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Relação entre vegetação não-fotossintética, intensidade do fogo e energia radiativa do fogo na Amazônia

Relationship between non-photosynthetic vegetation, intensity of fire and fire radiative power in the Amazon

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Resumo

As emissões de carbono por meio das queimadas podem anular os esforços de redução de emissões de carbono por desmatamento. Este trabalho tem como objetivo apresentar a possível relação entre a vegetação não-fotossintética (NPV), intensidade do fogo (dNBR) e energia radiativa do fogo (FRP) no sudeste da Amazônia Legal. Para tal, foram utilizadas duas imagens Landsat 8/OLI, correspondente à cena 227-068 de 2014, para mapear as cicatrizes de queimada na área. O mapeamento de cicatrizes de queimada do ano de 2014 resultou em 442,2 km² (2,2% da área total). Não foi observada áreas queimadas na região de floresta, longe de áreas agrícolas; torna-se claro que os incêndios registrados em áreas florestais ocorreram nas bordas das áreas agrícolas. A correspondência entre o NPV com dNBR e FRP foi baixa. A não-utilização de fogo como uma prática de gestão em áreas agrícolas e a utilização do sistema de plantio direto justifica a fraca correlação entre o NPV, dNBR e FRP.

Palavras-chave: Agricultura, Áreas queimadas, Mato Grosso, Modelo Linear de Mistura Espectral, Sensoriamento Remoto.

Abstract

Carbon emissions from fires can invalidate efforts to reduce carbon emissions from deforestation This paper aims to present the possible relationship between non-photosynthetic vegetation (NPV), the intensity of burning (dNBR) and fire radiative power (FRP) in southeastern Legal Amazon. For this purpose, two OLI/Landsat 8 images, corresponding to scene 227-068 of 2014, were used to map burn scars in the area. Mapping of burn scars in 2014 resulted in 442.2 km² (2.2% of overall area). It was not observed burned areas in forests fragments located far from agricultural areas, which means that forest fires recurrence occurred on the edges of agricultural areas. The correspondence between NPV with dNBR and FRP was low. The non-use of fire as a management practice in agricultural areas and the use of no-till system justified the weak correlation between the NPV, dNBR and FRP.

Keywords: Agriculture, Burned areas, Linear Spectral Unmixing, Mato Grosso, Remote Sensing.

I. INTRODUCTION

Amazon rainforest is the largest Brazilian biome and it has the highest ecological diversity among the Brazilian biomes (IBGE, 2004). In last decades, Amazon rainforest has been lost its original vegetation cover manly due to the human actions, such as deforestation and forest degradation caused by selective logging and forest fire. Fire is an important agent of landscape transformation in this region, used as a tool for the maintenance of agricultural areas and to prepare pasture for cattle raising. Forest fires cause biodiversity losses, affecting directly the carbon cycle, changing the climate, hydrological cycle and, in addition, fires also have impact on the health of the population (ANDERSON et al., 2005; SMITH et al., 2014).

Most of the fire occurrence in forest areas are associated to the escape of fire originated in agricultural areas and cattle raising. Besides, the intensification droughts occurrence can be associated to the increase of the extent of forested areas affected by fire (ARAGÃO et al. 2007, 2008). There are three basic elements needed to ignite of fire, which are oxygen, heat and fuel. The absence of any of these elements, the combustion does not occur. The non-photosynthetic vegetation (NPV), which mainly includes dried leaves, dead trunks and tree barks, is one of the main components of the combustible material (fuel). In Amazon Forest, this material is highly flammable during the dry season and it becomes an easy ignition component (WHELAN, 1995).

The occurrence and spread of fires are strongly associated to some risk factors, represented by the anthropic action, climate conditions, topography, vegetation type and combustible material. The evaluation of these variables provides a vision of temporal and spatial distribution of the risk of fires, which can be observed through remote sensing data, as long as subsidies the planning and establishment of prevention and control of fires plans. In this context, the use of remote sensing techniques is an important tool to measure and monitor fires in the Amazon Forest, mainly due to the scale of the region, associated to the spatial and temporal dynamism of these disturbances. Therefore, this paper aimed to present the relationship between non-photosynthetic vegetation (NPV), intensity of burning (dNBR) and fire radiative power (FRP). The hypothesis is that NPV is the combustible material of fires. In this case, one would expect a positive correlation between NPV and indicators of burned areas.

