Discriminating burned areas in Amazon and Cerrado regions using MIR/NIR information

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Abstract. Although the Brazilian Amazonia together with Cerrado region presents one of the highest numbers of occurrences of fire events, hardly any studies aiming to design burned area (BA) indices specifically for these regions have been attempted. This issue is of particular interest since the accuracy of BA maps is closed related to the characteristics of the location (e.g., pre-fire land-cover type and conditions, background soil, fire severity, post-fire processes, and atmospheric conditions) and in addition, index thresholds are often subjective or vary from region to region. Accordingly, a new spectral index, specifically designed for burned land discrimination in Amazon and Cerrado regions using the middle/near-infrared spectral domain, was tested on sets of Moderate Resolution Imaging Spectroradiometer (MODIS) images. The utility of the new index for burned land discrimination was assessed against other widely used spectral indices: Normalized Difference Vegetation Index (NDVI), Burned Area Index (BAI) and Global Environmental Monitoring Index (GEMI), defined in the red/near infrared space and the modified version on them, namely VI20, BAI20 and GEMI20 defined in the middle/near-infrared space of MODIS sensor. The ability of each index to discriminate between burned and unburned surfaces was assessed by means of a discrimination index. The new proposed (V,W) index works better than the traditional indices in all three cases analyzed, with the advantage of not requiring water masks, which is not true for the remaining indices.

Palavras-chave: middle-infrared, spectral index, vegetation, burns, remote sensing.

1. Introduction

Accurate burned area (BA) information is required and of particular interest for the scientific communities dealing with meteorological and climate models in what concerns reliable estimations of biomass burned. Currently, due to the very broad spatial extent and the limited accessibility of some of the largest areas affected by fire, the instruments on-board satellites are the only available operational systems capable to collect cost-effective BA data at spatial and temporal resolutions appropriate to most modeling applications (Pereira 1999). Several studies have been carried out using remote sensing images for burned land mapping, covering a variety of techniques based on different spatial, spectral and temporal resolutions. In particular, numerous efforts have relied on coarse resolution sensors such as the National

Oceanic and Atmospheric Administration/Advanced Very High Resolution Radiometer (NOAA/AVHRR) (Fraser et al., 2000; Pereira, 1999), SPOT-VEGETATION (Gregoire et al., 2003; Stroppiana et al., 2002), the Along Track Scanning Radiometer (ATSR) data (Eva and Lambin, 1998; Arino and Piccolini 2000) and more recently, the Moderate Resolution Imaging Spectroradiometer (MODIS) (Roy et al., 2002). A large number of theses studies have been undertaken using vegetation indices, in particular with the AVHRR sensor. However, since those indices were designed for vigorous vegetation, they may not adequately differentiate between the burned/unburned surfaces (Chuvieco et al., 2002; Pereira, 1999; Trigg and Flasse, 2001). Accordingly, there is a strong need for studies aiming particularly the BA discrimination. In this respect special attention has been devoted to investigating relationships between spectral bands that enhance the burned scar signal. For instance, the Normalized Burn Ratio (NBR) was proposed in the 1990s to discriminate burned areas (López García and Caselles 1991) based on the contrast between red and near-infrared (NIR) regions. Martín (1998) proposed the Burned Area Index (BAI) specifically for burned area discrimination in Mediterranean environments using AVHRR images. In an attempt to overcome the problems associated vegetation indices for BA identification, Pereira (1999) suggested to replace the red reflectance by the reflective component of the middle-infrared (MIR) in the Normalized Difference Vegetation Index (NDVI) and in the Global Environment Monitoring Index (GEMI), leading to two new indices in the AVHRR NIR/MIR bi-spectral space, namely, GEMI3 from GEMI and VI3 from NDVI. Barbosa et al. (1999) suggested a modified version of VI3 where the reflective part of MIR channel is replaced by the full MIR channel brightness temperature in Boreal and Mediterranean forests. The Mid-Infrared Burn Index (MIRBI) was developed by Trigg and Flasse (2000) in order to discriminate burned shrub-savannah using MODIS and Landsat images. The Simple Index for Burned Areas (SIBA) was suggested by Boschetti et al. (2003) using information from the visible and thermal infrared bands available on METEOSAT and GMS imagery. Martín et al. (2006) adapted BAI to the spectral resolution of MODIS (BAIM) using the NIR and short-wave infrared (SWIR) channels. More recently, Cao et al. (2009) proposed specifically for grassland the Global Environment Monitoring Index-Burn scar (GEMI-B), using MODIS SWIR bands as surrogates of the red and NIR bands in the original GEMI equation, as well as Stroppiana et al. (2009) suggested a methodology for integrating several vegetation and BA indices using fuzzy theory.

