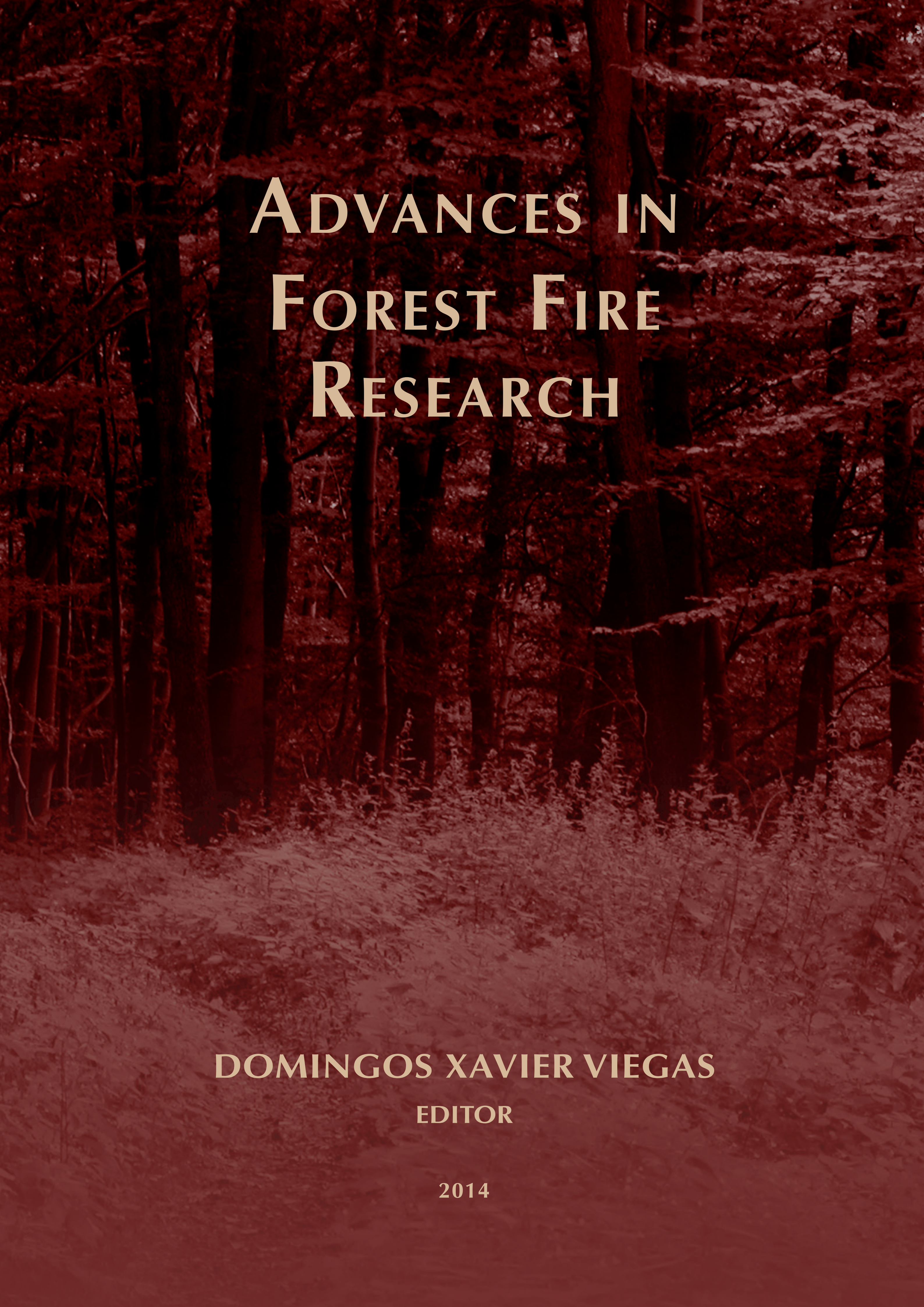

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Daily maps of fire risk over Mediterranean Europe based on information from MSG satellite imagery

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Abstract

Here we present a procedure that allows the operational generation of daily maps of fire danger over Mediterranean Europe. These are based on an integrated use of vegetation cover maps, weather data, and fire activity as detected by remote sensing from space. It is demonstrated that statistical models based on two-parameter Generalized Pareto (GP) distributions adequately fit the observed samples of fire duration and that these models are significantly improved when the Fire Weather Index (FWI), that rates fire danger, is integrated as a covariate of scale parameters of GP distributions. Probabilities of fire duration exceeding specified thresholds are then used to calibrate FWI leading to the definition of five classes of fire danger. Fire duration is estimated on the basis of 15-minute data provided by Meteosat Second Generation (MSG) satellites and corresponds to the total number of hours fire activity is detected in a single MSG pixel during one day. Defined classes of fire danger provide useful information for wildfire management and are on the basis of the Fire Risk Mapping (FRM) product that is being disseminated on a daily basis by the EUMETSAT Satellite Application Facility on Land Surface Analysis (LSA SAF).