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II. MATERIALS AND METHODS

Study area

This study was conducted using OLI/Landsat path/roll 227/068 image. This scene covers central part of Mato Grosso state and it encompass approximately 30.000 km² of southeastern Amazon Legal (Figure 1).

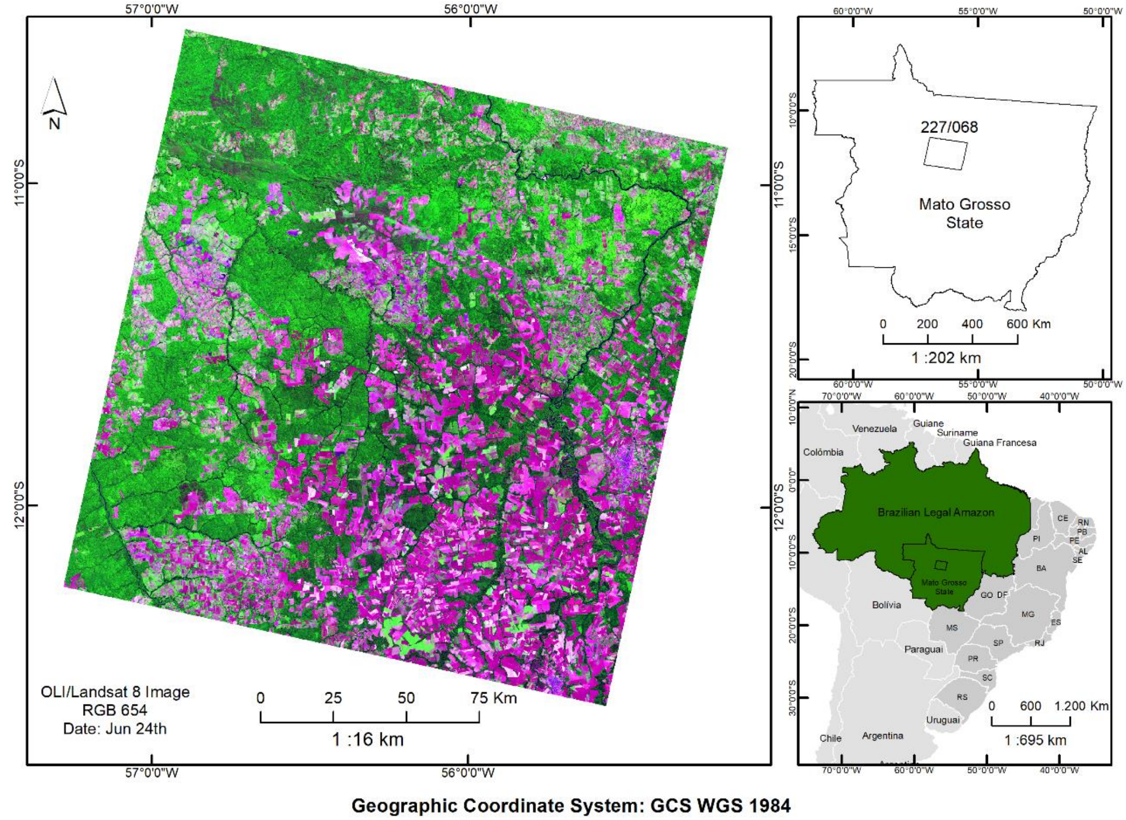

Figure 1. Geographic location of the study area, corresponding to OLI/Landsat 8 scene 227/68, encompassing the southeastern portion of Legal Amazona.

The colonization and development of the study area has occurred due to the construction of the federal highway BR-163 in the 1970s. Nowadays, the economic activities are agriculture and, in less proportion, livestock. However, in the beginning, the main activity was logging (MATRICARDI et al. 2010). This area was chosen due to its relative ecological importance, being considered a frontier region located at the "Arc of deforestation" in Brazilian Legal Amazon.

Data Set

It was used two OLI/Landsat imagens from different periods. The data acquisition were June 24th and October 14th of 2014, these dates were selected considering pre-fire and post-fire in the region, respectively.

In addition, it was obtained heat registers from INPE's Fire Monitoring System (inpe.br/queimadas/). This project register fire in the vegetation with satellites in near real-time and it also calculates and provides the fire risk in the vegetation. The heat registers were acquired between June and October, selected with 80% of confidence only. The main goal of this product is obtaining the Fire Radiative Power (FRP) of heat registers in the study area. The FRP provides an estimate of the amount of energy emitted as electromagnetic radiation during the combustion process. Thus, it may provide an estimative of the fire severity and amount of burned biomass.

