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Improving the performance of the BAIM index for burnt area mapping using MODIS data.

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ABSTRACT: The analysis of fire effects and its influence on the structure, composition and functioning of terrestrial ecosystems (*Michalek et al*., 2000) at regional and global scales relies on the feasibility of obtaining accurate estimations on burnt areas. Remote sensing has proven to be an adequate tool for this objective and many different methodologies have been proposed in order to obtain maps of burnt area on different scales. Most methodologies are based on the use of spectral indices, some of which have been traditionally applied to estimate vegetation conditions, such as the NDVI, whereas others have been specifically designed for burnt area mapping (*Kasischke and French*, 1996; *Barbosa et al.,* 1996; *Martín and Chuvieco*, 1998; *Trigg and Flasse*, 2001; *Chuvieco et al*., 2005). Among the latter is the Burnt Area Index (BAI) which was originally designed for burnt area mapping using NOAA-AVHRR data (*Martín, 1998).* BAI was recently adapted to MODIS data (BAIM) increasing its discrimination ability by including information from the MODIS SWIR bands (*Martín et al*., 2005). In spite of the good performance showed by the BAIM in discriminating recently burned areas in different environments (Martin et al., 2005; http://www.geogra.uah.es/aql/), some confusions have been reported regarding specific land covers. This paper proposes an improvement of BAIM by implementing two new factors in order to increase the discrimination capability and to reduce reported confusions between burnt and unburnt covers (especially those containing water bodies).
The design of the Improved BAIM index (IBAIM) is based on the statistical analysis of sample pixels obtained from MODIS images. The samples where selected using images from two different years (2001 and 2003) and include the most representative landcovers in the Iberian Peninsula as well as burned areas. The accuracy of the new index was tested using official fire perimeters obtained with GPS and also by visual interpretation of high resolution images.

1 INTRODUCTION

On a global and regional scale, satellite imagery has become a normal tool among researchers and public administration managers involved in forest fire contingency and damage assessment. Spectral indices are among the most widely used and tested techniques (*Kasischke and French*, 1995; *Barbosa et al.,* 1998; *Martín and Chuvieco*, 1998; *Trigg and Flasse*, 2001; *Chuvieco et al*., 2005). Within this line of research are indices specifically designed for burned area mapping and discrimination (*Martín and Chuvieco*, 1998; *Trigg and Flasse*, 2001; *Chuvieco et al*., 2005). In compliance with the spectral index design proposals from Verstraete and Pinty (1996), the BAI was designed by Martín (1998) to map burned areas on a regional scale using NOAA-AVHRR imagery. The author assumes that the ideal burned area index could be defined as a function of its spectral distance to reference values which are considered as standard in burned areas (convergence points). BAI was later applied to data from the *Moderate-Resolution Imaging Spectroradiometer* (MODIS) (Martín et al., 2005), after adjusting its parameters as follows:

$$BAIM = \frac{1}{(pc_{NIR} - \rho_{NIR})^2 + (pc_{SWIR} - \rho_{SWIR})^2}$$

where pc_{NIR} and pc_{SWIR} are the convergence values for the near infrared (NIR) and the shortwave infrared (SWIR) at 0.04 and 0.2, respectively.

Although BAIM was successfully applied for Martín *et al*. (2005), it continues to show confusion problems among certain landcovers (especially waterbodies).

2 AIMS AND METHODS

This paper attempts to improve the BAIM using two factors to increase the discrimination capacity and to decrease the level of confusion in certain covers. The improved index (IBAIM) has taken into account, an analysis of several sets of pixel samples from burned and unburned areas in two MODIS images acquired over the Iberian Peninsula (multitemporal composites based on maximum temperature criteria from two MODIS products: *MODIS/Terra Surface Reflectance Daily L2G Global 500m SIN Grid V004* and *MODIS/Terra Land Surface Temperature and Emissivity Daily L3 Global 1Km SIN Grid V004)*. The images were acquired in August 2001 and 2003. The samples (over 5.000 pixels) were randomly selected, based on the CORINE Landcover 2000 and fire perimeters supplied by fire managers in Spain and Portugal. This data, together with the literature available, was used to carry out a statistical study aimed at defining the factors which could be applied on the BAIM, bearing in mind the spectral behaviour of the burned and unburned landcovers in different spectral bands and the main confusions reported from the use of BAIM in previous works.

The efficiency of the new IBAIM versus the BAIM was tested using two validation processes: a sensitivity analysis and a comparison of burned area estimation validated with official perimeters. Thus, the two sample datasets (2001 and 2003) were used in the first validation process (sensitivity analysis). The aim of this test was to determine the degree of confusion between *burned* and *unburned* areas on condition that the indices detected 100 % of the sample pixels belonging to the *burned* class.

