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Fire risk assessment in the Brazilian Amazon using MODIS imagery and change vector analysis

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A B S T R A C T

Fires in the tropical forests are the main source of greenhouse gas emissions in Brazil. Current methods aimed at the detection and monitoring of fire events in the Brazilian Amazon are frequently insufficient for policy decisions which aim to prevent new fire events and identify the previous land cover of the affected areas. This research applies remote sensing and GIS technique to areas with high occurrence of forest fires in the Brazilian Amazon, with the aiming to recognize land use changes that could: 1) Identify areas with high risk of being burnt and 2) Improve current fire scars mapping methods by enabling the discrimination of fires in primary forests and fires in previously burnt areas. The Change Vector Analysis method was applied to the Red and NIR bands of two MODIS/Terra images from key dates prior to the 2005 forest fire season, resulting in one change vector image with two components: direction and magnitude of changes. A Decision Tree (DT) was designed and evaluated through the C 4.5 algorithm to classify 2400 sample pixels extracted from four selected classes inside the change vector images: A) Forest; B) Agricultural areas; C) Fire risk in primary forest; and D) Fire risk in already degraded areas. The DT achieved a global accuracy of 90.21%. Samples from classes B and D were the main contributors to the DT confusion, with omission errors of 9.5% and 24.5%, respectively. The method was tested in 14 municipalities for the year of 2005, 2006 and 2007 and compared with hotspots from the MODIS active fire product, resulting in a correlation coefficient of 0.84.

Introduction

Fires in tropical forests are responsible for nearly 20% of anthropogenic greenhouse gas emissions into the atmosphere (Gullison et al., 2007). Previous studies have shown that deforestation in the Brazilian Amazon is responsible for over 200 million tons of CO_2-equivalent carbon per year, representing about 75% of the total volume of CO_2 released in the country (Fearnside, 2007). If current trends persist, it is expected that tropical deforestation will release an additional 87–130 billion tons of Carbon by 2100 (Gullison et al., 2007).

According to Jaiswal, Mukherjee, Raju, and Saxena (2002), the causes of forest fires can be classified into three main categories: (1) natural causes, (2) deliberate human acts, and (3) accidental human acts. In the Brazilian Amazon, autogenic factors in primary forests create a microclimate that virtually eliminates the probability of natural or accidental fire (Uhl & Kauffman, 1990). Therefore, forest fires in the Brazilian rainforests are typically associated with deliberate human acts, namely the implementation of new agricultural areas (Eva & Fritz, 2003).

However, a long process precedes the transition between rainforests and agricultural activities. Selective logging is usually the first activity that takes place in the rainforest area. After commercially valuable wood has been extracted, the rest of forest is cut down with the use of chainsaws and tractors. Due to high moisture content, the remaining vegetation is left to dry until the next dry season. The vegetation is then burned in order to clear the area. On many occasions this process is repeated until the area is clear enough to allow for the use of agricultural machinery (Cochrane, 2003; Morton et al., 2008).

Currently, different remote sensing methods are used to detect and monitor forest fires in the Brazilian Amazon. The most common approaches consist in detecting land changes during and after the occurrence of fire events. The first is usually done by detecting changes in energy emission caused by biomass combustion (Giglio, van der Werf, Randerson, Collatz, & Kasibhatla, 2006), while the second is mostly based on mapping burn scars, as evident from changes in the vegetation reflectance (Almeida Filho & Shimabukuro,

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2004; Aragão et al., 2007). Although such approaches are essential for the monitoring of the spatial distribution and seasonality of fires, they are sometimes insufficient to support policy decisions which aim to prevent new fire events. Another drawback of current methods lies in the difficulty in identifying the previous land cover of the affected areas.

Aiming to improve forest fire prevention policies in the Brazilian Amazon, Nepstad et al. (1998) developed a methodology integrating the effects of drought and logging activities to assess forest fire susceptibility and to improve forest fire prevention policies in the Brazilian Amazon. This methodology employed data from soil water capacity maps, precipitation and evapotranspiration records, and maps of the spatial distribution of regional logging centres. Arima, Simmons, Walker, and Cochrane (2007) incorporated economical variables reflecting farm-gate prices of beef and soybean in a spatially explicit model. The authors found a positive correlation between fire and the prices of beef and soybean.

Nevertheless, Morton et al. (2008) suggest that to improve the understanding of greenhouse gases released by deforestation it is necessary to consider the interannual changes in the deforested areas that contribute to fire activity. The same authors show that in order to achieve an appropriate characterization of fire emissions, it is essential to discriminate between fires and the repeated burning of deforested areas from other fire types in Amazonia.

