

# Towards a Global Burned Surface World Atlas

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*This study demonstrates that burned surfaces can be detected worldwide using remotely sensed data. Due to the good geolocation accuracy and radiometry, the ATSR-2 sensor turned out to be well suited for a global analysis of burned surfaces at a low resolution. Different adaptive algorithms for burned surface detection have been tested on many ecosystems. The estimations obtained were validated using supervised classification on Landsat/TM data. These results will allow the definition of a method for the detection of burned areas from vegetation fire at a global level, allowing the production of a global burned surface atlas.*

## Introduction

Many vegetation fire events occur around the globe during the year, leading to environmental disasters at different levels: on a regional scale, with the destruction of vegetation reserve and danger for human activities; on a global scale, for the atmospheric emissions that contribute to the greenhouse effect and the rise of the mean temperature of the Earth.

Acknowledging the importance of the problems, many actions have been undertaken at an international level. In the 1997 Kyoto convention, the International Community defined guide lines and rules to assess and restrain the emission of all greenhouse gases. Each member was given the responsibility to "have in place a national system for the estimation of emissions of all greenhouse gases" and "cooperate in scientific and technical research and promote the maintenance and the development of systematic observation systems and development of data archives".

The CEOS pilot project, Global Observation of Forest Cover (GOFC), was defined with the aim to improve the quality and availability of satellite observation of forest and the information derived from these data. Recently, seeing the preliminary results of burned surface evaluation done using ATSR, GOFC has requested the production of 1-Km resolution regional and global area burned products with this sensor.

Since 1998, via an Announcement of Opportunity (AO-329), ESA promoted a project for the development and test of algorithms with the aim to achieve a global burnt area product using the remotely sensed data from ATSR-2. Partners in this work are the Department of Forestry of the Instituto Superior de Agronomia (DEF/ISA – University of Lisbon), the Global Vegetation Monitoring Unit at Space application Institute (GVM/SAI – JRC) and ESA.

The objective of the study is to design a single algorithm capable of detecting burnt areas from vegetation fires at a global level, across the major biomes. A set of algorithms is under evaluation and test across different ecosystems, in order to identify the strengths and limitations of each method related to the particular vegetation under analysis. These limitations were quantified considering the commission/omission errors and over/under estimation of burnt areas. For ground truth, high-resolution data were used.

## Methodology Used for Burned Surface Detection

The main physical variations that occur in a vegetation layer after a fire, which can be detected with remotely sensed data, were quantified with different methods in order to create six different scalar indexes, called K-parameters [Piccolini and Arino, 1999]. This results in a decrease in the amount of data to

be considered, without any loss of information. In particular, healthy vegetation shows higher reflectance in the range between 0,7  $\mu\text{m}$  and 1,3  $\mu\text{m}$  (NIR) than other natural surfaces. In general, this region of the spectrum contains the most useful information for burned surface detection, thanks to the strong reflectance variation that can be found after a fire occurrence [Pereira, 1999].

The second physical characteristic is the increase of temperature that occurs over a burned surface during daytime, due to strong solar irradiance absorption and the absence of evo-transpiration that normally transfers energy to the atmosphere in form of latent heat through water vapour. The presence of ash and carbon constitutes a dry layer that does not allow this cooling process, increasing the surface temperature by 7-8 K [Lambin and Erlich, 1996].

Knowing these two characteristics and plotting the graph between reflectance in the NIR (0.87  $\mu\text{m}$ ) and brightness temperature in the TIR (11.0  $\mu\text{m}$ ), it is possible to identify a geometrical behaviour of the points associated with pixels of burned surface (Fig. 1).

The burned pixels move away from the total distribution, in the upper left direction, independent of the vegetation type or atmospheric status. However, these daily differences determine a variation in the total distribution of the scatterplot and must be taken into account beforehand to define any estimation threshold.

