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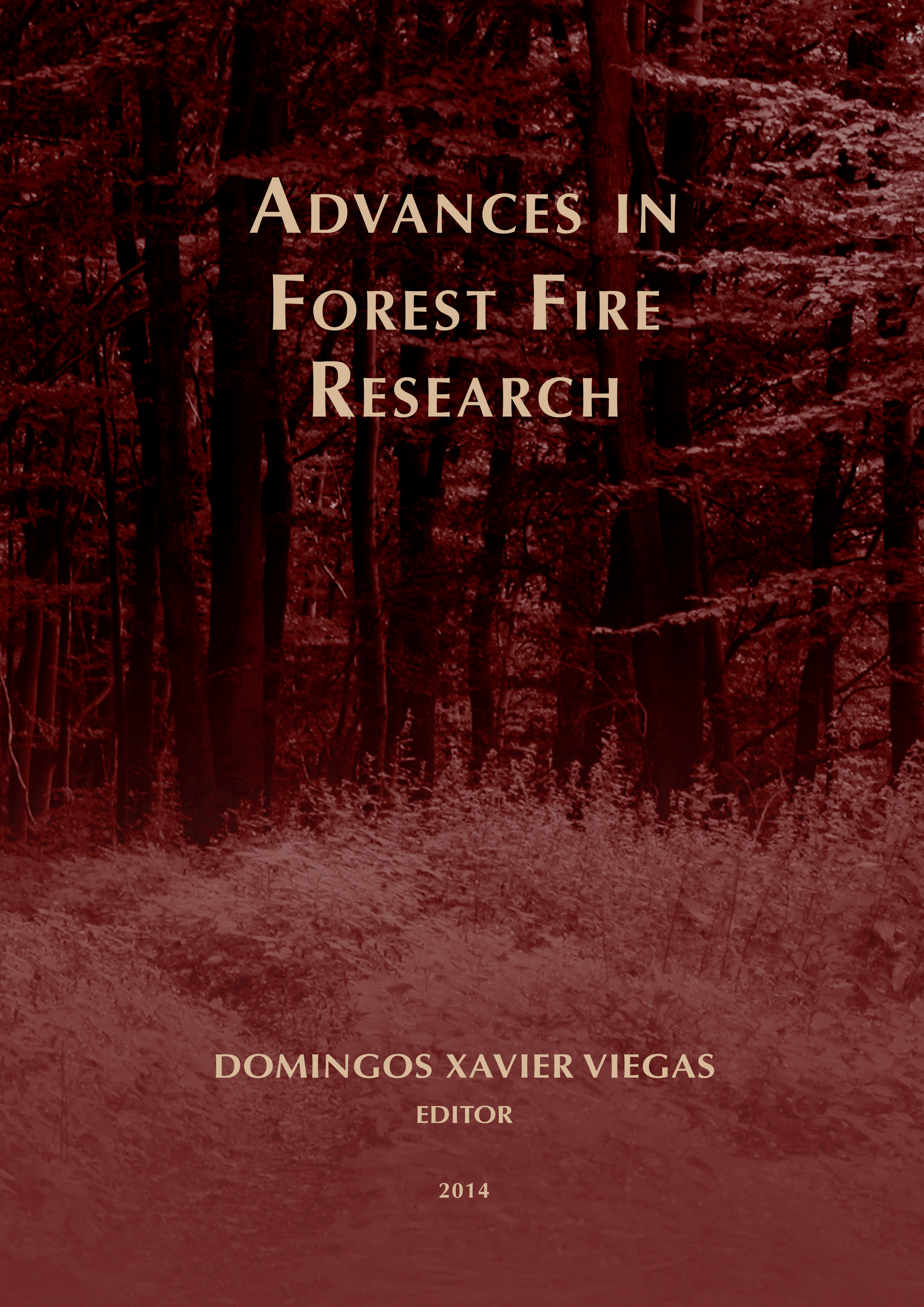

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A Landsat-TM/OLI algorithm for burned areas in the Brazilian Cerrado – preliminary results

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Abstract

Accurate burned area information is required and of particular interest for the scientific communities dealing with land use and climate changes. Currently, due to the very broad spatial extent and the limited accessibility of some of the largest regions affected by fire, instruments on-board satellites provide the only available operational systems capable to collect cost-effective burned area data.

