Wildfires Assessed by Remote Sense Images and Burned Land Monitoring

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Abstract—The tools described in this paper enable the location of burned areas where took place the annihilation of natural habitats and establishes a baseline for major changes in forest ecosystems during recovery. Moreover, the result allows the follow up of the surface fuel loading, allowing the evaluation and guidance of restoration measures to remote areas by phased time planning. This case study implements the evaluation of burned areas that suffered successive wildfires in Portugal mainland during the summer of 2017, killing more than 60 people. The goal is to show that this evaluation can be done with remote sense data free of charges in a simple laptop, with open-source software, describing the not-so-simple methodology step by step, to make it accessible for local workers in the areas attained, where the availability of information is essential for the immediate planning of mitigation measures, such as restoring road access, allocate funds for the recovery of human dwellings and assess further needs for restoration of the ecological system. Wildfires also devastate forest ecosystems having a direct impact on vegetation cover and killing or driving away the animal population, besides loss of all crops in rural areas that are essential as local resources. The economic interests are also attained, as the pinewood burned becomes useless for the noblest applications, so its value decreases, and resin extraction ends for several years.

Keywords—Image processing, remote sensing, wildfires, burned areas, SENTINEL-2.

I. Introduction

WILDFIRES and its impact in the destruction of forest habitats can be evaluated with a complex chain of processing that includes ESA satellite SENTINEL-2 Multi Spectral Images free of charges, open-source software and a geographic information system. Remote sensing multispectral images are used in well proved bands conjugations [1], [2] with some morphologic tools from image processing and can benefit from the knowledge of ecologists to establish which are the physiographic factors that will drive the vegetation recovery [3], to test any hypothesis. Additionally, remote sensing multispectral images can also be a key to plan sustainable forest restoration management [4], [5].

This case study describes the necessary methodology step by step, until it reaches the production of maps that can be crossed with any georeferenced layer available for the same area, such as administrative limits, the road network, local altitude identified in a digital elevation model or the proximity of water from thematic maps with hydrographic data (reservoirs, lakes, dams), as well as other relevant environmental and physiographic factors [6] cartographed and/or identifiable in remote sensed images.

The natural vegetation recovers rather fast, which can be monitored with successive satellite images, allowing the surveillance of surface fuel loading to prevent successive wildfires whenever a situation of new risk is assessed. This paper intends to provide the tools to elaborate a baseline to monitor the recovery of large severely burned areas that support effective ecological restoration projects, as well as the know-how to implement all the necessary steps to support the necessary administrative procedures with georeferenced data in a current laptop.

II. Materials

The remote sensed images used were acquired by ESA's Copernicus Sentinel-2 mission [7], a constellation of two polar-orbiting satellites phased at 180° to each other in the same sun-synchronous orbit operating between latitudes 56° south and 84° north [8] at a mean altitude of 786 km [9].

The constellation allows a revisiting time of 2 to 5 days [10], depending on latitude. Both satellites carry an optical instrument – the Multi Spectral Instrument (MSI) that samples 13 spectral bands at different ground resolutions: four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution [11].

The orbital swath width is 290 km and each image that can be downloaded in a short delay after acquisition is a tile or granule of 100x100 km², an ortho-image in UTM/WGS84 projection. The granules have a small area of juxtaposition that is directly handled in the software.

With level 2A of processing, the product delivered is the corrected bottom-of-atmosphere reflectance, with atmospheric correction already performed since April 2017.

The open-source software platform SentiNel Application Program (SNAP) provided by European Space Agency (ESA) to support Sentinel products was used to manipulate all data used in this study [12]. The version used in this work was SNAP 6.0.0.