Keywords*: Fire danger; Weather; Fire management; Generalized Pareto distribution; Remote sensing.*

1. Introduction

Representing more than 85% of burned area in Europe, the Mediterranean is one of the regions of the world most affected by large wildfires that burn half a million of ha of vegetation cover every year causing extensive economic losses and ecological damage (San-Miguel-Ayanz *et al.* 2013).
Fire in the Mediterranean is a natural phenomenon linking climate, humans and vegetation (Lavorel *et al.* 2007). Fire activity is therefore conditioned by natural and anthropogenic factors. Natural factors include topography, vegetation cover and prevailing weather conditions (San-Miguel-Ayanz *et al.* 2003) which are linked to several atmospheric mechanisms working at different temporal and spatial scales (Trigo *et al.* 2006). At the regional and at the seasonal or inter-annual time scales, rainy and mild winters, followed by warm and dry summers, lead to high levels of vegetation stress that make the region particularly prone to the occurrence of fire events (Pereira *et al.* 2005). At the local and daily scales, extreme weather conditions (e.g. temperature, wind speed, atmospheric stability, fuel moisture and relative humidity) play in turn a key role in the setting and spreading of wildfires (Amraoui *et al.* 2013).
Since 1990 the European Commission has been implementing actions aiming at the organization of a Community forest-fire information system and at the development and implementation of advanced methods for the evaluation of forest fire danger and the estimation of burnt areas at the European scale (San-Miguel-Ayanz *et al.* 2012).

Forecasts of fire danger over Mediterranean Europe up to three days in advance are also currently being disseminated within the framework of the Satellite Application Facility on Land Surface Analysis (LSA SAF, Trigo *et al.* 2011) which is part of the distributed Applications Ground Segment of EUMETSAT (the European Organization for the Exploitation of Meteorological Satellites).
The goal of the present study is to quantify and predict the randomness in the distribution of duration of fire events using statistical modelling, and therefore provide a robust estimation of fire danger instead of a simple characterization using basic FWI statistics.

2. Background

Fire prevention requires adequate knowledge about time when and location where a fire event is likely to happen as well as on the potential damage that may result on wildland and urban values (Finney 2005). These two aspects, respectively referred to as fire danger and vulnerability, constitute the two main components of fire risk assessment (Chuvieco *et al.* 2010). The first component deals with fire behaviour probabilities and wildfire potential assessment that encompasses potential fire ignition, propagation and difficulty of control. The vulnerability component includes the assessment of the negative effects which mainly relate to socio-economic values, degradation potential of soil and vegetation conditions and landscape value.
The focus of the present study is on wildfire potential assessment that is usually based on fire danger rating systems (Fujioka *et al.* 2009), which provide indices to be used on an operational basis for fire prevention management. Because of the availability of near-real time weather observations and forecasts, most of danger rating systems make use of indices that are based on meteorological parameters (Bovio and Camia 1997).
Here, fire danger is rated based on the Fire Weather Index that is part of the Canadian Forest Fire Weather Index System (CFFWIS, Van Wagner 1974). CFFWIS has shown to be particularly suitable as a fire rating system for Mediterranean Europe. Dimitrakopoulos *et al.* (2011) have shown that CFFWIS components, in particular FWI, are suitable to rate fire danger in the eastern Mediterranean. Since 2007, FWI is the main component of the EFFIS Danger Forecast module (San-Miguel-Ayanz *et al.* 2012).
When applied to ecosystems other than Canadian forests, CFFWIS must be calibrated to the new environmental conditions by means of a reliable database of fire events (Carvalho *et al.* 2008). The process of calibration usually involves establishing a set of break points that result from the analyses of fire weather history and time series of the CCFFWIS components, namely FWI (van Wagner 1987). Established break points are then used to define fire danger classes (Kiil *et al.* 1977). In the present study, breakpoints of FWI are based on estimates of fire danger provided by statistical models of fire activity based on the FD&M product from the LSA SAF. The proposed approach has the advantage of rating fire danger based on statistical models of extreme fire events, which allow quantifying the contribution of meteorological factors in terms of increasing or decreasing the probability that the duration of a fire event exceeds a given threshold.

3. Data and methods

3.1. Study area and period

Encompassing Mediterranean Europe, the study area (Figure 1) is delimited by the latitude circles of 35º and 45ºN and the meridians of 10ºW and 37ºE. In order to be consistent with related LSA SAF products, all data fields are mapped in the so-called Normalized Geostationary Projection (NGP) of MSG (EUMETSAT 1999). The MSG pixel resolution is 3 km at the nominal sub-satellite point (0º lat, 0º lon), progressively deteriorating with increasing distance, reaching values of about 5 km over Mediterranean Europe.

