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A comparison of remote sensing products and forest fire statistics for improving fire information in Mediterranean Europe

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Abstract
The impact of forest fires in Europe is assessed in the European Forest Fire Information System (EFFIS) from two independent information sources: field data collected at national level and remote sensing. This study analyzes the agreement between both data sources for all fires between 2000 and 2009 in five European Mediterranean countries. Remote sensing products allow the enrichment of the field data reported by countries as they provide detailed spatial positioning and temporal information of the fires. Also the relationship between the number of active fires detected from remote sensing (MODIS hotspots) and burnt area mapped in EFFIS was analyzed by means of linear and quantile regressions. For fires larger than 500ha our results show a general agreement of 56% (~70% in Spain and Greece, ~60% in France, ~55% in Italy and ~45% in Portugal). The estimation of burnt area from MODIS hotspots had a 68% fit.

Keywords: Burnt area, Euro-Mediterranean, fire occurrence, GIS, MODIS.

Introduction
In the European Mediterranean region (EUMED hereafter) an average 50,000 fires occurred annually in the period 1980-2012, burning approximately half a million ha of land [European Commission, 2013] every year. Natural fires play a key role in Mediterranean ecosystems, being essential to maintain biodiversity [Pausas and Vallejo, 1999]. In addition, in the rural areas of the EUMED fire has been a traditional tool widely used to manage the territory. In the last decades socioeconomic and associated land use changes had major influence, significantly modifying fire regimes in the region [Pausas, 2004; Pausas and Fernández-Muñoz, 2012]. The most important changes included among others the depopulation of rural areas, with a consequent increase in fuel load and fire hazard in the abandoned lands [Velez, 2005], the growth of urban population and expansion of wildland-urban interface areas [Velez, 2005; Pérez-Cabello et al., 2009], spread of tourism and recreational activities and the resulting increase in the number of occasional visitors to the forest [Ganteaumme

et al., 2013]. Significant alterations of natural fire regimes (fire frequency, intensity and severity) have aggravated their ecological, social and economic consequences in different parts of the globe and in EUMED as well [Westerling et al., 2006; FAO, 2007]. More than 90% of the fires with known origin in EUMED, are due to human causes (negligence or deliberate actions) [Ganteaume et al., 2013]. Accurate and reliable information on fire incidence is key to improve our understanding of mechanisms behind fire occurrence and enhance accordingly fire prevention activities [Chuvieco et al., 2009; Vilar et al., 2011]. Remote sensing techniques can be used in many ways to support the collection of reliable information on forest fires. Satellite based estimates are considered effective to map burnt scars [Mouillot et al., 2014]. Besides burnt area mapping [Urbanski et al., 2009; García et al., 2014; Alonso-Canas and Chuvieco, 2015; Boschetti et al., 2015; Hardtke et al., 2015], satellite imagery was used to detect active fires [Dwyer et al., 1998; Giglio et al., 2003, 2006; Arino et al., 2012; Gandhi and Singh, 2014; Coppo, 2015; Oliva and Schroeder, 2015; Zhang et al., 2015], to estimate surface and crown fuel loading [Nelson et al., 1988; Means et al., 1999; Lefsky et al., 2002; Falkowski et al., 2005; Saatchi et al., 2007; García et al., 2012; Jakubowksi et al., 2013], to assess active fire behavior [Kaufman et al., 1998; Wooster et al., 2003; Smith and Wooster, 2005; Dennison, 2006; Dennison et al., 2006; Merino-de-Miguel et al., 2010; Coen and Schroeder 2013; Shroeder et al., 2014], to monitor post-fire vegetation response [Turner et al., 1994; White et al., 1996; Díaz-Delgado et al., 2003; Chen et al., 2011; Sever et al., 2011; Tanase et al., 2012; Veraverbeke et al., 2012], to assess fire risk [Desbois et al., 1997; Jaiswal et al., 2002; Chuvieco et al., 2010; Bisquert et al., 2011; Knorr et al., 2011, Maeda et al., 2011] and to generate fuel maps [Riaño et al., 2002; Sebastián- López et al., 2002; Rollins et al., 2003; Pierce eta al., 2012].

Mouillot et al. (2014) provide an overview of global fire products derived from satellite imagery from 1995 to 2010. The available products include Global Fire Emissions Database version 3 (GFED3) [Giglio et al., 2010], MODIS Burned Area product for Collection 5 Level 3 (MCD45A1) [Roy et al., 2008], Global burnt area product L3JRC [Tansey et al., 2008a,b], Globcarbon Burt Area Estimates (BAE) [Plummer et al., 2006], Global Burned Surfaces (GBS) [Carmona-Moreno et al., 2005], GLOBSCAR [Simon et al., 2004] and Global Burnt Area (GBA2000) [Tansey et al., 2004].

