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Surface albedo in different land-use and cover types in Amazon forest region

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ABSTRACT

Albedo is the portion of energy from the Sun that is reflected by the earth's surface, thus being an important variable that controls climate and energy processes on Earth. Surface albedo is directly related to the characteristics of the Earth's surface materials, making it a useful parameter to evaluate the effects of original soil cover replacement due to human occupation. This study evaluated the changes in the surface albedo values due to the conversion of vegetation to other land uses and to analyze the applicability of the use of albedo in the spatial delimitation of land-use classes in the transitional region between the Cerrado and Amazon biomes. Surface albedo measurements were obtained from processing of Landsat Thematic Mapper data in the Geographic Information System (GIS), and land-use information were collected using Google Earth high-resolution images. The results show that human activities such as the cultivation of crops and burning have contributed substantially to variations in the surface albedo, and that albedo estimates from Landsat imagery have the potential to help in the recognition and delimitation of features of land use and cover.

Keywords: Landsat 5, reflectance, remote sensing.

Albedo de superfície em diferentes classes de uso e cobertura do solo em região de floresta amazônica

RESUMO

Albedo é a porção de energia solar refletida pela superfície terrestre, sendo assim, uma importante variável que controla os processos climáticos e energéticos sobre a Terra. Albedo da superfície está diretamente relacionado com as características dos materiais da superfície da Terra, tornando-se um parâmetro útil para avaliar os efeitos da substituição de cobertura do solo original devido à ocupação humana. Este estudo objetivou avaliar as alterações nos valores de albedo da superfície em função da conversão da vegetação em outras formas de uso do solo, e analisar a aplicabilidade do uso do albedo na delimitação espacial de classes de uso do solo em região de transição entre os biomas Cerrado e Amazônia. As medidas de albedo da superfície foram obtidas a partir de processamento de dados Landsat Thematic Mapper em sistema SIG e as informações de uso do solo foram obtidas usando imagem de alta resolução do Google Earth.

Os resultados demonstram que ações antrópicas sobre a superfície, como desenvolvimento de lavouras e queimadas contribuem substancialmente para as mudanças no albedo de superfície, e que as estimativas de albedo a partir de imagens Landsat apresentam potencial para auxiliar na identificação e delimitação de feições de uso e cobertura do solo.

Palavras-chave: Landsat 5, reflectância, sensoriamento remoto.

1. INTRODUÇÃO

The Amazon rainforest exchanges large amounts of water and energy with the atmosphere, and is therefore important in controlling the regional and global climate (Meir and Grace, 2005). However, the spatial distribution and temporal variation of rainfall (Curado et al., 2016), as well as duration of droughts (Rodrigues et al., 2016a), can have a profound impact on the dynamics of energy exchange by affecting the partitioning of energy between sensible and latent heat fluxes (Vourlitis et al., 2008; 2014; Rocha et al., 2009; Rodrigues et al., 2013; 2014). Because our current knowledge of the climate system is still insufficient to solve some of the divergent predictions about this topic, it is important to improve the understanding of mechanisms of vegetation-climate interaction in forested regions such as the Amazon (Gonçalves et al., 2013), whose seasonal patterns of certain biophysical and climatic parameters show complex interactions (Vourlitis et al., 2014; Rodrigues et al., 2016b).

The process of agricultural expansion and deforestation taking place in the Amazon, mainly in the region known as the 'Arch of Deforestation', has resulted in more intensive land-use and forest disturbance as a consequence of the conversion of original vegetation to different forms of land use and cover (Neeff et al., 2005; Soares-Filho et al., 2006; Costa and Pires, 2010).

One of the biophysical parameters influenced by the modification of original vegetation in forested regions is the surface albedo, which is the fraction of incident radiation reflected by a surface that acts as a factor for distribution of solar radiation and energy flow between the surface and atmosphere (Wang et al., 2006; Novais et al., 2015). Albedo is a parameter that varies both spatially and temporally given changes in surface properties, such as soil moisture and vegetation cover as well as changes in local natural light conditions (Franch et al., 2014). It influences the prediction of variables like near-surface temperature and relative humidity (Boussetta et al., 2015). Studies relating landscape features to land cover transformation may help in the understanding and planning of changes in landscape conditions over time, including projections of future land use as well as comparisons between alternative landscape scenarios (Paudel and Yuan, 2012; Swann et al., 2015).