By using an adaptive method, these scalar parameters were decorrelated to the possible daily variations (atmospheric, solar illumination, etc). In particular, the K1 parameter is proportional to the geometrical distance calculated in the previous scatterplot, from the point analysed and the point defined from the mean values of NIR and TIR of the image under analysis. A similar concept was used for the definition of the parameters K2 and K3, using the data in the IR (InfraRed) and the GEMI (Global Environmental Monitoring Index).

The K4, K5 and K6 were defined on temporal analysis of the remotely sensed data. The percentage difference between the NIR value and the mean NIR value in the image were used to create the K4 parameter's

viewing geometry, solar illumination or atmospheric conditions. For K1, K2 and K3 a bayesian method was used in order to decorrelate the final estimation from different vegetation types. In particular, K-parameter data are also calculated from a training set of 10 images of the same vegetation under analysis showing known burned surfaces. The resulting probabilities were used in the bayesian estimator, evaluating the probability  $P(BS/Kval)$ , that the pixels belong to the burned surface if its K value is at certain level. Finally, these burned surface probability images were compared with a threshold determined on the training set, allowing the definition of a burned surface map derived from each K's method.

A temporal approach has been used to define the rules for K4, K5 and K6

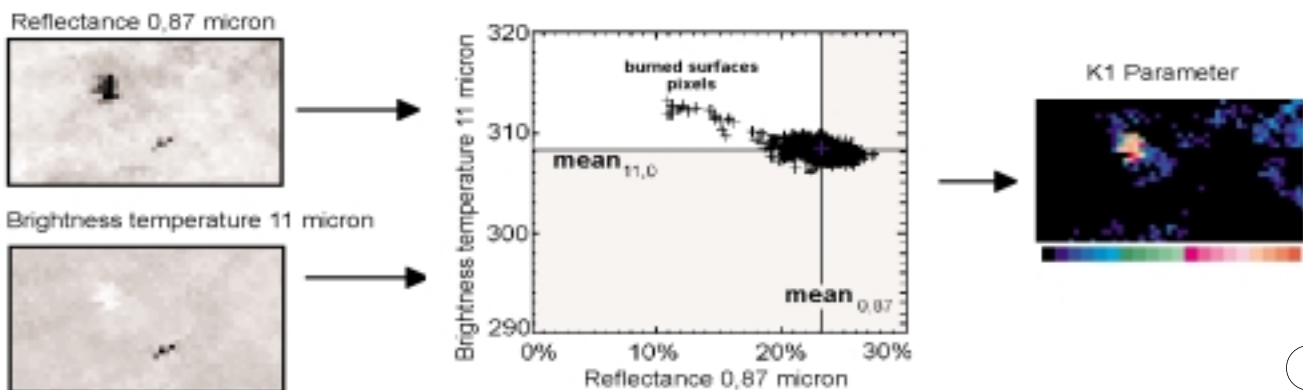
Therefore, if the decrease/increase in these time series exceeds a threshold based on the mean time series values, the correspondent pixel is identified as burned surfaces.

#### West Africa Test Site

A 1000 km<sup>2</sup> area was selected to develop and test the method (Fig. 2). This area has three main characteristics:

- a high level of fire activity
- a broad type of vegetation
- a fairly flat region which reduces geolocation error of remotely sensed data.

The period of the year chosen for the study corresponds to a phase of high-level fire activity within the area. From previous studies [Hao and Liou, 1994] it was demonstrated that the African con-



*K1 parameter design. The definition of this parameter is based on the geometrical characteristics of the burned surface pixels in the scatterplot between NIR and TIR value. These pixels present low NIR and high TIR values and are mapped away from the classical distribution of the entire image. The distance between normal and burned pixels is quantified in the K1 scalar parameter, using mathematical relations.*

image. Using the same concept, the K5 was defined by the difference between brightness temperature at 11 micron and the mean value for the entire image in the same channel. K6 was defined from the spatial feature identified over burn scars. It represents the variance calculated in the red channel for each 3x3 grid centered in the pixel under analysis.

