

Proceeding Paper

A Methodological Approach to Identify Thermal Anomalies Hotspots Misclassified as Fire Pixels in Fire Radiative Power (FRP) Products [†]

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Abstract: Thermal anomalies detected by Earth observation satellites have been widely used to identify active fires, even though with a high percentage of misclassified fire pixels. A total of about 75000 Fire Radiative Power (FRP) pixels have been spatially and temporally combined with EFFIS Burned Areas Database, distributed under the Copernicus Emergency Management Service, in order to identify thermal anomalies hotspots misclassified as fire pixels. The proposed approach uses a cluster analysis to partition FRP pixels dataset into discrete subsets, based on defined distance measures like the spatial distance of the pixel centroids and the temporal frequencies. Later, zonal statistics has been performed in order to evaluate fractional land cover within each identified hotspot. Results demonstrate that misclassified large surfaces, like industrial areas, can be identified from both spatial and temporal patterns, while other FRP false alarms are smaller in size.

Keywords: Fire Radiative Power; thermal anomalies; wildfires

1. Introduction

Wildfires are frequent across Italy, and satellite observation represent a valid tool to detect and assess the spread of wildfires. Unfortunately, only a fraction of fires is observed by satellites, many of which are too small to be detected or are masked by clouds. In addition, in some cases the duration of fires is too short as compared to satellites revisit time. In most cases the energy emitted through radiative processes released during the combustion (Fire Radiative Power - FRP) can be associated with fire intensity [1] and used as a proxy for the fire. On the other hand, active fire data assessments of FRP anomalies, other than fire burning due to both anthropogenic structures (like industrial areas, photovoltaic fields, and bright reflective roofs), and natural processes (such as volcanoes), can lead to false positives in the detection of active fires [2]. Permanent false-positive FRP pixels may recur during active fire detection due to their similarity in brightness, temperature, and spectral reflectance to fires.

Thermal anomalies detected by Earth observation satellites have been widely used to identify active fires. FRP can be estimated from the radiance at medium wave infrared (3–5 μm) wavelengths, measured by multiple polar-orbiting and geostationary satellite sensors, and represents the instantaneous radiative energy that is released from actively burning fires. FRP has been used to support mapping of burned scars, by identifying core areas, and estimating trace gas and aerosol rate of emissions, hence strengthen monitoring of wildfires activities and their impact on environment and ecosystems [3]. Algorithms to operationally generate FRP products from Earth observation satellite acquisitions in near real-time account for background window statistics, corrections, adjustments, and tests to

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eliminate false alarms, in order to distinguishing fire pixels from non-fire pixels. Nevertheless, a high percentage of thermal anomalies are misclassified as possible fire pixels.

This research study aims at presenting a methodological approach to identify thermal anomalies hotspots, misclassified as fire pixels. FRP products over Italy National territory, generated for the period 2022-2023 from SLSTR, MODIS and VIIRS satellite sensors and distributed by Copernicus, EUMETSAT and NASA FIRMS, have been collected and analyzed. Characteristics of FRP anomalies, other than fire-related combustion, were investigated in order to establish an approach for discriminating false-positive active fires, and to improve their recognition through spatio-temporal analysis. The experiment was carried out for the year 2022 and for the first seven months of the year 2023 (the latter period used for comparison exercise).

2. Materials and Methods

To carry out this study, two datasets for the period January 2022 – July 2023, were used. First one is the active fire pixel data from the Fire Radiative Power – Near Real Time Database (FRP-NRTD), consisting of a list of geographic coordinates of individual active fire pixels centroids, hereafter named FRP points, combining various datasets (Tab. 1). FRP represents emissive estimates of thermal anomalies, derived from data acquired during daytime and nighttime satellite overpasses using passive optical sensors at medium wavelengths (3-5µm). FRP provides quantitative information on the measurement of the radiant heat, and it is widely used as a proxy for fire events [4].

Table 1. Satellites and relative sensors used to generate the FRP-NRTD database.

