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LUÍS MÁRIO RIBEIRO

Mediterranean fire danger classes based on the Canadian Forest Fire Weather Index System, taking into account the Fire Radiative Power products from SEVIRI/MSG satellite

Mafalda Silva[1]; Rita Durão[1,2]; Catarina Alonso[1]; Célia Gouveia[1,3]

[1] *Instituto Português do Mar e da Atmosfera (IPMA), Portugal.*
[2] *Centro de Recursos Naturais e Ambiente, Instituto Superior Técnico, Universidade de Lisboa*
[3] *Instituto Dom Luiz, Faculdade de Ciências da Universidade de Lisboa, Portugal,*
{ana.silva, rita.durão, catarina.alonso, celia.gouveia}@ipma.pt
**Corresponding author*

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Canadian Forest Fire Weather Index System, Fire Radiative Power, Fire Danger Thresholds, SEVIRI/MSG satellite data, Mediterranean

Abstract

Fire danger rating systems (FDRS) are widely used across the world for many purposes, from planning for the daily deployment of fire suppression resources to the evaluation of fire management strategies. FDRS can also be incorporated into different types of models and regions to assess the short and long-term effects of specific fire regimes and fire management policies. The Canadian Forest Fire Weather Index System (FWIS) is a widely known FDR system, being extensively applied for fire danger early warning in several regions around the world, namely in Europe. The FWIS includes a set of six sub-indices, based on meteorological data, to predict fire weather danger and fire behavior over regions under study. In order to have a reliable assessment of the fire danger based on the FWIS, it is essential to define the most suitable threshold values for each danger class of the FWIS sub-indices over different regions. To establish those limit values for each class of the FWIS sub-indices, historical percentiles were computed for the period understudy, taking into account the occurred fire events (hotspots), despite the lack of information regarding fire events history and its relation to FWIS sub-indices. To accomplish the proposed validation, our approach is based on Fire Radiative Energy (FRE) released by each fire event that occurred in the Mediterranean region, over the study period. The FRE is computed from Fire Radiative Power (FRP) product as obtained from MSG/SEVIRI, generated and disseminated in near real-time by EUMETSAT in the framework of Land Surface Analysis Satellite Applications Facility (LSA SAF). Since FRP estimates the radiative power emitted by a given fire, it can be linked to local fuel burned amounts and be used as a proxy of fire intensity. By integrating FRP measures emitted during the lifetime of the fires that occurred over the regions under study, an estimate of the total FRE released can be easily obtained for each event. To obtain the FRE data for this work, it was considered the period of available FRP/SEVIRI data, from March 2010 to October 2021. Threshold values of each defined danger class for the FWI, FFMC, and ISI indices were calculated considering the total FRE hotspots registered, in agreement with the different fire regimes of the Mediterranean region. Since extreme wildfire patterns in Southern Mediterranean countries have been increasing over the last years, FRP/FRE products are a key tool to monitor and improve fire managing activities, preparedness-including planning for deployment of fire suppression resources, over affected regions.

