

# AN OPERATIONAL BURNT AREA RAPID MAPPING TOOL FOR FOREST FIRES IN THE EUROPEAN MEDITERRANEAN

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## ABSTRACT:

Every year forest fires occur across Europe, especially in Italy, Portugal, Greece and Spain. Wildfires require immediate action and reaction in order to prevent damages to private property, life and ecosystems. Furthermore, wild fires have an affect on global warming due to rising CO<sub>2</sub>-emissions.

Knowledge about past fire events and the damage they caused will greatly enhance the knowledge base, that will allow for a better understanding of the risks, and increase the forecasting quality of wildfire scenarios.

According to the main objective an algorithm was developed for a fast and accurate detection of areas that have been consumed by fire. Mapping burned areas with Remote Sensing is very important, on a short-term as well as on a long-term basis. A short-term application is e. g. the rapid mapping and the provision of satellite-based information products on natural and environmental disasters, for humanitarian relief activities, as well as in the context of civil security. This paper presents a semi-automated, object-based algorithm for burned area mapping that uses multisensoral, very high spatial resolution Remote Sensing data (like Spot 5 and Ikonos).

The data sets have been acquired over the recent years from contributions to the Center for Satellite Based Crisis Information (ZKI) of the German Aerospace Center (DLR). The robust algorithm will be tested on an example site in Spain (La Palma) where wildland fires occurred in July/August 2009. The algorithm includes a mono-temporal data analysis based on spectral indices like MSAVI, BAI and NDSWIR, as well as a multi-temporal data analysis based on their differences (dMSAVI, dBAI and dNDSWIR).

## 1. INTRODUCTION

Wildfires are one of the main causes of forest destruction in the countries of the Mediterranean Basin. About 50000 fires sweep through 700000 ha of forest and agricultural land each year, causing enormous economic and ecological damage as well as loss of human life.

Globally, and particularly in European countries located in the Mediterranean Basin, the frequency of wildland fires has significantly increased in the recent years (Figure 1). The increase of forest fire occurrences in the Mediterranean basin is due to the land-use changes (rural depopulation increases land abandonment and consequently, fuel accumulation) and climatic change (which is reducing fuel humidity and increasing fire risk and fire spread) (Chuvienco, 2009; JRC, 2010).

Natural wildland fires are caused by lightning, sparks from falling rocks, volcanic activity, natural heat waves and many other causes which can act as natural fire ignition source. But the primary cause of wildland fires is human activities. According to a study conducted by the European Commission over 80% of the forest fires in the Mediterranean Basin are caused by human activities (Schmuck et al., 2007). While the vast majority of wildfires are anthropogenic, the risk of such fires is expected to increase in forthcoming years under the impact of climate change. The vegetation becomes more inflammable (due to thermal stress and drought) and fire services are faced with difficulties when trying to suppress a fire due to increased inflammability and water shortage (Running, 2006).

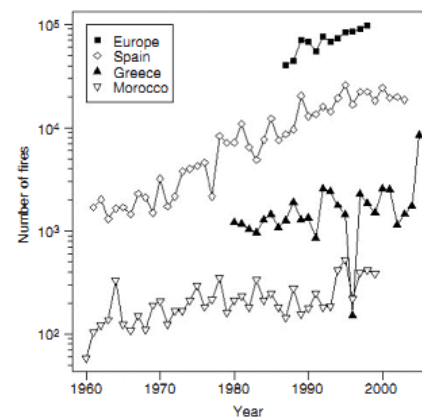


Figure 1: Evolution of the number of fires (in log scale) during the last decades in different Mediterranean regions (Spain, Morocco, Greece) and in Europe (Pausas et al., 2008).

The damage and loss which this disaster has caused is uncountable. For example the recent major wildland fire in Russia has affected 92.000 hectares of land and causing over 700 deaths each day. This forest fire lasted for over than one month from late July 2010 (Galphin, 2010).

Civil Protection Services, Forest Fire Services and Environmental Services were faced with the management of multiple fires, the evolution of simultaneous extensive fire fronts and the monitoring of heavy smoke emitted during wildland fires. Timely and reliable detection of new outbreaks is particularly crucial for effective wildfire management, particularly in largely inaccessible mountainous areas. Near real time tracking and monitoring of active hot spots is also very important during crisis management concerning the optimal

distribution of ground and aerial forces (Sifakis et al., 2011). The role of satellite observations in the resolving of the previous issues has considerably increased during the last twenty years as the spatial, spectral and temporal characteristics of the sensors have been constantly improving, and new methods for the exploitation of satellite data have been developed (Gitas et al., 2009; Justice et al., 2001; Lentile et al., 2006).

