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FRACTION IMAGES DERIVED FROM LANDSAT MSS, TM AND OLI IMAGES FOR MONITORING FOREST COVER AT THE RONDÔNIA STATE, BRAZILIAN AMAZON

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ABSTRACT

This article presents a new method for monitoring forest cover in the state of Rondônia, in the Brazilian Amazon. The proposed method applies the Linear Spectral Mixing Model (LSMM) to Landsat datasets (MSS, TM and OLI) to derive annual vegetation, soil, and shade fraction images for the period 1980 – 2020. These fraction images have the advantages of reducing the volume of data to be analyzed and highlighting the target characteristics. Then, we applied a threshold method to classify forest, non-forest, hydrography, and deforestation areas. The proposed method showed to be consistent and flexible allowing to change the threshold values according to the fraction images to obtain the results with high accuracy. The results obtained by the proposed method can be easily checked over the RGB image mosaic. This kind of information is very important for environmental and climate change studies and for supporting government conservation efforts.

Index Terms**—** Fraction Image, Image Processing, Deforestation, Forest, Linear Spectral Mixing Model, Brazilian Amazon, Landsat series

1. INTRODUCTION

Important techniques for mapping and monitoring Land Use and Land Cover (LULC) changes are based on Geographic Information Systems (GIS) and remote sensing products obtained by orbital platforms. In recent decades, remote sensing has become an important tool to monitor the Earth's natural resources, since it is possible to acquire data over large geographical extensions and monitor the processes that occur in these areas.

Continuous monitoring of deforestation in tropical forests is necessary due to its impact on climate, biodiversity, and soil degradation. Commonly, methods used to estimate the extent of deforestation on a regional scale are based on the visual interpretation of Landsat TM images [1,2]. However, many ecological, hydrological, and biogeochemical models require higher spatial resolution and georeferenced digital data (geographic information system - GIS) on deforested areas. This requires a lot of visual analysis and manual scanning. Even if the visual interpretation has reasonable accuracy, it is highly laborious and expensive, especially in areas where small deforestation patterns, such as the fishbone pattern in Rondônia, predominate [1].

Nowadays, with the large availability of remote sensors data, it is necessary to develop methods to classify land use and land cover (LULC) classes in a fast way. The most used technique to reduce the dimensionality of Landsat data, while still preserving most of the information needed for adequate vegetation characterization, is the normalized difference vegetation index (NDVI) proposed by [3]. A large number of studies and operational applications have traditionally used the Normalized Difference Vegetation Index (NDVI), considering its simple formulation and its ability to describe biophysical properties of vegetation [4]. However, the NDVI has a major limitation for characterizing deforestation in the Amazon because secondary forests tend to have higher NDVI values than primary forest, while other deforestation classes, such as pastures or exposed soils, have lower NDVI values. Therefore, it is difficult to define a simple algorithm for classifying deforestation in the Amazon using the NDVI. The generation of fraction images based on the analysis of the spectral mixture of the pixels is an alternative technique to overcome this difficulty [5 – 7].

Shade fraction image is well correlated with forest canopy structure [8 – 10]. Structure determines the amount of shade in the forest canopy, i.e., undisturbed tropical forests generally have medium amount of shade as opposed to deforestation classes such as exposed soil, pastures, or secondary forests with low proportion of shade [5]. PRODES Digital used this automated procedure to generate deforestation information, including mapping and area extent estimates, integrated into a GIS database. This approach based on the shade fraction image generated by a Linear Spectral Mixing Model (LSMM), followed by region growth segmentation and an unsupervised classification, is operationally viable for Amazon and was used for some years after 2000 by PRODES Digital.

Considering that the availability of large amounts of orbital data requires a fast method to classify the LULC classes, this work aims to present a fast classification method to monitor forest cover in the Rondônia state, located in the

Brazilian Amazon, based on vegetation, soil, and shade fraction images from the period of 1980 to 2020.

2. MATERIAL AND METHODS

2.1. Study Area

The study area is the state of Rondônia, located in the Amazon region (Figure 1). Rondônia is inserted within the North region of Brazil and occupies an area of 237,590.55 km^2. The relief is gently undulating, since 94% of the territory is between 100 and 600 meters in altitude. The climate is equatorial and the economy is based on livestock, agriculture (e.g., coffee, cocoa, rice, cassava, corn) and the extraction of timber, minerals, and rubber [11]. About seventy percent of Rondônia's surface is covered by the Amazon rain forest and the remaining thirty percent correspond to savanna areas. However, deforestation, which accelerated in the mid-1980s, for the exploitation of natural resources causes a lot of concerning for environmental studies.

