Identification of Burned Areas and Severity Using SAR Sentinel-1

Rosa Lasaponara and Biagio Tucci

***Abstract*— In this letter, we performed investigations on the potentiality of the Sentinel-1, C-band synthetic-aperture radar (SAR), for the characterization and mapping of burned areas and fire severity. To this aim, we focused on fire occurred on July 13, 2017, in Metaponto (South of Italy). Both VH and VV polarizations were considered. Radar Burn Difference (RBD) and radar burn ratio (RBR) were computed between Sentinel-1 data acquired before and after the fire using both single- and time-averaged scenes (to reduce speckle noise effects). The most marked differences between burned and unburned areas were observed in the VH polarization of both RBD and RBR. The novelty of our approach is based on the use of three steps data processing devised to identify different levels of fire severity without using fixed thresholds. The burned areas are first: 1) highlighted using the ratio between multitemporal data set acquired before and after the fire occurrence; 2) further enhanced by Getis–Ord spatial statistic; and 3) finally, categorized using ISODATA unsupervised classification. The approach herein proposed pointed out that: 1) the time-averaged ratio of VH polarization of Sentinel-1 well perform in mapping burned area and 2) the use of Getis–Ord spatial statistic coupled with ISODATA unsupervised classification suitably captures the diverse levels of burned severity as confirmed by *in situ* assessment.**

***Index Terms*— Burn severity, burned areas, fire, remote sensing, Sentinel-1, synthetic-aperture radar (SAR).**

I. Introduction

WILDFIRES yearly affect more than 50 million hectares all around the world, strongly impact soil–surface–atmosphere system, and cause enormous ecological and economic damages at different temporal and spatial cases. Fire destroys flora, fauna, and ecosystems rapidly, whereas the recovery processes are very long and sometimes impossible. Recently, wildfires have been particularly destructive in many countries, as in Canada (British Columbia) where over 6000 people were evacuated due to long and vast fires, in California, thousands of hectares of vegetation including vineyard have been totally destroyed, in Portugal, more than 55 people lost their lives in the fires occurred in June 2017 and more than 33 people died in the fires of October 2017. During the 2017 summer, in France, flames were closer than 15 km to the Nice city; in Croatia, fires also damaged the historic city of Split, and in Spain, fires affected the Donana National Park (nature reserves UNESCO World Heritage Site). In south of Italy, the 2017 summer has been one of the worse "fire seasons" of the last decades in terms of a number of fires and extension of burned areas. Additional fire-induced damages are expected in the next future, mainly during the "rainy season," due to the impact of rain on erosion process in the fire affected areas. After the fire, the ability to promptly map burned areas is of primary importance for an adequate management of damaged areas and for limiting additional postfire damage and danger. Prevention activities coupled with the use of reliable monitoring systems are the relevant strategies to limit fire and postfire damage. Accurate, detailed, and timely information on the impact of fire on vegetation is a critical issue for defining the most suitable strategies and actions addressed to mitigate fire effect in the immediate postfire management. These investigations are generally performed at stand level, but remote sensing can provide useful data to cope with these needs and gain information at different temporal and spatial scales see [1], [2]. In particular, Sentinel-1 and Sentinel-2 (for additional details see ESA website [3]) satellites offer for free reliable and timely radar and high-resolution optical imagery very useful for fire monitoring and damage assessment. Over the years, the majority of space-based studies on fire and fire impact on vegetation used optical data, even if several investigations also used satellite synthetic-aperture radar (SAR) in boreal and Mediterranean ecosystems (see [4]–[26]). The aim of this letter is to perform investigations on SAR Sentinel-1 sensors for mapping burned area and characterize the fire severity. The potential of using SAR for the mapping of burned areas mainly lies in the sensitivity of SAR backscatter to vegetation moisture content. Nevertheless, up until now, under different conditions, SAR backscatter was found to exhibit either an increase or decrease associated with burned conditions depending on the region under investigation, the incidence angle of the sensor and the surface conditions. Tanase *et al.* [21] analyzed SAR data at X-, C-, and L-bands to investigate the relationship between backscatter and forest focusing on both HH and VV polarizations as well as on cross polarized (HV). Results obtained in Spain highlighted that for X- and C-bands, the copolarized (HH and VV) backscatter increased with burn severity, in detail: 1) for all frequencies, the cross polarized (HV) decreased with burn severity; 2) C- and L-bands cross-polarized backscatter showed better potential for burn severity; and 3) the small dynamic range observed for X-band data could prevent its use in vegetation affected by fires.