This paper presents the initial results of an algorithm for automatic extraction of burned area scars using Landsat TM and OLI imagery in the Cerrado (savannah) biome of Brazil. Development and validation tests were conducted for the "Jalapão" region, which has been intensely affected by fire in the last years; during the 2010 dry season, it accounted for 60% of all active fire pixels detected in the Cerrado.

A series of Landsat TM and /OLI 52 scenes (path/row: 221/067) covering the period of 2000 - 2013 was used. Input images were accepted only with cloud cover up to 10%, and the maximum period of time between consecutive scenes was up to 1 month. Composite images with differences in NDVI (dNDVI) and NBRL (dNBRL) of consecutive scenes were used to identify fire scars. The algorithm computes and filters the rate of change in dNDVI and dNBRL indexes, relative to the pre-fire condition. The value of the dNBRL change is then used in the calculation of the burned area mask.

Results of the automatic extraction were evaluated against maps of burned scar produced by visual photo interpretation of the composite images for the reference period of 2004 - 2010. Omission and commission errors were obtained, and the reliability of the algorithm and the burned area match levels were calculated for the image series. Omission Errors ranged from 4.8% to 21.0%, and Commission Errors from 2.3% to 24.1%. Reliability of the Algorithm and Burned Area Match varied from 75.8 % to 97.2%, and from 79 to 95.2%, respectively. These values are comparable to the best reported in the literature for other regions. Commission errors were associated mainly to clouds and their shadows in the images; agricultural practices were another source of error. Detailed error analysis and results are included in the text.

The algorithm developed is currently being implemented for operational and automatic generation of burned scar maps at a regional scale, particularly for conservation areas.

***Keywords**: fires, burned area, automatic extraction, Landsat, Cerrado*

1. Introduction

The Brazilian Cerrado extends over 2000000km^2, occupying almost a fourth of the country's territory, and is considered the most bio diverse Savannah of the world. Deforestation already reduced this biome to be at least 50%, and if degradation is also considered, this value increases significantly (Klink and Machado, 2005). Conservation areas account only for 8.2% of the Cerrado, and an additional 4.4% are preserved as indigenous territories (MMA, 2014a; Klink and Machado, 2005). The study area is located in the Jalapão region, at the northeast portion of central Brazil, comprising the largest and more important conservation areas of the Cerrado biome – see Figure 1. Its elevation ranges from 150 m to 950 m, and the climate in the region is hot semi-humid, with a pronounced drought season. Rains are concentrated in the October-to-April so-called summer season, with up to about 600 mm of average precipitation in the rainiest trimester, while winter, from May through September, may accumulate as little as 25 mm. Soils have a large proportion of quartz sands, almost 50%; vegetation types include

the main physiognomies of the Cerrado/Savannah, and the population density is below 2.5 inhabitants/km^2 [INMET, 2014, SEPLAN, 2013; Prado dos Santos *et al*, 2011].
Increasing efforts are being made by federal and state agencies in this region to control deforestation processes and anthropic vegetation fires [MMA, 2012; MMA, 2014b]. During the severe drought period of 2010, 60% of all fires in the Cerrado biome were detected in the Jalapão ecologic corridor. Remote sites and fire brigade’s limited operational conditions contribute to an inefficient control of fires. The total fire pixel detections by Projeto Queimadas of INPE, Brazil [INPE, 2014], accounts for 83575 events in the period 2004-2013, with a mean annual value of 8357 [Candido 2014]; this value refers to multiple satellite platforms, when a unique fire event might have simultaneous detections from more than one satellite.
Mapping burned areas requires the development of methods to process massive mid-resolution (e.g. Landsat TM and OLI) image data bases to produce results of practical use; unfortunately, no reliable products are available on an operational basis. Remote sensing techniques are now recognized as the only cost-effective source of information for mapping burned areas from regional/national up to global scale [Stroppiana *et al* 2012]. Burned area mapping using mid-resolution sensors has been classically oriented toward local-scale studies, but the current availability of such images without costs allows their use in larger scales [Bastarrika *et al* 2011]. Our study area is contained in the Landsat TM/OLI scene path/row 221/067. Figure 1 shows the study area within the context of the South American continent.