1. Introduction

To establish fire danger conditions in a given location or region, a fire danger rating system (FDRS) or a model should be able to reproduce short and long-term variations of temperature, relative humidity, precipitation, and wind intensity, in the variation of fuel humidity, that can be used to forecast fire occurrence and it (Di Giuseppe et al., 2016, 2020; Stocks et al., 1989). FDRS are often included or linked to different types of models to assess the long-term effects of fire regimes and specific fire management policies (Dacamara et al., 2014; Durão et al., 2010; Flannigan et al., 2001; Pereira et al., 2011; 7. San-Miguel-Ayanz et a., 2012, 2013; Sousa et al., 2015). FDRS like the Canadian Forest Fire Weather Index System (FWIS) transforms daily meteorological observations into relatively simple indices that can be used to forecast fire weather danger, the dead fuel moisture content and consequentially fire behavior, and impacts; being widely used for a fire danger early warning in several regions around the world, namely in Europe (Stocks et al., 1989; Van Wagner, 1987). To obtain a reliable assessment of the fire danger based on the FWIS it is crucial to determine the limit values for each fire danger class of the FWIS sub-indices for a given region and day. One of the simplest methods to define the fire danger classes is to compute daily percentiles based on historical data, but this method lacks information regarding wildfire history and its relation to FWIS sub-indices. In order to overcome this lack of information, the Fire Radiative Power products, generated and disseminated in near real-time by EUMETSAT Land Surface Analysis Satellite Applications Facility, were used in this validation work. Since FRP consists of estimates of the radiative power emitted by fires it can be directly linked to the amount of fuel burned and smoke production (Wooster et al., 2005), being used as a proxy of fireline intensity helping to develop and improve suppression and mitigation strategies (Johnston et al., 2017; Smith and Wooster, 2005). Namely, in Mediterranean countries, the use of this type of FRP product is very useful, since extreme fires have been increasing in the last years, presenting an eruptive or erratic behavior pattern, running out the responsiveness and suppression capacities of local authorities (Dacamara et al., 2019; Evin et al., 2018; Fernandes et al., 2016; Pinto et al., 2020; San-Miguel-Ayanz et al., 2018).

2. Materials and Methods

2.1. Study Area

The study area of this work comprises the countries of the Mediterranean basin, accordingly to figure 1.

To be easier to evaluate and compare the local fire danger thresholds, the Mediterranean area was split into small areas of interest: Portugal (PT), Iberian Peninsula (IP), North Africa 1 (NA1), North Africa 2 (NA2), Southern France (SF), Italy (IT), Greece, Turkey and Cyprus (GTC), as can be seen in Fig 1 and Table 1.

2.2. Fire Radiative Energy

The analysis of the fire severity is based on the Fire Radiative Energy (FRE) released by each fire, computed as a daily accumulation of Fire Radiative Power (FRP) delivered by the Land Surface Analysis Satellite Applications Facility (LSA-SAF) from EUMETSAT (Trigo et al., 2011; Wooster et al., 2005). The FRP (Heward et al., 2013), registers data on the position, timing, and fire radiative power (in MWatts) output per pixel of fire events detected every 15 minutes. FRP is disseminated for the full spatio-temporal resolution of SEVIRI (*Spinning Enhanced Visible and Infrared Imager*) imager on board the Meteosat Second Generation (MSG) series of EUMETSAT geostationary satellites (Wooster et al., 2015), provided for the whole MSG disk (up to 72° view zenith angle), where each active-fire position is represented at the center of the SEVIRI pixel, with a 3 km spatial sampling distance at sub-satellite point (decreasing away from the West African sub-satellite point). Since FRP estimates the radiative power emitted by fire events, integrating it over the length of a fire event, an estimation of the total Fire Radiative Energy (FRE) emitted by each one can be computed. By definition, the daily FRE is the energy released by a fire at a given pixel, by the integration of the 15-minute FRP records, accordingly to Pinto *et al* (Pinto et al., 2018a, 2018b)' formula:

$$E_{pd} = 0.9 \times \left(\sum_{k=1}^{96} \mathrm{FRP}_{kp}\right)_d,$$

where k is the daily sequence of 15-minutes, FRP_{kp} is the fire radiative power (in megawatts) in a given pixel p of image k, and the 0.9 factor converts the obtained result into gigajoules units (GJ). In addition, the FRE can be defined as the emitted radiant energy released during biomass combustion, being proportional to the total amount of biomass burned during a given fire (Pinto et al., 2018a, 2018b).
The FRE values were computed for all the fire events that occurred over the period under study, as can be seen in Table1.