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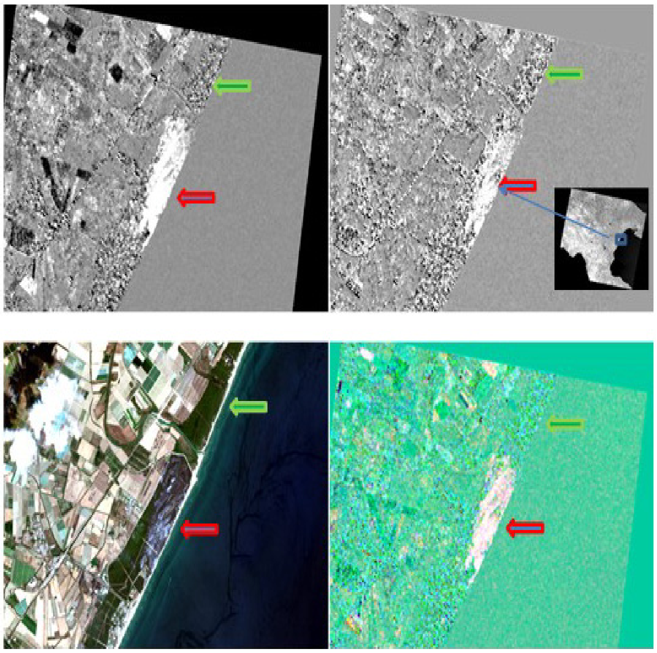

Fig. 1. (Top left) RBD computed on the averaged scenes. (Top right) Single scene. (Bottom right) RGB of Sentinel-2 acquired after the fire occurrence. (Bottom left) RGB composite of RBR_{VH} and RBD_{VV} and RBR_{VH}.

The novelty of our approach is based on the fact that we investigated and compared the diverse "fire indicators" available in the current literature (see [21]) and developed a methodology for the automatic extraction of burned areas and fire severity. The burned areas are first 1) highlighted using the ratio between multitemporal data set acquired before and after the fire occurrence; 2) further enhanced by Getis–Ord spatial statistic; and 3) finally, categorized using ISODATA unsupervised classification.

II. Study Area and Data Set

The study test is Metaponto, located on the Ionian coast (Southern of Italy, see Fig. 1), selected for the fire occurred on July 13, which affected a pine-dominated recreational camping area from which more than 600 tourists were evacuated. The area is quite homogeneous in terms of habitat type, topography (flat area), ecological set, and vegetation cover made by *Pinus halepensis*. For the purpose of our study, Sentinel-1 A and B data, acquired before and after the fire (see Table I), were investigated. No precipitation occurred during the whole investigated period and actually from 2017 spring and summer season.

III. Method

For the purpose of our analysis, we adopted the following methodological approach, whose various processing stages, used to generate the fire burned and severity maps, are briefly summarized as follows.

TABLE I

Dates of Satellite Acquired Before and After the Fire in a Descending Pass, by Sensors S1A and S1B, in the VV, VH Polarization With an Incidence Angle of 30.6° − 46.3° and Resolution at 20 × 22 m (in Range × Azimuth). The Type of Products Used Is GRDH. The Data Were Acquired Around 05 am (Descending)

Pre Fire date multi_image	Post-fire date multi_image
S1_A 2017/06/07	S1_B 2017/07/19
S1_B 2017/06/13	S1_B 2017/07/31
S1_A 2017/06/19	S1_A 2017/08/06
S1_B….2017/06/25	S1_B 2017/08/12
S1_B 2017/07/07	S1_B 2017/08/24
S1_A 2017/07/13	S1_A 2017/08/30
Pre-Fire date single_image	Post-Fire date single_image
S1_B 2017/07/07	S1_B 2017/07/19

1) Acquisition of the multitemporal images and identification of a section of interest.
2) *Preprocessing:* Orbit correction, calibration, coregistration, and filtering to reduce speckle.
3) *Processing:* Change detection for the identification of burned areas and fire severity—categorization of fire severity, field survey for validation.