In Europe the burnt area has been monitored since late '90 by the European Forest Fire Information System (EFFIS). In 2000 EFFIS produced the first map of burnt areas at the EUMED level on the basis of IRS WiFS data [San-Miguel-Ayanz et al., 2009]. From 2003 onwards, MODIS images have been used, covering the entire European window and shifting to a daily processing chain since 2008. The burnt area module of EFFIS is called Rapid Damage Assessment (RDA) and provides daily updates of burnt areas in Europe for fires of at least 40 ha, although fires of smaller size are often detected and mapped [San-Miguel Ayanz et al., 2009].

Another remote sensing product routinely used to monitor fire activity is the so called "hotspots", active fires detected using the MODIS imagery, Hotspots provide information about actively burning fires, including their location and timing, instantaneous radiative power and smoldering ratio [Giglio et al., 2006; Giglio, 2010]. A detection algorithm that identifies thermal anomalies in the images forms the basis of the product which does not provide direct information about the actual burnt area [Stolle et al., 2004; Miettinen et al., 2007; Hantson et al., 2013]. However hotspots were useful in identifying temporal patterns of burnings through detecting seasonal and yearly variation in the number of fires [Eva and Lambin, 1998; Giglio et al., 2006; Takahata et al., 2010] and were successfully used in burnt area estimation in both boreal and tropical regions by combining them with reflectance data or by calibrating the results with high spatial resolution data [Miettinen et al., 2007]. In South-East Asia, hotspots were used to confirm burnt areas detected on radar images [Siegert and Hoffmann, 2000]. Hantson et al. [2013] quantified the relation between MODIS Hotspots and burnt area obtained from Landsat images and for different ecosystems in order to better characterize fire occurrence at global scales. In EFFIS, Hotspots are used for the automatic geo-location of active fires combining them with ancillary data to reduce false positive detections.

The main aim of our work was to compare information on fire activity obtained from remote sensing and from reports provided by the countries in the EUMED region. We intended to assess the differences and verify to what extent these products can complement each other and improve burned area monitoring.

Two data sources were compared: (1) the European Fire Database (national fire statistics harmonized and hosted in EFFIS) and (2) the burnt area product of EFFIS-RDA .In addition, the burned area product was compared with the hotspot product for the period 2006-2009, exploring the relationships using linear and quantile regression analysis.

Study area

Our study area comprises the EU countries Portugal, Spain, Italy, Greece and the Mediterranean provinces of France (Fig. 1). Most of the 1 million km^2 of land of this area belong to the Mediterranean region [EEA, 2008], which is by far the region most affected by forest fires in the EU. Landscape features of the Mediterranean region are strongly driven by climate, the long and intense human impact on natural resources and the role of fire [Pausas and Vallejo, 1999]. The climate of the region is typically Mediterranean with mild, rainy winters and hot, dry summers [Merlo and Croitoru, 2005]. Reflecting the prevailing climate, Mediterranean forests are frequently characterized by species dependent on the presence on fire in the reproductive cycle [FAO, 2007]. Prolonged summers with very limited precipitation and high temperatures reduce the moisture content of forest fuels, often resulting in large fires when combined with strong winds. In this populated area of about 144 million people [Eurostat, 2014] most of the fires are directly or indirectly induced by human activity.

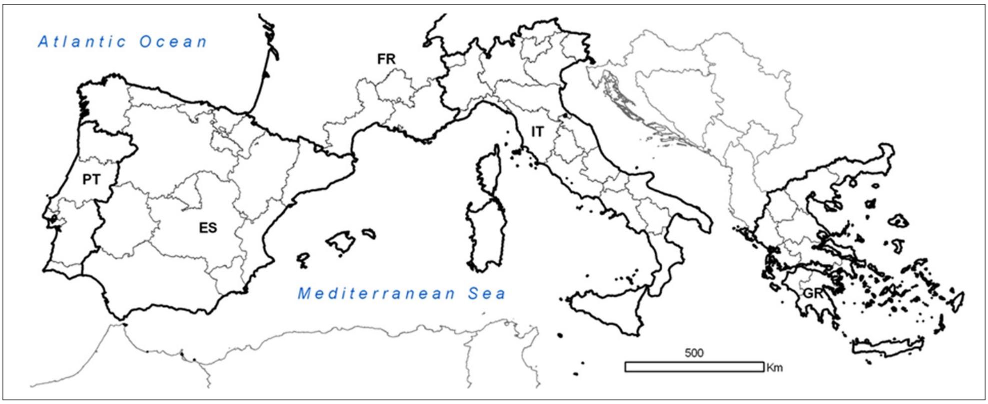

Figure 1 - Mediterranean Europe (EUMED): Portugal -PT-, Spain -ES-, South France -FR-, Italy -IT- and Greece -GR-. NUTS2 administrative level boundaries.