2.3. Meteorological Fire danger

Briefly, the FWIS consists of six sub-indices that account for the effects of fuel moisture and weather conditions on fire behavior, by providing numeric ratings of relative potential for wildfire occurrence (Stocks et al., 1989; Van Wagner, 1987; Wotton, 2009). The first three indices of FWIS (FFMC, DMC, and DC) are the fuel moisture codes, which are numeric ratings of the moisture content of litter and other fine fuels, and the average moisture content of deep and compact organic layers. The remaining FWIS indices (ISI, BUI, and FWI) are fire behavior indices, which represent the rate of fire spread, the fuel available for combustion, the frontal fire intensity, or the fire weather index. The values of these behavior indices increase as the fire danger increases (Stocks et al., 1989; Van Wagner, 1987; Wotton, 2009). The previous indices selected to perform this validation are the Fire Weather Index (FWI), the Fine Fuel Moisture Code (FFMC), and the Initial Spread Index (ISI).

FWI is defined as a numerical rating of the potential frontal fire intensity, that indicates fire intensity by combining the rate of fire spread given by the Initial Spread Index (ISI), with the amount of fuel being consumed given by the Build-Up Index (BUI). FFMC is defined as an indicator of the moisture content in litter and other fine fuels less than 1 cm in diameter (needles, mosses, twigs), being representative of the top litter layer less than 1-2 cm deep. FFMC values change rapidly because of a high surface area to volume ratio, and direct exposure to changing environmental conditions (Van Wagner, 1974, 1987; Van Wagner et al., 1985; Wotton, 2009). ISI is defined as the numeric rating of the expected rate of fire spread. It is based on wind speed and FFMC. Like the rest of the FWI system components, ISI does not take fuel type into account. Actual spread rates vary between fuel types at the same ISI.

The indices of the Canadian Forest Fire Weather Index System (FWIS) are computed based on the meteorological parameters (temperature at 2 m, relative humidity, wind speed at 10 m, and accumulated precipitation in 24 h) of the short-term forecasts of the numerical forecast models delivered by the European Center for Medium-Range Weather Forecasts, ECMWF. Then, FWIS data delivered by the ECMWF are interpolated into the MSG grid, generated, and distributed as layers of the Fire Risk Map (FRM) product of the LSA-SAF under the framework of the Land Surface Analysis Satellite Applications Facility (LSA SAF) project.

2.4. Methodology

The proposed calibration is based on two main steps: firstly the Fire Radiative Energy (FRE) emitted by the fires was computed as a daily accumulation of the Fire Radiative Power (FRP) from MSG/SEVIRI, over the period 2010-2021; secondly, the fire weather danger percentiles of the FWI, FFMC, and ISI indices were extracted for the areas of interest, to assess local fire weather conditions and the different fire Mediterranean regimes.

Considering the study period from March 2010 to October 2021, the P_k percentiles were extracted for the FWI, FFMC, and ISI indices, namely percentiles P25, P50, P60, P65, P70, P75, P80, P85, P90, P95, P98, and P99, considering the total number of hotspots occurred over the study areas.

Additionally, since 2000 GJ is the typical daily amount of the energy released by a severe fire and very difficult to suppress (Pinto et al., 2018), this calibration analysis was performed in two steps - without considering any FRE threshold (FRE > 0 GJ) and considering an FRE severity threshold of 1500 GJ (FRE > 1500 GJ). The rationale is to identify the Mediterranean areas with the most severe wildfires.

3. Results and Discussion

The number of the total events registered, without considering any FRE threshold (FRE ≥ 0 GJ), is 246444 over almost 12 years of the study period. The number of events registered considering the threshold of FRE >1500 GJ is 16366, which represents 6.6% of the total events, as can be seen in Table1.

Results show that a major part of the fire events considering FRE ≥ 0 GJ, occurs in Greece, Turkey, and Cyprus (GTC) region with approximately 35% of the total hotspots since this area spans most of the Mediterranean basin. Conversely, considering the 1500 GJ threshold, the Iberian Peninsula (IP) stands out with approximately 51% of the total hotspots, followed by Italy (IT) (18,3%), North Africa 2 (NA2) (18,1%), Greece, Turkey, and Cyprus (GTC) (16%), North Africa 1 (NA1) (3,2%), and finally South France (SF) (2,8%). However, it should be noted that some selected areas are overlaid.