Baseline information about land cover is obtained from the 1 km resolution Global Land Cover 2000 (GLC2000) dataset as derived from SPOT-4 VEGETATION (Bartholomé and Belward 2005). GLC2000 data comprise 22 land-use types which were grouped into three main classes of vegetation cover (Figure 1): forests (GLC2000 classes 1, 2, 4 and 6); shrubs (classes 11, 12 and 14); and cultivated areas (class 16). The three main classes were mapped from the original 1 km resolution to the NGP of MSG by assigning to each (~5 km) MSG pixel the most frequent class falling inside that pixel.

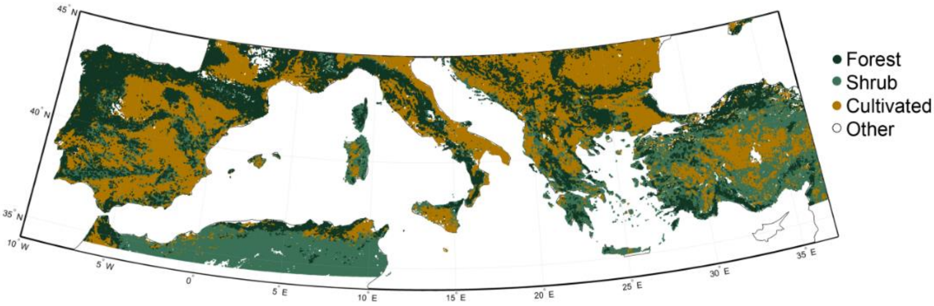

Figure 1. Geographical distribution of the three main vegetation types as derived from GLC2000.

The study covers the months of July and August of 2007, 2008 and 2009. This period may be regarded as representative of fire activity in Mediterranean Europe taking into account the official statistics of burned area provided by the European Commission for Portugal, Spain, France, Italy and Greece.

3.2. Meteorological data

Daily values of FWI over the study area are derived from meteorological fields provided by ECMWF operational model for 12 UTC, covering the period of July and August, from 2007 to 2009. Originally obtained over a 0.25°×0.25° latitude/longitude grid, the meteorological fields were re-projected onto NGP. Data consist of 2-meter air temperature, 2-meter dew point temperature, 10-meter wind speed and 24-hour cumulated precipitation; temperature and dew point were topographically corrected by applying a constant lapse rate of -0.67ºC/100m to the difference between ECMWF (coarser) orography and NGP pixel altitude. Relative humidity of air was computed by combining dew point temperature and temperature according to Magnus' expression (Lawrence 2005). For each pixel and day, anomalies of FWI, hereafter referred to as FWI*, were computed as departures from the 30-year means for the reference period 1980-2009, i.e., the anomaly FWI_{pd}^{*} for MSG pixel *p* and day *d* is defined as*:*

$$FWI_{pd}^{*} = FWI_{pd} - \overline{FWI}_{p} \tag{1}$$

where FWI_{pd} is the value of FWI for pixel *p* and day *d* and $\overline{FWI}_{p}$ is the time mean performed for that pixel and day over the 30-year reference period.

3.3. Fire activity and duration

Information on fire activity every 15 min on an MSG pixel basis is available from the above-mentioned FD&M product that is currently generated within the framework of the LSA-SAF (Trigo *et al*. 2011). Duration of fire δ may be estimated by summing the number detected fires in a given pixel *p* and a given day *d* during the study period. For each pixel *p*, at day *d*, there are 96 observations (one every 15 min) made by the SEVIRI instrument on-board MSG. Let $\mathbf{I}_{pd}(i)$ be an indicator function that is equal to one if the i^{th} MSG image has captured fire activity inside pixel *p* during day *d* and is equal to zero otherwise. The fire duration δ_{pd}, for pixel *p* during day *d*, is defined as:

$$\delta_{pd} = 0.25 \times \sum_{i=1}^{96} \mathbf{I}_{pd}(i) \tag{2}$$

Units of δ are hours, the coefficient 0.25 converting into hours the sampling interval of 15 min between consecutive MSG images. Fire duration δ may be viewed as a proxy of fire intensity and burn extent but it should be noted that δ is not to be interpreted as the duration of individual fire events.