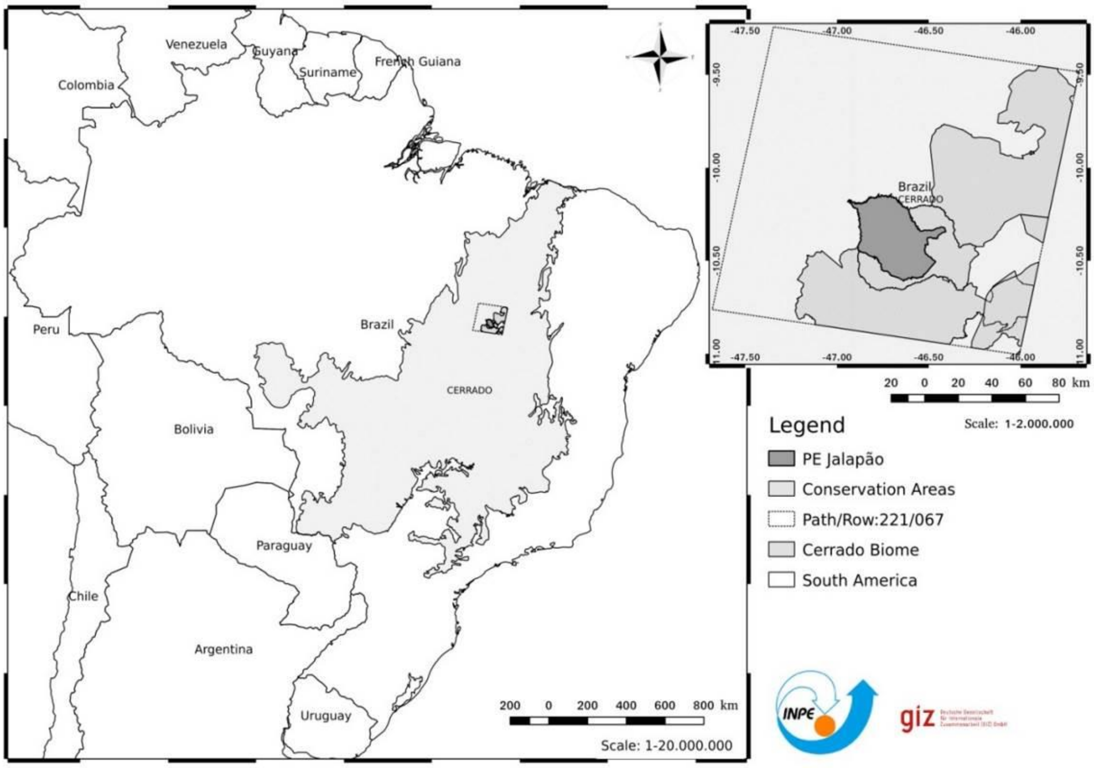

Figure 1. Location of the study area.

Landsat TM sensor images have been widely used for precise mapping due to its 30 meters spatial resolution in both visible and infrared channels [Stroppiana *et al*, 2012]. OLI sensor’s images present strong improvements regarding the TM sensor, in both spectral and radiometric resolution. While temporal resolution might be adequate for multi-temporal mapping in ideal atmospheric conditions, the occasional presence of clouds and cloud shadows over the study region impair the regularity of the temporal series, even causing its interruption.

In this present work, the cloud content of any image used in the temporal series was limited up to 10% of total image special coverage. The amount of cloud cover was established by visual inspection. All images were downloaded from the USGS server [USGS, 2014]. The high quality of their geo-processing grants their use in automatic and operational processes.
The entire procedure for image processing was developed in the Python 2.7.4 programming language, using freely available function libraries like gdal, numpy, scipy, scikit, among others. Inter-operation among these libraries greatly simplifies the process work flow. The application developed allows the processing of raw image series, generating derived series as a result. Results from the sub-process stages like statistical information, objects mapped, thresholds used for classification, among other data, are logged in a file for further analysis.