To analyze the relationship between land cover and fires, it was used a map from Brazilian Amazon Deforestation Estimation Project (PRODES) (obt.inpe.br/prodes/). PRODES performs monitoring through satellite of deforestation in Legal Amazon of Brazil since 1988. The used map was reclassified in two main land cover classes: forest and non-forest. Non-forest class included Savanna, deforestation (accumulated from previous mapping) and hydrography classes.

Mapping of burnt áreas

Radiometric calibration technics were conducted in all imagens to avoid radiometric degradations and order to obtain a radiance image required for input into FLAASH (Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes). Then, the images were converted to surface reflectance through an atmospheric correction algorithm support of FLAASH (ADLER-GOLDEN et al. 1999).

It was used Linear Spectral Mixing Model (LSMM) (SHIMABUKURO and SMITH, 1991) in the image acquired on October of 2014 to map the burn scars. LSMM is a technique which decomposes an RGB image into three different resultant fraction imagens which corresponding the main components, such as soil, vegetation and shade fraction imagens. The method was chosen because burn scars are particularly well evidenced in the shade fraction image (Lima et al., 2012).

The LSMM transformation was applied to OLI bands 2 (450 – 510, blue), 3 (530 – 590, green), 4 (640 – 670 nm, red), 5 (850 – 880 nm, near infrared), 6 (1570 – 1650 nm, short-wave infrared) and 7 (2110 – 2290, short-wave infrared) of postfire image. It was considered six bands presuming that the number of components should not be greater than the number of spectral bands employed (Shimabukuro and Smith, 1991).

The endmembers used as data input to LSMM were selected directly in the image. It was selected the most spectrally similar pixels to the expected theoretical spectral response curves for pure targets. The endmembers chosen were: photosynthetic vegetation, soil and shade. The next step was to performe the segmentation operation on the shade fraction. The shade fraction image and segmentation were subjected to a classification by growing region, through ISOSEG classifier, for delimitation of burned areas. Lastly, the assessment of mapping was done manually in order to avoid errors in burn scars areas.

Linear spectral mixing model

The Non-Photosynthetic Vegetation (NPV) was obtained from Carnegie Landsat Analysis System – Lite (CLASlite) of the OLI/Landsat 8 image acquired on June 24th in 2014 (pre-fire image). CLASlite is a software for automated detection of deforestation and forest degradation analyzing satellite images, in order to monitor forests and promote the environmental planning (Asner, 2009, 2015).

CLASlite determinates, in its analyses, three components of tropical forest structure: Photosynthetic Vegetation (PV), NPV and Bare Substrate (BS). These components are crucial and fundamental to understand the composition, physiology, structure, biomass and ecosystem biogeochemical processes (Asner, 2015).

CLASlite uses a spectral library to define the three endmembers. This library is based on data field collections made using spectroradiometer for NPV and BS fractions. It is important to highlight that, the library which contains BS fraction data is made up of a varied set of types of soil, consisting of different levels of organic matter and moisture conditions. The library which contains NPV fraction data includes samples of litterfall, dry grass vegetation, deforestation and waste coal, all collected from a wide range of species and states of decomposition. The PV data library of PV uses a dataset collected from Hyperion sensor of the Earth Observing-1 (EO-1) Mission (Asner, 2015).

Differenced normalized burn ratio

The differenced normalized burn ratio (dNBR) (Key and Benson, 1999) was calculated through the difference between normalized burn ratio (NBR) (Koutsias and Karteris, 1998) of the pre-fire and postfire image.

The NBR is a normalized difference index related to vegetation moisture concerning near infrared and short-wave infrared bands, respectively 5 and 7 bands of OLI/Landsat 8 (Equation 1). This index was defined to highlight burned areas. The burned areas were selected to be the standard spectral index to assess the severity of the fire (Veraverbeke et al., 2010).

$$\mathrm{NBR} = \frac{\rho\mathrm{NIR} - \rho\mathrm{SWIR}}{\rho\mathrm{NIR} + \rho\mathrm{SIWR}} \qquad (1)$$

Where: ρNIR means near infrared reflectance; ρSWIR means short-wave infrared reflectance.