Strongly influenced by anthropic occupation affecting land use in originally natural environments, the surface albedo is a parameter that both influences the radiation balance and modifies the absorption of shortwave radiation (Betts et al., 2007).

Thus, studies on albedo changes as a consequence of modifications in land use and land cover may contribute to the understanding of impacts resulting from human-environment interaction (Barnes et al., 2013; Boisier et al., 2013). There are still many regions, such as the Amazon region of the Brazilian state of Mato Grosso (Schwaiger and Bird, 2010), that require further investigation of the effects caused by land use and cover, since this region has experienced an expansion in economic activity over the last decades (Roberts et al., 2003).

Remote-sensing techniques can contribute to obtaining different information about the earth's surface in relatively large areas (Ban-Weiss et al., 2015) by allowing, for example, the investigation of albedo variations along different land-use and cover scenarios (Gao et al., 2014). Some researchers have explored the advantages of the use of biophysical parameters from satellite imagery in studies in the vast territory of the Brazilian Amazon. Some examples

of this are the publications of Tartari et al. (2015), Querino et al. (2016), and Silva et al. (2016), who used surface albedo among the investigated parameters. Such studies have increased the level of knowledge of the interactions between the Earth's surface and the atmosphere in this important biome.

Taking into account that albedo presents specific values for certain classes of land use and land cover (Wickham et al., 2015), it is possible to evaluate the effectiveness of this parameter in the identification and distinction of different forms of land use and occupation in order to promote future work on land-use evolution (Salifu and Agyare, 2012).

Although there are many studies showing the applicability of medium spatial resolution images in surface albedo behavior due to changes in land use classes, there are still very few studies evaluating the use of surface albedo in distinguishing land-use classes. Among the few studies with this focus, Salifu and Agyare (2012) showed that the use of surface albedo offers potential to distinguish different land-use and cover types in Volta Basin region, Ghana.

This study evaluated the effect of conversion of native forest to different types of land use and cover (LUC) on the surface albedo values in the Amazon-Cerrado transition region, as well as the applicability of surface albedo to the identification and delimitation of different land-use classes.

2. MATERIALS AND METHODS

2.1. Study Area

The total study area encompasses approximately 20,000 ha and is located between the towns of Ipiranga do Norte and Sorriso, a region of Amazon-Cerrado transition in northern Mato Grosso (Figure 1). The selected area shows several types of land use and presents an opportunity to perform studies on the behavior of biophysical variables in the different classes of land use from satellite imagery.

2.2. Image Pre-Processing

Land-use and cover data were collected and analyzed with high spatial resolution images from Google Earth Pro®, and albedo measurements of different land-use classes were retrieved from Landsat-5 TM. Thus, the study required combining images with the same date from Landsat and Google Earth Pro® to allow comparison of the results. The date of 30 September 2009 was selected as there were images available both from Google Earth Pro® and from Landsat-5 TM. Therefore, the results of this study refer to this date.

The image from the Google Earth Pro® software was acquired at the maximum resolution and then georeferenced using a high-resolution SPOT image through control points in both images. The Landsat-5 TM image used corresponds to the orbit and Point 227/68 in the Landsat Universal Reference System, and was acquired from the website espa.cr.usgs.gov, which provides a surface reflectance image that had undergone atmospheric correction and is cloud-free.

2.3. Surface albedo survey

The surface albedo estimates were calculated according to Liang (2001), who establishes equations for several orbital sensors that allows calculating the albedo through simulations of radiation transport using MODTRAN (Moderate Resolution Atmospheric Transmission). This work applies Equation 1 to Thematic Mapper (TM) images.

$$\text{Albedo} = 0.356\alpha 1 + 0.130\alpha 3 + 0.373\alpha 4 + 0.085\alpha 5 + 0.072\alpha 7 - 0.0018 \quad (1)$$

In which αi corresponds to the surface reflectance that is intrinsic to the bands “i” of the sensor Landsat-5 TM.