Satellite	Sensor	Resolution	URL
Aqua (EOS PM-1)	MODIS	1000 m	https://firms.modaps.eosdis.nasa.gov
Terra (EOA AM-1)	MODIS	1000 m	https://firms.modaps.eosdis.nasa.gov
SNPP	VIIRS	375 m	https://firms.modaps.eosdis.nasa.gov
Sentinel-3	SLSTR	1000 m	https://www.eumetsat.int/S3-NRT-FRP

The second dataset that was used is the Burnt Areas Database - Italian Terrestrial Ecosystems (BAD-ITE), a geodatabase containing spatially explicit information, which allows the quantitative analysis of the impact of the main fires in the spatial and temporal dimensions, with specific focus on natural protected areas and terrestrial ecosystems on the Italian national territory. The BAD-ITE database was generated from the real-time updated Burnt Areas database, distributed by EFFIS (<https://effis.jrc.ec.europa.eu>), which contains spatial polygons that delimit the areas affected by fire, identified from satellite sensor acquisitions (MODIS Aqua, MODIS Terra and Sentinel-2 MSI at spatial resolutions of 250 and 20 m), and contains time information related to fire events.

In addition, Corine Land Cover Backbone 2018 thematic mapping product has been used to perform zonal statistics for different land covers.

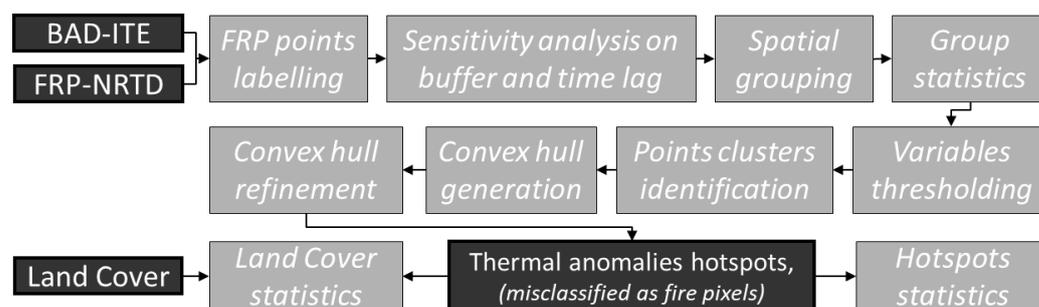


Figure 1. Flowchart for the FRP points analysis.

First step used for clustering analysis (Fig. 1) consists in labelling each of the about 75000 FRP pixel points with a class, belonging to legend reported in Tab 2. Space is the leading dimension used for FRP points labelling, each point is first checked as spatially residing within burned areas. Later, time information of burned areas, available from fields named 'FIREDATE' and 'LASTUPDATE' in BAD-ITE, is used to identify FRP points temporally occurred during each mapped fire event (Fig. 2). On one side, FRP products in Near Real-Time (NRT) mode may have a spatial displacement, due to approximated estimates of azimuth angle and satellite positioning [5], spatially collocating FRP points outside actual burned area polygons. On the other side, burned area polygons may have been mapped using a change detection method from satellite imageries acquired few days after the fire took place, resulting in temporal information lagged from actual fire date. To find best spatial buffer radius and time lag values, accounting for the above-mentioned constraints, a sensitivity analysis of FRP point labelling with respect to burned areas spatial buffer radius (range 0-2000 m) and temporal lag (range 0-96 h) was performed.