The NBR index was calculated to the image acquired on June 24th (NBRpre fire) and October 14 th (NBRpost fire). The dNBR measure the extent and severity of the burning through the difference between NBRpre fire and NBRpost fire (Equation 2).

$$\mathrm{dNBR} = \mathrm{NBR}_{pre\ fire} - \mathrm{NBR}_{post\ fire} \qquad (2)$$

Data analysis

For the purpose of spatial analysis, the original data of NPV, dNBR, FRP and burned area were converted into a regular grid of 8 x 8 km, where the mean was computed for each cell. This transformation was necessary to normalize the effect of variable areas resulting from the mapping procedure (Lima et al., 2012). The northern portion of the area was discarded due to the presence of clouds.

A dispersion diagram between (dNBR x NPV) and (FRP x NPV) was obtained based on the cell grid samples collected randomly selecting heat registers, which provide the FRP. In total, 95 samples were collected. It was calculated the mean of FRP to those grids which contained several heat registers, so, only one register was considered per grid. It was tasted the statistical significance of the regression analysis using analysis of variance (ANOVA).

The dispersion diagrams were represented in the form of boxplot, so, it was obtained the statistics for each interval of 0.2 NPV. It was applied analysis of variance to assess the significance of these classes of NPV, dNBR and FRP intervals and to verify whether there is difference between them.

III. RESULTS AND DISCUSSIONS

The mapping of burn scars in 2014 resulted in 442.2 km² of burned area; this value corresponds to 2.2% of the total area (Figure 2). From the total burned areas, 79.3% occurred in non-forest class of and 20.7% in forest class.

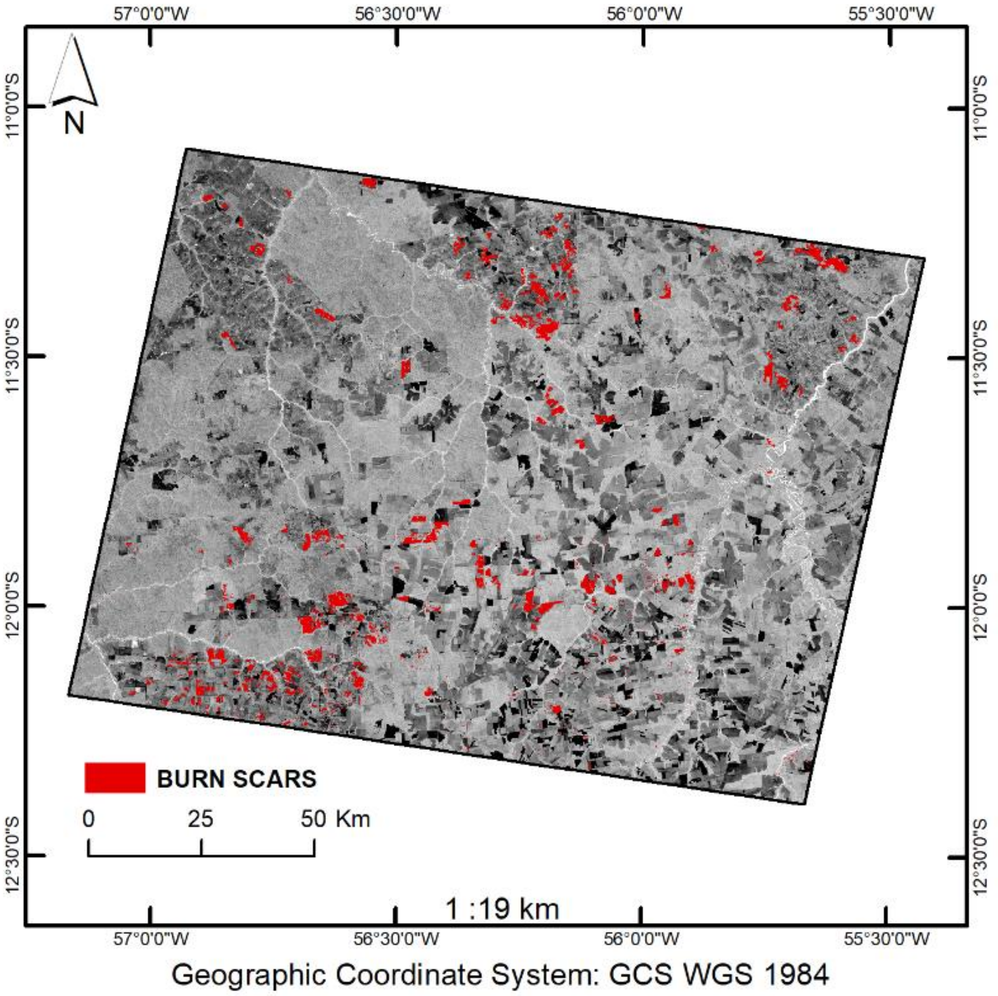

Figure 2. Mapping of burn scars using algorithm by growing region on shade fraction image. The image shows the total area of burn scars mapped in red.

