

A NEW OPTIMAL INDEX FOR BURNT AREA DISCRIMINATION IN SATELLITE IMAGERY

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Abstract

Biomass burning is a significant global source of greenhouse gases (e.g. carbon dioxide and methane) as well as of nitric and carbon monoxides, methyl bromide and hydrocarbons that lead to acid rain and the photochemical production of tropospheric ozone and destruction of stratospheric ozone which affect global climate. Other impacts relate to the biogeochemical cycling of nitrogen and carbon compounds, the hydrological cycle, the reflectivity and emissivity of the land, the stability of ecosystems and ecosystem biodiversity. An accurate identification of burnt areas is therefore of paramount importance and we present a new vegetation index with optimal properties for burnt area discrimination. We begin by demonstrating the advantages of using the reflective part of the middle infrared (MIR) signal for burnt area detection. This is achieved by evaluating the performance of MODIS visible (bands 1 to 7) and MIR (band 20) channels in burnt area detection. Performance of channel 20 data is both evaluated using surface full normalized radiances (i.e. the sum of emitted and reflected components of the signal) and restricting to the reflected component. A comparison is then performed on the ability of a set of indices to discriminate burnt areas. The set includes the well known normalized difference vegetation index (NDVI), the global environment monitoring index (GEMI) and the enhanced vegetation index (EVI) that are traditionally defined in the red-NIR space; as well as VI20, GEMI20 and EVI20 that were obtained by adapting the previous indices to the MIR-NIR space. Performance is evaluated based on confusion matrices and on signal-to-noise ratio measurements. Obtained results show that vegetation indices defined in the red-NIR space are not suitable to detect burnt surfaces and that better alternatives are available, namely if using solely channel 2. All vegetation indices defined in the MIR-NIR space exhibit an improvement in performance when compared to single-channels and to indices based on the red signal. Vegetation indices based on the reflective part of channel 20 show better results than those derived based on the normalized total radiance of channel 20. However the largest improvement in ability to detect burnt surfaces was obtained with the newly proposed EVI20 index, which consists of a modified EVI that uses the reflective part of MODIS channel 20 in place of channel 1. The new index has the advantage of significantly decreasing the number of omission errors which was still too high in the cases of GEMI20 and VI20.

INTRODUCTION

Biomass burning is an important aspect concerning climate change (Levine 1995). Current methods for detecting burnt areas have usually focused on using the red (0.64 μm) and near infrared (0.84 μm) regions of the electromagnetic spectrum. However, both red and near-IR channels are very sensitive to aerosol scattering and absorption in the atmosphere (Fraser and Kaufman, 1985; Holben et. al., 1986). Thus, in tropical regions such as the Amazon region, where there are heavy smoke layers due to biomass burning, the use of these two regions of the spectrum may be unsatisfactory for detecting burnt areas. On the other hand, the middle infrared (3.7 μm) part of the spectrum is also sensitive to vegetation changes due to the absorption of liquid water, and at the same time it is not sensitive to the presence of most aerosols (except dust) (Kaufman and Remer, 1994).

Furthermore, consideration of the possible effects of atmospheric water vapour on the attenuation of the electromagnetic spectrum has demonstrated that the MIR spectral region is one of the few regions with relatively little attenuation (Kerber and Schut, 1986), requiring approximately 10 cm of precipitable water to reduce transmission below 90% (Bird, 1984). Accordingly, there is an atmospheric window in this spectral region, where the atmospheric absorption is small and the radiance reaches the sensor without great losses. In addition, the MIR spectral region presents very low variation in solar irradiance (Lean, 1991) and the influence of the emissivity uncertainty on the land-surface temperature retrieval is small when compared with other thermal infrared regions (e.g., 10.5 and 11.5 μm) (Salisbury and D'Aria, 1994).

The aim of the present study is to demonstrate the advantages of using the reflective part of the middle infrared (MIR) signal (3.7 μm) for burnt area detection.

DATA

An analysis was performed on the potential of MODIS channels (Table 1), namely the visible channels (bands 1 to 7) and the MIR channel (band 20) to discriminate burnt areas. Channel 20 data were evaluated under two configurations, *i.e.* using the full normalized radiance of the surface (*i.e.* the sum of emitted and reflected components of the signal) and restricting to the reflected component of the signal. It is worth mentioning that channel 5 was not considered in this study because it was totally contaminated by noise.

Band	Band width	CW (μm)
1	0.620 – 0.876	0.645
2	0.841 – 0.876	0.858
3	0.459 – 0.479	0.469
4	0.545 – 0.565	0.555
5	1.230 – 1.250	1.240
6	1.628 – 1.652	1.640
7	2.105 – 2.155	2.130
20	3.660 – 3.840	3.788

Table 1. MODIS bands used in this study.