The retrieved images (K-parameter) were elaborated using different rules that allowed the burned/unburned characterisation for each pixel. The tests applied are all adaptive in order to alleviate the artifact due to different

parameters. Considering the time series value for each of these parameters on the same pixels, in order to obtain a temporal behavior filtered from error caused by cloud cover or great daily atmospheric variations, the time series were averaged with a temporal window of six-sample length. The resulting time series appear smoothed, but clearly showed the temporal variations connected with new burned surfaces occurrences. In particular, a decrease in the K4 time series or an increase in the K5 or K6 time series is associated with a permanent variation on the ground, mainly because the vegetation was burned.

continent contributes up to 46% to the total biomass burning in the world. Moreover, occurrences of fires in this continent shows a seasonal activity [Arino and Rosaz, 1999] linked to climate variation during the year. The period of the year identified was from January to April 1997, which corresponds to a maximum fire activity period.

The information concerning land cover was extracted from the vegetation map realised in the context of the International Geosphere Biosphere Program (IGBP 1996). The zone under analysis is mainly composed of savan-

nahs (northern central), grassland and cropland (north), woody savannah (southern central), and evergreen broadleaf forest (south).

*Preliminary results, subcontinental burned surfaces map in West Africa*  
 The different methodologies were evaluated on the defined zone, estimating the occurrence of the burned areas. To illustrate the distribution of these events from a temporal and spatial point of view, Figure 3 shows the estimation done in this area for three different months during the period under analysis.

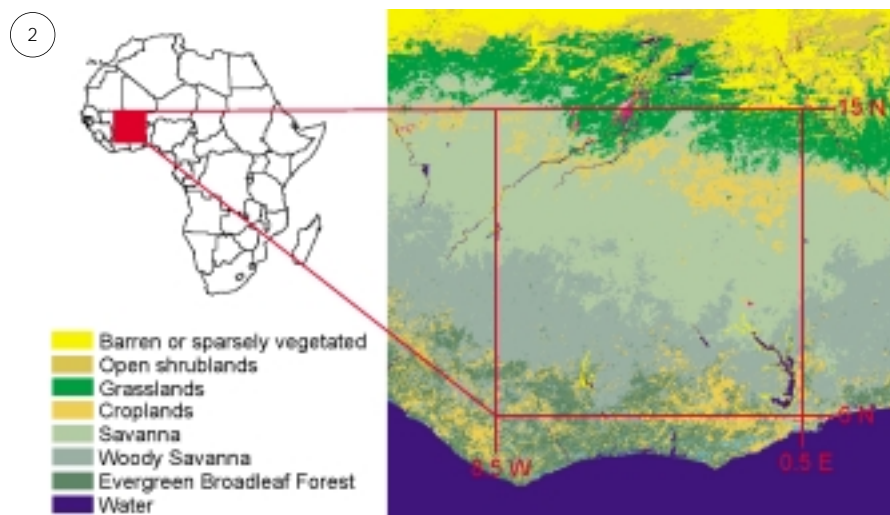
Various conclusions can be achieved with this map. Firstly, that the burn occurrences are related to the vegetation area and, in particular, with savannah and woody savannah representing the vegetation in the central part of this region. Secondly, the fire season in Burkina is the earliest in the entire zone. Many burned surfaces were detected in January (green) and a low amount of this is detected in February as well (yellow). Moreover, only few new burned surfaces appeared in February (red). (The opposite situation has been ascertained in Southern Mali and the Ivory Coast, where a large number of burned surfaces were detected in February.)

*Validation*

Due to the fact that no coherent field data exists, the different procedures were tested on the identified area and validated using nine Landsat/TM images, located on different vegetation zones and on different days (Fig. 4).

The burned surface area was estimated in Landsat/TM by supervised classification (SC), with the maximum likelihood method. In particular, five different classes were identified in the images (burned surfaces, vegetation, river, clouds and cloud shadows) and their spectral signatures in the seven TM channels were collected from a sample set identified by visual inspection.

In order to demonstrate in a visual way the accuracy of this estimation method, RGB composition of Landsat/TM channels, used in different studies for visually discriminate burned surfaces, are shown in Figure 5.