Although the Brazilian Amazonia together with Cerrado region presents one of the highest numbers of occurrences of fire events, as far as our knowledge, hardly any studies aiming to design BA indices specifically for these regions have been attempted. This issue is of particular interest since the accuracy of BA maps is closed related to the characteristics of the location (e.g., pre-fire land-cover type and conditions, background soil, fire severity, post-fire processes, and atmospheric conditions) and in addition, index thresholds are often subjective or vary from region to region.

In an attempt to fill the lack of indices specially designed to map BA in Amazon and Cerrado regions, Libonati (2010) has explored the development of a new BA index adapted to the spectral resolutions MODIS channels, in particular in the NIR/MIR region. This decision was based on two grounds: on a first hand, although the AVHRR sensor have been widely applied for BA mapping, it was identified a number of limitations which made AVHRR a less ideal tool for monitoring fire-effects (Barbosa et al., 1999; Martín and Chuvieco, 1995; Pereira, 1999). In contrast, the MODIS sensor was design to enhance fire-mapping capabilities and its spectral bands in NIR wavelength provide the better spectral discrimination among burned and unburned surfaces.Moreover, MODIS produce full global coverage everyday, with repeat cycle of approximately 1-2 days which is special relevant for BA detection in cloudy and smoky regions since it provides further alternative days for analysis. On a second hand, spectral response to fire in the MIR (around 3.75 -3.9 μm) is similar to that observed in the visible region, but with a larger increase in brightness and with an unequivocal reduction of sensitivity to atmospheric effects. As stressed out by Libonati et al. (2010), this is special relevant over the Amazon and Cerrado regions, where BA mapping is a challenging task due to the ephemeral character of the radiative signal and the presence of aerosols that prevent using classical approaches e.g. based on visible channels information.

In this study, we evaluate the performance of the new BA index derived by Libonati (2010) in identifying burned surfaces in the Brazilian Amazon and Cerrado using the NIR/MIR bi-spectral region of MODIS channels. Moreover, it is shown a comparison of the ability in discriminating burned and unburned surfaces when using traditional indices and the new proposed index.

2. Method and Data

The present study relies on data from remotely-sensed observation gathered over two main Brazilian biomes, namely the Amazon Forest and the Cerrado region (see Figure 1 and Table 1) as covered by three Landsat ETM+ images. Data consist of top of the atmosphere (TOA) values of MIR radiance, NIR reflectance and TIR brightness temperature, acquired by the Moderate Resolution Imaging Spectrometer (MODIS) instrument on-board Terra satellite during the year of 2002, together with the respective solar zenith angles. Data were obtained from the Terra/MODIS Level 1B 1 km V5 product, MOD021 (MCST, 2006) and correspond to channels 2 (centered at 0.858 μm), 20 (centered at 3.785 μm), and 31 (centered at 11.017 μm). Surface values of MIR reflectance were then retrieved by applying the methodology developed by Kaufman and Remer (1994), paying special attention to the possible drawbacks previously pointed out by Libonati et al. (2010).