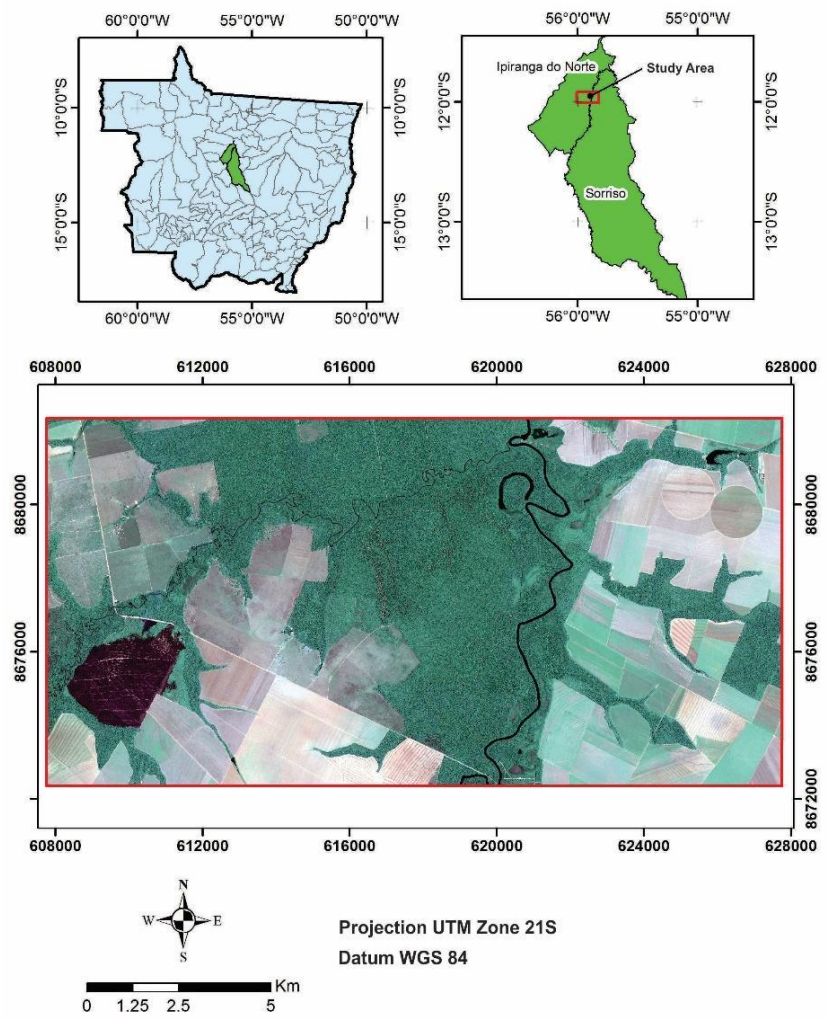

Figure 1. Top left: State of Mato Grosso in mid-western Brazil; Top right: towns of Sorriso and Ipiranga do Norte; Bottom: study area.

2.4. Land use and land cover

In order to identify and outline the types of soil use and cover, a high-resolution image dated 30 September 2009 was obtained from the Google Earth Pro® software for which vectorization class was later carried out using ArcGIS 10.1® at a scale of 1:5,000.

The following classes of land use and cover were considered for the study area: crop, forest, burned area and water. Crop areas were targeted through characteristic polygons that occur in the region in the form of squares, rectangles and circles in which the cultivation process is carried out. This class was not distinguished in terms of the different steps involved in the production process, such as planting and harvesting. The class mapped as forest corresponds to areas of dense vegetation, with visual appearance similar to those of the Amazon forest observed in high-spatial resolution images. The burned-area class is identified due to the characteristic visual appearance of an area that underwent combustion in which several band compositions of the Landsat-5 TM were further attempted following the procedures of Roza and Ribeiro (2013). Water areas are represented especially by water courses and abandoned meander channels.