In this context, the spectral profile of the forest, allied with multi-temporal aspects of land changes are important tools in the analysis of the problem. This research applies a Change Vector Analysis (CVA) in areas with high occurrence of forest fires in the Brazilian Amazon, aiming to recognize land changes that could: 1) identify areas with high risk of being burnt and; 2) improve current fire monitoring methods by allowing the discrimination of fires in primary forests and fires in previously burnt areas. After performing the CVA, Decision Trees (DTs) were evaluated to categorize the changes observed in the study area.

Study area

The study was carried out in 14 municipalities located in the northern part of Mato Grosso State, Brazil (Fig. 1). The first phase of the research concentrated on Porto dos Gauchos Municipality (striped in Fig. 1), where samples were extracted to train and calibrate the DTs. Subsequently, the method was applied to all municipalities displayed in Fig. 1. These municipalities are inserted in an agricultural expansion region known as the arc of deforestation (Cardille & Foley, 2003). The region has faced intense land use and land cover change over the past decades and continues to experience high deforestation rates. Such activities started back in the 1970s when the Brazilian Government initiated public policies promoting the occupation and development of the north region of the country, resulting in the deforestation of large areas of the Amazon forest (Alves, 2002).

The total area of the 14 municipalities is approximately 80 thousands square kilometres. The original vegetation in these municipalities is relatively homogeneous, consisting predominantly on Tropical Seasonal Forests and Humid Tropical Forest. The Tropical Seasonal Forests has canopy heights ranging from 10 to 40 m and its vegetation loses up to 50% of the leaves during the dry seasons. The Humid Tropical Forests are characteristic from regions with short dry season (0–2 months) and temperatures over 25 °C. It consists of trees with heights between 20 and 30 m, straight trunks and large number of different species.

Methods

The method proposed in this study can be summarized as follows: i) satellite images are acquired on two different dates prior to the Brazilian Amazon forest fire season; ii) a CVA is applied to the satellite images to characterize land cover changes; and iii) the results of the CVA are used as input for the DT, which will, based on the spectral changes, classify the region between four different classes, namely: A) Forest; B) Agricultural areas; C) Forest fire risk in primary forest; and D) Forest fire risk in already degraded areas.

Class A included all areas that were covered by forests in both satellite images, and consequently have no fire risk. Class B included pasturelands and croplands. Class C corresponds to areas that were covered with primary forest in the previous fire season but which vegetation is likely going to be burnt in the next dry season in order to clear the area for agricultural activities. In many occasions, the area cannot be totally cleared in only one fire season, and the fire practice is repeated in the same area during two or more consecutive years. These regions are represented by Class D, that is to say, degraded areas with high risk of being burnt.

Two overall steps can be identified in this study. Initially, the proposed method was designed and calibrated in Porto dos Gauchos municipality (striped in Fig. 1) for the year 2005. Subsequently, a preliminary evaluation of the method was performed applying the method in all the 14 municipalities displayed in Fig. 1 for 2005, 2006 and 2007.

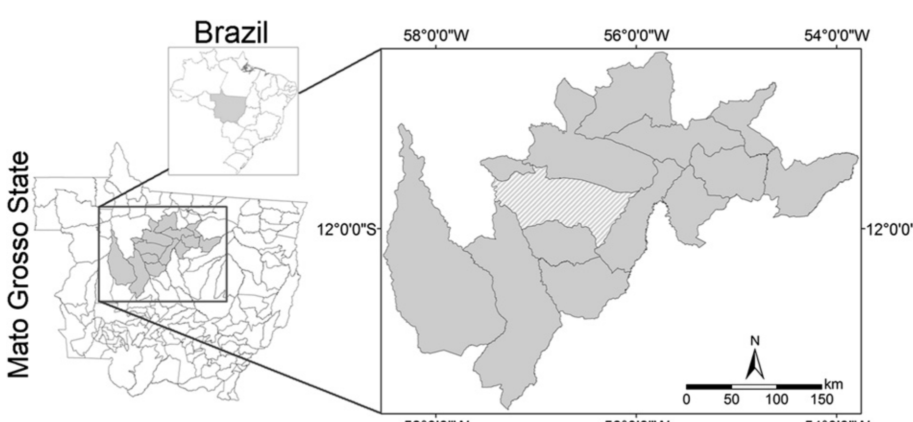

Fig. 1. Location of the study area in Mato Grosso State, Brazilian Amazon. The striped municipality represents the study site where the method was designed and calibrated, while the remaining municipalities were used to evaluate the method.