Visual inspection of a grayscale or color-coded image containing burned surfaces is not an adequate methodology for assessing the discriminant capability of spectral indexes. It is necessary to quantify this ability, taking into account both the magnitude of interclass differences as well as the magnitude of intraclass variance, for some predefined set of land cover classes. In this study, it was decided to consider only two classes, one formed by surfaces burned during the fire season and another containing all remaining land cover types. The ability of each index to discriminate between burned and unburned surfaces was assessed by means of a discrimination index similar to the one proposed by Kaufman and Remer (1994), i.e.

$$M = \frac{(\mu_u - \mu_b)}{(\sigma_u - \sigma_b)} \qquad (1)$$

where μ_u (μ_b) is the mean value for the unburned (burned) class and σ_u (σ_b) the standard deviation for the unburned (burned) class. M may be viewed as an estimator of signal-to-noise ratio, the absolute difference between the mean values of the two classes representing the signal (associated to between-group variability) and the sum of the standard deviations representing noise (associated to within-group variability). Values of M larger than one indicate good separability, whereas values smaller than one represent a large degree of overlap between the values associated to the two classes.

A set of 203 burned pixels, hereafter referred to as the burned class, was therefore selected from the above mentioned scenes, together with a set of 533 pixels that included the remaining land cover types (namely green vegetation, soil and water bodies), hereafter referred to as the unburned class. Choice of pixels in MODIS images was made by visual comparison between two LANDSAT ETM scenes. Hot spots detected by INPE were also used in the process of selecting pixels associated to burned surfaces.

Table 1. List of three Landsat ETM+ images, acquisition dates, locations and biomes covered.

Path/row	Date (mm/dd/yyyy)	Location	Biome
222/66	08/15/2002	Tocantins	Cerrado
222/67	08/15/2002	Tocantins	Cerrado
224/66	08/13/2002	Pará	Amazon Forest

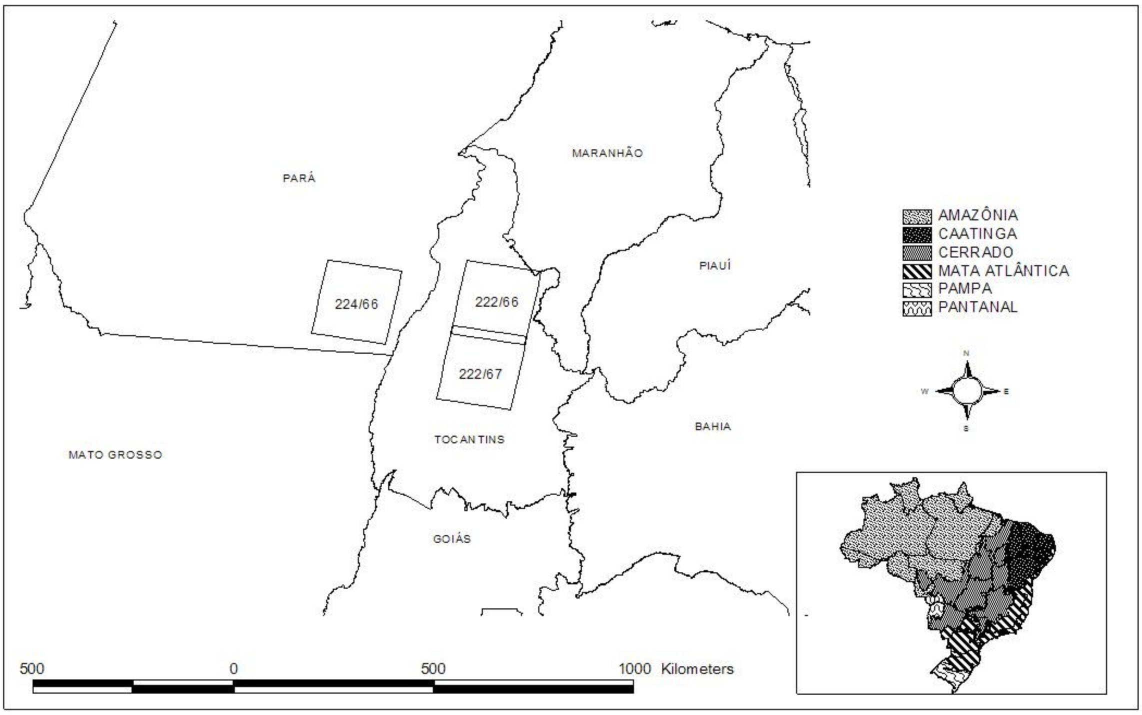

Figure 1. Map of Brazil showing IBAMA's classification of general biomes. Numbered frames provide the location of the three Landsat ETM+ scenes (as listed in Table 1).