Data

European Fire Database (EFD) and Rapid Damage Assessment (RDA)

The European Fire Database (EFD) contains information on forest fires compiled by European Union Member States and by other European countries within the framework of EFFIS [European Commission, 2010]. Contributing countries submit every year forest fire data derived from the collection of individual fire records, which are routinely compiled by local fire fighters once the fires have been extinguished. Data are checked, stored and managed by the Joint Research Centre within the EFD [Camia et al., 2014] Among other information EFD contains data about the date and time of the fire, fire location (administrative district), fire size by land use category, and fire cause.

For the study period (2000-2009) the total number of fires recorded in the EFD was 541,324 and the burnt area 4,253,207 ha in EUMED countries.

RDA provides a daily update of the perimeters of burnt areas in Europe from MODIS imagery for fires of 40 ha or larger [San-Miguel Ayanz et al., 2009]. In the study period 2000-2009, 8,890 fires were mapped, with a total burnt area of 2,814,264 ha. Table 1 shows the total number of fires and burnt area from the EFD and RDA databases, by country and in the whole EUMED for the period 2000-2009.

Table 1 - Number of fires and burnt area by country and in EUMED for the period 2000-2009. EFD and RDA databases.

Country	EFD Number of fires	EFD Burnt area (ha)	RDA Number of fires	RDA Burnt area (ha)
Portugal	254542	1608558	4003	1116393
Spain	182761	1269074	2575	745031
France (EUMED NUTS)	22145	164438	313	104433
Italy	73021	844993	1566	360252
Greece	8855	366142	433	479265
EUMED	541324	4253207	8890	2814264

Hotspots/active fire detections

Hotspots are processed by MODIS Rapid Response System using the same algorithm as the standard MODIS MOD14/MYD14 v5 Fire and Thermal anomalies product. Fire detection is performed using a contextual algorithm that exploits the strong emission of mid-infrared radiation from fires. The algorithm examines each pixel of the MODIS swath, and ultimately assigns to each one of the following classes: missing data, cloud, water, non-fire, fire or unknown (see Giglio et al., 2003a for further details). The algorithm heritages for the Advanced Very High Resolution Radiometer (AVHRR) and the Visible and Infrared Scanner (VIRS) [Giglio et al., 1999, 2003b]. MODIS can routinely detect both flaming and smouldering fires around 1000 m^2 in size. Under very good observing conditions (e.g. near nadir, little or no smoke, relatively homogeneous surface) flaming fires one tenth this size can be detected. Under pristine (and extremely rare) observing conditions even smaller flaming fires 50 m^2 can be detected. There is no upper limit to the largest and/or hottest fire that can be detected with MODIS [Giglio, 2010]. The Hotspots product has been obtained from the Earth Observing System Data and Information System (EOSDIS), from NASA's Earth Science Data Systems Program, which delivers near real-time Hotspots

(https://earthdata.nasa.gov/data/near-real-time-data/firms/active-fire-data). Each fire point contain information on the exact time and day of location, a global georeference system location (longitude, latitude), the brightness temperature of the fire and as mentioned before classified confidence level [Takahata et al., 2010].
As the RDA product contains the fire date from the year 2006 onwards, the set of Hotspots from the years 2006-2009 has been used. In this period 35,785 Hotspots were detected in EUMED. Table 2 shows the total number of Hotspots by country and in EUMED for the period 2006-2009.

Table 2 - Number of Hotspots by country and in EUMED for the period 2006-2009. Hotspots database.

Country	Number of Hotspots
Portugal	4449
Spain	7307
France (EUMED NUTS)	1579
Italy	15515
Greece	6935
EUMED	35785

Methods

Analysis of agreement between EFD and RDA

We first focused on the agreement between EFD and RDA, comparing all fires ≥0.1 ha recorded between 2000 and 2009 in EUMED. In the first stage of the analysis we used common variables recorded in both EFD and RDA such as date, location and fire size to match fire records. The spatial dimension is dealt with in the EFD database by attributing the municipality where the fire started. Thus, we overlaid the spatial explicit information on burnt areas from RDA layer on the municipality layer. We then checked for the coincident fire events within location, date (from 2006 onwards) and approximate fire size. In a second stage, when the exact date or location were unknown, we checked for coincident fires in the two databases by ranges of dates (7-10 days) and fire size.