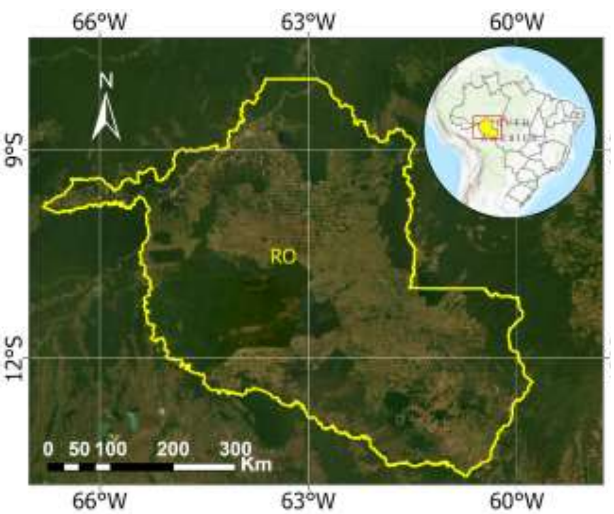

Figure 1. Location of the study area.

2.2. Dataset

The Landsat Multispectral Scanning System (MSS), Thematic Mapper (TM) and Operational Land Imager (OLI) annual datasets (Figure 2) were used to develop this work.

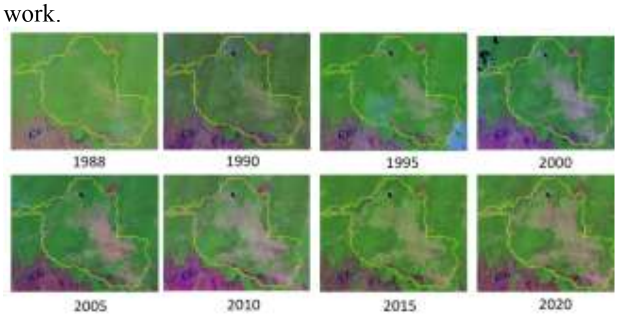

Figure 2. Landsat 5 TM (1988, 1990, 1995, 2000, 2005, 2010) and Landsat 8 OLI (2015-2020) images used in this work.

2.3. Linear Spectral Mixing Model

For achieving the proposed objective, we applied the Linear Spectral Mixing Model (LSMM) [12], which assumes that pixel values are linear combinations of reflectance from a number of components, called endmembers:

$$R_i = \sum_{j=i}^{n} f_i r_{i,j} + \varepsilon_i$$

where:

Ri - represents the spectral reflectance in the *ith* spectral band; $r_{i,j}$ - is the spectral reflectance of the *jth* component in spectral band *ith* (endmember); fj - is the proportion of the *jth* component within the pixel; *εi* - is the residual for the *ith* spectral band.

Figure 3 shows the fraction images derived from the 2020 Landsat 8 OLI mosaic.

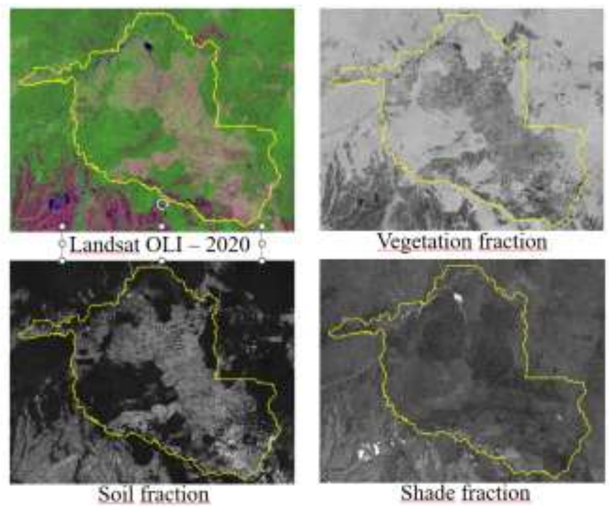

Figure 3. a) RGB color composite and b) vegetation, c) soil and d) shade fraction images derived from the OLI 2020 image mosaic.

Fraction images derived from the LSMM can be used to map LULC due to the following characteristics: 1) vegetation fraction images highlight forest cover conditions similar to vegetation indices, such as the Normalized Difference Vegetation Index (NDVI); 2) soil fraction images highlight areas with high reflectance values, such as exposed soil; and 3) shade fraction images are related to the structure of forests.