3.4. Statistical models of fire duration

The statistical distribution of fire duration δ is modelled using the Peaks Over Threshold (POT) approach (Pickands 1975), which is a commonly used tool to quantify fire danger (de Zea Bermudez *et al.* 2009). The POT approach uses the Generalized Pareto (GP) distribution as a model to assign probabilities to the exceedances of duration δ over a threshold, *i.e.* to values $x=\delta-\delta_{\min}$ (with $\delta>\delta_{\min}$) where $\delta_{\min}$ is a prescribed minimum value (de Zea Bermudez and Kotz 2010b).
The GP probability density function g is given by:

$$g(x \mid \alpha,\sigma)=\frac{1}{\sigma}\left(1+\frac{\alpha}{\sigma}x\right)^{-1-\frac{1}{\alpha}} \tag{3}$$

where x is the exceedance, and α and σ are the shape and scale parameters. The corresponding GP cumulative distribution function is:

$$G(x \mid \alpha,\sigma)=1-\left(1+\frac{\alpha}{\sigma}x\right)^{-\frac{1}{\alpha}} \tag{4}$$

When $\alpha<0$ the distribution is upper bounded, with $0 < x < -\sigma/\alpha$. A complete description of the GP distribution may be found in de Zea Bermudez and Kotz (2010a).
The minimum threshold $\delta_{\min}$ is estimated using a graphical approach (Coles 2001) where the chosen value is such that the sample mean of the values exceeding successive thresholds larger than $\delta_{\min}$ becomes a linear function when plotted against the respective thresholds.
Once $\delta_{\min}$ is determined, the shape (α) and the scale (σ) parameters are estimated using the maximum likelihood method (Grimshaw 1993); 95% confidence intervals for α and σ are asymptotically estimated using normal distributions for α and for log(σ) (Kotz and Nadarajah 2000). Goodness of fit is assessed by means of the A^2 test (Anderson and Darling 1952), a nonparametric test that is especially appropriate to models based on long-tailed distributions.
For each vegetation type, POT is applied to the exceedances x of all fire pixels that were recorded during the study period (July-August 2007-2009). Obtained models, hereafter referred to as static models, may be improved by incorporating daily anomalies, FWI*, as a covariate of scale parameter in the GP distributions, in particular by assuming a linear dependence of σ on FWI*:

$$G(x,FWI^* \mid \alpha,a,b)=1-\left(1+\frac{\alpha}{a\times FWI^*+b}x\right)^{-\frac{1}{\alpha}} \tag{5}$$

Estimates of shape parameter (α) and of coefficients of the linear relationship $\sigma=a\times FWI^*+b$ are again obtained using the maximum likelihood method. Performance of the new alternative models, hereafter referred to as daily models, is compared against the respective null models (i.e. the original static models) by using the so-called standard likelihood ratio test (Neyman and Pearson 1933). The test is based on statistic Λ defined as:

$$\Lambda = 2(\ln L' - \ln L) \tag{6}$$

where L is the maximum likelihood function of the static model and L' is the maximum likelihood function of the daily model.

3.5. Meteorological danger

Static models allow estimating baseline danger D_{b0} which represents the probability that exceedance x is above a given fixed threshold x_0:

$$D_{b0} = D_b(x_0) = 1 - G_{static}(x_0 \mid \alpha, \sigma) \tag{7}$$

Conversely, the threshold value of exceedance x_0, corresponding to a specified level of baseline danger, D_{b0}, may be estimated, for each vegetation cover, by inverting the previous relationship:

$$x_0 = x(D_{b0}) = G_{static}^{-1}(1 - D_{b0}) \tag{8}$$

In a similar way, daily models allow estimating daily danger D_d which represents the probability that exceedance x is above a given fixed threshold x_0 for a given value of FWI*:

$$D_d(x_0, FWI^*) = 1 - G_{daily}(x_0, FWI^* \mid \alpha, a, b) \tag{9}$$

The role played by meteorological conditions on wildfire potential may then be uncovered by defining meteorological danger D_m, which combines information about static and daily danger for a given day and pixel according to the following procedure:

1. A given threshold of baseline danger, D_{b0}, is fixed over the entire study area;
2. For each vegetation cover, baseline thresholds of exceedances x_0 are computed using the appropriate static models of fire duration (Eq. 8);
3. For each day and pixel location, daily models are then used to estimate daily danger, D_d, based on the corresponding baseline threshold and the observed daily value of FWI* (Eq. 9);
4. Meteorological danger, D_m, is finally defined by the ratio of daily danger D_d to prescribed baseline danger D_{b0}:

$$D_m(x_0, FWI^*) = \frac{D_d(x_0, FWI^*)}{D_{b0}} \tag{10}$$

Meteorological danger provides a coherent basis to set break points in FWI* to be used in the definition of classes of meteorological fire danger. Given a baseline danger D_b, break point BP_L will be defined as the value of FWI* associated to meteorological danger L, i.e.

$$D_m(x_0, BP_L) = \frac{D_d(x_0, BP_L)}{D_{b0}} = \frac{1 - G_{daily}(x_0, BP_L \mid \alpha, a, b)}{D_{b0}} = L \tag{11}$$

Values of BP_L may be estimated by inverting the previous equation e.g. using the bisection method (Faires and Burden 1985).