Analysis of agreement between RDA and Hotspots

Afterwards, we compared the RDA product with the MODIS active fires (Hotspots), for the years 2006-2009. We filtered the set of Hotspots to reduce the possibility of having false alarms. Hotspots have a detection confidence value, which is a measure of confidence for each detected fire pixel, based on a system of equations within the algorithm and is expressed as a percentage [Giglio, 2007]. It ranges between 0% and 100%, and is used to assign one of the three fire classes (low confidence fire-<30%-, medium confidence fire-30-80%- or high confidence fire->80%-) to all fire pixels within the fire mask. A subset of Hotspots was selected using the criteria routinely applied in EFFIS to reduce false alarms. Those with less than 20% of confidence were discarded and thus not used for the analysis; afterwards, using a buffer distance of 1,500 m [Hantson et al., 2013] we overlaid the Hotspots with the land cover data from CLC 2000, (reclassified as shown in Tab. 3) and Hotspots located in buffered areas with less than 5% of natural lands or in wetland uses and/or in areas with more than 65% of artificial use were removed.

Table 3 - Land use re-classification from CLC level 3 classes.

Land Use class	CLC level 3 code
Agriculture	211, 212, 213, 221, 222, 223, 231, 241, 242, 243, 244
Artificial Surfaces	111, 112, 121, 122, 123, 124, 131, 132, 133, 141, 142
Natural Lands	311, 312, 313, 321, 322, 323, 324, 331, 332, 333, 334, 335
Water bodies	511, 512, 521, 522, 523
Wetlands	411, 412, 421, 422, 423
No Data	255, 990, 995, 999

Afterwards, we carried out a spatial link of the Hotspots and RDA burnt areas (≥0.1 ha) for the study period 2006-2009. All Hotspots at a ≤1,500 meters distance of a burnt area were assigned to that burnt area [Hantson et al., 2013]. Then, we checked the dates of the Hotspots assigned by distance to a certain burnt area. We explored the frequency of the Hotspots dates by burnt area assigned to help deciding what time range to chose. When the difference between the dates was within a range of 10 days (3 days less or 7 days more) then we considered that the Hotspot belonged to that burnt area. We obtained a group of burnt areas with Hotspots assigned to them. We calculated within each burnt area the distances between Hotspots neighbors (1 to 1 neighbor). We checked then which was the maximum of the minimum distance among neighbors. That distance was then chosen as reference (called 'distance criteria' from now on).

Based on the previous distance criteria we analyzed Hotspots detected the same day with no burnt area assigned. If they could be spatially grouped following the distance criteria, it was considered they belonged to the same fire. Then, we studied the relationship between the number of Hotspots and the total burnt area (RDA product) with hotspots assigned by linear regression (LR) and by quantile regression (QR) analysis. Classical LR has the form [Draper and Smith, 1981]:

$$Y_i = \beta_0 + \beta_1 \mathrm{x}_{1i} + \varepsilon_i \qquad [1]$$

Where Y_i is the value of the response variable in the i^{th} observation, β_0 is the intercept parameter, β_1 is a slope parameter, x_{1i} is the value of the independent variable in the i^{th} observation, ε_i is a random error term of the i^{th} observation with mean $E(\varepsilon_i) = 0$ and variance $\sigma^2\{\varepsilon_i\} = \sigma^2$, with the error terms being independent and identically distributed, $i=1,...,n$.

QR focuses on the interrelationship between the dependent variable and its explanatory variables for a given quantile. The equations are designed to estimate the relation of x with y, conditional on quantiles (or percentiles) of y. It measures how the relation of x with y changes depending on the score of y. This method uses the median as the measure of central tendency rather than the mean. QR does not require the response variable (burnt area in this case) to be normally distributed, so is less sensitive to outliers [Logan and Petscher, 2013]. The first order QR model has the form [Koenker, 2005],

$$\mathrm{Q}_{yi}(\tau \mid x) = \beta_0 + \beta_1 \mathrm{x}_{1i} + F_u^{-1}(\tau) \qquad [2]$$

where, Q_{yi} is the conditional value of the response variable given τ in the i^{th} trial, β_0 is the

intercept, β_1 is a parameter, τ denotes the quantile (e.g. $\tau = 0.5$ for the median), x_i is the value of the independent variable in the i^{th} trial, F_u is the common distribution function (e.g., normal, Weibull, lognormal, other, etc.) of the error given τ, $E\ (F_u^{-1}(\tau)) = 0$, for $i=1,...,n$, e.g., F^{-1} (0.5) is the median or the 0.5 quantile [Young et al., 2008].
The spatial analysis and GIS operations were carried out using ArcMap 10 [ESRI, 2011] and Python 2.6 with ESRI ArcPy libraries. Data management was done using Microsoft Access 2003 and statistical analysis was performed using R 2.11.1 [R Development Core Team, 2008] with *car* [Fox and Weisberg, 2011] and *quantreg* [Koenker et al., 2013] packages.

