Validating MODIS burned area products over Cerrado region

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Abstract. We present a validation of three MODIS burned area products, namely AQM/INPE, MCD45A1/NASA and MCD64A1/NASA, covering a 6-year period (2005-2010) over Jalapão, a fire-prone region located in the Cerrado. As reference we use high resolution BA maps derived from Landsat imagery. Because the products to be validated have different spatial resolutions than that of reference maps (i.e. AQM with 1 km, NASA with 500 m and Landsat scars with 30 m), the error matrix was estimated following a new approach based on the assumption of mixed pixels, where the agreement/disagreement between product and reference data are computed taking into account the proportion of BA from reference data within the product pixel. The two NASA products present very low commission errors (< 10%) but they are affected by very high occurrence of omission errors (> 60%). The AQM product has larger commission errors (20 to 40%) but a large fraction of those (more than 40%) occur at the borders of the scars and may therefore not be strictly viewed as false alarms; there is also a clear reduction of the omission cases (< 40% in all cases). The AQM product presents a clear reduction of omission errors that reflects a higher probability of detection of burned pixels. The new product appears therefore as more sensitive to sub-pixel burned areas, even when working at a lower spatial resolution; this particular feature may be attributed to the use of middle infrared reflectance by the algorithm.

Keywords: Remote Sensing, Burned area, validation, MODIS.

1. Introduction

Several studies have been carried out using remote sensing images for burned area (BA) mapping, and special attention has been devoted to mapping burned areas using remote sensing at global scale. Nevertheless, there is a pronounced difficulty in validating global burned area products in a cost-effective and simple way. Currently methods used for validating such products include reference burned area data compiled using in situ measurements, airborne data and high resolution imageries (such as Landsat). Many of the efforts for validating global burned area products are concentrated over North America, Africa, Australia, Mediterranean countries and boreal forests, probably due to the absence of reference data at other places.

Accordingly, although the explicit vulnerability for fire of Brazilian ecosystems together with the unequivocal need of reliable fire information in such region, few studies have been dedicated to validate such global burned area products over Brazil. Roy et al. (2008) have performed an evaluation of MCD45 collection 5 by comparison with the MODIS active fire product over several regions including South America. In this work, the authors stressed out the need of comparison with independent reference data, and not only with active fires, since the differences between active fire and burned area products are complex.

The absence of evaluation of global burned area products over Brazil provided the motivation in the present work. Product comparison with independent reference data is needed to determine product accuracy and, combined with product quality assessment, to identify needed product improvements. Accordingly we focused on the assessment of uncertainties in three MODIS burned area products, namely AQM/INPE, MCD45/NASA and MCD64/NASA over Jalapão located at Cerrado region using reference burned area maps derived from Landsat imagery during the period 2005/2010.

2. Data and Methods

2.1 NASA/MODIS burned area data

We use here MODIS BA official products namely the MCD45A1 Burned Area Product (Roy et al., 2005) and MCD64A1 Direct Broadcast Monthly Burned Area Product (Giglio et al., 2006). They were freely downloaded from the University of Maryland ftp sites (ftp://user@ba1.geog.umd.edu and ftp://fuoco.geog.umd.edu/db/MCD64A1/. Tiles for the two BA products over Brazil between 2005 and 2010 were then mosaicked and remapped using the Modis Reprojection Tool.

MCD45A1 is a monthly Level 3 gridded 500 m product containing per-pixel burning and quality information, and tile-level metadata. Quality information is given using five confidence levels of detection from 1 (most confident) down to 4 (least confident). Confidence level 5 denotes detections over agricultural areas. The MCD45A1 data used in our analysis include quality assurance flags from 1 to 4. MCD64A1 is globally available on a monthly basis back to August 2000 at 500m resolution. The MCD64A1 product is currently used in the framework of the Global Fire Emissions Database (GFED) initiative and will replace MCD45A1 in the upcoming MODIS Collection 6. Among the five data layers from MCD64A1, only the Burn Date was used in our study, as this product does not have flags containing confidence levels.

2.2 INPE/MODIS burned area data

The AQM/INPE burned area is based on an automated regional algorithm (Libonati et al., submitted) using information from MODIS imagery at 1km resolution over Brazil. The algorithm relies on the so-called W burning index (Libonati et al., 2011) that is defined in a transformed NIR-MIR space. The AQM approach is currently in pre-operational phase at INPE and additional tuning experiments are currently being carried on. The AQM algorithm is also being applied to MODIS data since 2000 year until the present with the aim of building up a long-term database of BA for Brazil.

