USING AVHRR IMAGERY TO IMPROVE THE OFFICIAL DATABASE OF WILDFIRES IN PORTUGAL

Teresa J. Calado and Carlos C. DaCamara

Abstract

Forested areas cover circa 38% of Continental Portugal and the observed increasing trend in the extent and severity of wildfires points to the need for accurate and timely knowledge of the total burnt area. The official fire database (1980-2006) is the one provided by the Portuguese Forest Service (DGRF) and is based on information supplied by fire and forest services. Since 1990, maps of burnt areas have been yearly produced based on information from Landsat-TM. A recent study for the period 1984-1989 has pointed out severe discrepancies between ground- and satellite-based data, raising the need to devise procedures aiming to correct such discrepancies. The present work presents a method that makes use of NOAA/AVHRR imagery to assign dates to burnt scars on end of season maps as the ones derived from Landsat-TM. We begin by degrading the end of season map to the AVHRR scale. Then we build up a fuzzy Sugeno-type model that assigns to each AVHRR pixel the “possibility” of representing a burnt area. The model uses as input values channels 2 and 4 of AVHRR and is trained using the Landsat-TM end of season map. The model is then applied to individual images. Burning dates are assigned to each pixel based on a fuzzy clustering procedure to time series of outputs from the Sugeno model. The developed method presents the advantage that it does not require any a priori assumptions (e.g. pre-defined thresholds) about the characteristics of the radiative signature of burnt scars. We will present the results obtained for summer 2005 and discuss the potential of the developed method to improve the long-term official database of wildfires in Portugal.

INTRODUCTION

Mediterranean regions are some of the most affected by wildfires, which have become a major source of concern for environmental security. In particular, the seriousness of wildfire activity in Continental Portugal led to the urgent need for accurate databases of the number and time of occurrence of wildfire events as well as of the extent of associated burnt areas (e.g. Rego, 1992).

The main source of fire statistics information for Portugal is the official database that is provided by the Portuguese Forest Service (DGRF) based on information by fire and forest services. Each fire record contains information on fire initial location from the district down to the parish scales, date and time of ignition and extinction, total burnt area and type of burnt terrain. Remote sensing is another useful source of information (e.g. Chilar, 2000) and instruments of different spatial, temporal and spectral characteristics, e.g. AVHRR on-board NOAA platforms, TM on-board Landsat and MODIS on-board TERRA and AQUA, have been widely used for wildfire monitoring and management.

Since 1990, the Department of Forest Engineering (DEF) of the Portuguese Institute of Agronomy (ISA) has been using Landsat-TM information to produce maps of burnt areas, but recently it has extended the study to a period prior to 1990, i.e. from 1984 to 1989. Table 1 shows a comparison between the yearly amounts of burnt areas as provided by DGRF and Landsat-TM (J.M.C. Pereira, personal communication). Severe discrepancies are well apparent between the two datasets. Differences range from a factor of 1.4 to 2.2 and raise the problem of identifying the sources of errors.
as well as of devising procedures aiming to correcting the errors at different temporal scales, from the monthly up to the weekly or daily levels.

<table>
<thead>
<tr>
<th>Year</th>
<th>DGRF (ha)</th>
<th>Landsat-TM (ha)</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1984</td>
<td>52,710</td>
<td>116,872</td>
<td>2.22</td>
</tr>
<tr>
<td>1985</td>
<td>146,254</td>
<td>291,944</td>
<td>2.00</td>
</tr>
<tr>
<td>1986</td>
<td>89,522</td>
<td>113,161</td>
<td>1.26</td>
</tr>
<tr>
<td>1987</td>
<td>76,269</td>
<td>137,785</td>
<td>1.81</td>
</tr>
<tr>
<td>1988</td>
<td>22,434</td>
<td>31,499</td>
<td>1.40</td>
</tr>
<tr>
<td>1989</td>
<td>126,237</td>
<td>204,060</td>
<td>1.62</td>
</tr>
<tr>
<td>TOTAL</td>
<td>513,426</td>
<td>895,321</td>
<td>1.74</td>
</tr>
</tbody>
</table>

Table 1. Total burnt areas as derived from DGRF and Landsat-TM for the period 1984-1989.

The present work demonstrates how NOAA-AVHRR imagery may be used to assign dates of burning to scars as identified on an end of fire season map derived from Landsat-TM. Assignment of dates of burning to scar pixels is based on an operational method that relies on fuzzy logics concepts both in space using 0-order Sugeno model (Takagi and Sugeno, 1985; Sugeno and Kang, 1988) and time using C-means (Duda and Hart, 1973; Duda et al., 2000; Stork and Yom-Tov, 2004).