Results

Analysis of agreement between EFD and RDA

The level of agreement between the two fire data sources is summarized in Table 4. On the one hand, at the EUMED level, about 56% of the large fires (≥500 ha) of EFD were linked to the burnt area mapped (RDA). By country, large fires were linked in EFD in the following percentages, 70% in Spain and Greece, around 60% in France, and 55% and 45% in Italy and Portugal, respectively. The level of agreement increased with the size of the fires. Additionally, 94% of large fires from RDA database were linked to the records in EFD database. By country, large fires were associated in more than 90% of the cases except for Greece (68%). Also, the level of agreement increased with the fire size (from 10 ha), being bigger than the EFD matching.

Table 4 - Level of agreement (%) between fires registered in EFD with fires in RDA (white column named EFD) and level of agreement between fires registered in RDA with EFD (grey column named RDA) by fire size class in EUMED and by country. Study period 2000-2009.

	EUMED		ES		FR		GR		IT		PT	
Fire size class (ha)	EFD	RDA	EFD	RDA	EFD	RDA	EFD	RDA	EFD	RDA	EFD	RDA
0.01-1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.2	0.0
1-5	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.0
5-10	0.1	0.0	0.0	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.4	0.0
10-50	0.7	13.5	0.5	11.6	0.3	2.2	2.0	6.7	0.8	16.4	0.7	15.4
50-100	3.7	14.8	2.8	10.5	7.9	29.0	11.4	33.3	3.8	12.2	2.9	16.2
100-500	13.8	22.0	14.9	18.1	14.9	40.0	30.2	32.5	14.5	27.6	9.6	18.4
≥500	56.1	94.0	68.9	99.0	62.9	97.7	73.3	67.9	54.8	96.4	45.6	96.6

Taking into account the years in the RDA database, where the exact date of the fire was known (2006-2009) or not (2000-2005), Table 5 illustrates the percentage of agreement between EFD and RDA fires by period and by country. As the table shows, for the smaller fires (10-50 and 50-100 ha), the success in agreement is higher in the period 2006-2009, where the date of each event is available (except for Greece). In fires with size 100-500 ha, the agreement is higher in Spain, Italy and Portugal. Finally, for the largest fires (≥500 ha), the percentage is quite similar in both periods, being around 90% for the whole EUMED.

Table 5 - Level of agreement (%) between fires registered in EFD with fires in RDA by fire size class in EUMED and by country. Comparison between years 2000-2005 (00-05) and 2006-2009 (06-09).

		EUMED		ES		FR		GR		IT		PT	
	Years	00-05	06-09	00-05	06-09	00-05	06-09	00-05	06-09	00-05	06-09	00-05	06-09
Fire size class (ha)	0.01-1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	-	0.0	-
	1-5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	-	0.0	-
	5-10	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-	0.0	-
	10-50	0.6	40.2	0.0	55.2	0.0	55.2	12.5	6.5	0.0	32.7	0.6	53.5
	50-100	2.9	41.2	0.0	46.2	0.0	46.2	57.7	15.8	0.0	25	1.7	61.6
	100-500	5.2	55.8	0.3	68.5	0.3	68.5	45.3	24.8	0.0	47.8	3.5	71.7
	≥500	96.2	89.8	98.9	99.0	98.9	99.0	62.8	71	97.7	95.7	98.8	85

Analysis of agreement between RDA and Hotspots

After assessing the level of agreement between the above mentioned sources, we carried out a comparison between RDA burnt areas and the MODIS Hotspots of the years 2006-2009. For those RDA burnt areas with Hotspots associated we checked the level of coincidence with EFD records previously analyzed.

As mentioned in the methods section, the set of Hotspots was filtered for some known problems to reduce the possibility of having false alarms. We obtained a final set of 17,685 Hotspots for the analysis. The maximum of the minimum distances among neighbors of group of burnt areas with Hotspots assigned was 3,500 m (distance criterion). Then, following the date and distance criteria explained in the methods section a total number of 7,967 Hotspots out of 17,685 (~45%) were assigned to 1,208 fire perimeters (RDA burnt area). The remaining 9,718 Hotspots (55%) were not assigned nor constituted a fire perimeter. Table 6 shows the number and percentage of RDA burnt areas classified by fire class (≥0.1 ha) with Hotspots associated and those that were not linked to any Hotspot. The ones not associated with any burnt area constituted the false negatives or commission errors.

Table 6 - Number and percentage of RDA burnt areas (RDA-BA) classified by fire size class (ha) with Hotspots (HS) associated and no associated.

	Fire size class (ha)						
	0.01-1	1-5	10-50	50-100	100-500	≥500	Total
RDA-BA with HS	1 (100%)	5 (100%)	197 (57.1%)	281 (52.4%)	513 (54.3%)	211 (63.0%)	1208 (56%)
RDA-BA with no HS	0	0	148 (42.9%)	255 (47.6%)	432 (45.7%)	124 (37.0%)	959 (44%)
Total	1	5	345	536	945	335	2167

Table 6 shows 56% of the total RDA burnt areas had Hotspots associated (omission error 44%), while for fires larger than 50 ha the percentage ranges from 52% (50-100 ha) to 63%

in the case of large fires (≥500 ha), with an omission error of 37%.
Regarding the date of detection (Tab. 7), about 58% of the Hotspots assigned to the RDA burnt areas had the same date as the burnt area, reaching 90% of coincidence when detected the same date and two days after.

