Abstract

Wildfires are a major concern in Europe, especially in Mediterranean countries, where warm and dry spring and summer conditions may lead to high levels of vegetation stress. During summer months, Mediterranean countries suffer frequent large-scale fire episodes with dramatic consequences for the ecosystems and population but late winter and spring fires should not be disregarded in some southern European areas. This is particularly true in Continental Portugal where time series of burnt area show a positive trend since the early 80’s together with a large inter-annual variability.

We describe an operational procedure for assessing fire risk in Continental Portugal on a daily basis. The procedure is currently being developed within the framework of the Satellite Application Facility on Land Surface Analysis (LSA SAF) and consists of the following three main steps; i) characterising the background conditions associated to the heat and water stress of vegetation according to the late spring hydro-meteorological regime, ii) characterising on a daily basis the meteorological conditions that favour the onset and propagation of wildfires during the fire season, and iii) evaluating the fire risk taking into account both background and meteorological conditions.

Heat and water stress of vegetation is evaluated by means of statistical models that relate the amount of burnt area during the fire season with averages of relevant meteorological parameters (e.g. temperature and precipitation) over spring. The impact on vegetation of meteorological conditions is evaluated based on information provided by the Canadian Fire Weather Index (FWI).

INTRODUCTION

Mediterranean regions are especially prone to the occurrence of wildfires due to their type of climate, i.e., rainy and mild winters followed by warm and dry summers (Ventura and Vasconcelos, 2006; Pyne, 2006).

In Portugal wildfires are mostly a summer problem and although the observed increase in burnt area is partially attributable to changes in farming and land-use, inter-annual variability is partly due to temperature and precipitation conditions in the preceding spring season and partly to the occurrence of atmospheric circulation patterns of short-duration that induce extremely hot and dry spells over western Iberia. It is also worth noting that the spatial distribution of wildfires in Portugal is far from being homogeneous. For instance, fire occurrences are more frequent in the littoral that is highly populated, but fire damages are much more relevant in the central southern regions characterized by rural abandonment, elderly population, large area of forests, shrublands or a mixture of both type of vegetation and more prone to drought and heat waves (Pereira et al., 2005; Pereira et al., 2006).

The present work is being developed within the framework of the Satellite Application Facility on Land Surface Analysis (LSA SAF) and its aim is twofold: i) to present results from the prototype that is currently running in the parallel chain of the LSA SAF System and ii) to show how this information may be used for fire risk management in Portugal.
DATA

Data consisted on:

- A fire database provided by DGRF that contains detailed information about each fire event (e.g. date and time of ignition and extinction, the district where the fire started and the amount of burnt area) in Continental Portugal, within the period 1980-2007;

- Meteorological data respecting to daily values at 1200 UTC, averaged over Continental Portugal, of surface temperature and relative humidity, 10m wind speed and 24 h cumulated precipitation. The data were derived from large-scale gridded fields as retrieved from the National Centers for Environmental Prediction (NCEP) Reanalysis data sets for the period 1980-2007 (Kalnay et al., 1996; Kistler et al., 2001). It may be noted that reanalysis data were derived through a consistent assimilation and forecast model procedure that incorporated all available weather and satellite information.

THE RISK OF FIRE MAPPING (RFM) PRODUCT

Fire risk assessment is based on the so-called Canadian System (Figure 1). The system uses surface weather parameters (temperature, precipitation, wind velocity and relative humidity) and consists on six standard components that provide numerical ratings of relative wildland fire potential. The first three components (FFMC, DMC and DC) are fuel moisture codes that follow daily changes in the moisture contents of 3 classes of forest fuel with different drying rates. The other three components are fire behaviour indices, representing rate of spread (ISI), amount of available fuel (BUI) and fire intensity (FWI).

![Figure 1. Structure of the FWI Canadian System.](image)

A second fire index, the so-called Daily Severity Rating (DSR), may be derived from FWI. DSR is a function of FWI and was specifically designed to rate the difficulty of fighting and extinguishing a wildfire; it gives a measure of the human effort required to fight a fire (Figure 2).
Figures 3 and 4 show examples of the fire charts that are currently being produced in the parallel chain of the LSA SAF. Figure 3 presents an example of the fires that have occurred in Italy on the 24th of July, 2007. It is worth noting that fires inside the circle in the MODIS image correspond to high values of FWI (red pixels inside the circle).