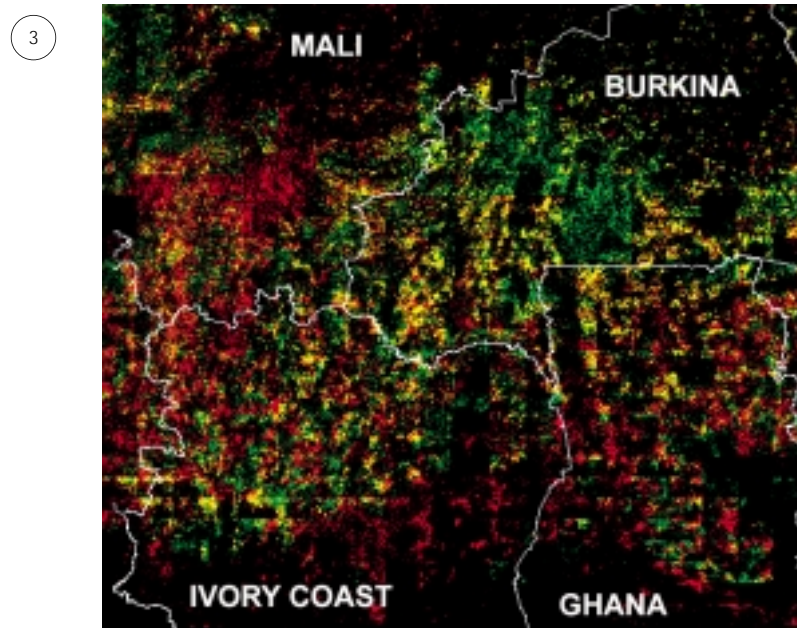
Area under analysis. The different colors show many vegetation types (IGBP 1996) inside the test area of 1000 km<sup>2</sup> in West Africa.

In Figure 6, it is possible to note a sample monitoring over the burned area. This large burn scar was found in the savannah using the described techniques and monitored with three samples in order to show the accuracy of the system. As can be seen, a large burned area appears in the second sample. It can be evaluated in high resolution by visual inspection on the NIR channel of Landsat, or by supervised classification on the different

channels. Based on ATSR data, the automated method allows a good estimation in low resolution, more suitable for continental or global analysis.

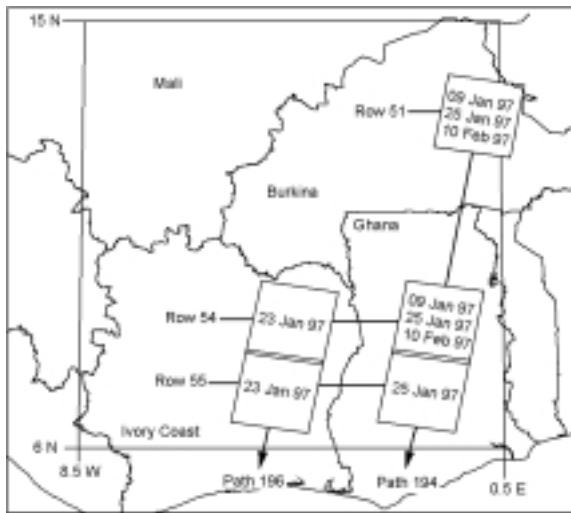
*Quantitative validation*

To compare the area estimated from the different K-parameters with the one obtained from TM supervised classification, taking into account the different sensor's resolution and geolocation problems, a set of sub-areas were



Burned surfaces detected with the K1 parameter in the entire zone under analysis (detection period: green-January, red-February, yellow-both January & February).

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Area under analysis and multi-temporal Landsat/TM coverage. We can see the acquisition date and path/row coordinates of TM images used for the validation.

**Conclusion**

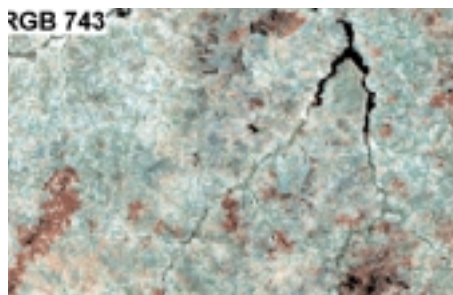
The burned areas can be detected using the ATSR-2 data. The physical characteristics of the biomass burned can be detected using the visible, near-infrared and infrared channels. Six algorithms have been developed using adaptive methods.