The analysis of the surface albedo in each one of the classes of land use and occupation was carried out at a scale of 1: 25,000, and all the geoprocessing routines were performed using the ArcGIS 10.1® software.

3. RESULTS AND DISCUSSION

Land-use and land-cover mapping shows a large predominance of crop and forest classes (Figure 2) that occupies 48.75 and 47.45% of the total study area, respectively. Burned areas and water bodies occupy a more restricted portion of the study area, making up 2.74 and 1.06%, respectively.

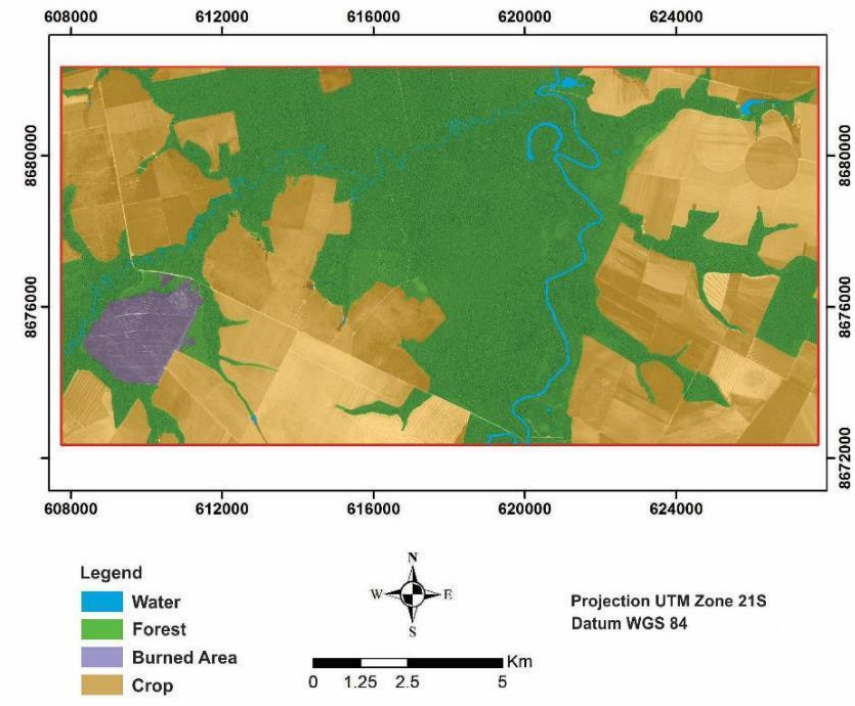

Figure 2. Soil use and soil cover.

Burned area mapping included analysis of false-color composites (RGB: 4,3,1) and (RGB: 5,4,3) of Landsat-5 TM, which allowed recognition of burned areas through dark (almost black) and purple tones, respectively, according to the criteria adopted by Roza and Ribeiro (2013) to identify burned areas using Landsat-5 TM images.

Figure 3 shows the surface albedo map of the study area with color-coded values. This map has an overall mean of 0.153 and a standard deviation of 0.021.