Accordingly, the ability of above-mentioned channels to discriminate burnt areas was assessed by means of a set of indices that includes the following three ones that are traditionally defined in the red-NIR space:

1. the normalized difference vegetation index (NDVI)

$$\text{NDVI} = (\rho_2 - \rho_1) / (\rho_2 + \rho_1) \quad (1)$$

2. the enhanced vegetation index (EVI)

$$\text{EVI} = G (\rho_2 - \rho_1) / (L + \rho_2 + C_1 \rho_1 - C_2 \rho_3) \quad (2)$$

3. the global environment monitoring index (GEMI)

$$\text{GEMI} = \eta (1 - 0.25 \eta) - (\rho_1 - 0.125) / (1 - \rho_1) \quad (3)$$

where:

$$\eta = (2 (\rho_2^2 - \rho_1^2) + 1.5 \rho_2 + 0.5 \rho_1) / (\rho_2 + \rho_1 + 0.5) \quad (4)$$

ρ_1 - TOA reflectance in ch1

ρ_2 - TOA reflectance in ch2

ρ_3 - TOA reflectance in ch3

- ρ_{20} - TOA reflectance/normalized radiance in ch20 (MIR)
- G - Gain factor
- C_1 - Atmospheric resistance red correction coefficient
- C_2 - Atmospheric resistance blue correction coefficient
- L - Canopy background brightness correction factor

The set also includes three indices that were obtained by adapting the previous indices to the MIR-NIR space:

- the $VI20$, *i.e.*

$$\begin{aligned} VI20 &= (\rho_2 - \rho_3)/(\rho_2 + \rho_3), & \text{for } \rho_2 \geq \rho_1 \\ VI20 &= 0, & \text{for } \rho_2 < \rho_1 \end{aligned} \quad (5)$$

- the $GEMI20$
- the $EVI20$

In the case of $GEMI20$ and $EVI20$, ρ_{20} takes the place of ρ_1 in (2), (3) and (4). Following Huete *et al.* (1997), coefficients were set to $L = 1$, $C_1 = 6$, $C_2 = 7.5$ and $G = 2.5$. EVI was selected as representative of the MODIS operational product, specifically designed to minimize both canopy and atmospheric background variations. EVI has been found to perform well in the heavy aerosol, biomass burning conditions in Brazil (Miura *et al.*, 1998).

The region selected is covered by Landsat 5 TM scenes 224/72 and 224/73 and the area covers three Brazilian states namely Góias, Mato Grosso do Sul and Mato Grosso. This is mainly an agricultural region where the Emas' National Park is located, *cerrado* is the dominant land type.

Four TM images dated 29/08/2005 (224/72 and 224/73) and 16/10/2005 (224/72 and 224/73) were used to provide validation data for the analysis performed on the MODIS Level 1B calibrated radiance 1km (MOD021KM) from 08/09/2005. We have chosen two classes, one formed by burned surfaces and another containing all remaining land cover types. Accordingly to Pereira (1999), this approach imposes a considerable degree of potential intra-class variability, at least on the generic background class and therefore it represents a very stringent test for the ability of vegetation index to detect and characterize burned areas. 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.*

$$M = \frac{\mu_u - \mu_b}{\sigma_u - \sigma_b}$$

Performance was also evaluated based on confusion matrices and on signal-to-noise ratio measurements.

RESULTS AND CONCLUSIONS

Figure 1 shows the histograms of the burned and unburned classes for each individually evaluated MODIS channel. The degree of overlap between burned and unburned areas is too high as shown in the histograms for the following channels: 3 ($M=0.10$), 7 ($M=0.24$), 4 ($M=0.40$), 1 ($M=0.51$), and 6 ($M=0.69$). Although some overlaps are still observed, obtained results clearly show that the two classes are better discriminated when channel 2 ($M=1.06$), the reflected component of channel 20 ($M=0.88$) and the total radiance of channel 20 ($M=0.80$) are used. The histograms illustrates that burnt surfaces tend to be darker than the background in channels 1 and 2, and brighter in channel 20.

