

Near real-time burned area mapping using Sentinel-2 data

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Key words: burned area mapping, SVM, Sentinel-2, Google Earth Engine, region growing

SUMMARY

This study presents the integration of a cloud platform (Google Earth Engine API) and an algorithm for automatic detection, for near real-time burned area mapping using Sentinel-2 images. The algorithm used differenced NBR images, a region growing algorithm and the OTSU thresholding method to maximize the level of automatization. The results were compared with the burned area maps obtained using WorldView-2 images and a Supported Vector Machine algorithm. Both burned area maps were validated using points verified in the WorldView-2 images and in the field. The KHAT coefficient showed a perfect agreement with reality for WorldView-2 (0.91) and a moderate agreement for Sentinel-2 burned area maps (0.66). The commission error (6.06% vs. 18.05%, respectively) shows that both data sources tend to overestimate the burned area, mainly due to misclassification of low albedo surfaces and significantly lower spatial resolution of Sentinel-2 data. However, the results provided by this approach to provide near real-time burned area maps using Sentinel-2 data are accurate enough to be an aid in post-fire management.

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1. INTRODUCTION

Wildfires are an important disturbance factor for ecosystems, involving land cover changes and playing an important role in the emission of greenhouse gases and biological diversity. The Mediterranean region is typically affected by wildfires every year, peaking in number and intensity during summer. Indeed, 2017 was characterized by a harsh fire season, making it the second worst season of the decade and among the worst affected counters of those covered by European Forest Fire Information System (JRC, 2018). Recent research of JRC Technical Reports shows that, due to climate change increasing air temperature and decreasing humidity, the area affected by forest fires in Europe could double in the near future (JRC, 2013). These new challenges need to be taken into account by authorities and call for new measures for dealing with wildfires.

Accurate and rapid mapping of burned areas is fundamental to support fire management and damage assessment, and for planning and monitoring the restoration of vegetation. Moreover, due to the high spatial and temporal variation, mapping of fire dynamics using ground measurements alone is challenging. Remote sensing data allows active fire detection, accurate mapping of burned areas, estimation of fire severity, characterization of fire drivers, and monitoring regeneration at global, regional and local scales ([Gomez et al., 2019](#)). Satellite images with low spatial and high temporal resolution such as MEdium Resolution Imaging Spectrometer (MERIS), Moderate Resolution Imaging Spectroradiometer (MODIS) and Advanced Very High Resolution Radiometer (AVHRR) enable near real-time active fire detection and monitoring at a global scale (Alonso-Canas and Chuvieco, 2015). However in case of small and fragmented fires, such as in the Mediterranean region, low spatial resolution images may significantly underestimate burned area and therefore medium or high resolution satellite images such as Landsat (Wozniak and Aleksandrowicz, 2016; Quintano et al., 2018), Sentinel 2 (Filipponi, 2018; Pepe and Parente, 2018), WorldView-2 etc. need to be used. Different methods of satellite-based burned area detection have been developed, including threshold based methods using multi-spectral bands or spectral indices such as Normalized Difference Vegetation Index (NDVI), the Soil-adjusted Vegetation Index (SAVI), and the Normalized Burned Ratio (NBR), supervised classification, logistic regression etc. (Quintano et al., 2018; Katagis et al., 2014; Bastarrika et al., 2014; Verhegghen et al., 2016; Jakovljevic et al., 2018). Since the consumption of healthy vegetation caused by fire leads to a reduction of chlorophyll absorption and therefore a decreased