In the second validation test, the performance of the new index was tested on the images, on which four windows were selected within areas of the Iberian Peninsula where official fire perimeter data was available. The areas were: (1) sectors in the Arribes del Duero and Catalonia, using the August 2001 image, (2) Portugal, using the August 2003 image and (3) Galicia, using the August 2006 image. The reference perimeters were obtained either using GPS (Catalonia 2001 and Portugal 2003), or via visual analysis using higher spatial resolution imagery namely Landsat and AWIFS (Arribes de Duero 2001 and Galicia 2006).

3 RESULTS

The improvement of the index was obtained using two weighting factors, both of which consisted in band ratios. The final formulation of the index would be the following:

$$IBAIM = \frac{1}{(pc_{ICR} - \rho_{IRC})^2 + (pc_{SWIR} - \rho_{SWIR})^2} * \frac{\rho_{SWIR}}{\rho_{NIR}} * \sqrt{\frac{\rho_{NIR}}{\rho_{RED}}}$$

Added factors to the original BAIM index are based on the use of the rSWIR, (MODIS band 7), and r_{NIR} and r_{RED}, (MODIS bands 2 and 1, respectively). The first factor is the b7/b2 ratio, which is a vegetation index in itself and has also been applied to burned area mapping (Bastarrika and Chuvieco, 2006). One of the immediate effects that this ratio produces is a reduction in the terrain effects, that is, radiometric variations in the same type of land cover due to changes in slope and illumination (Kushla and Ripple, 1998). When applying this ratio to the sample data (Table 1) it can be observe a tendency towards values above 1 for the *burned* class and below 1 for the rest of the classes, except for *bare rock* (which does not increase its confusion with burned areas since their BAIM values are sufficiently distant). Therefore, by multiplying the BAIM times the b7/b2 ratio, *burned* class values (and to smaller extent *bare rock*) increased, while in the remaining classes the values decreased.

Table 1. Multiplying effects of each of the factors.

	Factors	Burnt	Non irrigated arable land	Permanently irrigated land	Vineyard-olive-fruit	Agriculture with natural vegetation	Broad-leaf forest	Coniferous forest	Mixed forest	Natural grassland	Sclerophillous vegetation	Bare rock	Sparseley vegetation	Water bodies
August 2001	b7/b2	1.5	0.94	0.52	0.82	0.85	0.36	0.44	0.42	0.82	0.72	1	0.81	0.73
	$(b2/b1)^{1/2}$	1.31	1.23	1.98	1.34	1.39	2.69	2.23	2.32	1.50	1.70	1.31	1.33	0.97
	$b7/b2*(b2/b1)^{1/2}$	1.97	1.16	1.03	1.10	1.18	0.80	0.98	0.97	1.23	1.22	1.31	1.08	0.71
August 2003	b7/b2	1.51	0.88	0.51	0.8	0.75	0.36	0.43	0.43	0.72	0.67	1.04	0.83	0.68
	$(b2/b1)^{1/2}$	1.25	1.23	1.87	1.37	1.41	2.11	2.11	2.25	1.55	1.75	1.22	1.28	0.88
	$b7/b2*(b2/b1)^{1/2}$	1.89	1.08	0.95	1.1	1.06	0.76	0.91	0.97	1.12	1.17	1.27	1.06	0.46

The aim of the second factor, which is $(b2/b1)^{1/2}$, is to improve the discrimination capacity between water bodies and burned areas. This quotient works adequately well on the samples in terms of its capacity to distinguish *water* from other classes, including *burned areas,* as shown in table 1, where *water* values are below 1 whereas in the rest of the classes values are above 1. The values of some classes are greater than those of the *burned* class, such as *broadleaf forest, coniferous forest, mixed forest, irrigated crops* and *sparsely vegetation*. However, the low BAIM values for these classes, prior to applying this factor, compensates enough and thus does not add confusion, while still allowing to better discriminate the water class, which is the main aim. An excessive increase of the index value in these classes had to be avoided, hence the square root was used, which reduces the effect of this weighting factor on the final value of the index, but maintains the efficiency in discriminating between water and burned areas.

As a result of the joint use of these factors, BAIM original values for burned areas have almost doubled (1.97 in 2001 and 1.89 in 2003), whereas values for the rest of the classes are below 1.31 (in the case of water, a rather controversial class, the multiplying effect is under 1). This means a better discrimination between burned areas and the remaining classes together with a decrease in their confusion.

Two tests were carried out to validate IBAIM results: (1) a sensitivity analysis for the data of both samples and (2) a comparison with the verification perimeters available (from multitemporal composites using MODIS imagery).

BAIM and IBAIM indexes were computed on the same samples for each of the values. The threshold used for the *burned/not burned* separability analysis was set to detect 100 % of *burned* values, and confusion with other classes was compared. The result of this process is shown in Table 2.

Table 2. Sensitivity analysis results (%).