2. **Methods**

Several processing routines were defined to process the Landsat TM/OLI images and obtain burned scar maps in a semi-automatic mode, file downloads and decompressing, generation of a layer stack, cropping, processing and comparisons with reference data.
Input data consisted of compressed Landsat TM and OLI imagery in the tar.gz format, downloaded from the USGS server [USGS, 2014]. Output data were the burned scar maps, in raster and vector file formats, reflectance images, and composite RGB files used for burned scar visual photo analysis [Candido, 2014]. The download process involved selecting, within the available images, those with less than 10% cloud cover. An automated routine was developed to handle the compressed data and generate the corresponding layer stacks of radiance images; it avoids compression tools and GIS systems to prepare data for processing, saving many hours per image set for the operators. Each uncompressed radiance stack layer obtained is accompanied by its metadata file for later reflectance conversion.
The next step in the process is the cropping stage, where radiance stack layers are cropped to a polygon vector file of the study area, using another specific automated routine developed for this purpose. The cropped layer stacks, with their corresponding metadata file, are the input for the main procedure.

2.1. **Main procedure for burned area mapping**

The main core of this classification procedure is based on calculations of the NDVI (Normalized Difference Vegetation Index) [Gitelson *et al*, 1996; Stroppiana *et al*, 2012] and the NBRL (Normalized Burn Ratio Long SWIR Variation) [Bastarrika *et al*, 2012; Key & Benson, 2006] indexes calculated from reflectance data. Conversion from sensor radiance to TOA reflectance was done following the work of Chander *et al,* 2009.
The detection and extraction of burned scars in the images is based on the concept that in conservation areas, the behaviour of the vegetation cover does not present sudden changes, and if they occur, they are very likely the result of fires. To evaluate this pattern change caused by fires, the variation in time of NDVI and NBRL, as described in equations 1 and 2, was evaluated in a similar way to the work of Miller and Thode (2007). In that work, they have used the positive square root of the absolute initial value divided by 1000. In this case, we directly used the absolute values. Considering two consecutive images of the same area with a maximum period between images of one month, the change rate for each index is defined by:

$$crndvi = \frac{ndvi(data1) - ndvi(data2)}{abs\left(ndvi(data1)\right)}$$

$$crnbrl = \frac{nbrl(data1) - nbrl(data2)}{abs\left(nbrl(data1)\right)}$$

Outliers in ratio values may be found when a very low value (near zero) is present in data1. To avoid these extreme cases, a limitation threshold was used in the NBRL difference.

$$dnbrl = nbrl(data1) - nbrl(data2)$$

For each equation, a threshold was used to separate burned from unburned areas, where the complete masking procedure results as follows:

$$Bmask = (crnbrl \geq Tcnbrl) * (crndvi \geq Tcndvi) * (dnbrl > Tdnbrl)$$

Used thresholds were: *Tcrnbrl*= 0.5, *Tcrndvi*= 0.45 and *Tdnbrl*= 0.10, and they were obtained by qualitative comparisons. For OLI images, a different set of thresholds were used, and the NDVI threshold was lowered to 0.35, while *Tdnbrl* was lowered to 0.06.
The final operation is the vectorization, which is optional. To speed up the process, the vector file creation procedure can be cancelled. All these processes are straightforward using functions in the gdal, numpy and other python libraries. The complete work flow of the burned mapping process is presented in Figure 2.