reflectance in the near-infrared (NIR) region and the decrease in canopy moisture leads to an increase in mid-infrared reflectance (SWIR) (van Wagtendonk et al., 2004), the Normalized Burned Ratio (NBR) (which uses a ratio between NIR and SWIR regions) is widely used for mapping burned area (Ressl et al., 2009; Weber et al., 2008; Filippini, 2019). In addition, the delta Normalized Burned Ratio (dNBR) calculate using multi-temporal difference in NBR between pre-fire and post-fire images provide assessment of changes in reflectance of healthy vegetation, soils, and soil moisture due to fire (Key and Benson, 2006) minimizing the misclassification between burned and areas with low NBR. Whereas dNBR theoretically ranges from -2.00 to 2.00, dNBR values between 0.10 and 1.35 represent burned areas while pixel values from unburned areas are generally within a range of - 0.10 to 0.10, and vegetative regrowth is represented by values between 0.50 and 0.10 (Key and Benson, 2006). Nevertheless, those values are approximate and threshold values for burned area mapping are specific to geographic areas. (Kontoes et al., 2009; Alvarez-Taboada et al., 2007). Although dNBR represents fire occurrence within a certain time frame defined by two images and it can provide highly accurate burned area maps, scene selection is usually challenging. Ideally, scene pairs should represent similar phenology and moisture and have limited between-scene seasonal variation and changes in greenness as well as similar reflectance brightness, so that the differences in NBR are due to the fire scar (Song and Woodcock, 2003). Additionally, they should be cloud-free and contain limited haze, since cloud cover can drastically reduce the observation frequency in the visible/infrared domain and significantly change spectral reflectance, which, combined with low fire severity and fast vegetation re-growth after the fire, might result in a low spectral separability between burned and unburned surfaces (Stroppiana et al., 2015). Moreover, the spectral confusion of burned areas with multi-aged burned areas (frequent in the Mediterranean region) and low albedo surfaces, such as dark soils, water surfaces, built up and shaded regions can reduce the fire mapping capability.

This work presents the integration of automated algorithm and cloud platform for near real-time detection of burned area using Sentinel-2 satellite images. The developed methodology was validated over a selected study area against high spatial resolution WorldView-2 data and field data.

2. STUDY AREA

The study case chosen to test this method was the largest wildfire in Spain in 2017, known as the Losadilla Fire. It started on Aug. 21st 2017 and it was extinguished on Sept. 3rd 2017, after burning 9800 ha of shrubs (mainly heather), oak trees, pine trees and pastures (Incendios forestales 2019).

This wildfire took place in the region of La Cabrera (León, NW Spain) (Figure 1), which has a large wildfire recurrence, most of them (>90%) arsons or negligence related with the use of fire (Incendios forestales 2019). The Sierra de la Cabrera range dominates the landscape of this

mountainous area, dominated by shrubs, wooded land and pastures. Extensive livestock farming and slate quarries are the main activities. The climate is a transitional one between the Atlantic and the continent, with crisp winters and mild and dry summers. August is the warmest month with average temperature of 19.1 degrees, and an average rainfall of 24 mm. The average annual rainfall is 721 mm. In this paper

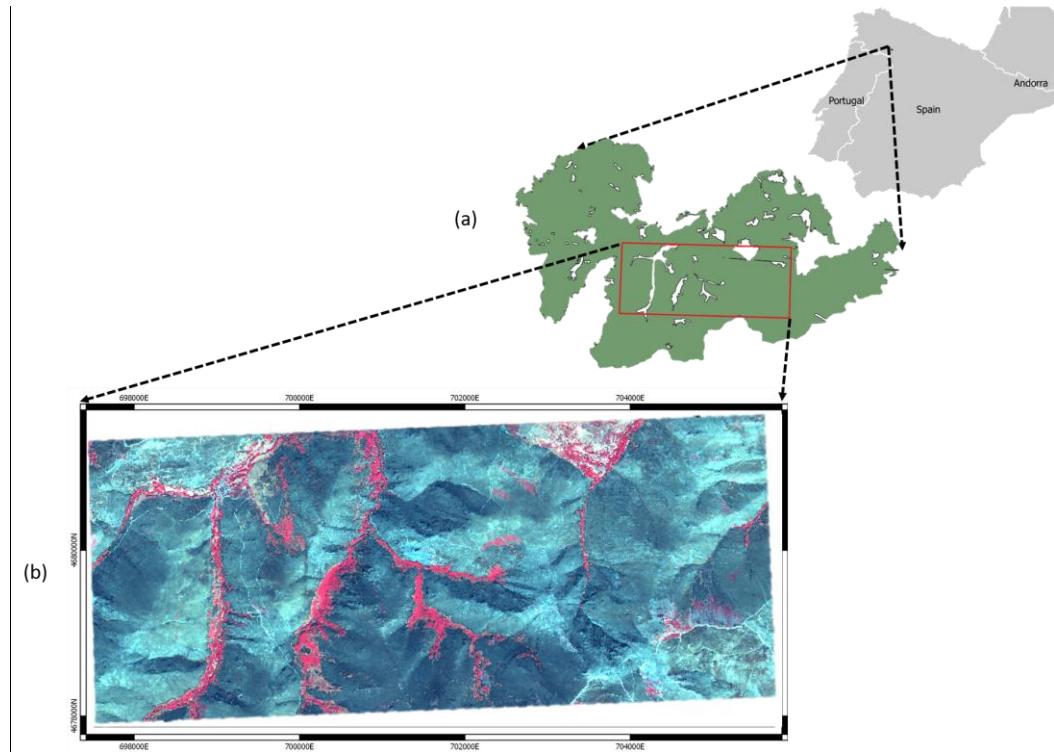


Figure 1. (a) the perimeter of the Losadilla forest fire, (b) study area in La Cabrera region, León, NW W Spain (WorldView 2 image – band combination NIR1-R-G)