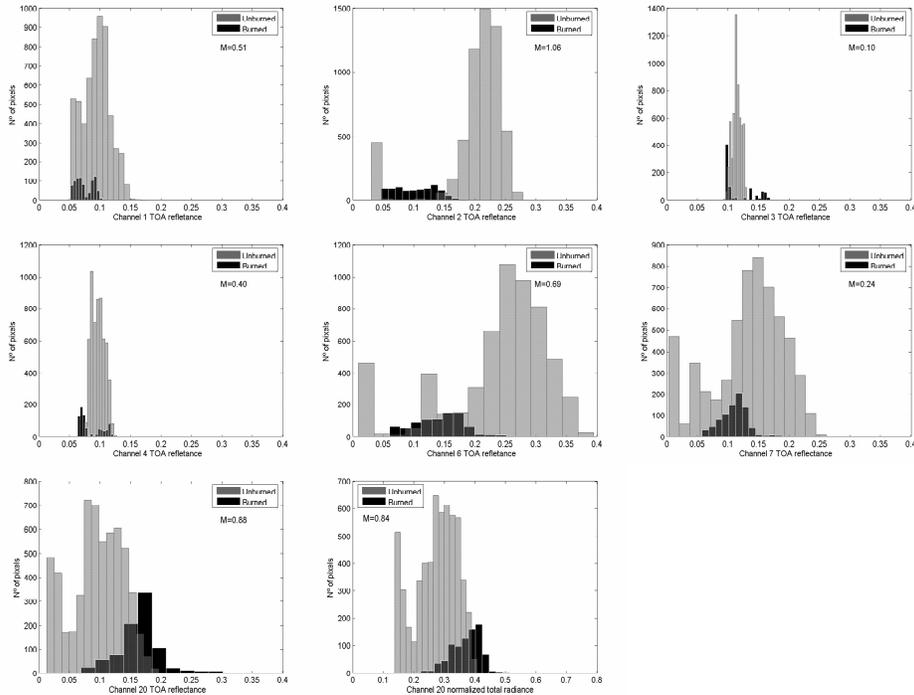


Figure 1. Histograms of the burned and unburned classes for MODIS individual channels.

Figure 2 presents the histograms of the burned and unburned classes for the evaluated vegetation indices. Two of the three indices defined in the red-NIR space (NDVI and EVI) display the poorest separation power, respectively $M = 0.67$ and $M = 0.76$. The GEMI presents a better performance ($M = 1.01$) than the two above mentioned indices. However, an overlap between burned and unburned surfaces is still noticeable. Results show that the NDVI, GEMI and EVI are not good indices to detect burnt surfaces, and better alternatives are available, namely, using solely channel 2. All vegetation indices defined in the MIR-NIR space exhibit improved performances compared to single-channels and also to those indices based on the red signal. Vegetation indices based on the reflective part of channel 20 show better results than those derived with the normalized total radiance of channel 20. EVI3 has proved to be the best discriminator ($M=1.52$), followed by EVI3 normalized radiance ($M=1.50$). Although the discriminating parameter is almost equal for both above mentioned indices, we may observe from the histograms that EVI3 is clearly more powerful than EVI3 based on the normalized radiance, due to the absence of overlapping between the two classes.

As mentioned before, we have chosen only two classes, one formed by burned surfaces and another containing all remaining land cover types. Accordingly the unburned class includes several vegetation types, soils and also water bodies (e.g., rivers and lakes). For instance, the peak observable around 0.2-0.3 in the GEMI3 and around 0.3 in the EVI3 normalized radiance histograms is due to water