4. **Results**

4.1. **General characteristics of fire duration**

Duration of fire activity for the three vegetation types (Table 1) is characterized by long tailed distributions, with values of δ <3 h representing about 85, 82 and 94% of the sample in the case of forest, shrub and cultivated areas, respectively . Besides being less frequent in both absolute and relative terms, duration of fire activity in cultivated areas has a shorter tail than duration in forest or shrub. For instance the relative frequencies of very long lasting fire activity (δ>12 h) over forest and shrub are 0.52 and 0.89% respectively, about three times and more than five times the value of 0.17% corresponding to cultivated areas. Long-lasting fire episodes are therefore more expected through shrub land and forests than over agricultural areas, a result in close agreement with findings in previous works either at the scale of the Mediterranean basin (Fernandes, 2013) or at the national levels of Portugal (Barros and Pereira 2014), Spain (Moreno *et al.* 2011) and Italy (Bajocco and Ricotta 2008). Such differences in land cover burning are likely to be driven by different interacting factors which include fuel connectivity, topography, population density, meteorological conditions and fire suppression (Brotons *et al.* 2013). For instance, the proximity of agricultural lands to populated areas and the social and economic value attributed to agricultural activities is expected to steer an increase of the level of effort in fire suppression and therefore to a decrease in the likelihood of large fire events (Moreira *et al.* 2010).

Table 1. Distribution frequencies of fire activity for the three types of vegetation. The distributions of fire activity refer to the study period of July-August 2007-2009; for each class the absolute frequency is shown together with the relative frequency (% in brackets).

Classes of duration δ (h)	0.25 to 3.00	3.25 to 6.00	6.25 to 9.00	9.25 to 12.00	12.25 to 15.00	15.25 to 18.00	18.25 to 21.00	Total
Forest	3 321	387	128	34	15	4	1	3 890
[%]	*[85.37]*	*[9.95]*	*[3.29]*	*[0.87]*	*[0.39]*	*[0.10]*	*[0.03]*	*[100.00]*
Shrub	2 240	292	114	47	17	7	0	2 717
[%]	*[82.44]*	*[10.75]*	*[4.19]*	*[1.73]*	*[0.63]*	*[0.26]*	*[0.00]*	*[100.00]*
Cultivated	2 205	118	23	4	3	1	0	2 354
[%]	*[93.67]*	*[5.01]*	*[0.98]*	*[0.17]*	*[0.13]*	*[0.04]*	*[0.00]*	*[100.00]*

4.2. **Static models**

Results from the previous exploratory analysis suggest choosing POT and use GP distributions to model the exceedances of duration δ for each vegetation type. For each vegetation type, a common minimum threshold of 3 h was therefore set for δ_{min}. The largest scale (σ) parameter is the one for shrub, followed by forest and cultivated areas (Table 2). The shape (α) parameters are negative for all vegetation cover types, indicating that exceedances are upper limited. The largest negative value is also the one for shrub, followed by forest and cultivated areas. The predominant effect of the scale (σ) parameter on the fitted GP models becomes apparent when plotting the cdf curves for the three vegetation cover types (Figure 2), the shrub model presenting the longest tail, followed by forest and cultivated areas.

4.3. **Daily models**

The role played by meteorological factors may be assessed by looking at the impact of FWI on fire activity. The dataset of exceedances x for each vegetation type was subdivided into subgroups associated with different ranges of FWI; 51 groups of fire pixels were defined as respectively associated with values of FWI between percentile 0 and percentile 50, between percentile 1 and percentile 51, and so on up to between percentile 51 and percentile 100. GP distributions were then adjusted to each subset and plots were made of estimated values of scale σ versus the mean value of FWI in the considered range.

For all types of vegetation cover, the scale (σ) parameter tends to linearly increase with increasing FWI. Each type presents a characteristic range of FWI, the largest values being observed for shrub and the lowest for forest. There is a close relationship between vegetation cover and range of FWI. However the spatial distribution of FWI is affected by other factors than vegetation. For instance, the Eastern and Southern borders of the Mediterranean basin present higher values of FWI. The impact of regional effects other than vegetation may be mitigated by replacing daily values of FWI at a given pixel by respective departures (FWI*) from 30-year means for the reference period 1980-2009.

Table 2. Static GP models for each vegetation type. Columns 1-5 indicate the following: vegetation type, sample size and corresponding percentile of original data sample (% in brackets), estimated values and 95% confidence intervals (in brackets) of the shape (α) and scale (σ) parameters, and confidence levels (CL) of the Anderson-Darling tests.