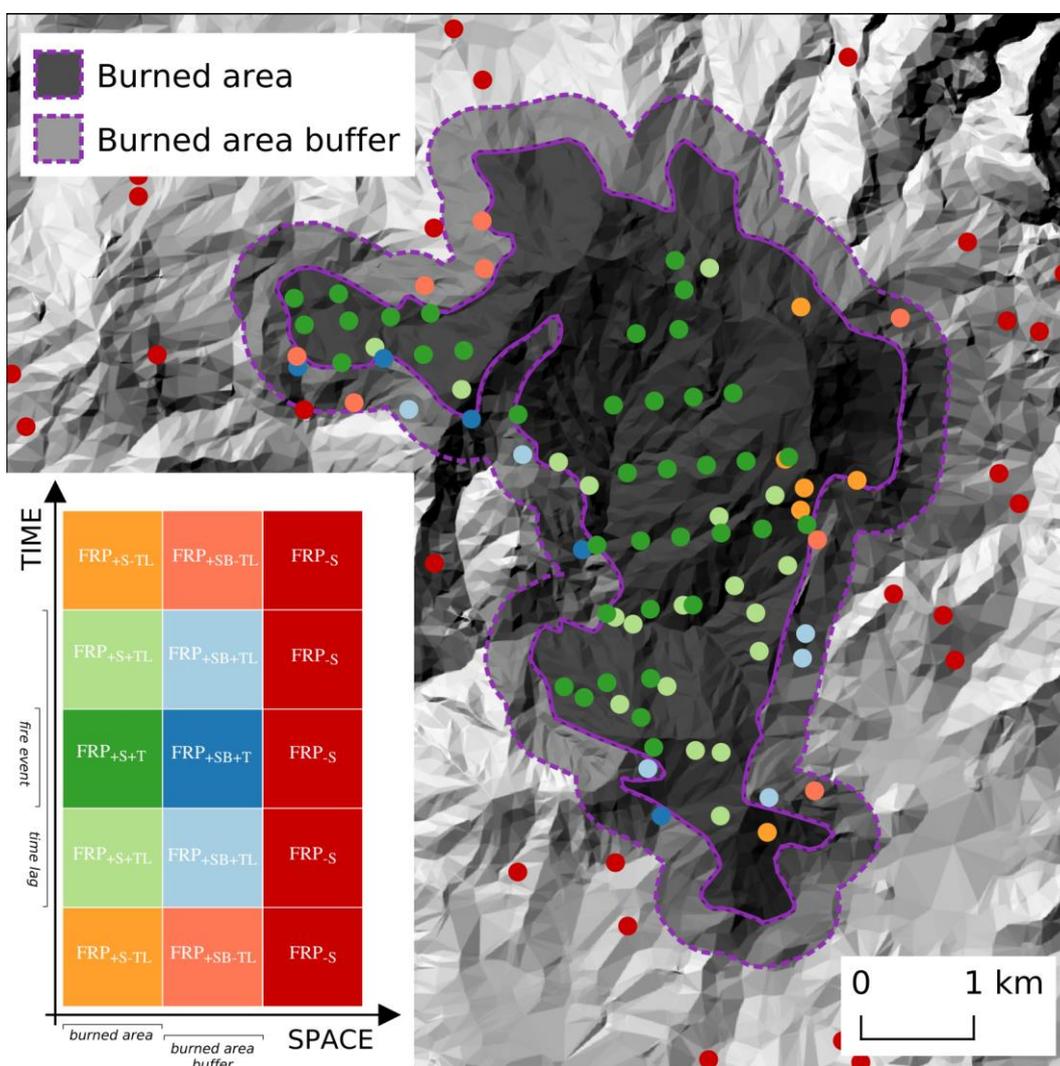


Figure 2. Map of the different FRP point classes, based on spatial and temporal overlay with burned areas. Plot representing classes positions in space and time dimensions.

Second step used for clustering analysis allowed to partition FRP points dataset into discrete subsets, based on statistical analysis of points spatial distance and temporal frequencies. For each FRP point, a spatial buffer with radius 1000 m has been used to identify the group of surrounding FRP points and compute group statistics. Specifically, variables used for clustering were the number of FRP points within the spatial buffer and the

number of singular day of year each FRP point in the group has been sensed by satellites. For each variable, a threshold value was selected by comparing variable values distributions for the different FRP points classes, in order to spatially identify points clusters that can be considered thermal anomalies hotspots, misclassified as fire pixels. For each points cluster, the corresponding spatial convex hull has been generated. Later, with the aim of refining thermal anomalies hotspots borders avoiding more isolated points, only areas with more than 3 overlapping convex hull have been used to generate final hotspots polygons.

Finally, zonal statistics has been performed in order to evaluate fractional land cover within each identified hotspot.