2.4. Classification procedure

The digital classification was performed using the SPRING software [13, 14]. Then, land cover classes were classified following a procedure based on fraction images threshold. The land cover classes were individually classified using the combined specific threshold fraction values (vegetation fraction highlights forest class, shade fraction highlights hydrography class, and soil fraction highlights non forest class) [15]. The threshold values were:

1) For hydrography: shade > 150, vegetation < 125 and soil < 125;

2) For non-forest: shade < 140, vegetation < 140 and soil > 120;
3) For deforestation: shade < 130, vegetation < 140 and soil > 130;
4) For forest: shade > 140, vegetation > 140 and soil < 120.

These thresholds can be modified according to the fraction images to get the best classification results. Then, the classification map was composed by the mosaic algorithm following the order of class entry.

3. RESULTS AND DISCUSSION

3.1. Classification of the 2020 OLI mosaic

Figure 4 shows the classification of land cover classes for 2020 using the proposed method that were applied to the other years.

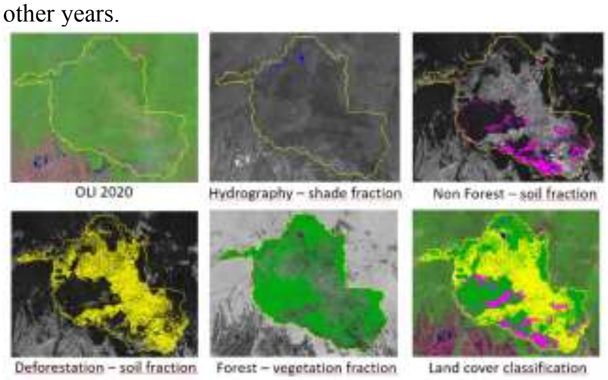

Figure 4. Classification of land cover classes for 2020 (hydrography in blue, non-forest in magenta, deforestation in yellow, and forest in green, respectively).

3.2. Classification of Landsat 1980 to 2020 image mosaics

Figure 5 shows the land cover class maps of Landsat mosaics from 1980 to 2020 obtained following the proposed method described in the previous section. In this study, we produced maps for 1980, 1988, 1990 and then for 5 years period up to 2020.

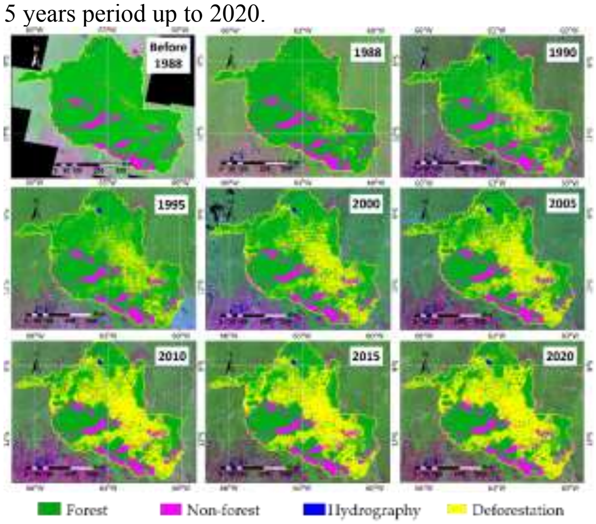

Figure 5. Classification of land cover (forest, non-forest, hydrography and deforestation) classes for the period before 1980 to 2020.

The land cover changes can be obtained by comparing the annual results using GIS and can be compared to the available products such as PRODES [1] and MapBiomas [16] projects.

4. CONCLUSIONS

The increasing availability of high quality temporal remotely sensed images emphasizes the need for methodologies able to process and support the analysis of the resulting high data volume. Vegetation fraction images represent the proportional contribution of vegetation to the total energy received by a remote sensor having, therefore, close relationship with bio-physical characteristics of the forest cover. Among other advantages, vegetation fractions offer a physically-based representation of vegetation conditions and are less prone to saturation when representing dense canopies, when compared to NDVI. In addition, the shade component represents the proportional contribution to the forest structure and hydrography, while soil fraction represents the proportional contribution to the non-forest and deforestation areas. These fraction images highlighted land cover classes such as forest, non-forest, deforestation, and hydrography mapped in this study. Then the thresholding approach allowed to produce the annual maps of Rondônia state, located in the Brazilian Amazon region, in a very fast way. The proposed method showed to be consistent and flexible to change the threshold values to obtain the best results. The results were obtained for the period from 1980 to 2020, allowing to monitor land cover changes over this period. The results are very important for environmental and climate change studies and for supporting government conservation efforts.

5. ACKNOWLEDGEMENTS

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