2.3 INPE/Landsat reference burned area data

We use BA reference data as derived from Landsat TM imagery over Jalapão, a region located in the state of Tocantins (Figure 1).

The BA scars dataset was derived using a semi-automatic algorithm developed at INPE and the results were verified by independent analysts. The methodology is based on multi-temporal compositing of Landsat imagery, the composites being preferably made of cloud-free images less than 32 days apart (Table 1). The study region covers about 187 x 187 km2 and lies within Landsat TM paw/row 221/67. The region belongs to the Cerrado biome and has been increasingly affected by fire in the last years. For instance, during the 2010 dry season, Jalapão has accounted for 60% of all fire events detected in the Cerrado biome.

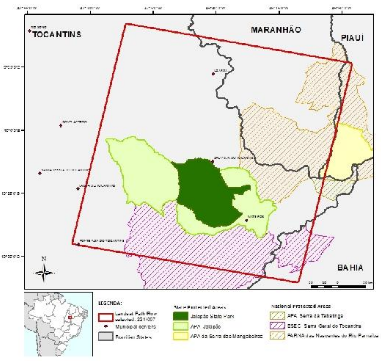


Figure 1. Location of the validation site of Jalapão in the state of Tocantins.

Table 1. Dates of Landsat images that were used to derive reference maps of burned scars.

Year	May	Jun	Jul	Aug	Sep	Oct
2005			7^{th}, 23^{rd}	8^{th}, 24^{th}	9^{th}	
2006	23^{rd}	8^{th}, 24^{th}	26^{th}	11^{th}, 27^{th}	28^{th}	
2007	26^{th}	27^{th}	13^{th}, 29^{th}	14^{th}, 30^{th}	15^{th}	1^{st}
2008		13^{th}	15^{th}, 31^{st}	16^{th}	17^{th}	
2009			2^{nd}	3^{rd}, 19^{th}		
2010		3^{rd}, 19^{th}	5^{th}	6^{th}, 22^{nd}	7^{th}, 23^{rd}	

2.4 Methods

The evaluation is made based on four verification measures derived from the contingency table (Foody, 2002) as show in Table 1:

The overall accuracy (OA), defined as the fraction of correctly classified pixels, either as burned or unburned:

$$OA = \frac{a+d}{a+b+c+d} \quad (1)$$

The omission error (OE), defined as the fraction of burned pixels in the reference map that were not classified as such in the BA product:

$$OE = \frac{c}{a+c} \quad (2)$$

The commission error (CE), defined as the fraction of pixels classified as burned in the BA product that are unburned pixels in the reference map:

$$CE = \frac{b}{a+b} \quad (3)$$

The bias (B), defined as the ratio of the number of pixels classified as burned in the BA product to the number of burned pixels in the reference map:

$$B = \frac{a+b}{a+c} \quad (4)$$

Whereas OA reflects the agreement between the BA product and the reference map, OE and CE provide information about the reliability and discrimination power of the developed classifier. An unbiased classification exhibits in turn a value of bias equal to one, whereas a bias greater (less) than one indicates the events were over (under) classified.

Table 2. Contingency table for pixels classified as burned vs. unburned.

		Reference Map		
		Burned	Unburned	
BA Product	Burned	a	b	a+b
	Unburned	c	d	c+d
		a+c	b+d	a+b+c+d

In the present work, the agreement/disagreement between the Landsat TM reference data (30 m resolution) and either our product (1 km resolution) and MODIS MCD64A1 and MCD45A1 products (500 m resolution) are computed taking into account the proportion of BA from reference data within the product pixel. This approach is based on the work by Boschetti et al. (2004) who pointed out the need of taking into account the percentage of BA in each pixel of the coarse product when comparing coarse and high resolution BA maps. For instance, if a pixel is classified as burned by the BA product and has 60% of BA from reference data, so this pixel will have a proportion of 0.6 as true burned and 0.4 as commission error (as opposed to a weight of 1 as true burned and 0 as commission error that would be assigned following the traditional approach). In the same way, if a pixel is classified as unburned by the BA product and has 20% of BA from reference data, so this pixel will have a proportion of 0.8 as true unburned and 0.2 as omission error of the non-occurrence. This kind of approach seems to be fairer to the computation of the measures accuracy than the traditional one, since it takes into account the real proportion of reference burned pixel within the product pixel. Recently, Padilla et al. (2014) and Tsela et al. (2014) have conducted similar approaches when validating algorithms for global BA.