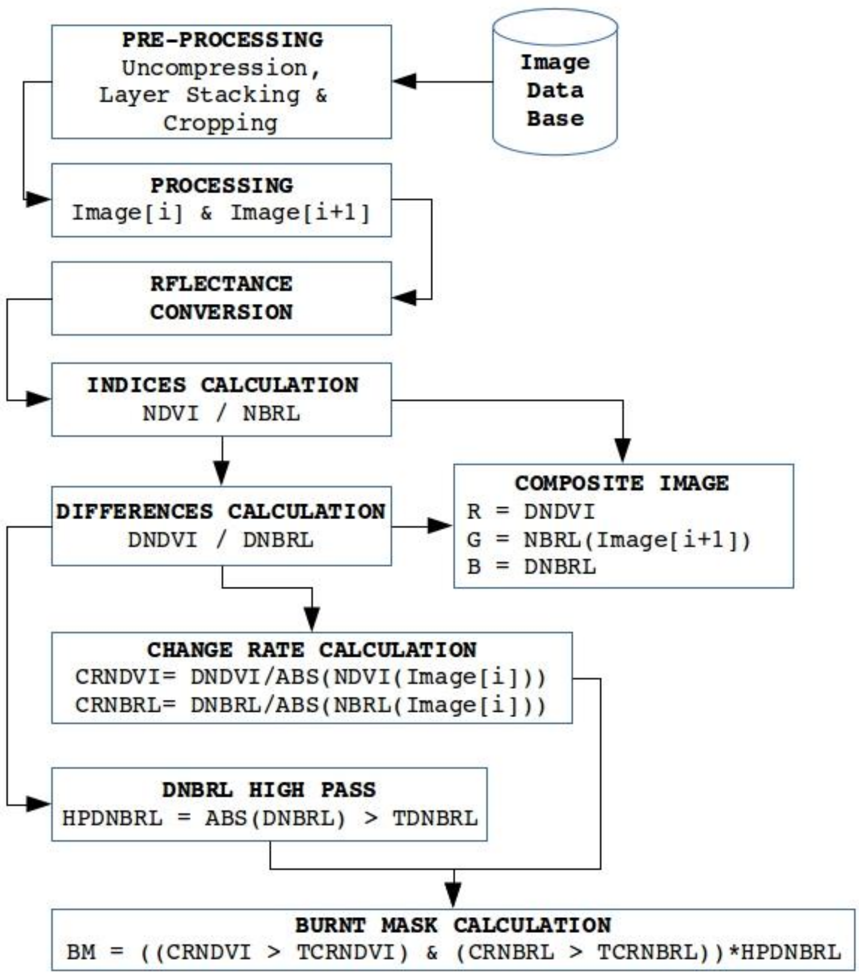

Figure 2. Flux diagram of developed process.

Evaluation of the algorithm's performance was made using burned area manually mapped from visual photo interpretation in the period 2004 – 2010 [Candido, 2014]. As mentioned by Congalton 1991, the accuracy of photointerpretation has been accepted as correct without any confirmation, and digital classifications are often assessed with reference to it leading to sometimes poor and unfair assessments. According to Blaschke *et al* (2008), visual photo interpretation is the ultimate benchmark for any classification and segmentation procedure. Omission and commission errors were obtained from image differencing between the reference data manually digitized and the algorithm's burned area (BA).

$$Omission\ Error = Reference - Algorithm's\ Burned\ Area$$

$$Commission\ Error = Algorithm's\ Burned\ Area - Reference$$

Burned Match (BM) and the Algorithm Reliability (AR) were obtained with the following formulas.

$$Burned\ Match = \frac{Algorithm's\ BA - CommissionError}{Algorithm's\ BA}$$

$$Algorithm\ Reliability = \frac{(Algorithm's\ BA - Commission\ Error)}{Reference}$$

3. Results

A total of 52 Landsat TM/OLI scenes from path/row 221/067 covering the period of 2000 – 2013 were processed. Over two thirds of the complete set was evaluated against visual photo interpretation of the burn scars, while the remaining 15 images were processed without a visual evaluation because this works was not yet available. For the 37 images in the 2004 – 2010 period, the obtained results are presented in the following tables.

Table 1. Scene date (day/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2004.

2004	Alg [ha]	Ref [ha]	Comm %	Omission %	B. Match %	A. Reliability %
02/06	57415	57435	15.8	15.9	84.1	84.1
04/07	96064	98558	11.7	14.3	86.0	88.2
20/07	42975	44628	8.9	12.8	87.6	91.0
05/08	73097	76786	4.5	9.5	90.9	95.5
06/09	207589	213562	7.2	10.1	90.1	92.7
Total	**477140**	**490968**	**9.6**	**12.5**	**87.8**	**90.3**

Table 2. Scene date (day/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2005.