Burn scars are spread throughout the study area, except in the southeast portion of the scene. It was not observed burned areas inside of the forest and far away from agricultural areas; it becomes clear that the fires recorded in forest areas occurred on the edges of agricultural areas. This pattern suggests the loss of control of fire used as a management tool in agricultural areas. The fire escapes from these areas and invades areas of native forest, changing the structure and composition of the forest, through continuous enlargement of forest edges, increasing area of secondary forest cover and making it more susceptible to future fires (COCHRANE et al., 1999; ZARIN et al., 2005; ARAGÃO and SHIMABUKURO, 2010).

NPV's relationship with the dNBR and FRP

Visual assessment of Figure 3a, 3b and 3c shows the spatial distribution of variables NPV, dNBR and FRP, respectively. The scale of the Figure is qualitative only, in purple are the highest values. In FRP case, white color is the absence of heat register within the cell. The highest values of NPV are located in the southeastern portion of the scene, median values are in the central, southern and northeastern portions, the lowest values are in the western portion. The dNBR presents relatively diffuse spatial distribution in the study area. The spatial distribution of FRP data are concentrated in the eastern and northeastern portions of the scene. It is observable the spatial correspondence between the dNBR and FRP, however, it is not clear the spatial similarity between the NPV with the other variables.

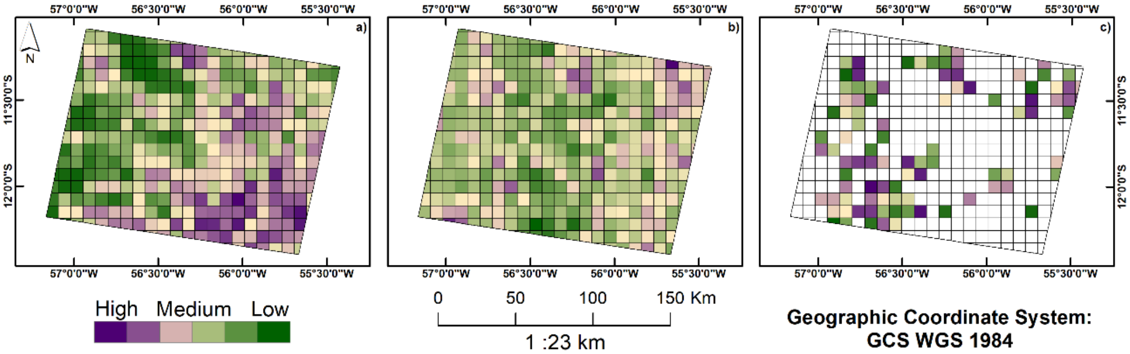

Figure 3. Visual representation of the zonal statistics between NPV, dNBR and FRP: a) NPV, b) Difference Normalized Burn Ratio (dNBR) and c) Fire Radiative Power (FRP). The cell sizes are 8 x 8 km

The NPV is a dead organic material or senescence state with low humidity. The biggest change of photosynthetic vegetation to the NPV can be better detected observing SWIR (shortwave infrared) region. NPV is scattered across the spectrum. In the SWIR region, the dispersion is much more efficient, in contrast to the photosynthetic active vegetation, which presents strong absorption of the electromagnetic radiation in this region due to the presence of water (ASNER, 1998).

Due to the marked difference between the photosynthetic vegetation and NPV in the SWIR region, NPV is expected to correspond (direct or inverse) with indexes that operate in the SWIR, like the NBR and dNBR. The Normalized Burn Ratio (NBR) is calculated using the normalized difference between peak reflectance in NIR

(Near-Infrared) (0.85 – 0.88 nm) and SWIR (2.11 – 2.29 nm) regions (ALLEN and SORBEL, 2008). This combination highlights the difference between the burned vegetation and healthy vegetation. Therefore, the dNBR isolates the changes caused by fire in the period considered as pre-fire and postfire (ALLEN and SORBEL, 2008).

Thus, our first assumption is that there is a direct relationship between the NPV and dNBR, and NPV, theoretically, is the combustible material available for burning and ignition. However, according to the dispersion diagram the correspondence between theses to variables was low ($R^2 = 0.107$ and p-value = 0.52).