To compare and validate the results, we consider the European thresholds of the European Forest Fire Information System (EFFIS), established by the European Commission for supporting the services in charge of the protection of forests against fires in the EU and neighboring countries (http://effis.jrc.ec.europa.eu).

The EFFIS network adopted, as well, the Canadian Forest Fire Weather Index system with the main goal of providing a harmonized picture of the spatial distribution of fire danger levels throughout Europe, the Middle East, and North Africa (https://effis.jrc.ec.europa.eu/about-effis/technical-background/fire-danger-forecast). Currently, FWI is classified into seven classes [Very Low, Low, Moderate, High, Very High, Extreme, and

Very Extreme] accordingly to the update of the last fire season whereas; FFMC and ISI are still classified in five classes (see Table 2.).

The obtained FWI percentiles (P50, P75, P85, P95, P99), considering FRE >1500 GJ, for the seven areas of interest, are presented in Table 3. It can be seen, that 50% of the fire events that occurred in the Mediterranean basin and all areas, belong to the four last fire danger classes: High, Very High, Extreme, and Very Extreme, accordingly to EFFIS classification (see Table 2).

Histograms for the FWI were computed for the Mediterranean basin and the Portuguese hotspots (Figures 2 and 3, respectively). Regarding both figures, where percentiles P50, P75, P85, P95, and P99 are marked, it is clear the increment of the FWI values, when the more severe fires are considered, namely when FRE>1500GJ. It is also noted the large number of hotspots related to low danger classes, and, therefore, lower fire intensity, concurrently to more severe fires.

Taking a closer look at Portuguese FWI values in Table 3, it can be seen that 50% of the fire events are classified in the last three classes: Very High, Extreme, and Very Extreme. Moreover, this pattern indicates that Portugal itself or considering the Iberian Peninsula, has more fire events, with more severe behavior and intensity than the remaining Mediterranean interest areas under study.

4. Conclusion

Results highlight the robustness of the proposed methodology that will also be applied to FFMC and ISI indices. Therefore, an overall discussion of the fire danger thresholds would be very fruitful and will be done in further work. However, these first results regarding the FWI clearly show already the differences in the fire regimes and fire intensity for the Mediterranean basin countries. They also reveal that all the fire-related activities of local authorities, such as fire danger assessment, monitoring, planning, and mitigation activities should be adopted or taken accordingly to these local patterns.

5. Figures

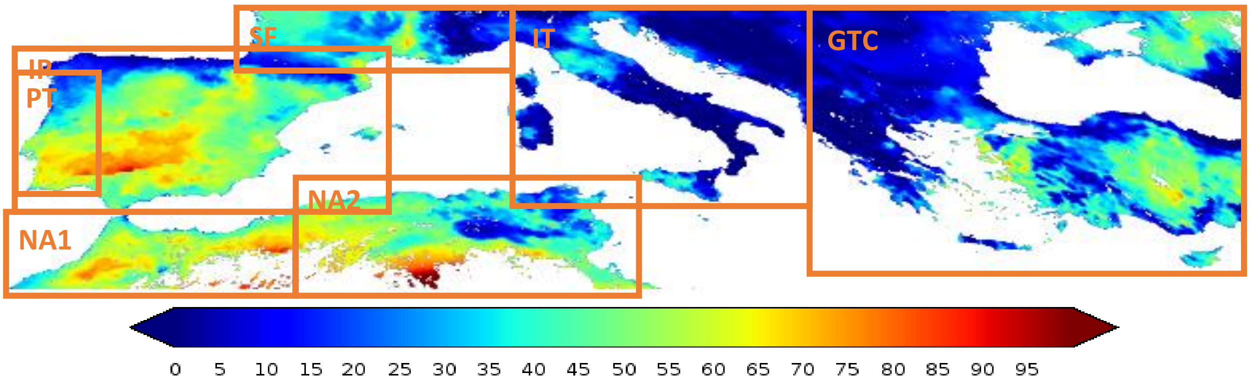

Figure 1: Fire Weather Index (FWI) for 5th August 2018 on the Mediterranean basin and selected study areas. IP – Iberian Peninsula, PT- Portugal, NA1 – North Africa 1, NA2 – North Africa 2, SF – Southern France, IT- Italy, GTC – Greece, Turkey, and Cyprus.