Table 7 - Number and percentage of Hotspots assigned to RDA burnt areas (RDA-BA) by days of difference within the exact date of the fire event (day "0").

Days of difference	-3	-2	-1	0	1	2	3	4	5	6	7
Frequency of HS assigned to RDA-BA	60	96	406	6254	1982	1019	334	267	127	116	59
% of HS assigned to RDA-BA	0.6	0.9	3.8	58.3	18.5	9.5	3.1	2.5	1.2	1.1	0.6

Figure 2 shows the average RDA burnt area (ha) by group of Hotspots associated and also the average of burnt area with no linked Hotspots. The maximum number of Hotspots assigned to the same burnt area was 317. More than 50% of the RDA burnt areas had equal or less than 4 Hotspots assigned. The range of burnt area with Hotspots assigned went from 0.81 to 45,809.23 ha. As Figure 5 also shows there was a trend regarding the average size of the burnt area and the number of Hotspots that were linked or not to those burnt areas. On average, RDA burnt areas with no Hotspots associated were around 300 ha in size.

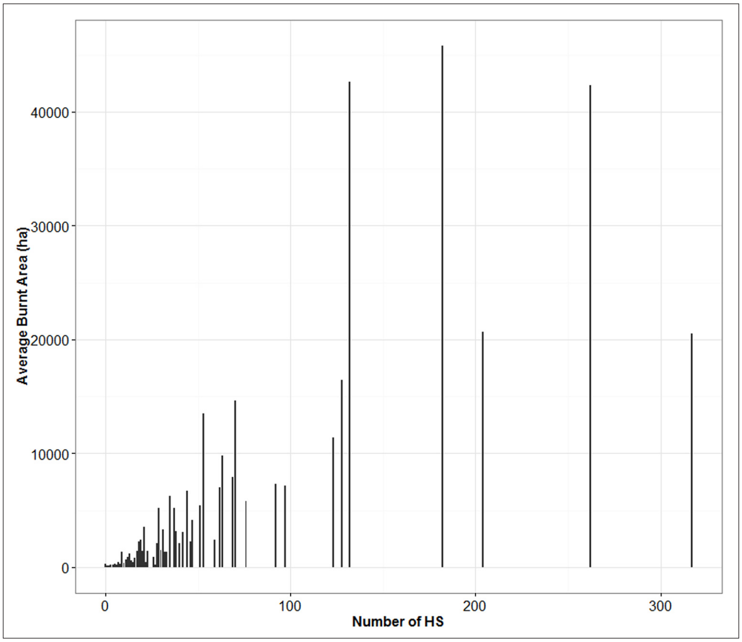

Fig. 2 - Average RDA burnt area (BA) in ha by number of Hotspots (HS) by group of Hotspots number.

The percentage of Hotspots assigned to RDA burnt areas by country and by fire size class is shown in Table 8. The level of agreement increased with the fire size. Hotspots assigned to large fires (≥500 ha) ranged from 32% (Portugal) to 80% (Greece).

Table 8 - Percentage of hotspots assigned by Fire size class in RDA by country in 2006-2009.

Fire size class (ha)	ES	FR	GR	IT	PT
0.01-1	0.0	-	-	-	-
1-5	0.6	-	-	-	-
5-10	-	-	-	-	-
10-50	4.2	6.8	2.7	7.6	9.3
50-100	7.9	11.6	3.0	14.5	16.1
100-500	23.6	24.9	10.4	37.5	42.2
>=500	63.6	56.6	84.0	40.4	32.4

Regarding fire perimeters from the RDA database with Hotspots associated, 989 out of 1,208 had EFD records related (81%). The average number of Hotspots by fire perimeter was 9.8. RDA burnt areas were ~900 ha on average and EFD records ~550 ha. By country, Portugal, Italy and Spain had the highest number of RDA burnt areas linked to Hotspots and EFD data (32%, 31% and 27% respectively), while in France and Greece this number was less than 10%.

To analyze the relationship between the number of Hotspots assigned to the RDA burnt areas linear and quantile regression models were fitted. Table 9 shows the parameters of the linear and quantile regression equations.

Table 9 - Parameters of the linear regression model: estimated coefficient, standard error and significance measured by the p-value. Coefficients for each quantile (quantile regression): 10th, 25th, 50th (median), 75th and 90th.

