USING REMOTE SENSING AND GIS FOR GLOBAL ASSESSMENT OF FIRE DANGER

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ABSTRACT

Forest fires are an important environmental concern worldwide, since they are the main source of land cover transformation in Tropical areas, and severely affect temperate forest, by transforming land protection factors, modifying biodiversity and the hydrological cycle and increasing soil erosion.

Several attempts to assess fire danger conditions have been undertaken in the last years for different spatial and temporal scales. The use of Geographic Information Systems (GIS) and satellite data are becoming more common in those attempts, since they provide a spatial comprehensive view of some fire danger factors.

This paper presents the results of the fire danger component of the Spread project, a European funded project which tried to assess fire risk conditions at several spatial scales. Within this project, a GIS database covering all the EUMed countries (Portugal, Spain, Italy, Greece and Southern France) was developed. The fire danger assessment system included an estimation of fuel moisture content derived from satellite data (live fuels) and meteorological variables (dead fuels), as well as an estimation of the historical patterns of human-caused fires, and the fire propagation potential, generated from fire-behaviour simulation programs. The results were derived for the whole EUMed area at 1x1 km grid size spatial resolution (with the exception of meteorological data that were only available at 50x50 km^2 grid sizes, and NOAA-AVHRR images with 4.4 x 4.4 km^2 pixel size). The resulting product shows promising potential for helping fire managers in simulating different danger scenarios, as well as to obtain a single evaluation of fire danger conditions for the whole EUMed area.size

INTRODUCTION

Forest fires are a critical natural hazard in many regions of the World, where fire is used as a tool for land use change or pasture improvement. Additionally, fire is a recurrent factor in Mediterranean areas, with dry and warm summers that favour the occurrence of fire ignition and propagation. Every year, millions of hectares are burned in Tropical, Boreal and Mediterranean forest (Morgan et al. 2001), which causes a wide variety of effects, from atmospheric emissions (Palacios-Orueta et al. 2004), to soil erosion, biodiversity loss and drainage alterations (Ahern et al. 2001).

Reduction of those negative effects of fire require to improve current fire risk assessment methods. Within the European project Spread (http://www.adai.pt/spread/) a fire risk integration scheme was proposed and tested in several study sites. This paper presents a review of this scheme and its application to the European Mediterranean area, covering the Southern territory of the EU, which is the most severely affected by fires. The Fire Risk Index includes two components, related to danger and vulnerability (Chuvieco et al. 2003). The former refers to the potential that a fire occurs in a particular area and time on one hand, and to its propagation capability on the other. The other component of fire risk is named fire vulnerability, and concerns the potential effects of a fire, either on human values and lives and environmental resources. The final index should be computed as the product of the two components. Within this paper, the danger component of the fire risk index will be covered.

METHODS

1. Scheme for fire danger estimation

Fire danger is considered in a broad perspective, covering the probability of a fuel to ignite (ignition danger) and the potential hazard that this fire propagates in space and time (propagation danger). The consideration of both components forms the wildland fire danger assessment (WFDA), as illustrated in figure 1. This paper presents the generation of the different input variables, as well as the integration of them in a single danger index. The study area covers the whole European Mediterranean basin (EUMed), including most Portugal and Spain (the Azores and Canary islands were excluded), Italy, Greece and the Southern part of France. The index includes the estimation of risk associated to human factors, to live and dead fuel moisture conditions, and to the estimation of propagation behaviour. Other factors, such as risk associated to lighting, and vulnerability, could not be derived for the whole EUMed, and will need to be worked out in future projects. All the input variables are geographically referenced and included into a dedicated Geographic Information System (GIS), which was distributed to potential end-users (fire brigades, fire managers) through a cartographic web server.