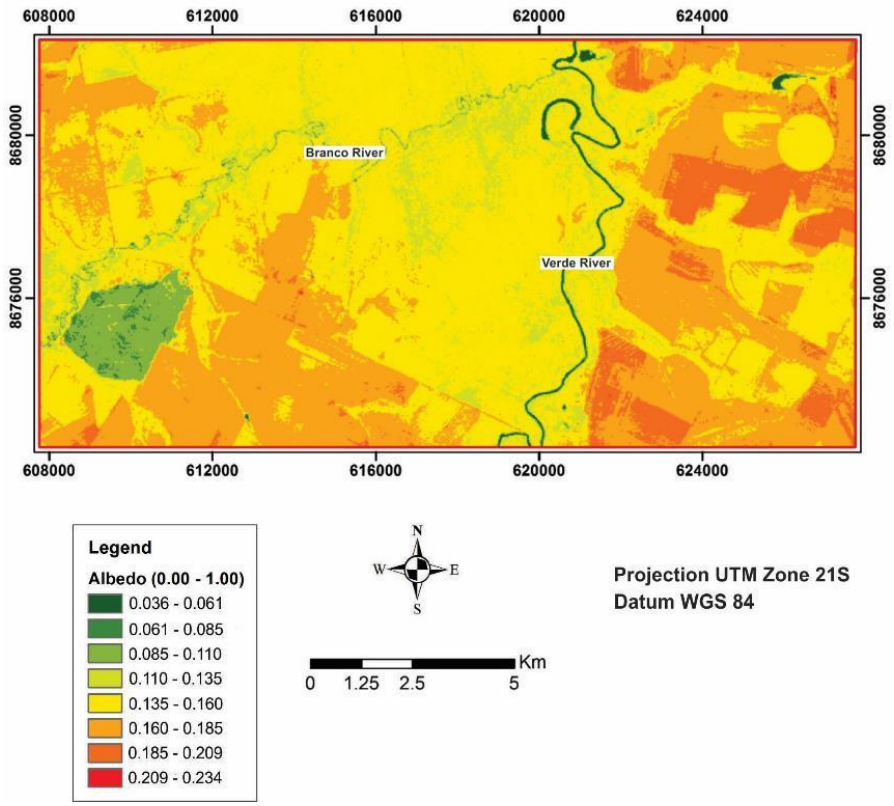

Figure 3. Surface albedo.

Summary statistics with mean, median and standard deviation of the surface albedo for each land use class are shown in Table 1. Figure 4 presents a box-plot of the summary statistics of the surface albedo for all classes of land use.

Table 1. Summary statistics of surface albedo for the classes of soil use and cover.

Land use and cover	Mean	Median	Standard Deviation
Crop	0.163	0.164	0.013
Forest	0.142	0.140	0.011
Burned area	0.094	0.090	0.010
Water	0.083	0.075	0.029

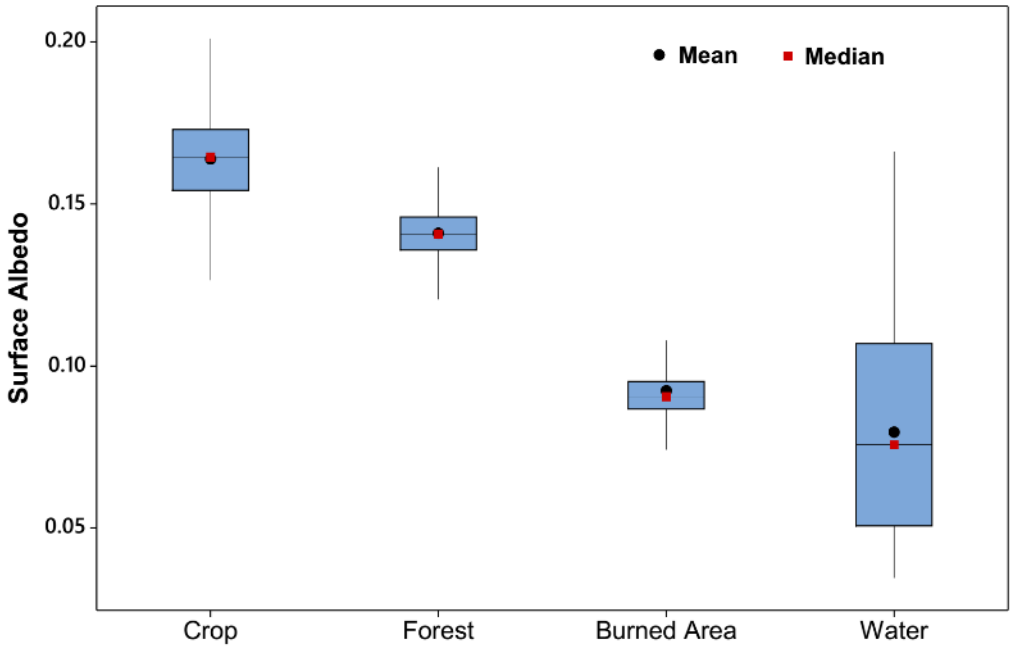

Figure 4. Box-plot showing summary statistics of surface albedo in each land use class.