Figure 3. Example of fires in Italy on the 24th of July, 2007. Red dots in the bottom left panel represent fires; pixels in red in the bottom right panel limited by a circle correspond to high values of FWI.

Figure 4 shows a very large fire that occurred in Algarve (South of Portugal) on the 12th of September, 2003. Again fires recorded by MODIS appear as red pixels in the FWI map. It is worth noting that red pixels in Alentejo are not to be taken into account, since this region is a bare soil area and therefore not prone to wildfires.

Figure 4. Example of a very large fire in Portugal on the 12th of September, 2003. Pixels limited by a circle in the right panel represent active fires; red pixels in the left panel limited by a circle correspond to high values of FWI.
FIRE MANAGEMENT IN PORTUGAL

In order to evaluate the relevance of DSR as a fire risk indicator we have analysed the relationship between daily DSR and the logarithm of daily burnt area. Figure 5 shows an example for 2003 and 2007.

Figure 5. Scatter plot of DSR vs. logarithm of burnt area for the years of 2003 (black dots) and 2007 (open circles).

The scatter plot in Figure 5 clearly shows that low (high) values of DSR correspond to low (high) values of the logarithm of burnt area. However, intermediate values tend to be associated to high (low) values of burnt area in 2003 (in 2007). The differences between 2003 and 2007 point out that DSR is just an indicator of how prone is vegetation to burn due to meteorological factors and that it is up to the user to evaluate the real risk, taking into account other non-meteorological factors (e.g. vegetation stress).

We have therefore performed an exploratory analysis aiming to evaluate the relationship between burnt area and meteorological conditions along the year. For that purpose we classified years based on the values of the terciles of burnt area and we have then computed monthly composites of temperature and precipitation for severe years (i.e. values of burnt area above the second tercile) and weak years (i.e values below the first tercile) in the period 1980-2007 and respective anomalies, defined as departures from the mean over the considered period.

Figure 6. Monthly anomalies for (a) temperature and (b) precipitation. Black dots and open circles respect to severe and weak years, respectively.

Obtained results are shown in Figure 6 and it is well apparent that severe (weak) years are characterised by colder and wetter (warmer and drier) early spring (March and April) that favour (inhibit) vegetation growth, warmer and drier (colder and wetter) late spring (May and June) contributing to (preventing) vegetation stress and hot and dry (cold and wet) summers (July and August) that favour (inhibit) fire ignition.

Taking into account that DSR depends on both temperature and precipitation, we have also computed its monthly anomalies for severe and weak years as shown in Figure 7. It may be noted that higher (lower) values of DSR in late spring and summer that favour (inhibit) vegetation stress and consequently fire ignition.
In summary, two factors have to be considered when evaluating the risk of fire associated to a given DSR; i) the background meteorological conditions associated to the temperature and precipitation regimes during spring and ii) the occurrence of days characterised by extreme synoptic situations.

The scatter plot in Figure 5 strongly suggests choosing a linear model that uses daily values of DSR to predict daily amounts of the logarithm of burnt area, i.e., using the following regression model:

$$ \log(BA)_{day} = a_1 + a_2 \times DSR_{day} $$

where $a_1$ and $a_2$ are the regression coefficients to be estimated.

The regression model was calibrated using daily values of logarithm of burnt area and of DSR during July and August, from 1980 up to 2007. Obtained coefficients were $a_1 = 1.3597$ and $a_2 = 0.0889$ and values of RMSE and of correlation were respectively 0.64 and 0.63.

The robustness and performance of the developed model was assessed by performing a leave-one-out-cross validation (LOOCV), which in this case refers to one year, and then using a set of measures of prediction accuracy as derived from contingency tables (Tables 1 and 2).

<table>
<thead>
<tr>
<th>Modelled</th>
<th>Weak</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td>367</td>
<td>146</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>154</td>
<td>225</td>
<td>194</td>
</tr>
<tr>
<td></td>
<td>52</td>
<td>202</td>
<td>336</td>
</tr>
</tbody>
</table>

Table 1. Contingency table of observed daily classes of fire events during July and August vs. corresponding predicted classes using the regression model in LOOCV mode.