Vegetation type	Sample size [Percentile]	α	Σ	CL
Forest	569 *[85%]*	-0.06 *[-0.13,0.02]*	2.92 *[2.61,3.26]*	98%
Shrub	477 *[82%]*	-0.14 *[-0.22,-0.05]*	3.70 *[3.27,4.18]*	93%
Cultivated	149 *[94%]*	-0.01 *[-0.15, 0.12]*	2.31 *[1.87,2.86]*	91%

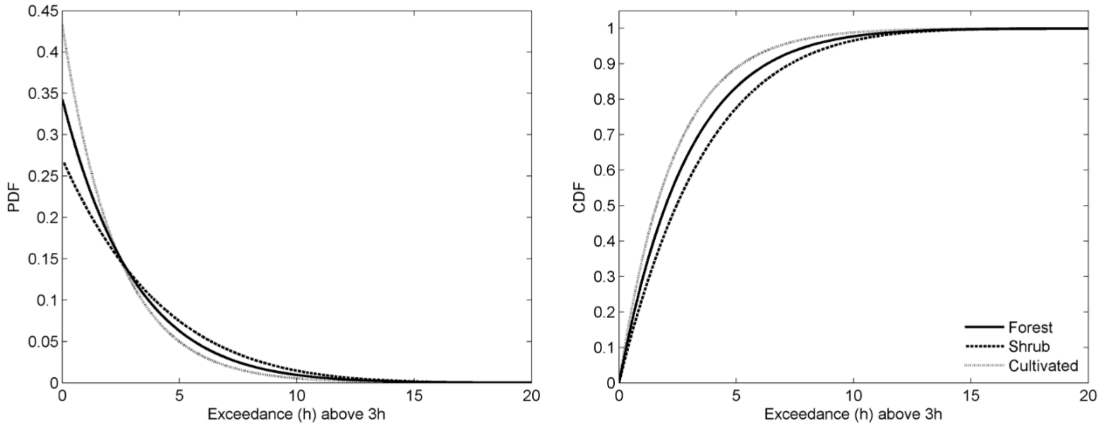

Figure 2. Probability density functions (left panel) and cumulative distribution functions (right panel) of fitted GP models of exceedances x=δ-δmin (with δmin = 3 h) for forests (solid curve), shrubs (dashed curve) and cultivated areas (dotted curve).

Impact of meteorological conditions was therefore modelled by introducing FWI* as a covariate of the scale parameter of the GP models using linear relationships of the type σ=a+b×FWI* (Table 3). In all cases p-values of the maximum likelihood ratio test are lower than 0.5% meaning that the null hypothesis that the daily models have a better fit than the corresponding static ones cannot be rejected at the 0.5% significance level. The sensitivity of scale parameters to changes in FWI* also reflect on the probabilities of exceedance of duration (Figure 3).

Table 3. Daily GP models for each vegetation type. Columns 2-4 indicate the following: shape (α) parameter, dependence of scale (σ) parameter on FWI* and p-values of the maximum likelihood ratio tests.

Vegetation type	α	σ=a+b×FWI*	p-value (%)
Forest	-0.074	σ=2.04 + 0.038×FWI*	1.39×10^{-5}
Shrub	-0.15	σ=2.37 + 0.052×FWI*	1.20×10^{-6}
Cultivated	-0.027	σ=1.33 + 0.042×FWI*	0.46

4.4. **Calibration of FWI**

For each vegetation type the respective static and daily models were used to compute the dependence of meteorological danger D_m on FWI* (Eq. 10). For a fixed baseline danger D_b = 33%, four break points of FWI* were obtained, respectively associated to levels of meteorological danger of 0.25, 0.50, 0.75 and 1.00. Estimates of break points (Table 4) were obtained by solving Eq. (11) using the bisection method. The three vegetation types present differences that are worth being noted. The largest value of the baseline threshold of fire duration (associated to baseline danger D_b=33%) is the one of shrub (x_0=3.8 h) followed at similar intervals of about 0.6-0.7 h by forest (x_0=3.1 h) and cultivated areas (x_0=2.5 h). The four defined break points allow defining five classes of meteorological fire danger, respectively "low" when $D_m < 0.25$, , "moderate" when $0.25 \leq D_m < 0.5$, "high" when $0.5 \leq D_m < 0.75$, "very high" when $0.75 \leq D_m < 1$ and "extremely high" when $D_m \geq 1$.

Table 4. Break points of FWI* for each vegetation type. Lines 2-6 indicate the following: baseline threshold of fire duration (x0) associated to a fixed baseline danger (D_b=33%) and break points of FWI* ($BP_{0.25}$, $BP_{0.50}$, $BP_{0.75}$ and $BP_{1.00}$) corresponding to different levels (L) of meteorological danger D_m (0.25, 0.50, 0.75 and 1.00, respectively).