### 1.1 Disaster cycle

According to the management disaster cycle, which represents the different stages before and after a disaster, the following points should be taken into a consideration of any type, but especially for wildland fires: prevention/preparedness (e.g. fire risk), emergency response (e.g. fire locations, burn scars, affected infrastructure) and recovery (e.g. monitoring of the fire effects) (Figure 2).



Figure 2: Disaster management cycle.

The main objective of the presented paper is emergency response activations. Next to the rapid mapping services the DLR/ZKI offers an operational service on active fire detection from space (ZKI-Fireservice, 2011). Based on data of the NASA owned MODIS sensors on board of the Terra-1 and Aqua-1 satellites, wild and forest fires can be detected. Users can view, download and automatically receive information on current fires in Europe. The algorithm used for fire detection was developed at the University of Maryland and is an internationally acknowledged standard. In Europe, the German Remote Sensing Data Center (DFD) is the only institution operating two X-band antennas enabling it to receive and process observation data from both satellites simultaneously and allowing for up to eight daily observations. DFD is offering its capability to the European community and its people providing daily hot spot detection free of charge. The software has been developed in close cooperation between Mexico's National Commission on Biodiversity Research (Conabio) and DFD.

### 1.2 Rapid Mapping

After the occurrence of a natural or man-made disaster the necessity of fast and reliable spatial information is important not only for crisis control centers but also for relief organisations and rescue teams. Civil protection authorities have to meet the demand for adequate crisis information in order to ensure an appropriate decision process and an effective crisis management. Therefore all possibilities obtaining spatial crisis information have to be taken into account, particularly earth observation data proved to provide significant information input. In order to cover these user requests in crisis situations, DLR set up a rapid mapping service to ensure fast access to available, reliable and affordable crisis information worldwide. After the mandatory decision process whether satellite analysis is appropriate for the respective crisis, the area of interest has to be defined and cross checked to avoid false geo location.

Following this iterative process, it has to be assured that all applicable satellites are programmed for data acquisition. This can either be coordinated within the International Charter "Space and Major Disaster" or a GMES initiative like the project SAFER (supported by the Seventh European Frame Work Programme) by the responsible project manager, or through commercial satellite tasking.

The ZKI presents a service of the DFD of DLR. It provides a 24/7 service for the rapid provision, processing and analysis of satellite imagery during natural and environmental disasters, for humanitarian relief activities and civil security issues worldwide. The resulting satellite based information products are provided to relief organisations and public authorities and are also freely available on the ZKI website. According to the requirements of the user, the information products are delivered in the form of maps, GIS-ready geodata or dossiers which are then used to support disaster management operations, humanitarian relief activities or civil security issues. The rising number of natural disasters, humanitarian emergency situations and threats to the civil society increases the demand for timely and precise information on many different types of scenarios and situations. ZKI uses all kinds of satellite imagery for the extraction of relevant crisis information like flood extent, damaged infrastructure, burnt areas or evacuation areas. Besides response and assessment activities, ZKI derives geoinformation products for the use in medium term rehabilitation, reconstruction and crisis prevention activities. It operates in national and international context, closely networking with German public authorities at national and state level, non-governmental organisations, satellite operators and space agencies (Voigt et al., 2007). Since 2003 the ZKI prepared about 33 maps in 9 activations in the context of wildfires (<http://www.zki.dlr.de/>).

In the next chapters an operational object-based algorithm for a burnt area mapping will be presented using the example of wildland fires that occurred between July 31, 2009 and August 3, 2009 on the Canary Island of La Palma, Spain. 30 houses and several vineyards were destroyed. More than 4000 residents were evacuated from the area on August 1, 2009. In the course to these fires the International Charter *Space and Major Disasters* was activated in order to supply and analyse satellite data for rapid mapping purposes.

## 2. STUDY SITE AND DATA

The study sites were located in the south of the Canary Island La Palma, which belongs to the Mediterranean Basin.

Forest fires in Mediterranean Basin are significantly determined by predominating climatic conditions. Prolonged summers, with virtually no rain and average temperatures above 30°C, reduce the moisture content of forest litter to below 5 %. Together with heat and lack of moisture, wind is also an influential factor. The inland summer winds are characterised by high speeds and strong desiccating power. The dry and cold winds of Mediterranean winters can also augment the danger of fire (Dimitrakopoulos and Mitsopoulos, 2006). The topography of this case study is characterised by a high topography elevation ranging from sea level up to 1900 meters.

The fires in La Palma were located in the south of the island and affected an area covered by coniferous forest, pastures, sclerophyllous vegetation, sparsely vegetated areas and agricultural areas which consisted of permanently irrigated land, fruit trees and berry plantations (CORINE land cover, 2010).