2.1 Indices tested

For this study, two sets of indices were analyzed. The first set corresponds to widely used spectral indices: NDVI, BAI and GEMI, defined in the red/near-infrared spectral space. The second set of indices corresponds to the modified version on the above mentioned indices defined in the middle/near-infrared space of MODIS sensor.

The VI3 is a modified version of the traditional NDVI, where the red reflectance is replaced by the reflective part of the middle-infrared signal (channel 3 from AVHRR sensor). It was firstly proposed by Kaufman and Remer (1994) aiming the identification of dark, dense vegetation, based on the fact that MIR reflectance is well correlated to the red one. After that, Pereira (1999) suggested the application of VI3 into burned scars mapping, founded on the particular characteristics of MIR spectral region for distinguishing between burned/unburned surfaces as well as it's non-sensitivity to atmospheric effects.

Pinty and Verstraete (1992) have proposed the so-called GEMI, which was specifically designed to minimize contamination of the vegetation signal by extraneous factors, such as the atmosphere and the soil background. Pereira (1999) explored the synergistic effects of the desirable properties of the AVHRR channel 3 reflective components for BA mapping with the sophisticated nonlinear design of the GEMI. Therefore, the GEMI3 index is an empirical modification of the GEMI, since the values of the coefficients in the GEMI equation, which were kept unchanged, are not expected to retain their original physical interpretation.

The BAI was proposed by Martín (1998) as a non-linear index specifically designed for BA discrimination in AVHRR images over Mediterranean environments. The index is based on maximizing the spectral distance between charcoal and other land covers, especially those potentially confused with burned areas.

Since we are focusing on MODIS sensor and on the MIR/NIR spectral space, it seems reasonable to adapt the three above-mentioned indices to those characteristics. The equations for the selected indices in the R/NIR space, using the MODIS sensor, are the following:

$$NDVI = (\rho_2 - \rho_1)/(\rho_2 - \rho_1) \quad (2)$$

$$GEMI = \eta(1 - 0.25\eta) - (\rho_1 - 0.125)/(1 - \rho_1)$$
(3)

$$BAI = \frac{1}{(\rho_2 - \rho_{C2})^2 + (\rho_1 - \rho_{C1})^2} \quad (4)$$

where:

$$\eta = \left(2\left(\rho_2^2 - \rho_1^2\right) + 1.5\rho_2 + 0.5\rho_1\right)/(\rho_2 + \rho_1 + 0.5) \quad (5)$$

ρ_1 is the TOA reflectance in ch1, ρ_2 is the TOA reflectance in ch2, G is the Gain factor, C_1 is the atmospheric resistance red correction coefficient, C_2 is the atmospheric resistance blue correction coefficient, L is the canopy background brightness correction factor. ρ_{C1} and ρ_{C2} are the coordinates of the convergence point, given by the NIR minimum and R maximum values of reflectance for burned vegetation. Martín (1998) has fixed the convergence points as 0.1 and 0.06, respectively.

The second set of indices corresponds to the modified version on the above mentioned indices defined in the middle/near-infrared space of MODIS sensor, namely VI20, GEMI20 and BAI20. The reflectance convergence values were set as 0.05 for NIR and 0.24 for MIR based on spectral signatures of charcoal measured at laboratory and from samples of recent burned pixels extracted from MODIS imagery covering the region of study as shown by Figure 2.