The first validation studies were performed in West Africa using high-resolution data. The results indicate very good accuracy, particularly considering sparsely burned surfaces for different types of vegetation. Further improvements are expected from the ongoing validation on different biomes.

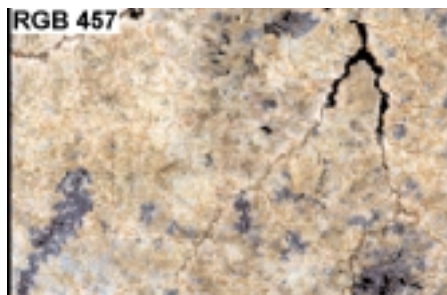
The perspective is to derive a harmonised global method simple enough to run on 1-km global data sets for several consecutive years, in order to maintain an upgraded archive of burned surface occurrence all over the world.

identified around burn scar occurrences in the supervised classified images. Inside each sub-area, the burned surfaces (in square kilometres) was calculated with the estimations derived from each K-parameter and from the supervised classification. Performing a

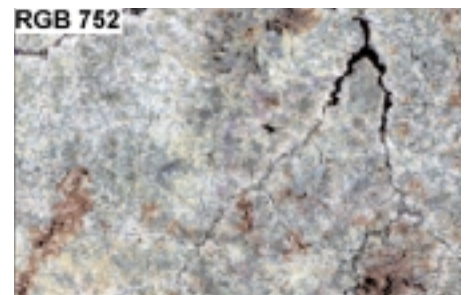
regression analysis on the retrieved areas, on sparsely burned occurrence areas, the regression coefficient from K1 and K3 estimator are near to one ( $m_{K1}=1.03$ ,  $m_{K3}=1.11$ ) and the offsets are also very low (Fig. 7).



5a

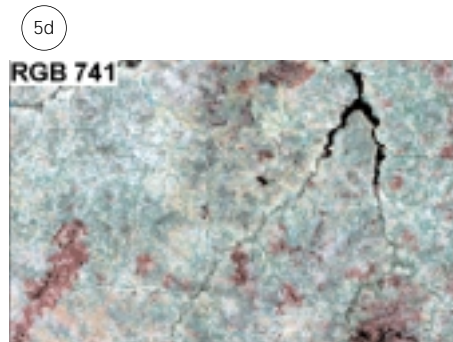


5b

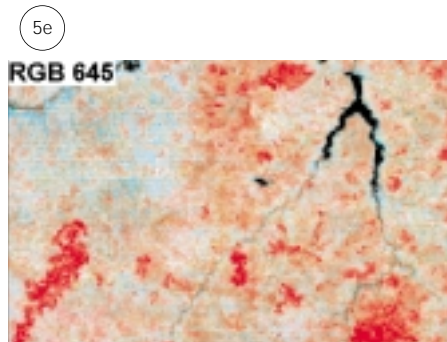


5c

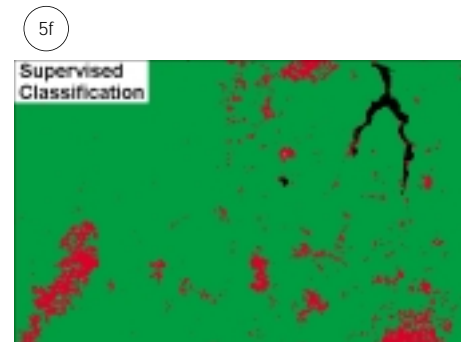
Many studies have been done for burned surface detection using RGB composition on Landsat/TM data. As we can see in these pictures, different RGB compositions allow the identification of this surface by visual inspection. (a) RGB 743 - Pereira J.M.C. et al., (b) RGB 457 - Williams C.M., (c) RGB 752 - Eurimage's analysis, (d) RGB 741 - Koutsias and Karteris 98, (e) RGB 645 - Piccolini 98. Supervised classification (f) allows this evaluation in an automated way and the results are in accordance with previous visual analysis (red-burned surfaces, green-vegetation, black-water).