The satellite images are multispectral pre- and post-disaster scenes from the SPOT 5 sensor with a spatial resolution of 10 m (Figure 3). Prior to the mapping of the burned areas, the

satellite images were pre-processed. Pre-processing of the satellite images included their atmospheric and geometric correction.

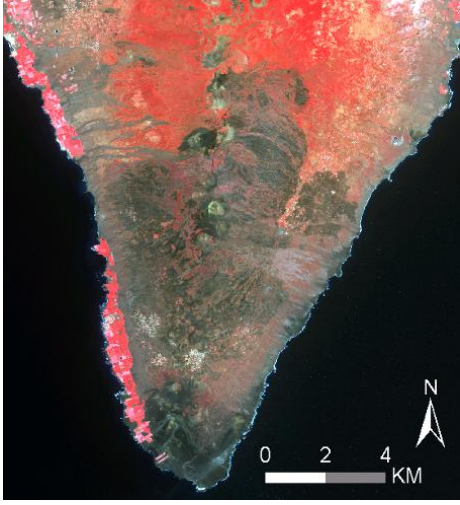


Figure 3: Study sites in La Palma, (SPOT 5 image (©SPOT - CNES 2009) acquired on 07.08.2009 -after the forest fires- (band combination: NIR, Red, Green).

### 3. METHODOLOGY

The analysis of the pre-processed satellite images were realised with the Software eCognition. The object-based segmentation and classification was separately applied to both measurements. The algorithm is implemented for mono-temporal (post-disaster scenes) as well as for multi-temporal analysis. Since a pair of SPOT 5 images was available for the forest fires in La Palma, change detection approaches were applied to these images. Finally, a combination of both algorithms was used. In order to simplify and accelerate the classification, a user interface was generated with eCognition Architect.

In previous studies the object-based image classification has proven itself to provide promising results in a adequate computing time for burnt-area-mapping. The basic processing units of the object-based image analysis are objects/segments and not single pixels. The advantages of this analysis are meaningful statistical spectral and texture calculations, an increased uncorrelated feature space, using shape and topological features, as well as the close relationship between real-world objects and image objects (Benz et al., 2004; Blaschke, 2010; Chubey et al., 2006).

In the following, the algorithms get explained in more detail.

The first step applied to all SPOT 5 images was segmentation. Burned areas do not show any uniform texture or spectral characteristics, which has to be considered, in order to receive a useful and transferable segmentation. This challenge was solved by means of a two-dimensional segmentation approach. Therefore the “multiresolution segmentation” was used for the generation of small scale and diverse objects, and the “spectral difference segmentation” was used for the generation of spectrally similar and more homogenous objects by their average spectral intensities. The spectral information of the near and middle infrared bands were of the highest interest. The parameters used can be modified interactively by the user

interface. The second step was the classification of the burned area, based on the following spectral indices:

$$BAI = \frac{1}{(0.1 - \rho_{RED})^2 + (0.06 - \rho_{NIR})^2} \quad (1)$$

$$MSAVI = \frac{2\rho_{NIR} + 1 - \sqrt{(2\rho_{NIR} + 1)^2 - 8(\rho_{NIR} - \rho_{RED})}}{2} \quad (2)$$

$$NDSWIR = \frac{\rho_{NIR} - \rho_{SWIR}}{\rho_{NIR} + \rho_{SWIR}} \quad (3)$$

Where:  $\rho_{RED}$ ,  $\rho_{NIR}$ ,  $\rho_{SWIR}$  = reflectance in red, NIR and MIR.

To avoid misclassifications, the first step of the classification was to exclude unburned parts of the image. The unaffected areas were classified during a fuzzy classification using the indices MSAVI and NDSWIR. Subsequently, cloud shadows were extracted with the help of the (normalised) middle infrared. Finally, the burned area was classified by means of a fuzzy classification approach using the MSAVI, BAI and NDSWIR. All applied classification steps were threshold based. The different threshold values were determined in an iterative process, based on a broad literature survey/review.

In order to take multi-temporal data sets into account, an algorithm based on change detection approaches was further developed. For this task the temporal differences of the previously listed spectral indices were used, namely:

$$dBAI = BAI(post\_fire) - BAI(pre\_fire) \quad (4)$$

$$dMSAVI = MSAVI(post\_fire) - MSAVI(pre\_fire) \quad (5)$$

$$dNDSWIR = NDSWIR(post\_fire) - NDSWIR(pre\_fire) \quad (6)$$

The extraction of unburned objects follows through the same steps as the previously mentioned approach for burned areas. For the detection of burned areas, a fuzzy approach based on the reflectance difference between pre and post disaster objects was used. To avoid misclassifications between harvested and burned areas the dBAI brought best results.