The BA index proposed by Libonati (2010), called (V,W) is based on information from the NIR and MIR channels of the MODIS sensor. The approach is based a transformation of coordinates such that the index represent an optimal combination of the spectral channels. The transformation is based on the difference between MIR and NIR in conjunction with the distance from a convergence point in the MIR/NIR space, representative of a totally burnt surface. It may be noted that the transformation contains the relevant characteristics of BAI20 and VI20, namely, the distance to a pre-defined convergence point and the difference between MIR and NIR reflectances. The transformation allows defining a system of coordinates, one coordinate, namely V, having a small scatter for pixels associated to vegetation, burned surfaces and soils containing organic matter and the other coordinate, namely W, covering a wide range of values, from green and dry/stressed vegetation to burned surfaces. The strict scale character of first coordinate (V) makes it a good classifier (of vegetation, burned surface and soils with organic matter) whereas the large scale character of the second coordinate (W) makes it a good quantifier of water stress. More detailed about the (V,W) equations and derivations are presented in Libonati (2010).

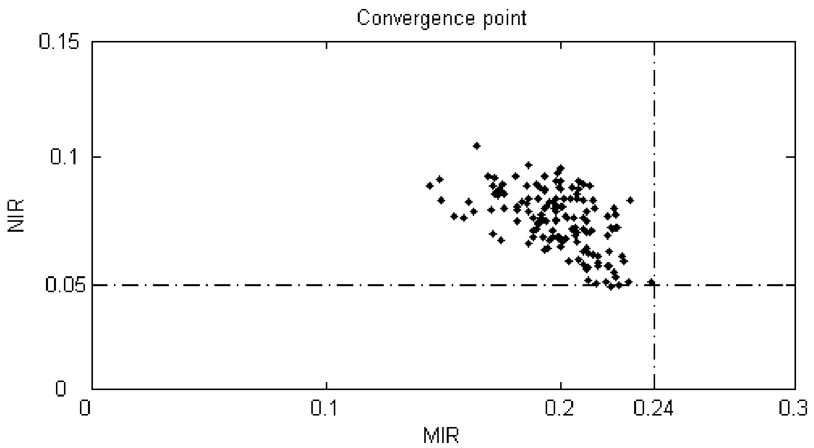

Figure 2. MIR and NIR reflectance bi-spectral space showing the reflectance convergence point of recently burned areas samples extracted from MODIS imagery covering the north, northwest and midwest of Brazil. Dashed-dot lines delimit the upper and lower bounds in MIR and NIR and their intersection is the convergence point.

3. Results

Figure 3 shows the histograms corresponding to the burned and unburned classes for each index evaluated, and Table 2 presents the comparison of the discriminating ability between them (M index) for three regions over Amazon and Cerrado (see Table 1). The distances between the mean values for the two classes, the amount of spread in the data, and the consequent extent of histogram overlap determine the values of the spectral discrimination index M.

Table 2. Comparison of the discriminating ability between burned and unburned surfaces (M index) by means of traditional indices and using the new proposed (V,W).

	M index
(V,W)	2.15
NDVI	0.44
VI20	1.52
BAI	1.37
BAI20	1.70
GEMI	0.90
GEMI20	1.30

It may be noted from Figure 3 that the degree of overlap between burned and unburned areas is too high for NDVI (M=0.44) and GEMI (M=0.90), which are defined in R/NIR spectral space. BAI achieved the better performance between those defined in R/NIR spectral space (M=1.37) although some overlaps are still observed. Indexes defined in the MIR/NIR spectral space present improved results compared to those in R/NIR spectral space, namely VI20 (M=1.52), GEMI20 (M=1.30) and BAI20 (M=1.70). Most of confusion problems remaining in these three indices seem to be due to water bodies. The (V,W) index displays the highest discriminant power (M=2.15), showing a small overlap between the histogram classes, with the advantage of not requiring water mask.