3. DATA

WorldView-2 and Sentinel-2 satellite images were used in this study. WorldView-2, launched October 2009, was the first high-resolution 8-band multispectral commercial satellite. Operating at an altitude of 770 kilometers, WorldView-2 provides 46 cm panchromatic resolution and 1.86 meter multispectral resolution (Table 1). Its has an average revisit time of 1.1 days and is capable of collecting up to 1 million square kilometers of 8-band imagery per day (Verhegghen et al., 2016). The high spatial and spectral resolution provides improved ability to support large scale vegetation changes monitoring. Also, WorldView-2 imagery can be used to test out the effectiveness of free available satellite images.

Near Real-Time Burned Area Mapping Using Sentinel-2 Data (10759)
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Sentinel-2 is the latest generation Earth observation mission of the ESA (European Space Agency), and it includes the identical Sentinel-2 A and Sentinel-2 B polar-orbiting satellites which were launched in June 2015 and March 2017, respectively, placed in the same orbit. Their wide swath width and high revised time (5 days with two satellites) are meant to monitor the variability in land surface conditions (ESA, 2019).

Table 1 shows the spectral (W) and spatial resolution (R) for Worldview-2 and for Sentinel-2 (MSI sensor) imagery. The bands used in the study are depicted as *..

Table 1. Spectral (W) and spatial resolution (R) for Worldview-2 and for Sentinel-2 imagery.

*** bands used in this study**

Bands	WorldView-2		Sentinel-2	
	W [μm]	R [m]	W [μm]	R [m]
Coastal Blue	0.39-0.46	1.86		
Blue	0.44-0.52*	1.86	0.46-0.52	10
Green	0.51-0.59*	1.86	0.55-0.58	10
Yellow	0.58-0.63	1.86		
Red	0.62-0.69*	1.86	0.64-0.67	10
Red Edge	0.70-0.75	1.86		
Near Infrared 1	0.76-0.90*	1.86	0.78-0.90 *	10
Near Infrared 2	0.86-1.04	1.86		
Pan	0.45-0.80	0.46		
SWIR 1			1.57-1.65*	20
SWIR 2			2.10-2.28	20

Two Sentinel-2 Level 1 and two WorldView-2 images were used in this study. One image was acquired after the fire events while second is acquired before fire (Table 2).

Table 2. Date used in the study

Data	Imagery	
	WorldView-2	Sentinel-2
Pre-fire	11.06.2017	04.07.2017
Post-fire	05.09.2017	07.09.2017

4. METHODOLOGY

The methodology comprised of three main steps: input data preprocessing, detection of the burned area, and accuracy assessment of the burned area maps obtained from WorldView-2 and Sentinel-2 imagery (Figure 2).