	Forest	Shrub	Cultivated
x_0	3.1 h	3.8 h	2.5 h
$BP_{0.25}$	-17.5	-10.4	-6.5
$BP_{0.50}$	-4.7	0.8	-2.9
$BP_{0.75}$	8.7	12.6	12.8
$BP_{1.00}$	24.0	26.2	24.1

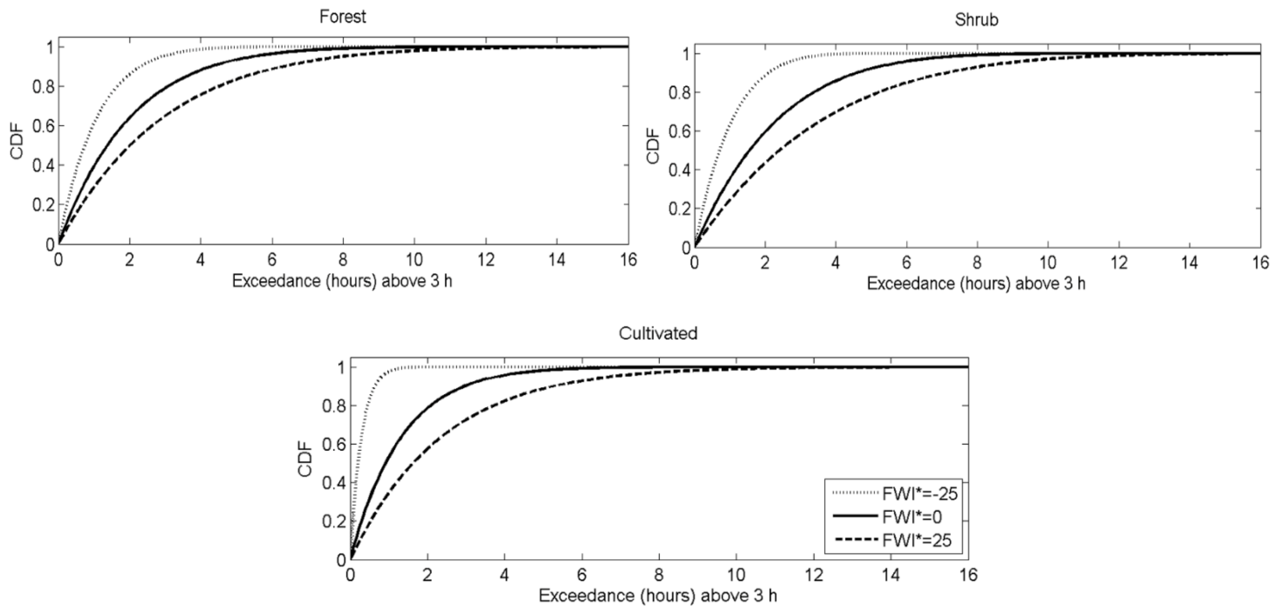

Figure 3. Cdf curves for three fixed values of FWI* (-25, 0 and +25) in the case of the daily GP model for forests (top left panel), shrubs (top right panel) and cultivated areas (bottom panel).

5. **Discussion**

The case of August 25th 2007, when Greece and Albania were struck by very severe fire events, provides an interesting example of the obtained product that is worth analysing in detail. Two impressive clusters of fire pixels with duration longer than 6 hours may be observed over Greece

(Figure 4, bottom panel). The larger cluster spreads over western Peloponnese and contains a large number of fires that lasted more than 12 hours, and the other one locates over eastern Attica and Evia. The map of classes of fire danger (Figure 4, top panel) shows that both clusters are part of a large core labelled "extremely high" which covers the entire territory of Greece and extends eastwards into Anatolia and towards the northeast over Bulgaria and Romania up to Crimea. An event lasting more than 12 hours also occurred in Albania, inside a large patch labelled "very high" which covers the territories of Albania, Montenegro and Bosnia and Herzegovina, and extends towards the northeast up to Ukraine. No fire events occurred in regions labelled "low", and "moderate".

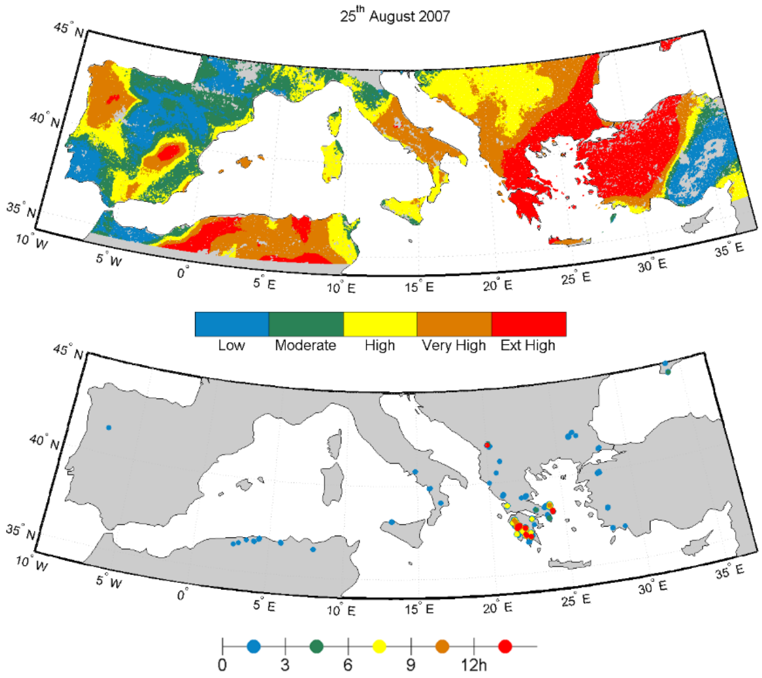

Figure 4. Map of classes of fire danger (top panel) and corresponding spatial distribution of observed fire events and respective duration (bottom panel) for August 25th 2007. Colorbars identify classes of fire danger (upper panel) and fire duration (lower panel).