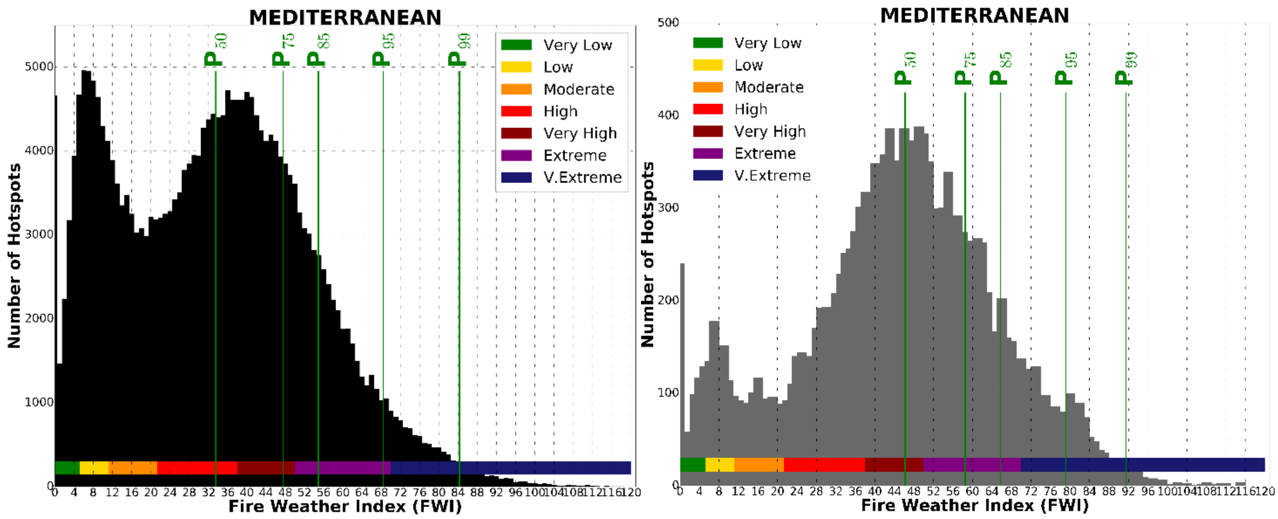

Figure 2: FWI histogram for Mediterranean basin hotspots with FRE≥0 GJ (left) and the selected threshold of FRE≥1500 GJ (right). Percentiles 50, 75, 85, 95, and 99 are marked with green lines.