3. Results and Discussion

In general, the overall accuracy (OA) for MCD64A1 and MCD45A1 BA products is slightly higher than for AQM, the maximum and minimum values being observed in 2005 and 2007, respectively for the three products (Figure 2). It may be however noted that OA satisfies the principle of equivalence of the events (Wilks, 2006), giving equal credits for burned and unburned classes. This property is not always desirable, particularly in the case of BA detection studies where the burned event is more relevant than the non-occurrence event (unburned event).

Both MCD64A1 and MCD45A1 products present very low values of CE (Figure 3) but they are affected by quite high values of OE (Figure 3); the two NASA BA products appear therefore as conservative in the sense that a low level of false alarms is attained at the cost of quite high occurrence of omission cases. Values of OE for MCD45A1 are always larger than the corresponding ones for MCD64A1, and the same is true in the case of CE except in 2008 when MCD64A1 is slightly larger. The AQM product presents in turn a rather low value of CE together with a clear reduction of OE that reflects a higher probability of detection of burned pixels. The minimum value of OE is consistently observed in 2010 for all products and a similar consistency is observed for the maximum value of CE that is recorded in 2008. The maximum value of OE is observed in 2005 for AQM and in 2009 for MCD64A1 and MCD45A1 products, whereas the minimum value of CE is again observed in 2010 for AQM and in 2006 for both NASA BA products.

With the exception of 2008 where B reaches 1.56, the AQM product presents an unbiased behavior, with values of B very close to unity (Figure 3). The NASA BA products in turn tend to underestimate the number of pixels classified as burned and this is particularly true in 2009 where B is as low as 0.20 and 0.14 for MCD64A1 and MCD45A1; an opposite behavior may be found in 2010 when values of B reach maxima of 0.69 and 0.48 for MCD64A1 and MCD45A1, respectively.

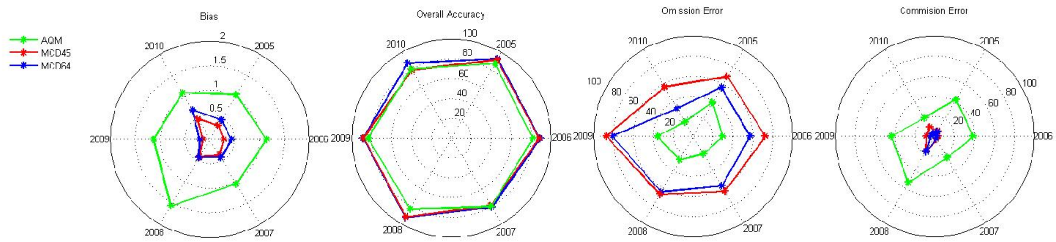
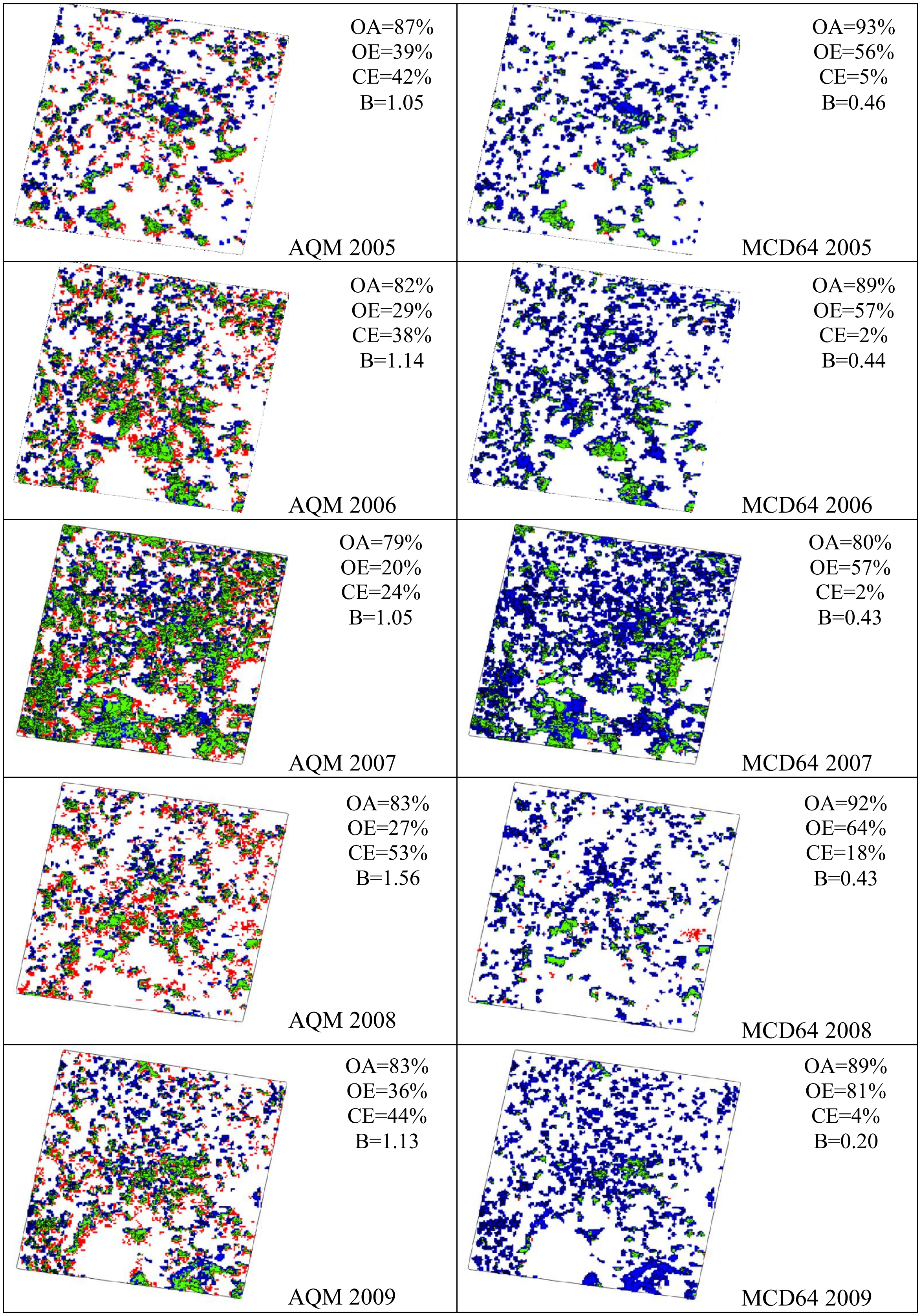