5d

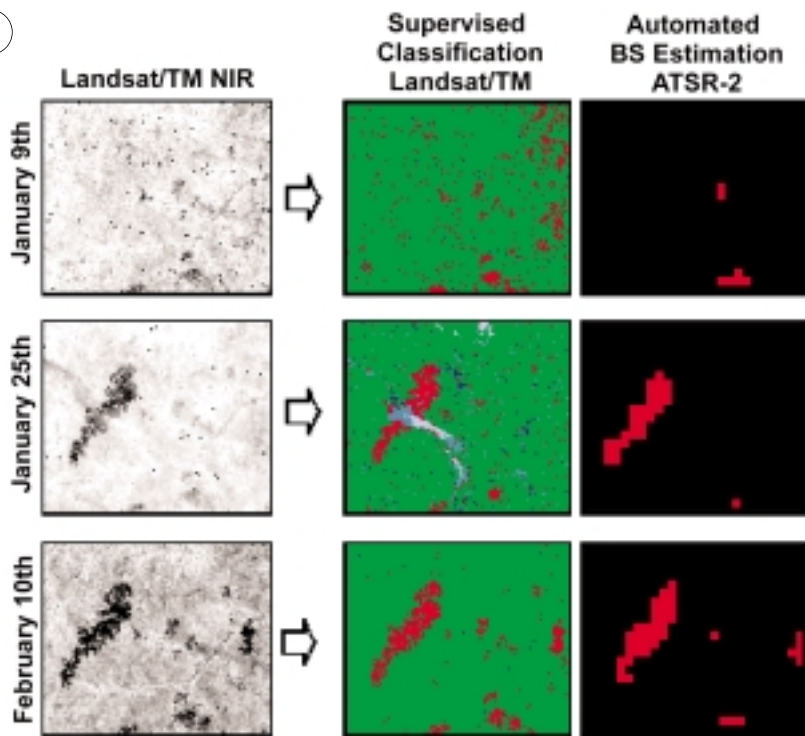


5e



5f

6



Temporal monitoring of burned areas. A large burned area appears on the second sample. It can be detected in the Landsat NIR image by visual inspection, or with supervised classification on Landsat channels. Based on ATSR data, the automated method allows a good estimation in low resolution, more suitable for continental or global analysis.

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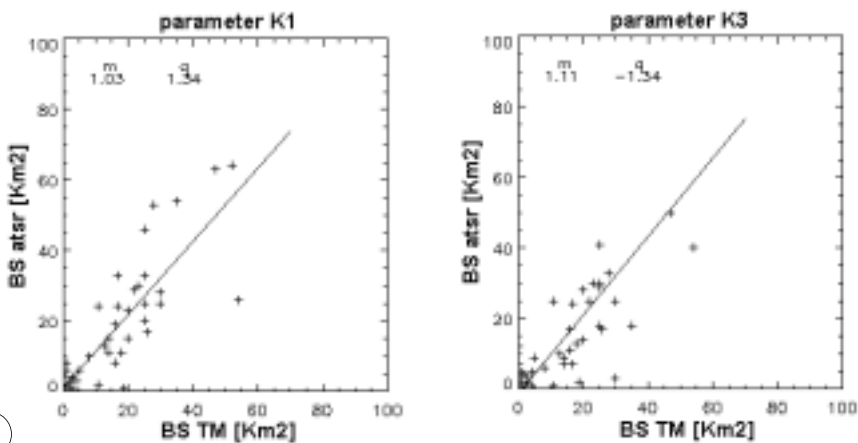
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Regression analysis between the BS area estimated from the K-parameter and from Landsat supervised classification (zone with sparsely burned surface occurrence). Also represented in the graphs are the regression coefficient  $m$  and the offset  $q$ .