	Linear regression				**Quantile regression**				
	Estimate	Std.error	t-value	p-value	10th	25th	50th	75th	90th
Intercept	-229.220	46.033	-4.979	7.3e-07***	-28.0419	-49.129	-42.682	-54.681	-27.594
Number of Hotspots	127.073	2.479	51.261	<2e-16***	19.395	38.349	**64.979**	128.940	209.646

Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

According to LR, on average, one Hotspot accounted for around 127 ha. R^2 of the model was 0.68. QR results indicate the relation of burnt area with Hotspots was 19.39, 38.34, 64.97, 128.94, 209.64 at the 10th, 25th, 50th, 75th and 90th quantile respectively (median, 50th quantile, 64.97). The relationship with Hotspots varies across the distribution of burnt area. Figure 3 illustrates the scatter plot of the number of Hotspots assigned to RDA burnt areas, showing the LR, QR (median) and the quantile fit lines.

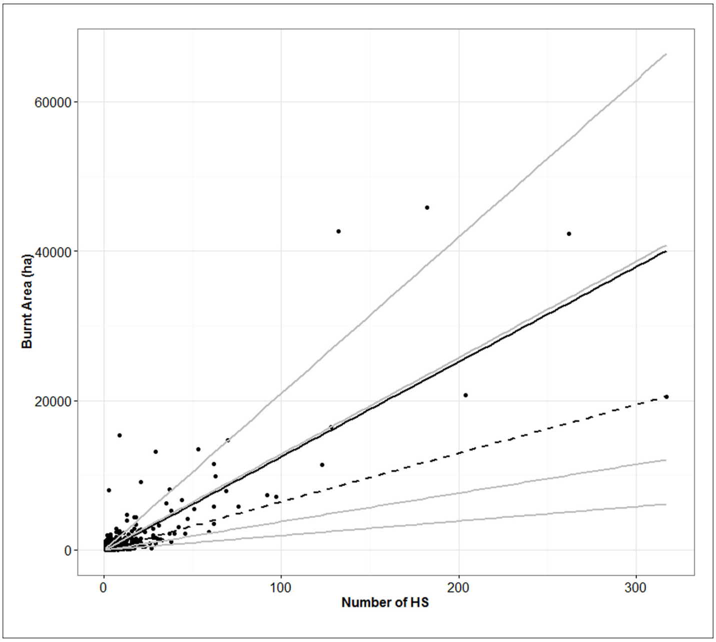

Figure 3 - Comparison of LR fit (black line) with QR quantile 50th or median (dashed line) and quantile fits (grey lines, from bottom to top: 10th, 25th, 75th, and 90th).

The slope varies for each quantile. We found that the influence of number of Hotspots on the lower quantiles of burnt area was smaller than in the midrange and higher quantiles. This influence was smaller but always positive. The outliers biased the slope in the case of linear regression model. For that reason QR, being this a more robust regression, was also explored.

Discussion

In this study we compared EFD (fire statistics) and RDA (burnt area) and how MODIS thermal product (Hotspots) could provide additional information to the above mentioned forest fire data sources. Regarding the assessment of the EFD and RDA databases, the results showed that around 56% of the large fires (≥500 ha) from the EFD were linked to RDA burnt area (fire perimeters). The level of agreement was around 70% in Spain and Greece, 60% in France, 55% in Italy and 45% in Portugal. The level of coincidence increased with the size of the fires. The overall agreement for the EUMED was mainly influenced by the less satisfactory link in the cases of Italy and Portugal, as previously mentioned, where mismatches were found between the location of the events and the differences of the burnt area estimated. Generally speaking, the differences in area size between the EFD and RDA might be due to (1) the different procedures followed by country or region to estimate it (EFD) or (2) the fact the RDA burnt area estimation depends on the MODIS fairly coarse resolution (250 m) [San Miguel-Ayanz et al., 2009], which may not allow distinguishing small burnt areas in some cases, leading to an underestimation of the burnt area.

Fire perimeters from the RDA that were larger than 500 ha were assigned to a correspondent fire in the EFD in 94% of the cases. By country, the level of agreement was higher than 90% except for Greece (68%). This may be due to the small number of reported fire events in the EFD for this country. The agreement increased with the size of the fires, which agrees with the fact that the RDA product maps fires larger than 40 ha, providing a reliable detection of the large fires. Also, when the date of the fires was known (years 2006-2009) the level of agreement increased between RDA fire perimeters and EFD data for fires larger than 10 ha. For large fires (≥500 ha) the matching was higher than 90% no matter the date, except for Greece; it increased from 63% in 2000-2005 to 71% in 2006-2009. Knowing the exact date of the fires allowed us to do a more precise evaluation, large fires were properly detected and mapped independently of the knowledge or not of the date.