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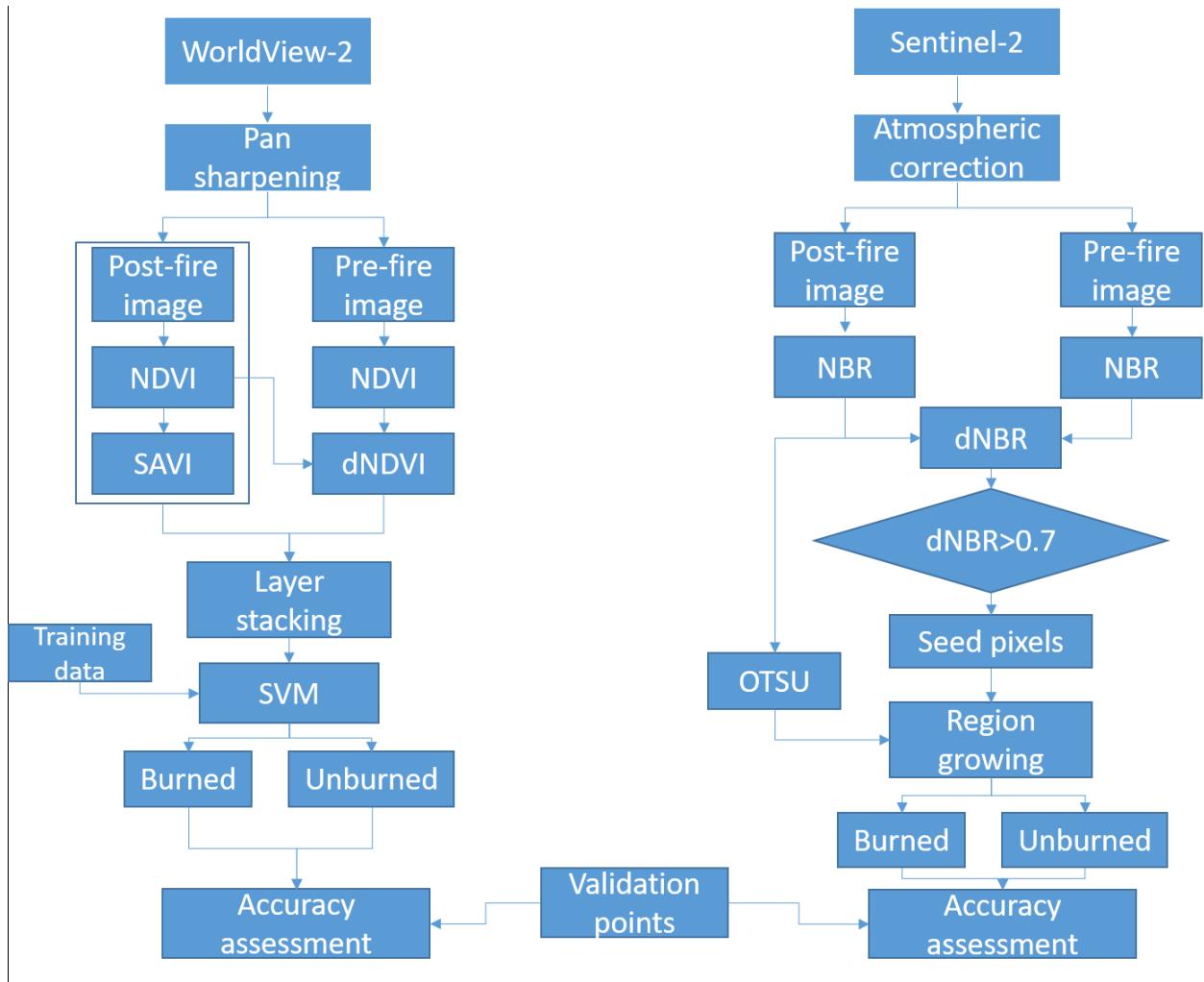


Figure 2. Workflow

WorldView-2 image was pan sharpened to a pixel size of 0.46 m by using the HCS resolution merge algorithm implemented in Erdas 16.5 software. In addition to the spectral bands, NDVI (1), dNDVI (2) and SAVI (3) indices were computed according to the following equations. NBR or dNBR could not be computed, since WordView-2 imagery does not include SWIR data.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (1)$$

$$dNDVI = NDVI_{pre} - NDVI_{post} \quad (2)$$

$$SAVI = \frac{NIR - RED}{NIR + RED + 0.5} (1 + 0.5) \quad (3)$$

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A SVM non-parametric supervised learning technique which tries to find optimal hyper plane to define the boundary between burned and unburned class during the training phase was used. training data were located following a stratified random sampling design, and assigned to classes according to the visual inspection of WorldView-2 images.

Two cloud free Sentinel-2 Level 1 images were accessed through Google Earth Engine (GEE) API. In order to minimize the effect of the atmosphere (including atmospheric absorption and scattering, sensor and solar geometry), an atmospheric correction was made in GEE using Py6S. Py6S is an interface to run the Second Simulation of the Satellite Signal in the Solar Spectrum (6S) atmospheric Radiative Transfer Model through the Python programming language (Wilson, 2013). For implementation of Python scripts in GEE the GEE Python API was used. After the atmospheric correction of the images, the NBR images for the pre and post fire event and dNBR were calculated according to equations (4) and (5):

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \quad (4)$$

$$dNBR = NBR_{pre} - NBR_{post} \quad (5)$$

The burned areas are classified by using a region growing algorithm. The region growing technique is an iterative process by which regions are merged starting from seeds, and growing iteratively until every pixel is processed. Seeds represent the generation of representative and homogenous regions that are used as inputs for the region growing algorithm. In this study, seeds represented high fire severity pixels ($dNBR > 0.7$), which are therefore burned areas. A 3x3 squared Kernel was used to define the potential neighboring pixel candidates for region growing. The potential candidates which had a dNBR value higher than the threshold were added to their neighbor seed. To avoid subjectivity in the choice of the threshold and to maximize the level of automation, we utilized a histogram thresholding approach using the Otsu algorithm [18]. Otsu algorithm determines a threshold under the assumption that the digital image contains a bimodal histogram, one corresponding to the burned class and another corresponding to the other classes. Its maximizes variance between the burned class and background noise, minimizing the probability of misclassification.