The used measures of prediction accuracy were sensitivity (or probability of detection), specificity and overall correctness (or hit rate). Sensitivity corresponds to the ratio of the total number of correctly classified events (years in a certain class) to the total number of events; specificity refers to the ratio of total number of correctly classified non-events (years that do not belong to the class) to the total number of non-events; overall correctness is simply the fraction of well classified events by the model.

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Correctness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>64.0</td>
<td>82.3</td>
<td>76.3</td>
</tr>
<tr>
<td>Moderate</td>
<td>39.3</td>
<td>70.1</td>
<td>59.9</td>
</tr>
<tr>
<td>Severe</td>
<td>56.9</td>
<td>77.8</td>
<td>70.7</td>
</tr>
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</table>

Table 2. Measures of prediction accuracy as derived from the contingency table (see Table 1).

Analysis of contingency table and prediction accuracy measures show that the performance of the model is reasonable; however the two extreme classes present a very large amount of misclassified
events, i.e., 60 events in the weak class were classified as severe and 52 events in the severe class were classified as weak. These results led us to consider including the meteorological background effect into the model. Accordingly, we developed a new linear regression model adding a new predictor, the mean cumulated DSR from 15th of May until the day before:

$$\log(BA)_\text{day} = A_1 + A_2 \times \left(\overline{DSR}_{\text{cum}}\right)_{\text{day}-1} + A_3 \times DSR_{\text{day}}$$

where $A_1$, $A_2$ and $A_3$ are the regression coefficients. Obtained coefficients are $A_1 = 0.5897$, $A_2 = 0.0953$ and $A_3 = 0.0745$ and values of RMSE and correlation are 0.57 and 0.73, respectively.

Obtained results for LOOCV (Tables 3 and 4) clearly show that taking into account the background meteorological conditions brings a significant improvement, both in the contingency table and in the accuracy measures.

<table>
<thead>
<tr>
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<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weak</td>
<td>399</td>
<td>150</td>
<td>24</td>
</tr>
<tr>
<td>Moderate</td>
<td>138</td>
<td>253</td>
<td>182</td>
</tr>
<tr>
<td>Severe</td>
<td>36</td>
<td>170</td>
<td>384</td>
</tr>
</tbody>
</table>

Table 3. As in Table 1 but for the model based on daily DSR and mean cumulated DSR.

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Correctness (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weak</td>
<td>69.6</td>
<td>85.0</td>
<td>80.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>44.2</td>
<td>72.5</td>
<td>63.1</td>
</tr>
<tr>
<td>Severe</td>
<td>65.1</td>
<td>82.0</td>
<td>76.3</td>
</tr>
</tbody>
</table>

Table 4. As in Table 2 but for the model based on daily DSR and mean cumulated DSR.

The improvement is especially conspicuous in the total of correctly classified cases (increase in the number of cases in the diagonal, from 928 to 1036) as well as in total misclassified events in the two extreme classes (decrease from 60 to 24 and from 52 to 36 on the weak and severe classes, respectively).

Figure 8 shows two examples, for 2003 and 2007, of the positive impact of the background effect in the performance of the model. In both cases it is notorious that the background effect tends to approximate the predicted burnt area to the observed one, although the model tends to underestimate burnt areas in severe years (2003) and to overestimate in weak years (2007).
Figure 8. Observed (black dots), modelled including (open circles) and excluding (asterisks) the background effect of burnt area in July and August, for 2003 (upper panel) and 2007 (lower panel).

For operational purposes, days were characterised in terms of three classes of risk (i.e. weak, moderate and severe). Figure 9 shows an example for 2005 of the observed and modelled logarithm of burnt area in terms of magnitude and class type. The overall good agreement in observed and predicted time series is well apparent in both magnitude and class types.

Finally, results that were operationally obtained during the summer season of 2008 are shown in Figure 10. Although, daily observations are not yet available, DGRF released the total burnt area in Continental Portugal for July and August. The observed and modelled burnt area values are 3000 ha and 15000 ha, respectively, which confirms the good performance of the developed model.

Figure 9. Observed (dots) and modelled (open circles) logarithm of burnt area in July and August, for 2005. Green, yellow and red respect to weak, moderate and severe classes, respectively.
REFERENCES