2005	Alg [ha]	Ref [ha]	Comm %	Omission %	B. Match %	A. Reliability %
23/07	60536	68046	4,1	16,5	85,3	95.9
08/08	67321	71017	7,9	13,4	87,3	92.1
24/08	78788	85490	2,7	11,2	89,6	97.2
09/09	112800	125704	3,0	14,4	87,0	97.0
Total	**319445**	**350256**	**4.4**	**13.9**	**87.3**	**95.5**

Table 3. Scene date (day/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2006.

2006	Alg [ha]	Ref [ha]	Comm %	Omission %	B Match %	A. Reliability %
08/06	36319	35851	13.4	9.3	87.7	86.5
24/06	46208	41725	20.9	11.2	87.6	79.1
26/07	97734	95515	10.4	8.1	91.7	89.6
11/08	73420	75630	7.1	10.1	90.2	92.9
27/08	105949	106607	4.2	4.8	95.2	95.8
Total	**359631**	**355328**	**11.2**	**8.7**	**90.5**	**88.8**

Table 4. Scene date (day/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2007.

2007	Alg [ha]	Ref [ha]	Comm %	Omission %	B. Match %	A. Reliability %
27/06	122041	129975	7.1	13.3	87.5	92.9
13/07	106922	111613	4.2	8.6	91.7	95.7
29/07	84500	86719	5.4	8.1	92.1	94.5
14/08	83659	87798	4.4	9.3	91.1	95.6
30/08	153121	155883	4.2	6.0	94.1	95.8
Total	**550602**	**571987**	**5.1**	**9.1**	**91.3**	**94.9**

Table 5. Scene date (day/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2008.

2008	Alg [ha]	Ref [ha]	Comm %	Omission %	B. Match %	A. Reliability %
15/07	77942	91987	6.7	24.8	79.0	93.2
31/07	57383	53040	24.1	16.5	82.1	75.8
16/08	51192	59116	5.9	21.4	81.4	94.0
17/09	139085	157851	3.2	16.7	85.2	96.7
Total	**325602**	**361994**	**10**	**19.9**	**81.9**	**90.0**

Table 6. Scene date (day/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2009.

2009	Alg [ha]	Ref [ha]	Comm %	Omission %	B. Match %	A. Reliability %
19/08	58495	69751	2.3	21.5	81.9	97.2

Table 7. Scene date (date/month of the last image), algorithm burned area, reference burned area, commission error, omission error, burned match and reliability in percentages for year 2010.

2010	Alg [ha]	Ref [ha]	Comm %	Omission %	B. Match %	A. Reliability %
19/06	73822	65861	18.1	7.4	91.7	81.8
05/07	111983	114114	8.2	10.1	90.1	91.8
06/08	150513	145396	10.7	7.3	92.4	89.3
22/08	152316	154458	6.8	8.2	91.9	93.2
07/09	194168	190690	6.9	5.1	94.8	93.1
23/09	211921	222384	4.4	9.3	91.1	95.6
Total	**894723**	**892904**	**9.2**	**7.9**	**92.0**	**90.8**

Table 8. Algorithm burned area, reference burned area, commission error, omission error, burned match, reliability in percentages and total scenes processed for the period 2004-2010.

Year	Alg. [ha]	Ref. [ha]	Comm %	Omission %	B. Match %	A. Rel.%	T. Scenes
2004	477140	490968	9.6	12.5	87.8	90.3	6
2005	319445	350256	4.4	13.9	87.3	95.5	5
2006	359631	355328	11.2	8.7	90.5	88.8	6
2007	550602	571987	5.1	9.1	91.3	94.9	6
2008	325602	361994	10	19.9	81.9	90.0	5
2009	58495	69751	2.3	21.5	81.9	97.2	2
2010	894723	892904	9.2	7.9	92.0	90.8	7
Mean	**426520**	**441884**	**8.2%**	**11.8%**	**88.6%**	**91.8%**	**Sum=37**

The mean burned Match for the whole 2004 – 2010 series was 88.6%, while the mean algorithm reliability was 91.8%. Mean commission error was 8.2%, while mean omission error was 11.8%. These results are considered excellent when one analyses similar studies found in the literature [Bastarrika, 2011], which normally indicate more limited classification skills; in addition, the study region is particularly difficult for mapping burned areas with mid-resolution imagery due to the low biomass volume and sparse vegetation in many locations. The results of the classification algorithm for the remaining 15 images of the series, without validation of the fire scars, are listed in Table 9, with total burned area for each year and the corresponding number of processed images.