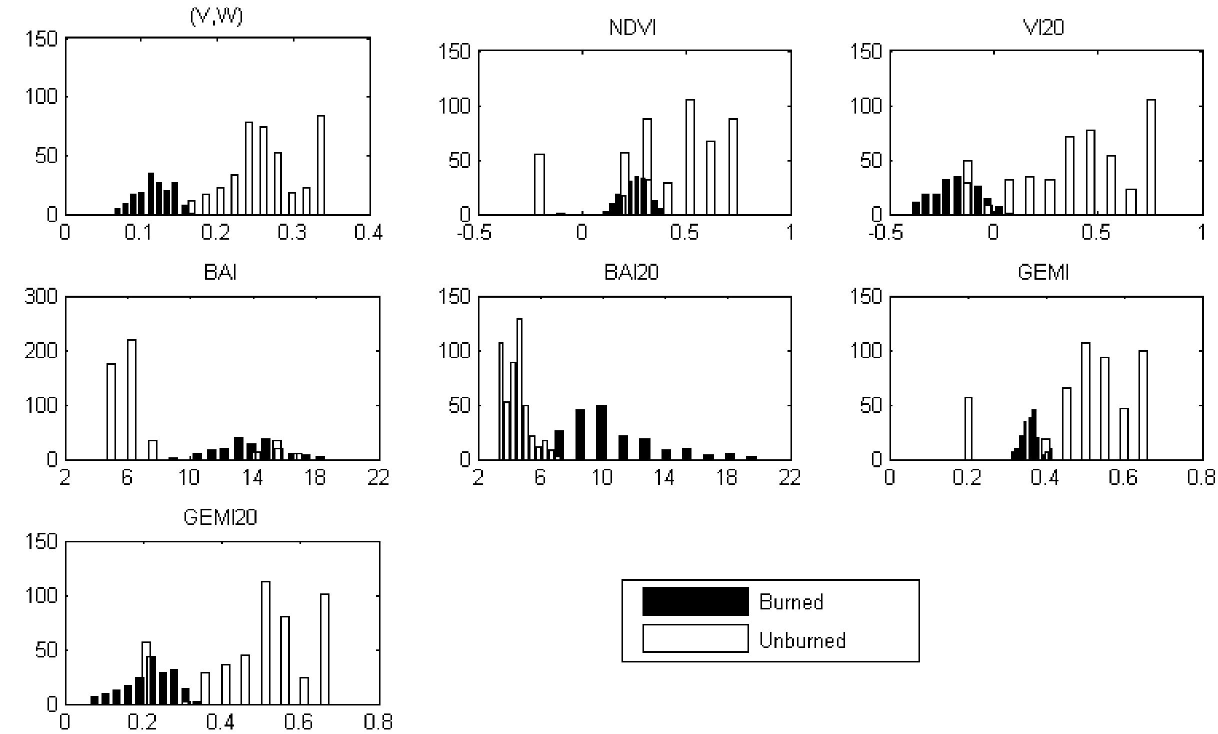

Figure 3. Histograms of the burned and unburned classes for the vegetation indexes evaluated.

4. Concluding remarks

The utility of the new proposed index (V,W) for burned land discrimination was assessed against other widely used spectral indices: NDVI, BAI and GEMI, defined in the red/near infrared space and the modified version on them, namely VI20, BAI20 and GEMI20 defined in the middle/near-infrared space of MODIS sensor. The ability of each index to discriminate between burned and unburned surfaces was assessed by means of a discrimination index. All indexes defined in R/NIR have the worst performance when compared to those defined in MIR/NIR spectral space. The new proposed (V,W) index works better than the indices evaluated here, both in R/NIR and MIR/NIR space. Besides the (V,W) index has the advantage of not having been heuristically derived as opposed to VI20 (or more precisely VI3, suggested by Kaufman and Remer, 1994) and GEMI20 (or more precisely GEMI3, suggested by Pereira, 1999). In addition, the (V,W) index has the advantage of not requiring water mask.

The preliminary results found in this work open interesting perspectives for the potential of the (V, W) index to be operationally used to discriminate burned areas in the Amazon and Cerrado regions of Brazil.

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