3. Results and Discussion

Based on sensitivity analysis results, spatial buffer radius from burned area polygons used for subsequent analysis was set to 400 m, and the time lag set to 26 h (Figure 3).

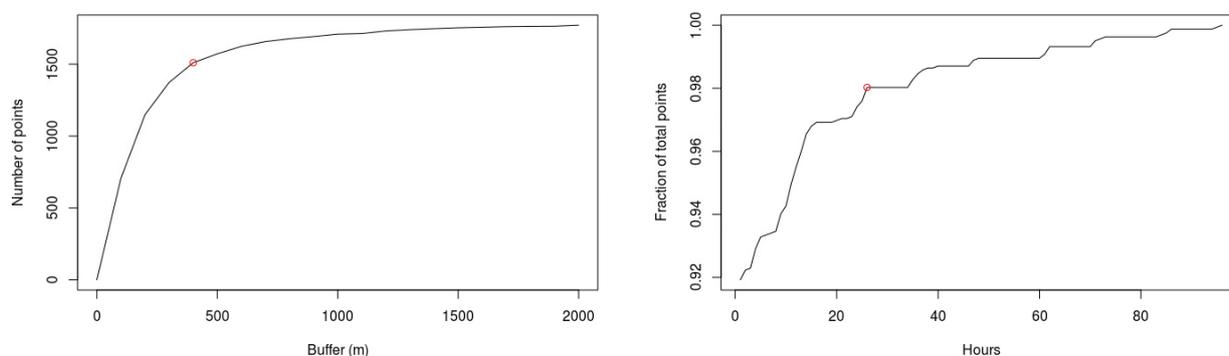


Figure 3. Spatial buffer radius and time lag sensitivity analysis plots.

Combination of spatio-temporal information of burned area polygons and FRP points allowed to assign each point to a specific class, identifying which FRP points are potentially related to the fire and which other are false positives. Results reported in Tab. 2 show that about 85% of FRP points do not match any fire event.

Table 2. Statistics for FRP points class legend.

Class	Description	Count	Percentage
FRP-s	Outside burned area polygon	42670	83.61
FRP+S-TL	Inside burned area polygon, outside fire event time lag	329	0.64
FRP+S+T	Inside burned area polygon, within fire event time range	2397	4.70
FRP+S+TL	Inside burned area polygon, within fire event time lag	1590	3.12
FRP+SB-TL	Inside burned area buffer polygon, outside fire event time lag	1590	1.17
FRP+SB+T	Inside burned area buffer polygon, within fire event time range	1510	2.96
FRP+SB+TL	Inside burned area buffer polygon, within fire event time lag	1939	3.80

From spatial intersection between burned area polygons and FRP points, with corresponding spatial buffer and time lag, 79.01% of burned areas have a FRP point sensed by satellites during fire event in 2022. Comparison exercise from January 2023 – July 2023 acquisitions resulted in 77.88% of corresponding points (77.67% from the same year period in 2022).

Based on variable values distributions for the different FRP points classes, threshold value for number of points in group has been set to 100 and threshold value for number of singular day of year set to 10 (Fig. 4). Overlay statistics of convex hulls allowed to finally identify 120 thermal anomalies hotspots, misclassified as fire pixels.