The regions occupied by forests presented a mean albedo value of 14.2%, which is similar to that of albedo of tropical rainforests (Berbet and Costa, 2003; Querino et al., 2006; Liberato, 2011). The results indicate that the variation of the albedo values for forest is relatively low, suggesting that forest has albedo with substantially homogeneous behavior in the study area. The small variation of albedo values for forest regions can be caused by variation of vegetation types in this class of land use.

The mean albedo of the crop areas was 16.7%, which represents the highest mean among the classes of land use and cover. This land use class showed a large range between the values of albedo, which can be due to the presence of different stages of agricultural production in the study area, such as planting and harvesting.

The burned area was the class that presented the lowest variation of surface albedo values, and its standard deviation was 1.0%. The mean albedo for burned area was of 9.4%, which is significantly lower than the classes of crop and forest. This low value is explained by the decrease in reflectance due to the loss of photosynthetically active material and by the accumulation of ashes on the soil (Cardozo et al., 2014).

Albedo values for burned areas vary according to the time elapsed after burning, but the mean value found in this study is relatively similar to the values for burned areas identified by other authors, although for different types of vegetation. Pereira et al. (2007) found a mean albedo value of 9.3% for recently burned areas in the Pantanal region of Mato Grosso do Sul, whereas Cardozo et al. (2014) identified a mean albedo value of 6% for burned areas in the state of Rondônia.

The water class shows a mean albedo value of 8.3%, which is the lowest value among all of the land-use classes studied. This value is within the range found by other authors (Giongo et al., 2010; Liberato, 2011). The water class presented a standard deviation (2.9%) and variation of albedo values significantly higher than the other studied classes. The highest standard deviation is largely due to pixel contamination given the limited spatial resolution of Landsat images. This was mainly observed in the area of the Rio Branco River, an affluent of the Rio Verde River, whose mean width is around 20 meters and, therefore, below the spatial resolution of Landsat TM images used in the study. The appearance of mixed pixels is a consequence of albedo values influenced by other features of the terrain other than water.

The differences in albedo values among the land-use classes (forest, crop, water and burned area) mapped by Google Earth images (Figure 5) shows that surface albedo retrieved from medium-spatial resolution images has the potential to help in the characterization of land use classes in the Amazon region.