It was also evaluated the correspondence between the NPV and FRP. The fire radiative power refers to electromagnetic energy emitted by the fire (PEREIRA et al., 2011). In this regard, the material with the highest presence of lignin and low humidity has greater power of combustion, consequently greater emission of electromagnetic radiation. However, according to the dispersion diagram the correlation between these variables was low as well ($R^2 = 0.03$ and p-value = 0.9).

Based on the analysis of variance (ANOVA), p-values showed high values, which means that the relationship between the variables are weak. It can be related to the fact that the land-use areas in study area is not directly proportional to the number of fires set, hence the correlation coefficient may be low. In many Amazonian regions is very common the use of fire to manage the land and clear the vegetation in preparation for agriculture and livestock (SORRENSEN, 2000). Due to agricultural production scale in the region to supply the national and foreign markets, heavy machinery is employed. Thus, the use of fire is not a common management practice in the region under study, unlike the itinerant agriculture.

Allied to this, the no-tillage system (NTS) has been widely used in Mato Grosso agriculture. The rapid expansion of the NTS can be explained, in part, by lower production costs and easy operability, combined with greater protection of soil, water and wildlife. This conservation practice has three basic principles of soil management: the no-tillage, crop rotation and permanent cover (dead or alive). This last principle is one of the main representatives of the NPV in the region under study.

Non-use of fire as a management practice in agricultural areas in most part of the study area and the use of no-till system can be associated to the weak correlation between the NPV and the variables evaluated (dNBR and FRP). Eva and Lambin (2000) studied the role fires in vegetation-cover change and, conversely, the role of land use as a controlling factor of fires, and observed the unrelated between fire occurrence and land-cover change in an area in East Africa. The authors point out that in these areas, where the operations are heavily mechanized, there is no fire associated with them.

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The analysis of the box plot of the polynomial dispersions showed a growing trend of dNBR, until about 0.5 of NPV. From 0.5 onwards NPV, dNBR decreases (Figure 4a). The average FRP value grows to about 0.7 NPV, and then, FRP values fall (Figure 4b). This shows that the increasing of dNBR and FRP values follow NPV values growth until to about 0.5 (to dNBR) and 0.7 (to FRP), and then, despite the increase of the NPV, dNBR and FRP values decrease.

One way ANOVA tests of Figure 4a and Figure 4b showed that the p-value are small ($p < 0.0001$), so, it is unlikely that the differences observed are due to random sampling and it shows that not all of the intervals have equal means.

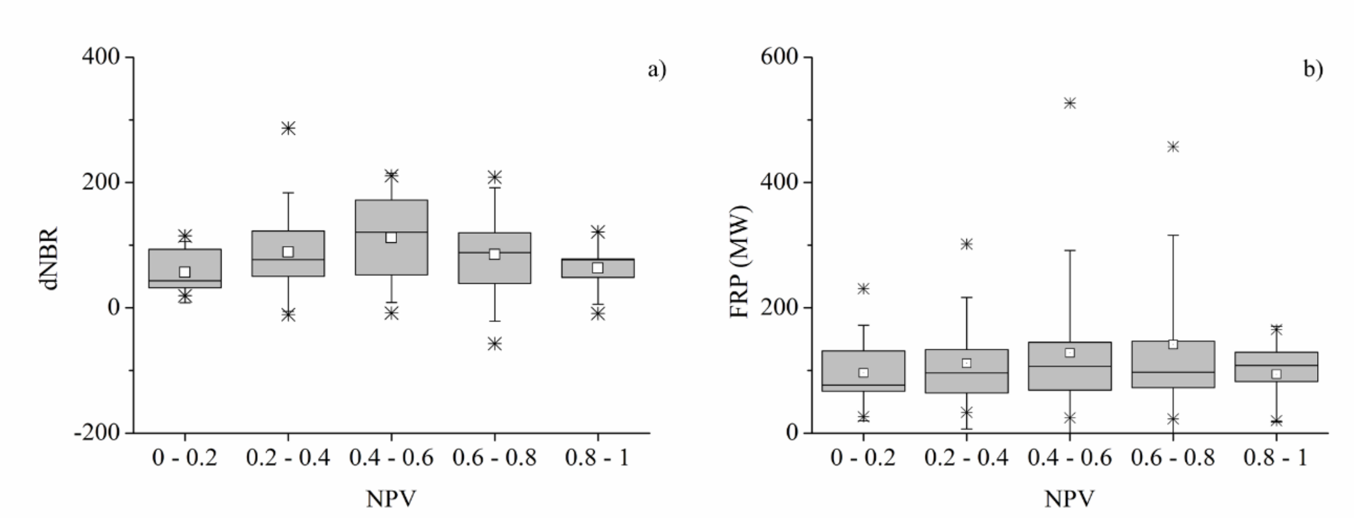

Figure 4. a) Polynomial dispersion diagram between the NPV and dNBR represented in the box plot form; b) Polynomial dispersion diagram between the NPV and FRP also represented in box plot form.