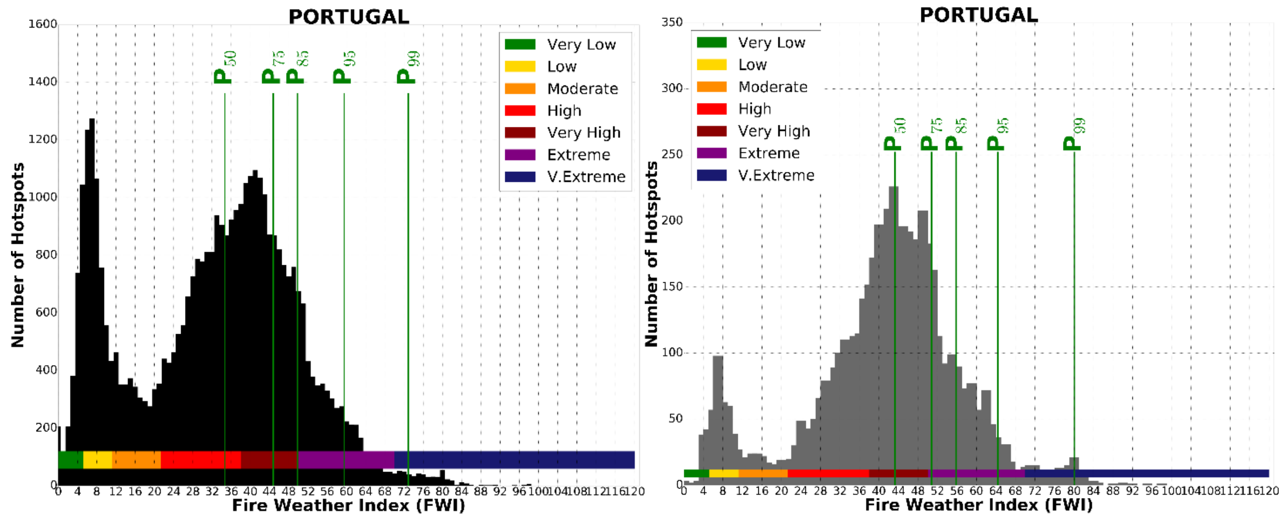

Figure 3: FWI histogram for Portuguese hotspots with FRE≥0 GJ (left) and the selected threshold of FRE≥1500 GJ (right). Percentiles 50, 75, 85, 95, and 99 are marked with green lines.

6. Tables

Table 1. The number of hotspots registered over the study area with FRE ≥ 0 GJ and the selected threshold of 1500 GJ.

Region	Hotspots			
	FRE≥0		FRE≥1500	
	#	%	#	%
Mediterranean Basin	**246444**	**100**	**16366**	**100**
Greece, Turkey and Cyprus (GTC)	87157	35,4	2710	16,6
Iberian Peninsula (IP)	73533	29,8	8310	50,8
Italy (IT)	51916	21,1	2992	18,3
Portugal (PT)	39636	16,1	5595	34,2
North Africa 2 (NA2)	36582	14,8	2963	18,1
Southern France (SF)	9652	3,9	464	2,8
North Africa 1 (NA1)	6779	2,8	519	3,2

Table 2. Fire Danger Classes of FWI, FFMC, and ISI accordingly to the European Fire Forecast Information System (EFFIS, http://effis.jrc.ec.europa.eu/).

Fire Danger Classes	FWI	FFMC	ISI
Very Low	FWI < 5,2	FFMC < 82,7	ISI < 3,2
Low	5,2 ≤ FWI < 11,2	82,7 ≤ FFMC < 86,1	3,2 ≤ ISI < 5,0
Moderate	11,2 ≤ FWI < 21,3	86,1 ≤ FFMC < 89,2	5,0 ≤ ISI < 7,5
High	21,3 ≤ FWI < 38,0	89,2 ≤ FFMC < 93	7,5 ≤ ISI < 13,4
Very High	38,0 ≤ FWI < 50,0	FFMC ≥ 93,0	ISI ≥ 13,4
Extreme	50,0 ≤ FWI < 70,0		
Very Extreme	FWI ≥ 70,0		

Table 3. FWI percentiles, considering the FRE severity threshold of 1500 GJ (FRE > 1500 GJ).

FWI					
P_k	P_{50}	P_{75}	P_{85}	P_{95}	P_{99}
Region	**FRE≥1500**	**FRE≥1500**	**FRE≥1500**	**FRE≥1500**	**FRE≥1500**
Medit.	**46,19**	**58,48**	**65,71**	**79,16**	**91,47**
IP	43,85	53,50	59,66	70,53	81,01
PT	43,27	50,78	55,83	64,38	80,07
NA[1]	50,34	57,77	63,03	74,87	106,9
NA[2]	59,03	69,58	76,27	84,32	95,52
SF	42,18	61,43	69,12	93,25	106,69
IT	40,29	57,21	65,18	77,73	86,99
GTC	48,70	64,82	72,33	85,71	96,56

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