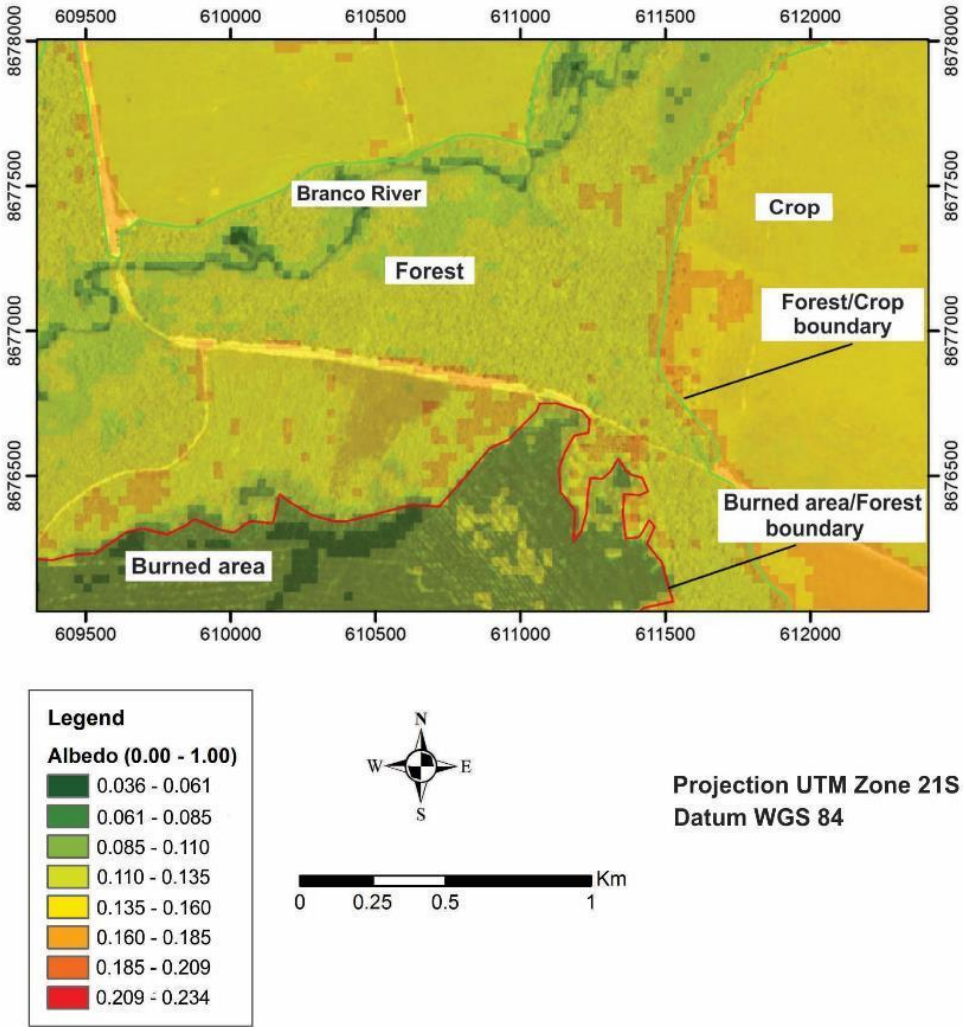

Figure 5. "Zoom" on the study area showing an overlay of albedo estimates and Google Earth Pro® image (transparency of 65%).

In general, surface albedo mapping allowed for the identification of water surfaces on the basis of their lower values in comparison to the other classes of land use. In addition, it was possible to identify features such as abandoned meander channels and water courses with a mean of over 30 m in width. It was also possible to infer traces of water surfaces with a mean width lower than 30 m, as is the case for the Rio Branco River, when some pixels of the image show typical values of a wet surface.

The mapping of albedo also allowed for distinguishing forests and crop areas from other forms of soil use and occupation; however, the distinction between forest and crop areas was more challenging to identify since these two classes may present subclasses that are only better classified after field work and since they consist of native forest, regenerating forest and planted forest, as well as different types of crops in their respective production phases.

The albedo survey was shown to be effective in identifying and delimiting burned areas, which have overall values lower than those of crops and forests. However, it is important to

pinpoint that a reliable interpretation of burned areas requires a complementary analysis using band composites able to highlight this soil cover class.

Therefore, the results showed that the estimation of surface albedo from orbital sensors, which was calculated according to Liang (2001), in combination with the resulting interpretation of band combinations as proposed by Roza and Ribeiro (2013), favors the identification and delimitation of burned areas in forests of the Amazon-Cerrado transition region.

The comparison between surface albedo values calculated for forests and crop classes shows that the conversion of forests to agriculture produced an albedo increase of 0.025. This increase due to large-scale deforestation, as suggested by other studies (Culf et al., 1996; Giambelluca et al., 1997), tends to have a direct effect on the radiation budget and energy partition given the lower amount of energy absorbed by the earth's surface.

4. CONCLUSIONS

The values of albedo surveyed for classes of soil use and cover in the Amazon-Cerrado boundary in Mato Grosso are reasonably similar to those found in the literature in previous studies. Concerning areas of crops and forests, due to their heterogeneity there may be areas where the boundary between these two classes is difficult to establish using only albedo estimates. However, as a rule-of-thumb, crops have significantly higher albedo values than those of forest areas and other land-use classes studied here.

The albedo estimates calculated from the Landsat image show a significant potential to help in the identification and delimitation of anthropic and natural features in the Amazon-Cerrado transition region once the classes of soil use and cover have distinctive albedo values that allows them to be distinguished from each other using medium-spatial resolution images.Among the classes considered in this study, albedo estimates were more effective to spot burned areas as well as water features, such as abandoned meander channels and water courses, especially when these features have a mean width of over 30 meters.

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