The area of interest is a mountainous region in the center of Portugal mainland, around the locality of Pedrógão Grande at latitude 39.917835N and longitude -8.14581W. The granules used to cover this area are the references TME, TNE and TPE, codes of the tiles referring to the Military Grid Reference System (MGRS) and its naming convention derived from the UTM (Universal Transverse Mercator) system, where the first letter correspond to the UTM zone and the two last letters to each unique granule identity [18], covering the central part of

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Portugal (Fig. 1) around Pedrógão Grande, a mountainous area with limited access to some more remote villages, where we had in summer 2017 the largest wildfire ever documented here [13], with 66 people killed, 253 injured, 261 households destroyed, and 50 industrial facilities severely attained.
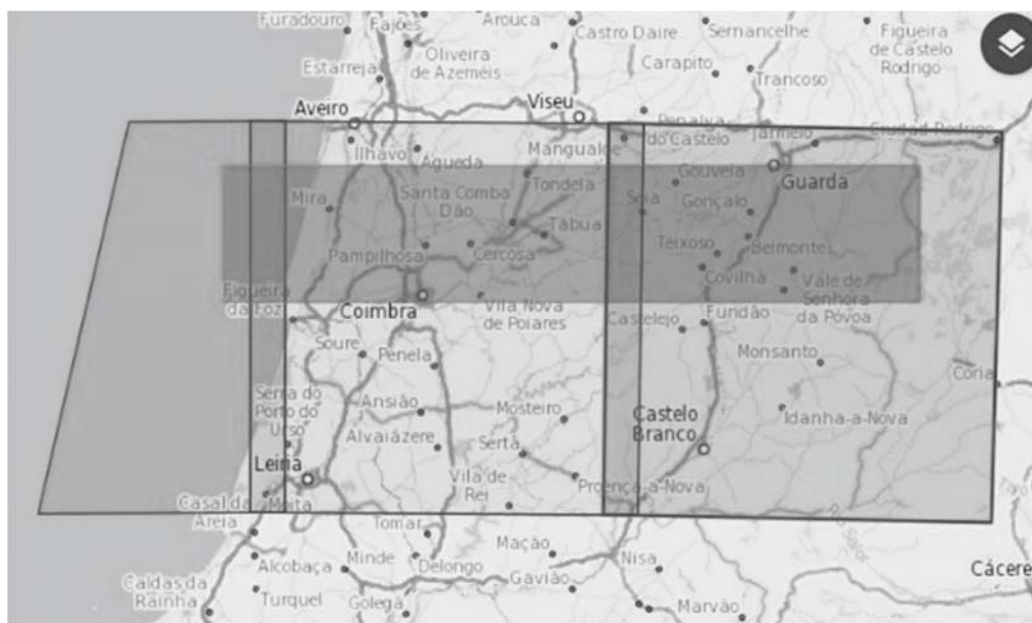

Fig. 1 The three granules used, reference TME, TNE and TPE

After an attentive choice of the dates for before and after fire images, and considering only cloud free images, the three granules were multi-mosaicking in SNAP.

The indices we are planning to use are Normalized Difference Vegetation Index (NDVI) [14] and the Normalized Burn Ratio (NBR), used in the relativized version of burn severity (RBR) [15], which considers the areas with low vegetal cover pre-fire (rocks, bare soil) to avoid a wrong classification.

For NBR index, the definition of [17][17] uses the short-wave infrared (SWIR), corresponding to band 12 in Sentinel-2, along the near infrared band computed using (1):

$$NBR = \frac{band_{NIR} - band_{SWIR}}{band_{NIR} + band_{SWIR}} \qquad (1)$$

The relativized burn severity will be the difference in NBR in the images before and after fire, with an additional factor in denominator to avoid bare soil errors as in (2):

$$RBR = \frac{NBR_{pre-fire} - NBR_{post-fire}}{NBR_{pre-fire} + 1.001} \qquad (2)$$

The NDVI is computed as the difference between the near infrared and the red bands, divided by its sum as in (3):

$$NDVI = \frac{band_{NIR} - band_{red}}{band_{NIR} + band_{red}} \qquad (3)$$

In Sentinel-2 the band correspondence is band 8 for near infrared and band 4 for red [16].