### 4. RESULTS

The resulting map was delivered to the Spanish user Directorate General for Civil Protection and Emergencies (Dirección General de Protección Civil y Emergencias - DGPCE) (Figure 4).

The total burned area was estimated to 2700 ha. The majority of the areas affected by the fires were dense forests (56,4 %) and dry pasture (isolated shrub and trees) with 32 %.

The results show that the object-based implemented methodology can improve the mapping of the burnt area in comparison to traditional pixel classification approaches.

During the development of the presented algorithm the following points summarised the main problems:

- Spectral overlapping between slightly burned areas and other non vegetated land cover classes (especially water bodies, urban areas and bare soil),
- Spectral overlapping between burned areas and shaded unburned areas, and
- Spectral overlapping between slightly burned areas (especially understory fires) to unburned forest.



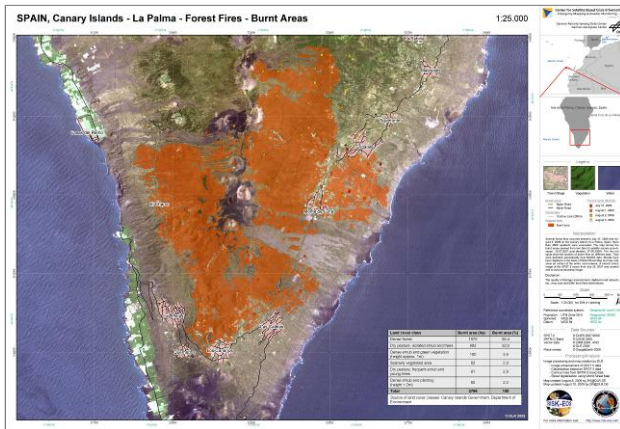


Figure 4: Result of the burnt area mapping. La Palma, Canary Island (Spain) (©ZKI, 2009).

The accuracy of the algorithm was assessed by using the fire perimeter that resulted after visual interpretation and digitisation of the image and additional data from the European Forest Fire Information System (EFFIS). The mono-temporal classification shows an accuracy of 87 %, where the multi-temporal approach shows an accuracy of 92 %. In regard to the high accuracy of the classification it should be noted that when applying it to other regions in the Mediterranean Basin modifications of the thresholds are usually necessary (Polychronaki & Gitas, 2010).

This depends on the following reasons:

- differences in the atmospheric conditions
- differences in the degree of burn severity
- differences in the time period between the fire incident and the acquisition of the satellite images and
- the existence of old fire scars and recently burned areas in the same image.

The transferability of the algorithm was assessed by applying it to other wildland fires sites in Sardinia and Greece 2009.

## 5. CONCLUSION

The examples show, that earth observation can successfully provide a beneficial support for an operational burnt area mapping. The object-based, multisensoral, fast but at the same time precise algorithm is a highly useful tool for the detection of wildland fires in the European Mediterranean. The integration of the algorithm (ruleset) into a user friendly graphical user interface (GUI) in eCognition Architect supports the operational efficiency during a disaster event.

Because of the large spatial extent and high spatial and temporal variability of wildfires, robust post-fire monitoring tools are needed on the one hand to inform humanitarian relief activities and civil security issues and on the hand to an improved adaptive management and advance the understanding of post-fire vegetation response rates and ecosystem health. In combination with additional geographic data (e.g. land cover), possible threats to properties, infrastructures and to human life can be predicted and ideally, mitigated. Low-cost, rapidly available, and accurate assessment of landscapes following the disaster will lead to improved predictive capabilities and more informed management decisions (van Leeuwen et al., 2010).

The greatest limitation of optical sensors in hazard assessment as for example with wildfires or other disaster scenarios is the inability to obtain imagery through clouds, smoke and haze.

To reduce these effects further work will focus on an algorithm, which combines optical and radar data. Furthermore combined data from multiple satellites included in order to improve the timeliness and accuracy of burned area mapping.

In the case of multi-temporal approaches, the identification of the burnt areas is easier as the post-fire image is acquired temporally closer to the disaster event.

Due to the fact that all forest fires cause similar effects to vegetation by the loss of crown foliage, branches and the removal of understory layers, it is likely that similar results can be achieved in other Mediterranean regions. However, different trends may be observed in other environments such as boreal or tropical forests which might be challenging for the developed algorithm. Thus, an enhancement of the developed method and its transferability to other study sites in different parts of the world and under varying weather conditions is necessary in the future.

For a comprehensive prevention/preparedness requires the monitoring of the burnt areas for several years following the wildfire. The operational implementation of the burnt area mapping can also provide information on the availability of dead and live fuel, as an input for a fire risk assessment (Hardy 2005).

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