Table 9. Year, algorithm burned area and number of scenes processed.

	2000	2001	2013	Mean	Total
Burned Area [ha]	472817	461377	401922	**445372**	
Scenes	3	5	7		**15**

The means for the Algorithm Reliability and Burned Match obtained for the other subset of 37 images can be also included, thus resulting in a mean annual burned area for the total period of 432175 ha. The figure with the accumulated burned pixels was obtained for the whole period 2000-2013, and as it can be seen on Figure 3, most of the area covered by the image was burned; from the total 30707018 pixels of our study area, 23021994 were burned at some occasion, or almost 75% of the pixels.

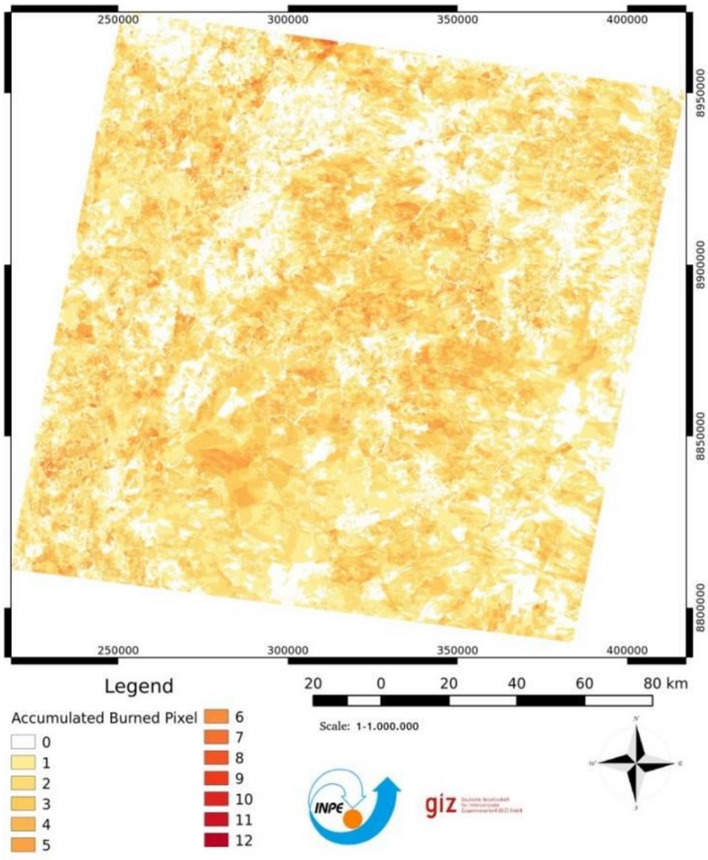

Figure 3. Cumulative burned pixels for the study area in the period of 2000-2013.

4. Conclusion

A relatively simple and reproducible concept for mapping burned area at the Cerrado-Jalapão region based on NDVI and NBR is presented. The Algorithm Reliability and Match coefficients suggest the usefulness of the tool developed and its application in other biomes. In particular, its use for conservation units could minimize the impact of land cover changes of anthropic origin.
Sudden changes in the spectral reflectance of the vegetation normally indicate perturbing events. The overlap of mapped burned scars with updated land use cover maps can identify the type of vegetation burned, allowing estimates of carbon and pollution emissions.
Agricultural land practices were a source of error in the mapping of fire scars, together with clouds and cloud shadows. Masking these three classes automatically will reduce the uncertainty of the process and improve the Burned Match; further work in this direction is currently in progress.
A reliable spatial reference is fundamental to validate a digital automatic process [Congalton 1991], but this condition is rarely found in the analysis of the results of algorithms to map burned area at regional and continental scales. The systematization of the processing stages herein proposed and their integration with a geographical data base engine could foster an operative system to process large image repositories. The implementation of software applications without proprietary libraries or closed systems grants the portability and free distribution of the developed tools, either in a dedicated system or as part of any processing chain.

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