The overall accuracy, commission and omission errors were calculated for the accuracy assessment of the burned area maps obtained. A random stratified sampling design was followed in order to choose the validation points: 286 for the burned class and 204 for the unburned one. The validation points were assigned to each class based on official perimeter and visual interpretation of the WorldView-2 satellite image.

5. RESULTS

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The visual comparison of the automated algorithm (Figure 3) shows that burned areas extracted from Sentinel-2 image using followed a similar pattern as the burned area detected by WorldView-2 image.

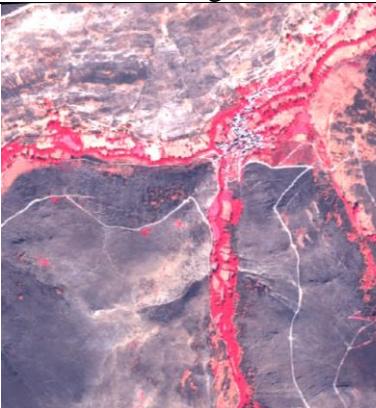
Site	WorldView image	Burned area (WorldView-2)	Burned area (Sentinel-2)
A			
B			
C			

Figure 3. Visual comparison of false color WorldView-2 (NIR1, R, G) post-fire image, burned area map using WorldView-2 and SVM, and burned area map using Sentinel-2 and an algorithm for automatic classification algorithm.

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The results of accuracy assessment were presented in Table 3. As a measure of agreement or accuracy, KHAT is considered to show strong agreement when it is greater than 0.75, while values lower than 0.40 indicate poor agreement [16]. Therefore the Worldview-2 classification showed strong while the classification using the Sentinel-2 image provided moderate agreement with reality.

Table 3. Results of accuracy assessment

	KHAT	Overall Agreement (%)	Commission error (%)		Omission error (%)	
			Unburned	Burned	Unburned	Burned
WV-2	0.91	95.93	1.95	6.06	6.66	2.20
Sentinel-2	0.66	88.52	5.06	18.05	28.09	3.25

The accuracy assessment shows significant commission error for burned class i.e. omission error for unburned class. Therefore both algorithms tend to overestimate burned area. Through visual inspection it is noticed that low albedo surfaces such as roads and buildings are misclassified as burned area by SVM. The same problem is noticed for Sentinel-2 images where misclassification of buildings was produced large omission error for unburned class. In addition to buildings, due to significant lower resolution (0.46 m vs 20 m), smaller unburned areas as well as roads are not visible in the burned area map from Sentinel-2. Nevertheless the methodology provided here reaches more accurate results than Philipponi (2019), which mapped burned areas at national level using Sentinel-2 time series, obtaining omission and commission errors of around 40% and 25%, respectively, which are significantly higher than the ones presented here (3.25% and 18.5%).

6. CONCLUSION

In this study, the algorithm for automatic detection of burned area based on Sentinel-2 satellite images was presented. The algorithm used the difference of pre-fire and post-fire NBR, region growing algorithm and OTSU thresholding method. In addition, this paper provides a comparison of WorldView-2 and Sentinel-2 burned area maps. All algorithms were implemented at Google Earth Engine API. We found that the KHAT coefficient show a perfect agreement for the WorldView-2 burned area map (0.91) and moderate agreement with reality for the Sentinel-2 classification (0.66). The commission error (6.06% vs. 18.05%) showed that both data sources tend to overestimate the burned area. The visual inspection of the results showed that low albedo surfaces such as asphalt roads and buildings were misclassified as burned area. In addition, due to lower spatial resolution, small unburned areas, roads etc. are not detected at Sentinel-2 producing a significant error.

This study shows that Sentinel-2 data with a temporal resolution of 5 days and free access, Google Earth Engine API and the developed algorithm are very attractive and suitable for providing near real-time burned area maps. In the future, the validation of the developed algorithm against WorldView-3 data would provide a deeper insight in the algorithm capabilities.

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