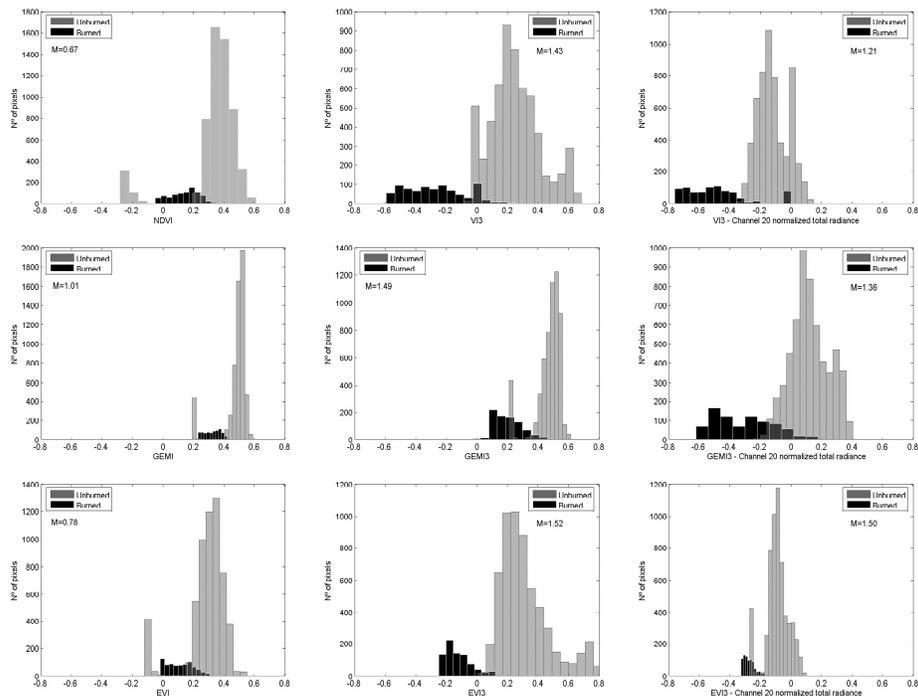


Figure 2. Histograms of the burned and unburned classes for the vegetation indices evaluated.

EVI3 threshold 0.0	Landsat image		
		Burned	Unburned
	Burned	741	0
	Unburned	122	5827
Overall Accuracy = 98.20%		\hat{k} statistic = 0.91	

Table 2. Confusion matrix of the classification obtained from application of a threshold of 0.0 in the EVI3.

VI3 threshold -0.1	Landsat image		
		Burned	Unburned
	Burned	558	0
	Unburned	305	5827
Overall Accuracy = 95.46%		\hat{k} statistic = 0.76	

Table 3. As in Table 2 but for a threshold of -0.1 in the VI3.

GEMI3 threshold 0.2	Landsat image		
		Burned	Unburned
	Burned	464	0
	Unburned	399	5827
Overall Accuracy = 94.06%		\hat{k} statistic = 0.67	

Table 4. As in Table 2 but for a threshold of 0.2 in the GEMI3.

Burned Class	Producer's Accuracy (%)	Omission errors (%)	User's Accuracy (%)	Commission errors (%)
EVI3 0.0	86.00	14.0	100.00	0.00
VI3 -0.1	64.80	35.2	100.00	0.00
GEMI3 0.2	53.69	46.31	100.00	0.00

Table 5. Producer's accuracy and user's accuracy of burned class.

bodies. The VI3 formulation described by equations (17.1) and (17.2) circumvents the problem of the index being applied to water areas, given the null value for this land cover type. However the restriction $\rho_2 \geq \rho_1$ leads to erroneous classifications in the case of some burned areas where $\rho_2 < \rho_1$, as shown in the VI3 normalized radiance histogram.

Additional indications about the performance of analysed vegetation indices were derived based on the so-called confusion matrix approach. A confusion matrix is an effective way of displaying the number of correctly and erroneous classified pixels on a category by category basis (Lillesand and Kiefer, 1994).

Diagonal elements represent the pixels correctly classified, whereas non-diagonal elements represent pixels that were erroneously classified. Tables 2 to 4 show the confusion matrix, the overall accuracy and \hat{k} statistic respecting to the Landsat image (reference data) versus vegetation indices, after applying pre-defined thresholds. Table 5 presents the producer's accuracy and the user's accuracy of the burnt class.

EVI3 displays the largest overall accuracy (98.20%) and \hat{k} (0.91), followed by VI3 with an overall accuracy of 95.46% and \hat{k} of 0.76. GEMI3 is the worst of the three indices, showing an overall accuracy of 94.06% and \hat{k} of 0.67. When compared to the correctly identified pixels (464), the number of omission errors (399) is too high in the case of GEMI3. This feature translates into low values of the producer's accuracy (53.69%). In the case of VI3 the amount of omission errors was also quite large (producer's accuracy of 64.80%) when compared to EVI3 as shown by the values of the producer's accuracy (86.00%). All three indices presented a user's accuracy of 100%, i.e. no commissions errors were carried out.

Obtained results show that NDVI, GEMI and EVI are not suitable to detect burnt surfaces, and that better solutions are available, namely by using solely channel 2. All vegetation indices defined in the MIR-NIR space exhibit improved performances when compared to single-channels and also to those indices based on the red signal. The vegetation indices based on the reflective part of channel 20 show better results than those derived with the normalized total radiance of channel 20. The largest improvements in ability to detect burnt surfaces with MODIS data was obtained with EVI3, a modified EVI, that uses the reflective part of MODIS channel 20 in place of channel 1. When compared to the correctly identified pixels, the number of omission errors is too high both for GEMI3 and VI3. Most of confusion problems that remain in these three indices seem to be due to wetlands and inland water bodies.

This work may be viewed as a first step to designing an optimal vegetation index for burnt area discrimination. It is also particularly helpful for evaluating the benefits of considering the reflective part of the MIR signal and to a better understanding of the behaviour of pre-existent vegetation indices when using TOA reflectance/normalized radiance of MIR.

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