An assessment of the global consistency (in space and time) of results obtained was performed by analysing, for the entire study area and the entire study period, the number of observed events that belong to a given interval of fire duration and were assigned to a given class of fire danger (Table 5). The percentage of fires within any given duration interval (***bold italics***) steadily decreases with decreasing danger, with the exception of fires of very short duration (less than 1h) where the "high" class is the modal one. Such decrease is especially steep in the cases of the upper intervals of duration. With the exception of fires of very short duration where the fraction is only 1%, there is no fire activity in the case of "low" danger. When considering fixed classes of danger, it may be noted that the percentage of events associated with any given duration interval (<u>*underlined italics*</u>) always decreases with increasing duration, the steepest declines being observed in the lower danger classes.
When looking at maps of classes of fire danger (Figure 4) it may be noted that areas of "high" and "very high" fire danger spread over regions where no fire activity is detected. This is to be expected since both static and daily models allow computing probabilities of exceedance provided there is an event with minimum duration of 3 h.

6. Conclusions

The calibration approach adopted in this study is based on an integrated use of information about meteorological conditions provided by the European Centre for Medium-Range Weather Forecasts (ECMWF), vegetation land cover from Global Land Cover 2000 (GLC2000) and fire duration as detected by the SEVIRI instrument on-board Meteosat Second Generation (MSG) satellites. The main difference of the proposed methodology to existent others is that it takes full advantage of the temporal resolution of SEVIRI that allows detecting fire events every 15 minutes. This information is used to make daily records of fire duration that are essential to calibrate meteorological danger and establish classes of fire danger. Traditional approaches rely on calibration procedures performed through analyses of fire weather history based on ground observations of amount of burned area or number of fire occurrences. Several factors may affect the reliability of ground observations; recorded values are not only determined by visual inspection which may nevertheless affect their accuracy but they are also determined by the policy of individual countries, which may further change in time (Pereira *et al.* 2011). Approaches based on the use of satellite data have the advantage of being more consistent in space and time. They also benefit from not depending on the availability of ground fire records from each country, which are neither easily obtainable, nor available in the short term.

Finally, it is worth stressing that the Fire Risk Mapping (FRM) product is entirely based on a set of estimated probabilities, in particular meteorological danger. These probabilities are derived from statistical models that may be readily updated and continuously tuned, which represents an advantage from the operational point of view. The fact that the FRM product is currently being disseminated within the framework of the Land Surface Analysis Satellite Application Facility (LSA SAF) will also allow tailoring the product according to specific needs of a broad community of users.

Table 5. Distribution of fire events by classes of fire danger and by fire duration. Each cell contains the number of observed daily fire events (first line), the corresponding fraction (%) of the total number of events with the same fire duration interval (second line, bold italics) and the corresponding fraction (%) of the total number of events in the same class of fire danger (second line, underlined italics).

	Classes of fire danger					
Duration (hours)	Low	Moderate	High	Very high	Extremely high	All Classes
0 – 1	68	634	2111	1853	1327	5983
	1 *99*	***11*** *89*	***35*** *75*	***31*** *66*	***22*** *53*	***100***
1 – 2	1	46	361	379	382	1169
	0 *1*	***4*** *6*	***31*** *13*	***32*** *13*	***33*** *15*	***100***
2 – 3	0	14	132	215	225	586
	0 *0*	***3*** *2*	***22*** *5*	***37*** *8*	***38*** *9*	***100***
3 – 6	0	12	180	267	338	797
	0 *0*	***2*** *2*	***23*** *6*	***33*** *9*	***42*** *14*	***100***
6 – 9	0	7	29	77	150	263
	0 *0*	***3*** *1*	***11*** *1*	***29*** *3*	***57*** *6*	***100***
9 –12	0	0	6	28	51	85
	0 *0*	***0*** *0*	***7*** *0*	***33*** *1*	***60*** *2*	***100***
12 – 15	0	0	2	8	25	35
	0 *0*	***0*** *0*	***6*** *0*	***23*** *0*	***71*** *1*	***100***
15 – 18	0	0	1	3	8	12
	0 *0*	***0*** *0*	***8*** *0*	***25*** *0*	***67*** *0*	***100***
> 18	0	0	0	0	1	1
	0 *0*	***0*** *0*	***0*** *0*	***0*** *0*	***100*** *0*	***100***
All durations	69	703	2822	2830	2507	8931
	100	*100*	*100*	*100*	*100*	***100***

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