The preprocessing is made up of diverse steps: 1) the orbital correction of the datum is performed exploiting the knowledge of the orbital position of the sensor; 2) the calibration is done to extract physical information from the SAR backscattering. This process is essential for analyzing the images in a quantitative way and it is mandatory for comparing images from different sensors, modalities, processors or acquired at different times, as in the current analysis; 3) the coregistration (to ensure that two or more images are overlapping) is performed selecting an image as reference and then coregistering all the subsequent images with respect to it; and 4) the filtering speckle to reduce the salt and pepper effects is done using the well-known Lee filter, implemented in the most common software (both open and commercial ones). The data processing for the identification and mapping of burned areas and burned severity is based on 1) the time-averaged ratio of VH polarization of Sentinel-1 further processed using; 2) statistical analysis based on Getis statistics; and 3) unsupervised (ISODATA) classification to automatically classify and map burned areas and burned severity without using fixed thresholds. One of the most important expected advantages of our approach compared to the traditional ones is that both burned areas and different levels of burn severity can be identified automatically and without using fixed threshold values. This is a particular critical issues, because as suggested by many authors (see [2] and references therein quoted), such fixed threshold values are generally not suitable for fragmented landscapes and inadequate for vegetation types and geographic regions different from those for which they were devised. The novelty of our approach is to jointly analyze the change in SAR data using Getis statistics and unsupervised classification sequentially applied to SAR-based change detection parameters: 1) the radar burn ratio (RBR) is defined as the ratio of the backscattering coefficients between prefire to postfire computed for a specific polarization (or radar-based index) in power units (1) and 2) the Radar Burn Difference (RBD) defined (2) as the difference between prefire to postcomputed for a specific polarization (or radar-based index) in power units

$$\begin{aligned} \text{RBR}_{\text{xy}} &= \text{Postfire average backscatter}_{\text{xy}} \\ &\quad /\text{Prefire average backscatter}_{\text{xy}} \qquad (1) \\ \text{RBD}_{\text{xy}} &= \text{Postfire average backscatter}_{\text{xy}} \\ &\quad - \text{Prefire average backscatter}_{\text{xy}}. \qquad (2) \end{aligned}$$

RBR and RBD were calculated for each polarization (HH and HV) and using both 1) one prefire and one postfire images (acquired under dry conditions) and 2) backscatter time averaged of prefire and postfire scenes. Statistics, based on Getis and Ord (see [2]), was applied both to the RBD and RBR maps, following the approach already adopted by the same author group for optical data [2]. The family of G statistics was developed by Getis and Ord to study spatial analysis patterns. The general G statistic is global or local. The global statistics are usually too general producing one single value for the whole data set (image in our case). In image analysis, the local G statistic is recommended to have a new image (i.e., one Getis value for each pixel) in order to capture the spatial heterogeneity and radar capability in sensing bunt areas and fire severity. Outputs from Getis were further processed using unsupervised classification based on ISODATA.