DATA

Data consisted on:

- An end of season fire map as derived from Landsat-TM, consisting of a vector map of burnt scars as obtained from visual interpretation and on-screening digitising. The spatial resolution is 30 m and the data were kindly provided by DEF/ISA;

- Two sets of remote-sensed data for Portugal, covering the month of August 2005 (Table 2):

  1. NOAA-AVHRR raster images of the morning and/or early afternoon orbits for channels 1 (0.58 - 0.68 μm), 2 (0.72 – 1.10 μm), 3 (3.55 – 3.93 μm), 4 (10.3 – 11.3 μm) and 5 (11.5 – 12.5 μm). The images were retrieved from the database of by the Portuguese Meteorological Institute and pre-processing was performed using an orbital model, relying on satellite ephemeris data supplied by the NAVY Space Surveillance Centre. In order to obtain precise georegistration positional accuracy of 1 km RMSE, image navigation was based on data from Digital Chart of the World Database (DCW) to extract identifiable features such as coastlines, water bodies, and rivers and to correlate them with the matching raw image. Adequately navigated and attitude corrected images were then resampled to the Universal Transverse Mercator (UTM) WGS 84 North, zone 29 projection.

  2. MODIS data from TERRA and/or AQUA, consisting of daily vector maps (based on morning and/or afternoon orbits) of burnt scars as obtained from visual interpretation and on-screening digitising of RGB colour composites of channels 7 (2.105 μm – 2.155 μm), 2 (0.8411 μm – 0.876 μm) and 1 (0.620 μm – 0.670 μm). The spatial resolution is 250 m and the data were also provided by DEF/ISA.

- DGRF information respecting the month of August 2005, containing the date and time of ignition and extinction, the district where the fire started and the amount of burnt area.

MODIS data together with in situ DGRF information were used for validation purposes.
<table>
<thead>
<tr>
<th>Day of Month</th>
<th>AVHRR (UTC)</th>
<th>MODIS</th>
<th>Day of Month</th>
<th>AVHRR (UTC)</th>
<th>MODIS</th>
</tr>
</thead>
<tbody>
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<td>4</td>
<td>-</td>
<td>X</td>
<td>15</td>
<td>11:40</td>
<td>X</td>
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<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>16</td>
<td>11:17</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
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<td>-</td>
<td>17</td>
<td>10:55</td>
<td>X</td>
</tr>
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<td>7</td>
<td>11:23</td>
<td>X</td>
<td>18</td>
<td>-</td>
<td>-</td>
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<td>X</td>
<td>19</td>
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<td>X</td>
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<td>9</td>
<td>10:38</td>
<td>-</td>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>-</td>
<td>-</td>
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<td>11:03</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>-</td>
<td>X</td>
<td>22</td>
<td>10:40</td>
<td>X</td>
</tr>
<tr>
<td>12</td>
<td>-</td>
<td>-</td>
<td>23</td>
<td>13:52</td>
<td>X</td>
</tr>
<tr>
<td>13</td>
<td>10:46</td>
<td>-</td>
<td>24</td>
<td>13:42</td>
<td>X</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>-</td>
<td>25</td>
<td>13:32</td>
<td>X</td>
</tr>
</tbody>
</table>

*Table 2. Data availability for August 2005. Days with both AVHRR and MODIS are in bold.*

**PRE-PROCESSING**

The different spatial resolutions of the end of season map as derived from Landsat-TM (30 m) and AVHRR (1.1 km) make the combination of information a complex task. Degradation of the Landsat-TM map to the AVHRR scale was performed by simply counting the number of TM pixels inside a given AVHRR pixel and then computing the fraction of burnt pixels. As a result of the degradation process, a number between 0 and 1 was assigned to each AVHRR pixel (Figure 1), a value of 0 (1) indicating an AVHRR pixel containing no (totally filled by) burnt Landsat-TM pixels.

*Figure 1. End of fire season map as derived from Landsat-TM information degraded to NOAA-AVHRR scale.*

Pixels partially or totally contaminated by clouds were masked by applying thresholds to reflective (channels 1 and 2) and thermal (channel 5) AVHRR channels. Dark pixels contiguous to cloud masks that did not remain dark in the following image were classified as cloud shadows and also masked. Finally, a water mask was obtained by applying a subtractive clustering method (Chiu, 1994) to AVHRR channels of a clear sky image.

In order to mitigate the effects of day-to-day variability e.g. due to changes in illumination conditions, viewing angles and surface heating, we have normalised NOAA-AVHRR channels of unmasked pixels. Normalisation was performed taking into account the land cover type and for this purpose pixels were grouped into three different classes (Figure 2a), that were obtained by means of a cluster analysis (C-means). Finally, a composite based on normalised images was built choosing the pixel with minimum reflectance value from the 3 pixels with highest temperature (Figure 2b).
IDENTIFICATION OF BURNT AREAS

We began by performing several sensitivity studies over burnt and non-burnt areas in order to determine which AVHRR channels presented the greatest discriminating power. In this context, a principal component analysis was performed on the normalised composite for all pixels and restricting to those pixels that, according to the end of season map, appeared as burnt ones (i.e. all pixels with a fraction of burnt area greater than 0). A sigmoid was then fitted to PC2 (PC1) vs. fraction of burnt area if all pixels (only burnt pixels) were considered. A statistical analysis showed that restricting to burnt pixels would give better results and that AVHRR channels 2 and 4 were the ones with higher discriminating ability.

