation of actions to protect the forests as compared to Landsat imagery (Grecchi et al., submitted; Shimabukuro et al., 2014).

## Acknowledgement

This work was done in the framework of the collaboration between the Brazilian National Institute for Space Research (INPE) and the European Commission, Joint Research Centre (JRC), under the 8th EU-Brazil Sector Dialogue. Sentinel-2 imagery has been made available through the EU Copernicus Programme. L.E.O.C.A. acknowledges the support of Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) grants (304425/2013-3 and 458022/2013-6).

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