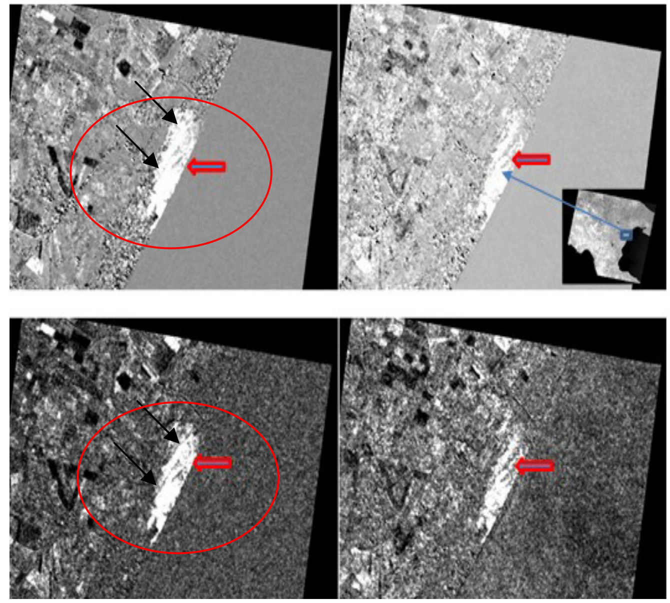

Fig. 2. (Top right) Averaged RBD as obtained from VH and VV polarizations. (Bottom left) Averaged RBR as obtained from VH and (Bottom right) from the VV polarization. Both RBD and RBR from VH polarization provide similar performance and the black arrows indicate the areas where the major differences are evident.

IV. Results and Discussion

To assess the capability of Sentinel-1 in the identification of burned areas, both the VV and VH polarizations were investigated, using: 1) single-date scene acquired prefire and postfire and 2) multidate averaged prefire and postfire (as listed in Table I) scenes. To enhance the fire-induced variations, two simple change detection methods were considered: the difference (RBD) and the ratio (RBR) computed using both: 1) the single scene acquired prefire and postfire and 2) the average of several scenes acquired prefire and postfire. Fig. 1 shows the RBD computed on the averaged scenes and on the single scenes, on the left and right, respectively. The red arrows indicate the area affected by fire and the green arrows indicate fire unaffected area characterized by the same cover (pinus tree) as the burned area. The fire-affected area is clearly evident in all the figures as an increasing of backscattering due to fire occurrence. Burned areas are the lighter pixels well distinguishable from the rest of the scene. The main difference visible is the effect of speckle noise that is significantly reduced in the averaged difference shown on the left of the top of Fig. 1. Moreover, the fire-affected area exhibits a strong patch homogenization that is very clear from a visual comparison of the texture between fire-affected and fire unaffected areas (indicated in Fig. 1 with red and green arrows, respectively). Fig. 2 shows the RBD and RBR of prefire and postfire averaged scenes as obtained from VH and VV polarizations. RBD and RBR from VH polarization provide similar performance and the black arrows indicate the areas (in fire-affected regions) where the major differences are evident. The visual comparison clearly highlights that both RBD and RBR from VH polarization (shown in the top part of Fig. 2) tend to exhibit a higher contrast between burned and unburned areas. In the RBD map, burned areas are clearly different with respect to the vegetated unburned areas; nevertheless, RBR makes clearer the burned areas compared to all the other targets (see red circles in Fig. 2), exhibiting a higher contrast between changed and unchanged surfaces. For this reason, RBR was selected for the following processing steps.

In order to discriminate the fire affected from fire unaffected areas, without using fixed thresholds, unsupervised classification (ISODATA) was applied to RBR (VH polarization) but some commission errors occurred. To overcome this drawback, we applied Getis–Ord statistic to RBR following the approach of the same author group [2] further improved using ISODATA classification to obtain a general fire severity categorization.

The results obtained from ISODATA pointed out that the application of Getis–Ord before the classification not only enabled us to reduce the commission errors in burned area mapping but also to improve the classification of burned severity. The results from the classification were validated on the basis of field survey conducted in the investigated area and shown in Fig. 3 as cyan points. *In situ* validation was made to assess the accuracy of both burned area mapping and burned severity characterization.

All the pixels affected by fire are characterized by high severity with an increasing level from blue, to yellow, fuchsia and cyan, as corresponding to the field survey. The number of classes and, in turn, different levels of burned severity were based on the following "guideline," below described, defined considering a quantification of the direct impact of fire.

1) *No Change:* Unchanged surfaces, i.e., fire unaffected areas.

Fig. 3. Ciano dots indicate the areas of the field survey.