The analysis of the NPV values spatial distribution (Figure 5) showed that the highest values are located in the non-forest class and in agricultural areas. The highest values of NPV in this region are, probably, associated to the large areas covered with dead organic material, remains of the previous crops due to no-tillage system, previously mentioned. These regions have a highly mechanized agriculture, where the use of fire is not a common practice. The regions with high concentration of NPV, culminates in the reduction dNBR and FRP. Thus, the relationship between NPV and dNBR and FRP was low. The lowest values of NPV are situated on the natural environment areas, where the presence of dead organic material is smaller and more diffuse.

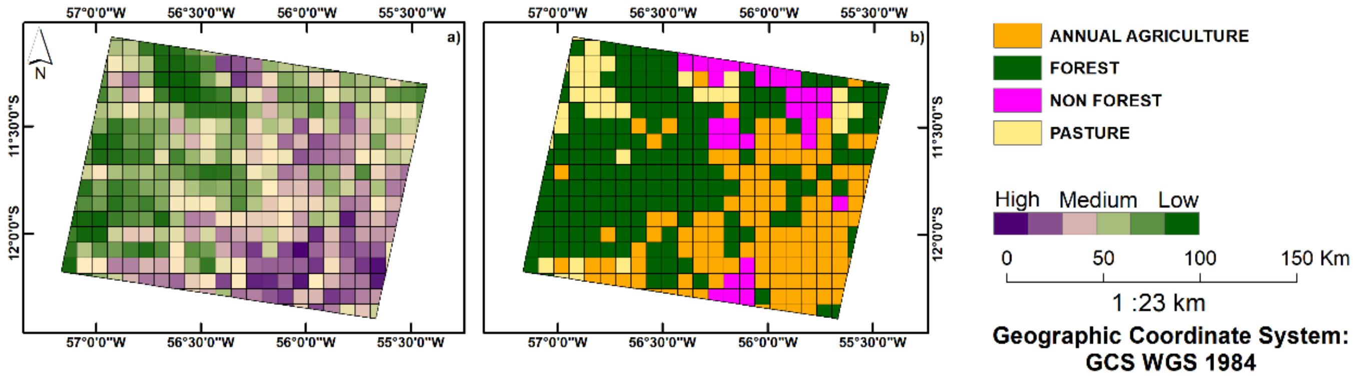

Figure 5. Visual representation of the zonal statistics between non-forest class and NPV: a) NPV; b) non-forest land cover class. The cell sizes are 8 x 8 km.

Figure 6 shows the statistics (arithmetic mean, variation, median and quartiles) of NPV, dNBR and FPR of burned areas in forest and non-forest classes. Higher values of NPV and the higher variability occurred in burned areas of non-forest class (Figure 6a). This reaffirms what has been discussed above; high concentration of NPV in agricultural areas due to no-tillage system, and small and diffuse concentration of NPV in forest areas.

The average value of dNBR in the burned areas in forest and non-forest classes were similar (Figure 6b). The greatest variation of dNBR and the highest values occurred in burned areas in forest class. This indicates that the greatest disturbance of fires occurred in forest areas, which was expected. When comparing the same area pre and post-fire, obviously, the biggest change will happen in forest areas than in agricultural areas.

In turn, the highest values of FRP are shown in the burned areas of non-forest class (Figure 6c). This result corroborates the fact that in the non-forest cover class there is a higher concentration of NPV. In other words, drier material, higher lignin content, have greater combustion power.

It is important to note the limitations of the heat data. The heat registers are detected only during the day, all night fires, normally, used by farmers attempting to escape detection, remain undetected. Furthermore, fires obscured by cloud cover are not detected. Geolocation problem may occur due to coarse spatial resolution of satellite images, however, is not expected major problems considering that was generated 8 km grids (EVA and LAMBIN, 2000).