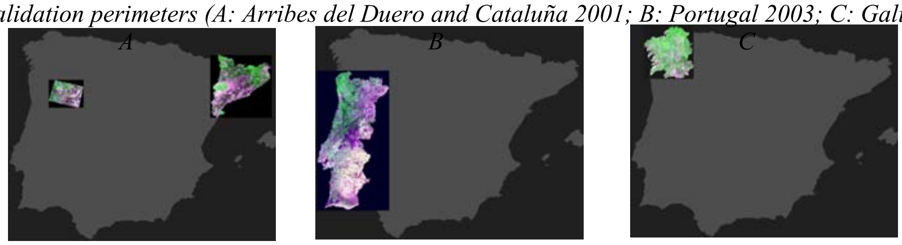
		2001		2003	
		BAIM	IBAIM	BAIM	IBAIM
Burnt area detection (%)		100	100	100	100
Confusion	Non irrigated arable land	3.4	3	1,4	1,8
	Permanently irrigated land	0.2	0.2	0	0
	Vineyard-olive-fruit	0.8	0.4	0	0
	Agriculture with natural vegetation	1.8	0,8	0,6	0,8
	Broad-leaf forest	6.4	1.4	0	0
	Coniferous forest	2	0,6	0,2	0,2
	Mixed forest	2.2	0.6	0	0,2
	Natural grassland	1	0,2	0,2	0,6
	Sclerophillous vegetation	11.6	7.8	2,6	3,4
	Bare rock	1.01	1.01	0	0
	Sparseley vegetation	13	4.06	3,6	0,8
	Water bodies	40.46	12.12	7,36	3,16
	Total	6.98	2.68	1,33	0,91

Compared to BAIM, for 2001 sample data, IBAIM shows a reduction in confusion with all classes except *bare rock,* which has identical values for both indices.

For 2003 data, IBAIM confusion is greater than BAIM for *non irrigated arable land, agriculture with natural vegetation* and *sclerophillous vegetation*, but confusion is significantly lower for sparse vegetation and water, which improves IBAIM average confusion values (0.91 IBAIM versus 1.33 BAIM).

The second test consisted in applying each index on four different sectors of the Iberian Peninsula for three different years, in order to discriminate burned areas in each of the images and to compare afterwards commission and omission errors obtained from each index, using the available validation perimeters as reference. Provided that official perimeters were available, four windows on different sectors of the Iberian Peninsula were selected (Figure 1).

Figure 1. Validation perimeters (A: Arribes del Duero and Cataluña 2001; B: Portugal 2003; C: Galicia 2006)



The threshold used in the discrimination for both indices was set as the value which had detected all existing validation perimeters with areas greater than 200 ha. This decision was based on experience in previous work regarding the minimum surface size that can be reliably mapped using MODIS imagery (Martín et al., 2005). The verification was carried out first using number of polygons incorrectly detected and afterwards using the incorrectly and correctly detected surface percentage. In the analysis all the perimeters were used, independently of their surface. Results are shown in tables 3 and 4.

Table 3. Number of polygons (fires) incorrectly detected (commission errors)

	IBAIM	BAIM
Arribes, August 2001	4	4
Cataluña, August 2001	3	3
Portugal, August 2003	408	1006
Galicia, August 2006	253	265
Total	**668**	**1278**

Table 4. Incorrectly and correctly detected surface percentage

Burnt area detection (%)	Index	Portugal 2003	Arribes 2001	Cataluña 2001	Galicia 2006	Mean
Accuracy	IBAIM	76.35	35.50	26.93	61.36	46.26
	BAIM	82.32	35.70	31.03	61.90	49.68
Errors	IBAIM	0.85	0.09	0.00	2.01	0.32
	BAIM	1.55	0.18	0.01	2.01	0.58

Commission errors (polygons incorrectly detected) for IBAIM are fewer than for BAIM (Table 3). In terms of burnt area, although correct detection percentages are higher for BAIM, incorrect detection percentages are lower for IBAIM (Table 4). Results show that, compared to BAIM, IBAIM performs better during the forest fire dicrimination phase since it contributes to reduce commission errors, whereas the BAIM is better suited for burned area delimitation in each forest fire.

4 CONCLUSIONS

Specific burned area indices are an adequate method for regional scale mapping. In this context, improving of the existing indices or designing new ones is a line of research that requires further development. The results obtained in this study show that the factors added to the BAIM could improve burned area discrimination when carried out in two phases. IBAIM improved the capacity to spectrally discriminate burned areas from other landcovers, thus reducing commission errors which, according to previous work (Brivio et al., 2003), is especially helpful for regional/global scale studies. However, further analysis is required to asses the full capacity of the index proposed and its potential for discriminating burned area from other land covers in other geographic environments using sensors with spectral bands in the visible, NIR and SWIR, such as MODIS.

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