The water mask whenever is needed, is computed with green (band 3) and near infrared band using (4):

$$WaterMask = \frac{band_{green} - band_{NIR}}{band_{green} + band_{NIR}} \qquad (4)$$

So, the subset of bands needed is B3, B4, B8, B12. After the extraction of the dataset and execution of the mosaic, each mosaic is resampled to one of the bands chosen as reference (B3 in our case) with bilinear interpolation and saved in the native format of SNAP, BEAM-DIMAP. The necessary commands can be found in the sequence Raster - Geometric operations - Resampling.

The tile at far left in the case of Portugal cover a large portion of ocean, so our option was to crop the first 12.000 columns using the Raster - Subset command. The images for each date pretended, pre and post fire, can now be collocated, to have an exact register of the datasets of different dates, with the command Collocation; the same master image will be used for all the dates.

The water mask is implemented as a condition (5), resulting in a binary image with the value 1 only in the water area, 0 elsewhere.

$$if \left(\frac{B3 - B8}{B3 + B8} \right) \geq 0, then\ 1; else\ 0 \qquad (5)$$

All the datasets were prepared with the same procedure, applying the formulas above to the bands in each date with the command Band maths in the Raster menu, and using the water mask whenever relevant.

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III. RESULTS

A. NDVI

First results with NDVI for the initial fire at Pedrógão Grande at 2017 that starts in June 17 can be observed with the pre-fire image captured June, and July 4 for the post-fire image (Fig. 2).
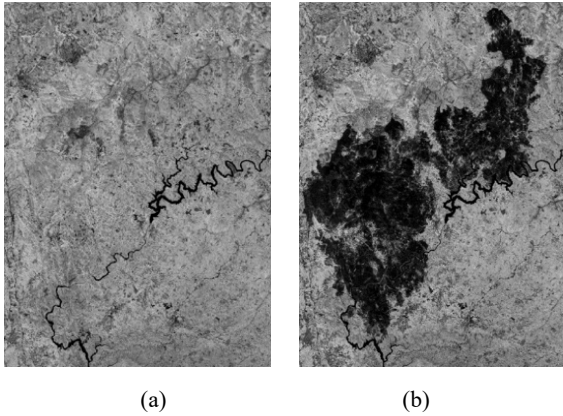

(a)   (b)

Fig. 2 Close-up of a burned area using NDVI index and images from two dates (a) pre-fire June 14 and (b) post-fire July 4, 2017

Comparing the histograms of both NDVI images, the histogram of the second image (Fig. 3 (b)) shows a clear deviation to the left, reflecting all the pixels accounting for burning areas now with low NDVI intensity that were previously forested.

In late summer, several fires took place around the same region, with smaller dimensions. We can observe in the sequence of mosaics of three granules prepared as described in the previous section the difference in NDVI intensity, as the initial larger area begins to recover its vegetation (Fig. 4).

The evolution in the NDVI signal of the initial area that was prone to fire in June, in the center of the image, can be observed in Figs. 4 (b) and (c); with a very low intensity in July image (Fig. 4 (b)), it becomes much less dark in October (Fig. 4 (c)), regaining intensity as the first small vegetation begins contributing to the NDVI.