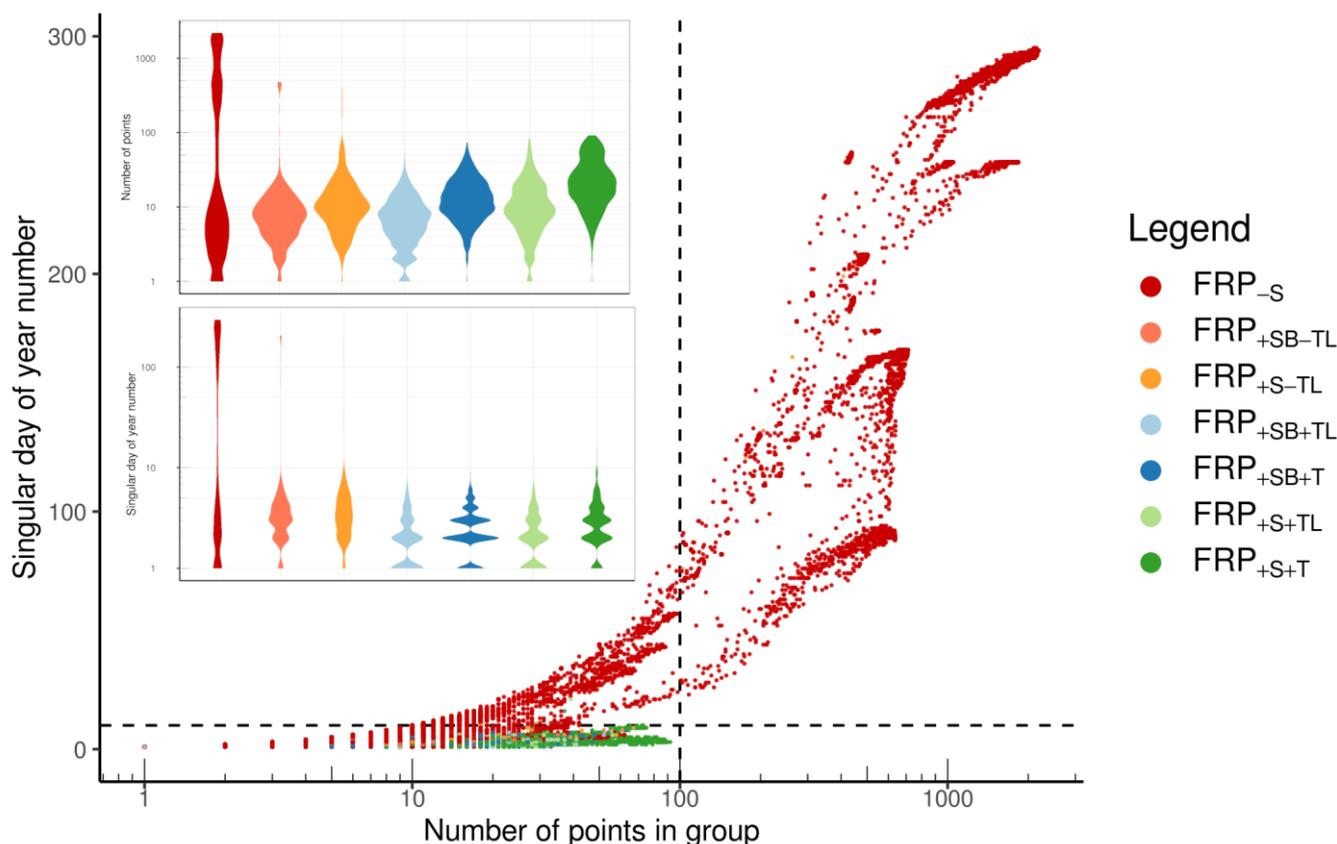


Figure 4. FRP points scatterplot relative to the number of points in group and number of singular day of year. Distribution of number of points in group and number of singular day of year according to legend classes.

Identified hotspots (Fig. S1), although they are a small number and correspond to about 165 km² (0.05% of Italy national territory), allow the removal of about 40% misclassified FRP points (Tab. 3). Comparisons exercise using year 2023 data showed that 4 FRP points fall within burned areas in 2023, that overlap thermal anomalies hotspot of misclassified fire pixels identified from 2022 data analysis. These points are located in a single grassland area where a fire event occurred in the surroundings of a large industrial area.

Table 3. Number of FRP points and statistics on removed misclassified FRP points.