The sigmoid-type of relationship between PC1 and fraction of burnt areas suggested developing a 0-order Sugeno model using pairs of channel 2 and channel 4 as input and fraction of burnt areas as output. The output sigmoid curve (Figure 3a) may be viewed as expressing the degree of membership of each pixel to the set of burnt pixels, i.e. it gives an indication of the “possibility” of a pixel to be identified as burnt. We also computed a histogram of the errors, i.e. the difference between membership values and fraction of burnt Landsat-TM pixels when degraded to AVHRR scale (Figure 3b), and verified that the model presents a good performance, which is confirmed by values of RMSE and BIAS of 0.3 and -0.004, respectively.

The model was then applied on each NOAA-AVHRR image. Figure 4 shows an example for August 24 of obtained membership values; the redder the pixel the higher is the possibility of being burnt.
DATING BURNT SCARS

Once burnt areas were identified in every NOAA image, we proceeded with dating the scars. For that purpose we applied the C-means, a method based on fuzzy clustering.

Since the purpose was to date the scars as identified by Landsat-TM, methodology was only applied to pixels identified as burnt in the end of fire season map.

The method consisted in the following steps:

1. Choose a burnt pixel as identified in the end of season map;
2. For the considered pixel define for a given day, \( d \) the index, \( i_d \), as follows:
   \[
   i_d = \mu_d \times \mu_{d+1}
   \]
   where \( \mu_d \) and \( \mu_{d+1} \) are the degree of membership of the pixel to the set of burnt pixels in day \( d \) and day \( d + 1 \), respectively as obtained from the 0-order Sugeno model.

   It may be noted that index \( i \) expresses the “possibility” of burning and is based on the characteristic of persistence of the radiance signature that is to be expected in a freshly burnt pixel.

3. Assign each index \( i \) of the considered time series to one of the two clusters (i.e. burnt and no-burnt) as obtained using the C-means algorithm;
4. Identify the earliest index \( i \) that belongs to the cluster of burnt pixels (i.e., associated to the highest centre). Let \( D \) be the selected day. The day of fire ignition is then chosen as the one that presents the maximum degree of membership between days \( D \) and \( D + 1 \);
5. The procedure continues until all burnt pixels have been processed.

The major advantage of the developed method is that thresholds to identify the day of ignition of a fire are dynamic. A pseudo-colour end of season map showing dates of burning of each scar is presented in Figure 5. A zooming of a particular scar is also shown. It may be noted that, excluding a few number of pixels (mostly in the border of the scars, e.g. blue pixels in the bottom of the zoomed scar), dates of burning present spatial continuity, which indicates that the method has consistency.
RESULTS AND CONCLUSIONS

Validation of the model was performed by comparing the amount of daily and cumulated burnt areas as obtained from the three sources of data for Continental Portugal (Figure 6) i.e. MODIS, AVHRR and in situ data. Validation was also performed on a district by district basis (Figure 7).

Figures 6a) and 7a) show a generally good agreement between the two remote sensing data, since discrepancies in the amount of burnt areas in consecutive days may be due to differences of orbital times of passage. In what respects to Figures 6b) and 7b) of cumulated burnt area all sources of information present similar trends although both NOAA and MODIS tend to underestimate the amount.
of burnt areas. However these differences may be attributed to differences in spatial resolution and to the fact that in situ data are based on visual estimation.

In order to evaluate the ability of AVHRR to assign dates to burnt scars, differences between assigned dates of burnt pixels based on AVHRR and MODIS databases were assessed by computing deviations of AVHRR estimated dates from the MODIS ones (Figure 8).

Figure 8. a) Differences between initial dates of burnt area pixels as obtained from AVHRR and MODIS; b) Histogram of differences.

The mean (bias) and the standard deviation of differences between estimated AVHRR and MODIS dates are -0.2 and 2.2 days, respectively. The first quartile, the median and the third quartile are -1, 0 and 1 days, respectively. On the one hand value of bias reflects a very slight negative skewness of the distribution of deviations, an indication that there might be a tendency of NOAA dates to occur earlier than the TERRA/AQUA ones, but on the other hand value of median is 0, showing that both satellites are well synchronised. Results are however quite encouraging, especially if one notes that deviations between -1 and +1 days represent 68% of the total and may be simply explained in terms of lags between orbital times of passage of NOAA and TERRA/AQUA.

REFERENCES