The contrast with the new burned areas is striking in Fig. 4 (d) where the terrain burned just to the limits of the area where the initial fire took place.
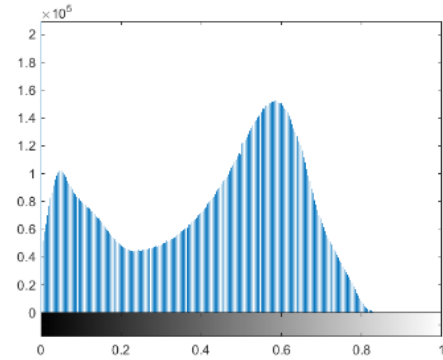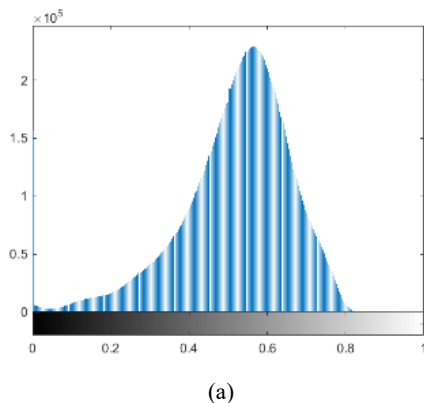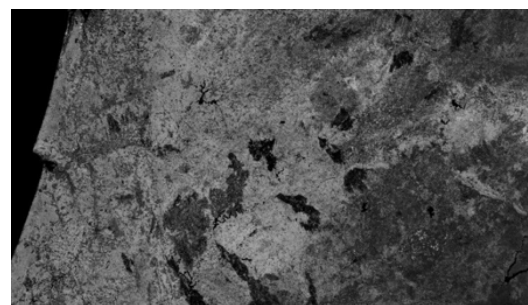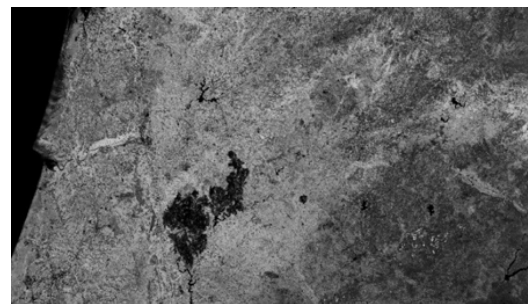

(b)

Fig. 3 Histogram of the NDVI image before the fire (a), and after the fire (b)

(a)

(b)

(c)

(a)

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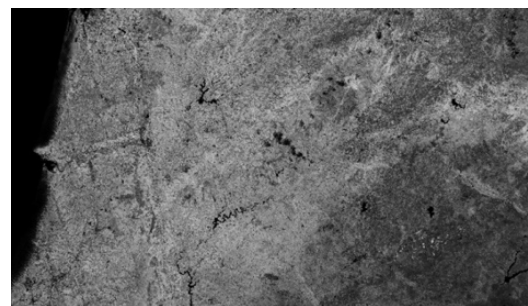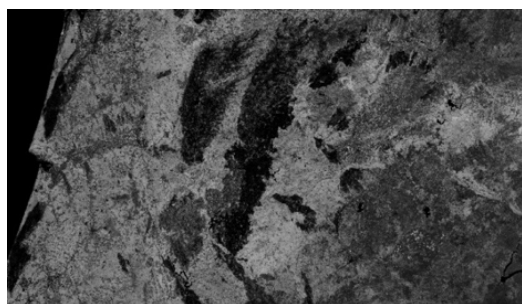
(d)

Fig. 4 Evolution of NDVI through summer 2017: (a) June 14 (b) July 4. After some smaller fires in August and September that can be seen in (c) October 12, several big fires occur late October (d) image of October 27. The pine areas near the coast were planted by royal decree around 1250; more than 85% of the 11.000 ha were consumed by the fire

B. RBR

The relativized burn ratio was used to have a sequence from month-to-month, computing the normalized burn ratio with images around 1 month apart whenever possible – the regularity of cloudless images in summer allowed for the sequence June 4, July 4, August 3, September 2, October 2, and November 11.

The final RBR image for each month, using each pair of NBR dates considered pre- and post-fire for that interval, was segmented using the threshold 0.27 as a condition, with (6):

$$if\ RBR > 0.27\ then\ RBR; else\ NaN \qquad (6)$$

Each mosaic with just 3 bands (B3, B8 and B12) took around 4h30 to build in a workstation with two Intel 5160@3.00 GHz and 8 GB RAM, and the resampling took around 50 minutes. The computation of each NBR is almost instantaneously, as well as the water mask, both done with the function Band maths in SNAP (version 6.0.0). The collocation of each pair of mosaics to compare two dates, although with the simplest resampling method (nearest neighbor), took between 2 and 3 hours. The RBR was computed only where the water mask had the value 0, and the processing time was less than 1 minute for each mosaic. The final image was exported in GeoTIFF format (more than 2 hours) to use as input in a geographic information system (GIS). Saving all the bands produced during the procedure to disk took around 6 hours.