Temporal Period	FRP Points Number	Number of Misclassified FRP Points (FRP-S FRP+S-TL FRP+SB-TL)	Number of Removed Misclassified FRP Points (FRP-S FRP+S-TL FRP+SB-TL)	Percentage of Removed Misclassified FRP Points (FRP-S FRP+S-TL FRP+SB-TL)
01/01/2022 31/12/2022	51033	43597	16428	37.68
01/01/2022 31/07/2022	32732	27485	11637	42.34
01/01/2023 31/07/2023	23386	18817	7686	40.85

From a comparison with land cover classes (Fig. 5), identified thermal anomalies hotspots are characterized by high cover percentage of sealed surface. From a visual inspection of geolocation of the hotspots, it has been possible to observe that they are mainly located in correspondence of industrial areas, metallurgical industries, cement factories, warehouses, and volcanoes. Herbaceous cover has higher cover percentage values compared to other vegetation cover classes, suggesting that trying to use exclusively sealed

surfaces to generate a mask to remove FRP pixels in anthropic areas could not be sufficient. This likely happen because of approximated estimates of azimuth angle and satellite positioning in NRT product, that may generate FRP points horizontal displacements in the order of hundreds of meters.

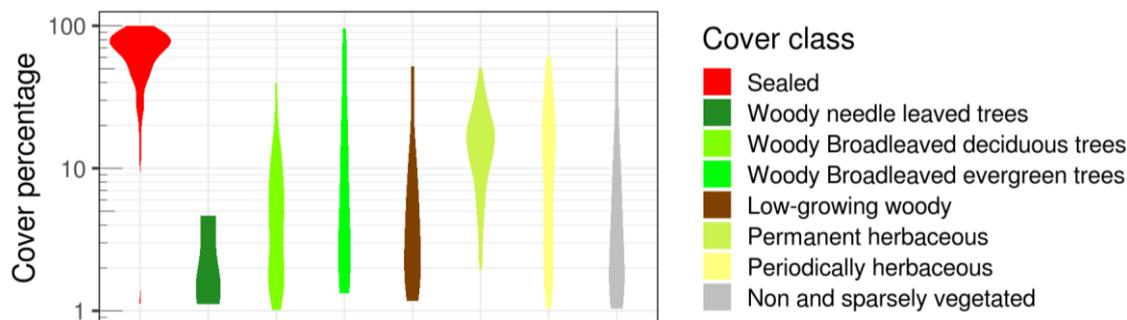


Figure 5. Violin plot for land cover classes percentage within identified hotspots.

The presented approach showed the capability to identify thermal anomalies hotspots and reduce of about 40% number of misclassified fire pixels, in order to generate static masks for FRP products post-processing, improving the capacity of FRP products in providing prompt and accurate information for operational services addressing the monitoring of wildfires and their impact on environment and ecosystems.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: Distribution map of identified thermal anomalies hotspots.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. Barrett, K.; Kasischke, E. S. Controls on variations in MODIS fire radiative power in Alaskan boreal forests: Implications for fire severity conditions. *Remote Sens. Environ.* 2013, 130, 171–181. <https://doi.org/10.1016/j.rse.2012.11.017>
2. Sofan, P.; Fajar, Y.; Anjar, D. S. Characteristics of False-Positive Active Fires for Biomass Burning Monitoring in Indonesia from VIIRS Data and Local Geo-Features. *ISPRS International Journal of Geo-Information* 2022, 11, no. 12: 601. <https://doi.org/10.3390/ijgi11120601>
3. Li, F.; Zhang, X.; Kondragunta, S.; Schmidt, C. C.; Holmes, C. D. A preliminary evaluation of GOES-16 active fire product using Landsat-8 and VIIRS active fire data, and ground-based prescribed fire records. *Remote Sens. Environ.* 2020, 237, 1–17, 111600. <https://doi.org/10.1016/j.rse.2019.111600>
4. Hernandez, C.; Keribin, C.; Drobinski, P.; Turquety, S. Statistical modelling of wildfire size and intensity: a step toward meteorological forecasting of summer extreme fire risk. *Annales Geophysicae, European Geosciences Union*. 2015, 33 (12), 1495–1506. <https://doi.org/10.5194/angeo-33-1495-2015>
5. Freeborn, P. H.; Wooster, M. J.; Roy, D. P.; Cochrane, M. A. Quantification of MODIS fire radiative power (FRP) measurement uncertainty for use in satellite-based active fire characterization and biomass burning estimation. *Geophys. Res. Lett.* 2014, 41. <https://doi.org/10.1002/2013GL059086>

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