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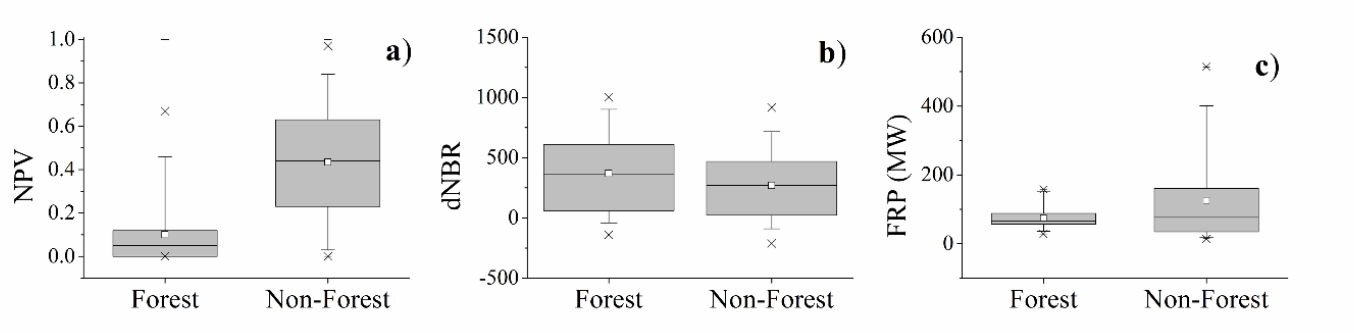

Figure 6. Box plots showing the statistical parameters of NPV, dNBR e FPR in forest and non-forest land cover class: a) NPV, b) dNBR and c) FRP. The values were obtained from original data.

The fire patterns may vary according to various biophysical and socioeconomic factors, such as biome and land use (EVA and LAMBIN, 2000; MORTON et al., 2006; BRONDIZIO and MORAN, 2008; SORRENSEN, 2009).

Morton et al. (2006) claim that in areas with few or no economic incentives, the natural vegetation conversion into clear cut is initially followed by pasture for livestock. In this case, repeated burning has been used for pasture renewal and maintenance. On the other hand, Eva and Lambin (2000) mention that the conversion process of forest to agriculture includes removal vegetation from forest areas and at the edge of the savanna to implement agriculture. These activities will be accompanied by fire by 'slash-and-burn' system. After the implementation of agriculture, the use of fire is still used in some regions. However, mechanized agriculture and plantation cropping will not normally be accompanied by fire activity. The use of fire in these cases occurs for eliminate crop residues, much lower than with pastures.

Aragão and Shimabukuro (2010) argue that fire in the Brazilian Amazon is likely to follow three possible pathways: (i) the occurrence of fires can decrease with the reduction of deforestation (ALENCAR et al., 2006; ARAGÃO et al., 2007; ARAGÃO et al., 2008); (ii) despite the reduction of deforestation, the fire incidence may increase through the use of fire for maintenance of secondary vegetation (FEARNSIDE et al., 2007); (iii) the occurrence of fires can decrease due to intensification of agriculture, using more technology management practices (Eva and Lambin, 2000). Aragão and Shimabukuro (2010) showed that in rural areas with large property and strong vocation for agriculture, changes in management practices of extensive agriculture to intensive agriculture has dramatically reduced the use of fire.

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IV. CONCLUSIONS

The highest percentage of burnt scars was evidenced in agricultural areas. The use of fire in these cases occurs for eliminate crop residues. Fires in forest areas occurred, in general, in the borders of the agricultural areas, which brings attention to the problem of the loss of fire control that escapes into native forests.

The initial hypotheses of this study was that the NPV is the fuel material of fires. In this case, so, it was expected a positive correlation between NPV and indicators of burned areas. However, the correspondence between the NPV, dNBR and FRP variables was weak. Note that the land use in area under study is not directly proportional to the number of fires set. This result is a strong indicator that the intensification of agriculture in the region eliminated the fire as the main management tool.

The relationship between the tested variables was weak and this can be related to the non-use of fire as the main management tool, which associated to the highly mechanized agriculture and the use of no-tillage system, that leaves on the land the rest of the dead material from previous crops.

The purpose of this study was not to evaluate the increase or reduction of fires in the region under study. However, the low correlation between NPV and the occurrence of fires identified in this study clearly support the idea a positive relation between technological approaches, represented by the highly meccanization of the agricultural, and the decreasing fire usage. Our results can be useful to support efforts to incentive the technological approaches applied at the agricultural practices to avoid the use of fire as a tool of land management.

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