Figure 2. Verification measures as obtained from confusion matrices of AQM and MODIS MCD64A1 and MCD45A1 versus reference map of burned scars derived from Landsat TM over Jalapão from 2005 to 2010.

Figure 3 shows for AQM (left panel) and MCD64A1 (right panel) the spatial distribution of hits, omissions and commissions over Jalapão during the period 2005-2010. The AQM product shows lower OE than MCD64A1 that presents a higher value of OE and a very low value of CE. A large fraction of pixels with commission errors in AQM are located in the external borders of the scars (delimited by the black lines).

A better insight into the different characteristics presented by AQM and the two NASA BA products is obtained by looking at the characteristics of pixels correctly classified as burned areas (hits) or contributing to omission and commission errors (Table 3), as obtained when comparing AQM and MCD64A1 and MCD45A1 versus reference map of burned scars derived from Landsat TM over Jalapão from 2005 to 2010. Corresponding fractions of pixels located inside (I), in the external border (B) and outside (O) the reference scars were also computed and, for hits and omissions, evaluations were also made of the fractions of low burned pixels (L), i.e. those covered less than 50% by burned areas in Landsat reference map and of high burned pixels (H), i.e. those covered more than 50% by burned areas. As shown in Table 3, for all three products the large majority of hits is associated to pixels located inside burned scars, but the AQM is able to correctly identify a substantially larger number of burned pixels, 31% of them located in the external borders of the scars (an amount quite larger than those by the NASA products that are that are 19% and 22% for MCD64A1 and MCD45A1, respectively). On the other hand, the AQM product is able to correctly identify as burned 44% of pixels with low fraction of burned area (less than 50%), an amount that is more than the double of that by MCD64A1 (22%) and almost the double than that by MCD45A1 (24%). The AQM product presents a substantially lower number of omission errors than the NASA products, but for all three products the larger fractions are associated to pixels located in the borders of scars and to pixels with low fraction of burned area. The very large number of commission errors by AQM also presents a large contrast with the very low number by the two NASA products; however, more than two fifths of commission errors in AQM are associated to occurrences in pixels located in the borders of the scars suggesting that they are not to be viewed as ‘false alarms’ in the strict sense, but as an overestimation of the size of the real scars. This problem is likely to be associated to errors in geo-referencing of a small number of MODIS images that propagate into the multi-image composites.