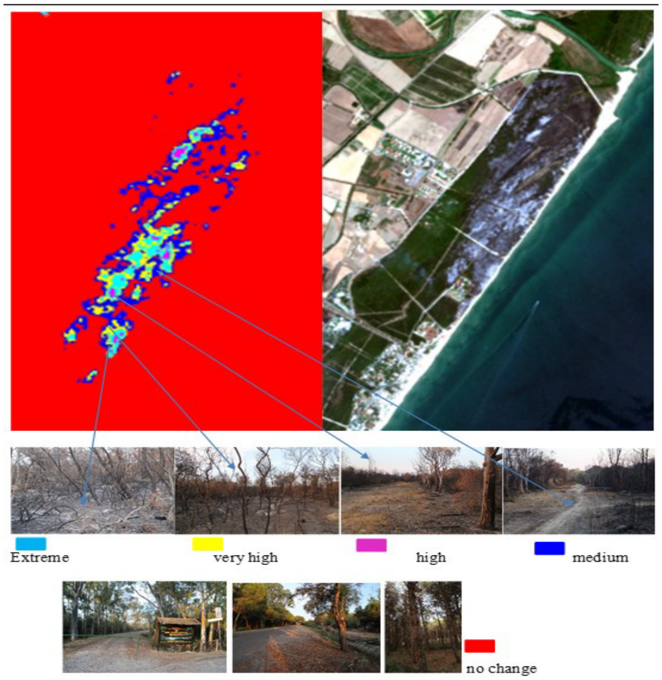

Fig. 4. Classification from ISODATA and correspondence with the field survey, as evident from the categorization automatically obtained.

2) *Low:* Areas of surface fire occurred with little change in cover and little mortality of the structural dominant vegetation.
3) *Moderate:* The area exhibits a mixture of effects ranging from unchanged to high severity within the scale of one pixel.
4) *High:* Vegetation has high to 100% mortality.
5) *Very High:* Soil burn severity assessment with characteristics of high severity, including heavy white ash deposition indicating loss of substantial levels of organic matter and loose unstructured soil. The comparison between satellite-based results and *in situ* analysis (see Fig. 4) confirmed that different classes of fire severity actually correspond to areas affected by fire at different levels, as reported in the photographs shown in Fig. 4. As a whole, the comparison between Sentinel-1-based results and the validation, made *in situ* with GPS (see Fig. 4) immediately after the fire event and 1 year after the fire occurrence, shows that for the burned area mapping, the accuracy was around 91%, and for fire severity of around 89%. The approach, herein proposed, enabled us to 1) have a reliable mapping of burned areas and 2) identify and characterize the diverse fire severity levels, thus facing the critical challenges linked to the fact that the effects of fire on plants vary significantly inside fire perimeter due to fuel types and distribution, fire behavior, fire residence time, and heat rate. Therefore, the diverse degrees of severity are the function of all of these parameters that together affect the level of plant damages and all together are well captured by the Getis-based statistical analysis made before the classification step. For burned area mapping, some commission errors were only found in areas that were vegetated before the fire, and later, after fire, completely plowed for agricultural purposes, so they showed the same behavior as fire-affected areas. To cope with this issue, the methodology can only be applied to natural areas filtering out the agricultural lands identified using Corine Land Cover map.

V. Conclusion

This letter illustrates the potential for Sentinel-1 for burned area mapping and for the characterization of burned severity for quite small fires in Mediterranean ecosystems. To this aim, a test area, Metaponto located in South of Italy, was selected because affected by fire (around 200 hectares) occurred on July 13, 2017. The investigated area is characterized by uniform topography features and vegetation cover made of Pinus tree (*P. halepensis*). The homogeneity of the study area coupled with the absence of the precipitation for the whole investigated period makes Metaponto fire an excellent case study to characterize and model the fire effects as sensed by Sentinel-1. The novelty of our approach is the automatic identification of burn severity obtained using the following three steps: 1) a change detection based on the ratio of multitemporal SAR data (acquired before and after the fire occurrence) enriched by; 2) statistical analysis (Getis); and 3) unsupervised (ISODATA) classification. The satellite-based results were evaluated by *in situ* campaigns that confirmed the full reliability of Sentinel-1-based results. One of the most important advantages of our approach compared to the traditional ones is that both burned areas and different levels of burn severity can be identified automatically and without using fixed threshold values. This is a particular critical issues, because fixed thresholds are generally not suitable for fragmented landscapes and inadequate for vegetation types and geographic regions different from those for which they were devised.

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