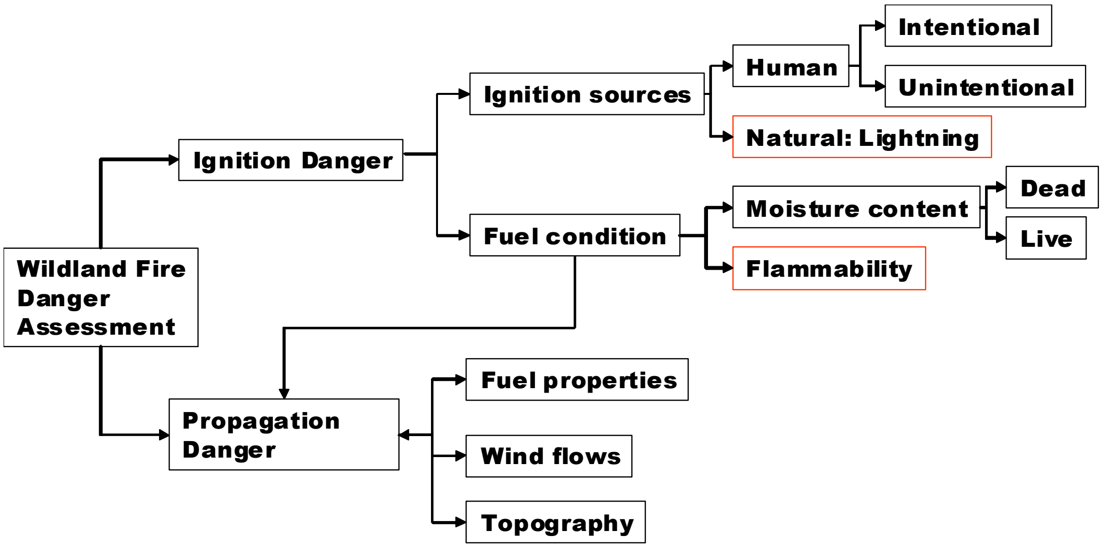

Figure 1: Structure and components of the Wildland Fire Danger assessment (WFDA)

2. Generation of input data

2.1. Human component.

The human danger ignition layer was generated from historical data of fire occurrence. A probability surface was generated from the location of ignition points using the kernel density approach. Kernel density estimation is based on the estimation of the density at each intersection of a grid superimposed on the data, after placing a probability density (kernel) over each point event (Gatrell et al. 1996, Levine 2002). It has been introduced in fire occurrence by Koutsias et al. (2002, 2004) for assessing fire occurrence patterns at landscape level by addressing some of the inherent positional inaccuracies of the fire ignition locations. De la Riva et al. (2004) applied also the kernel density to express however fire occurrence patterns at municipality level by using fire ignition observations.

The number of fires observed at community level for the period 1992-2000 has been calculated from national fire statistics and expressed using the community centroids. The adaptive kernel density estimation mode has been chosen due to the non-homogeneous spatial distribution of community centroids. The adaptive approach allows for the adjustment of the bandwidth size in relation to the concentration of the interpolated points (Worton 1989). Locally varying bandwidth size of 10 community centroids proved to perform best showing a reasonable variability in the resulting density surfaces avoiding an under- or over-smoothing. To avoid over- or under-estimation within and among countries because of heterogeneities of different sources we processed the kernel density values within each country before merging them. Actually kernel densities have been reclassified to 10 classes based on the equal area criterion within each country, presupposing equivalence for fire hot spot areas among the countries.

The kernel density interpolation produced continuous, fire occurrence density surfaces, which in the Mediterranean context is mainly related to human fire danger factors, and therefore can be considered as a static representation of fire danger associated to human factors thorough a whole fire season. Figure 2 shows the results of this exercise, which provides a global view of fires, which are mainly caused by human factors, with higher occurrences in the NW of Spain and Portugal, SW of Italy and Greece, the Southern part of the maritime Alps, and most territory of Corsica and Sardinia.

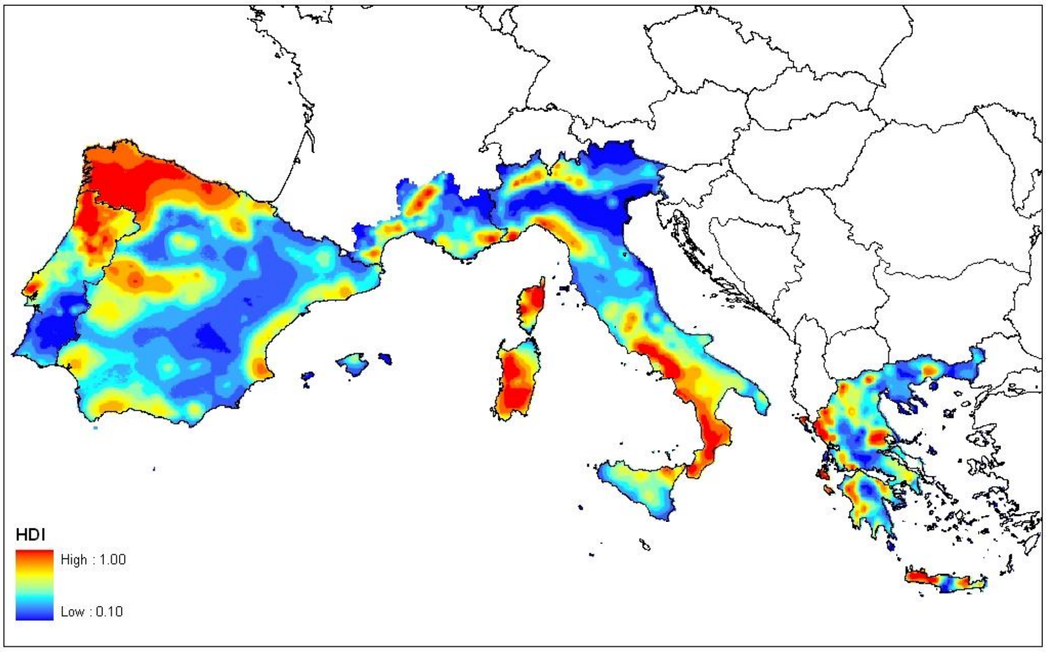

Figure 2: Fire ignition danger in Southern Europe: an estimation of human fire danger factors spatial distribution