OA=87%
OE=39%
CE=42%
B=1.05
AQM 2005
OA=93%
OE=56%
CE=5%
B=0.46
MCD64 2005
OA=82%
OE=29%
CE=38%
B=1.14
AQM 2006
OA=89%
OE=57%
CE=2%
B=0.44
MCD64 2006
OA=79%
OE=20%
CE=24%
B=1.05
AQM 2007
OA=80%
OE=57%
CE=2%
B=0.43
MCD64 2007
OA=83%
OE=27%
CE=53%
B=1.56
AQM 2008
OA=92%
OE=64%
CE=18%
B=0.43
MCD64 2008
OA=83%
OE=36%
CE=44%
B=1.13
AQM 2009
OA=89%
OE=81%
CE=4%
B=0.20
MCD64 2009

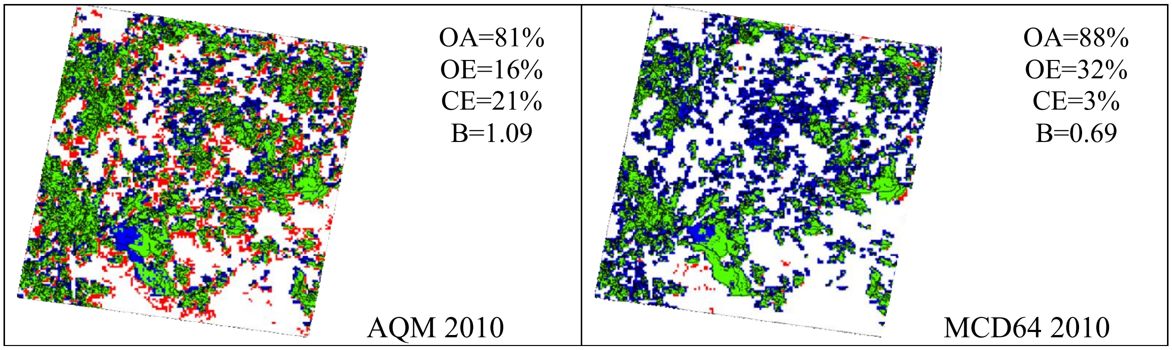


Figure 3. Maps showing pixels where true burned areas were detected (green), together with omission (blue) and commission (red) errors. TM reference scars (black lines) are superimposed.

Table 3. Hits, omission errors and commission errors for AQM, MCD64A1 and MCD45A1 versus the reference maps. Each cell also presents the corresponding fractions of pixels located inside (I), in the external border (B) and outside (O) the scars in reference maps and, for hits and omissions, the fractions of low burned pixels (L), i.e. covered less than 50% by burned areas in Landsat reference map and of high burned pixels (H), i.e. covered more than 50% by burned areas.

	Hits	Omissions	Commisions
AQM	28255 I=69%;B=31% L=44%; H=56%	23637 I=44%; B=56% L=65%; H=35%	14581 O=58%; B=42%
MCD64	13425 I=81%; B=19% L=22%; H=78%	38467 I=49%; B=51% L=65%; H=35%	579 O=58%; B=42%
MCD45	9332 I=78%; B=22% L=24%; H=76%	42560 I=53%; B=47% L=60%; H=40%	786 O=52%; B=48%

4. Conclusions

We have performed a validation of three BA products, namely AQM/INPE, MCD64/NASA and MCD45/NASA, against reference maps of scars derived from Landsat TM imagery over a study region located in Cerrado. Because the products to be validated have different spatial resolutions than that of reference maps (i.e. AQM with 1 km, NASA with 500 m and Landsat scars with 30 m), the error matrix was estimated following a new approach based on the assumption of mixed pixels, where the agreement/disagreement between product and reference data are computed taking into account the proportion of BA from reference data within the product pixel.

The two NASA products present very low commission errors (below 10%) but they are affected by very high occurrence of omission errors (greater than 60% in almost all cases analyzed). The AQM product has larger commission errors (20 to 40%) but a large fraction of those (more than 40%) occur at the borders of the scars and may therefore not be strictly viewed as false alarms; there is also a clear reduction of the omission cases (below 40% in all cases). The AQM product presents a clear reduction of omission errors that reflects a higher probability of detection of burned pixels.

Differences between results from the three products may be traced back to major differences among the respective algorithms. The MCD45 product does not make use of information about fire activity and detection of BA is based on changes in values of reflectance. The MCD64 product takes advantage of information about hotspots as detected by the MODIS instrument and uses a burned area index to classify pixels as burned. The larger number of burned pixels detected by the AQM product (when compared with MCD45 and MCD64) may be attributed to two main factors. First the usage by the algorithm of the W index that was specifically designed for ecosystems in Brazil, taking advantage of the ability of MIR reflectance to discriminate burned areas. Secondly, the usage of active fire observations from multiple sensors that considerably contributes to mitigating the problem of failing to uncover BA due to active fire omissions either because of the time of satellite overpass or due to obscuration by clouds, smoke and vegetation.

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