The final images of RBR were imported to a GIS (ArcGIS by ESRI), to consolidate the areas burned through spatial analysis tools. In the GIS environment, the GeoTIFF data can be used with other layers of data such as administrative limits, to evaluate precisely the area burned in each county, or making a more exact evaluation of damages in remote areas or visualize the road network superposed to the burned areas and the digital elevation model to assess new and possible alternatives for access. As an example, the area burned shown in Fig. 2 (b) becomes the binary mask shown in Fig. 5.
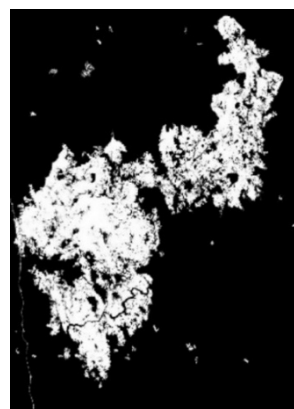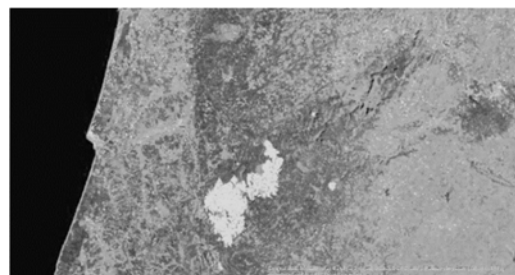

Fig. 5 Binary mask corresponding to the burned area identified in Fig. 2 (b)

The sequence of fires could be isolated by month, as shown in Fig. 6. The image used as background to project the fires is from ESRI Digital Globe, from the satellite GeoEye, available through GIS Servers to ArcGIS desktop users.
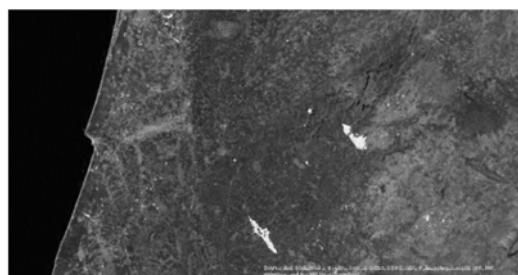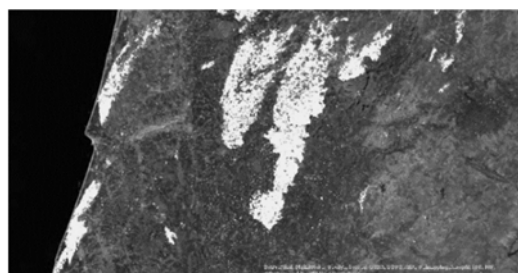

(a)

(b)

(c)

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(d)

(e)

Fig. 6 Fires during the summer 2017 - areas burned in each month, computed from RBR data: (a) June, (b) July, (c) August, (d) September, (e) October

The images from Sentinel-2 are available in a short delay after acquisition, so it is possible to monitor the evolution of a situation like this one in near-real time.

IV. CONCLUSIONS

We describe a procedure to evaluate and monitor burned areas to establish a baseline for major changes in the recovery of forest ecosystems, human land use and damages assessment. Besides the changes in land cover that drives this mapping, mitigation planning by stakeholders and economic interest's developments can both use this information to target efforts in the recovery process, as well as insurance companies that need precise and georeferenced information on damages. Moreover, the resulting maps allows the follow up of the surface fuel loading in remote areas, enabling the targeting and evaluation of restoration measures in a time basis planning.

Future work could be used to establish a link between burn severity and surface re-loading, as we know that the vegetation recovery is led by small and more resilient vegetation in areas that suffered severe burning.

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