The main difficulties found in analyzing the agreement between the two databases were: (1) lack of coincidence in the date of the event; (2) the fact that some fires that were not reported in the EFD; (3) often the exact location of the fire was not reported in the EFD database; (4) country assignment of fires that happened in border areas between countries or regions; (5) presence of fires in which the burnt area covered more than one municipality unit (NUTS5) and which appear in the EFD as more than one record according to the municipalities where they occurred; (6) large differences in burnt area size reported in both sources of information. Most of these issues were solved by doing manually checks, as it was possible to determine if a fire was double counted (border areas, more than one municipality). One of the main issues in the evaluation of the level of agreement between both data sources is the lack of information about the different procedures used by countries or regions to estimate burnt areas.

Regarding the level of agreement between the RDA product and the thermal activity from MODIS (Hotspots) we first analyzed the distance between Hotspots assigned to RDA burnt areas. Then, we decided that the minimum of the maximum distance would be used as reference to group those Hotspots that had not been assigned to a burnt area in the previous step. The chosen distance was 3,500 m, which could be used as an approximation for these Mediterranean areas with similar characteristics of fire occurrence. The results showed that most polygons were those composed of few points (2-6) or even individual Hotspots "polygons". Following the spatial and temporal criteria, more than 90% of these Hotspots were coincident in date or plus/minus 2 days in relation to the date of the burnt area, noting that most fires in the EUMED last a maximum of 2 days (EFD database).

56% of the total RDA burnt areas had Hotspots associated for the period 2006-2009. For fires ≥500 ha the assignation was 63%, with an omission error of 37%. By country, in Portugal, 32.4% of RDA burnt areas ≥500 ha had Hotspots assigned, with approximately 67% of omission error. Hantson et al. (2013) found an omission error of 6% for this country indicating that the RDA product might be underestimating the total burnt area. The best assignment was found in Greece, 80%. During 2007, about 27% of the fires occurred in Italy and Greece, accounting for approximately 79% of the total burnt area in the EUMED countries [Forest Fires in Europe, 2007], with 44% of the RDA burnt areas with no Hotspots associated (omission errors). The no detection of a possible fire by MODIS might be due to several reasons: a fire may have started and ended in the lapse between the satellite overpasses; the fire may have been too small or too cold to be detected in the 1 km^2 MODIS footprint; cloud cover presence; heavy smoke presence; tree canopy that may completely obscure a fire, among others [Giglio, 2010].

Approximately 80% of the RDA burnt areas with Hotspots associated were also related to EFD records. By country this assessment was less satisfactory in the case of Greece, may be due the lack of reported fires in the EFD database.
A reasonable linear relation between the number of Hotspots and RDA burnt area was observed, with a R^2 of 0.68. One hotspot accounted for 127 ha. Hatson et al. [2013] obtained an estimation of 79 ha (they took into account detected and no detected fires). Their global range in the different study areas analyzed was from 68 to 389 ha. Because LR is sensitive to outliers, we also fit a QR. The median (50^{th} quantile) was ~65, lower than the mean value for LR fit. It provided us a better approximation of estimated burnt area from Hotspots.
Hotspots do not provide information about the actual burnt area [Stolle et al., 2004; Miettinen et al., 2007], they represent the centre locations of the 1 km^2 pixels that have been regarded as fire pixels, but the actual size is unknown [Miettinen et al., 2007]. Hantson et al. [2013] mentioned that although MODIS Hotspots had been extensively used for a wide range of fire-related applications, their results indicated they should be used with caution due to the high spatial variability. However, Hotspots could provide additional information about timing, seasonality or location [Eva and Lambin, 1998]. In fact, they are being already used for automatic geo-location of active fires in the RDA burnt area product.

Conclusions

This analysis aimed at analyzing the similarity and complementary of three sources of fire data information in the European Mediterranean region were: EFD (statistics), RDA (burnt area) and MODIS Hotspots. For large fires, most of them were reported in EFD and RDA databases and are coincident in more than 90% of cases, with the exception of Greece (68%). This lower level of agreement may be related to changes in the Greek services in charge of collecting and reporting forest fire statistics. Regarding smaller fires, the reliability decreases. This might be due to the lack of information related to the spatial location, time of the event, or more precise burnt area data in the EFD. The level of agreement increases with the size of fires. Remote sensing allows the enrichment of the fire data reported in the EFD as it provides explicit detailed positioning of the burnt areas in the countries. The MODIS thermal product (Hotspots) provides additional spatial and time data information to the burnt area already mapped. The analysis done in our study does not provide information on the accuracy of each single product. A comparison of each product with an independent dataset would be required for that purpose. Linking statistical and spatial information on forest fires allowed us to enrich the existing database, e.g. patterns of spatial distribution of causes, fire sizes, and location. EFD and RDA in EFFIS provide standardized forest fires information at European and recently in North Africa and Middle East countries, which is used for the decision-making processes, management actions and policy making.

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