2.2. FMC of live fuels

The estimation of Fuel moisture content (FMC) of live fuels was based on an empirical formula derived from satellite data. Moisture content is expressed as percent of dry weight. The formula was generated for grasslands and shrublands based on multitemporal series of NOAA-AVHRR images ((Chuvieco et al. 2004b)). The index has been derived and tested in Central Spain. For the calibration study, AVHRR images were acquired daily at the University of Alcala's HRPT receiving station, but 8-day composites were created to avoid cloud and atmospheric contamination. The compositing criterion was maximizing surface temperature of the daily series.

For extending this experience to the whole area covered by EU Mediterranean countries, we used the 10-day NDVI composites of MARS NOAA-AVHRR images produced by the Joint Research Centre (JRC). The composites were derived from LAC data resampled from the original 1.1x1.1 nadir resolution to 4.4x4.4 km^2 pixel size. To maintain the original time sequence used for the developing the empirical formula for FMC estimation, in the application to the EUMed area the 10-day composite was updated every 8 days. In addition auxiliary information on the extents of grasslands and shrublands in each pixel needed to be derived. This information was extracted from the Corine land cover map of Europe, version 1990, since the updating to 2000 was not yet available for the whole territory.

Figure 3 shows an example of the FMC generated from AVHRR images for the whole EUMed area. The higher contents were observed in the Northern part of Spain, Italy and Greece, while the lowest values were found in South of Italy, the East of Greece and most central and Southern Spain.

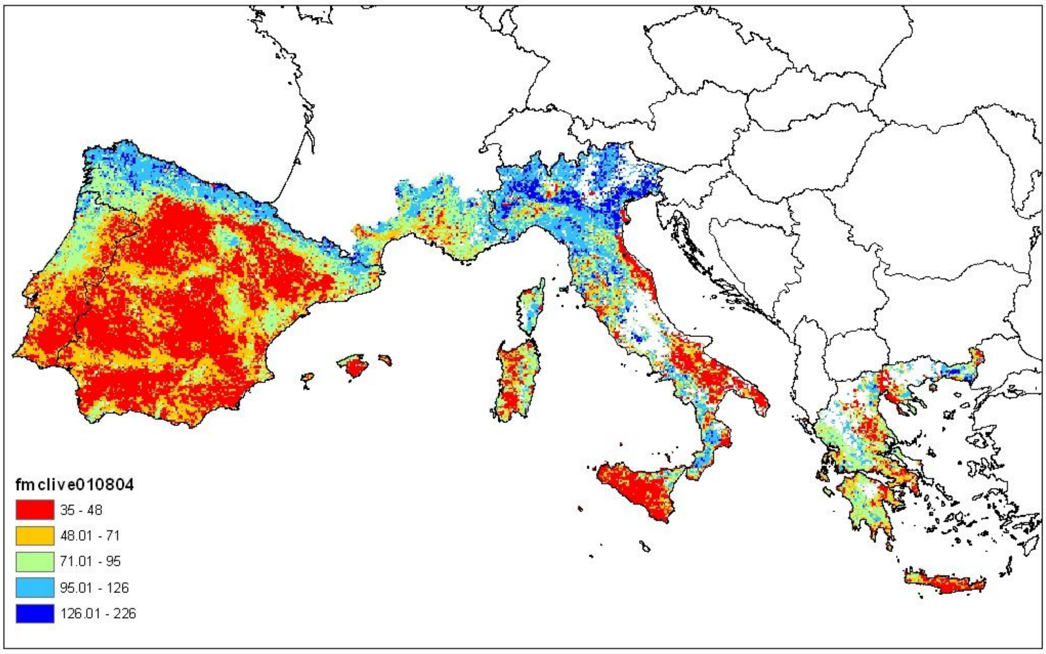

Figure 3: FMC of live fuels for the first week of August, 2004

2.3. FMC of dead fuels

This map is based on the 10h moisture code of the USA National Fire Danger Rating System, which requires a basic set of input meteorological variables (air temperature and relative humidity). It was shown that this index can be used to estimate the average FMC of dead fuels in Central Spain (Aguado et al., in preparation), the area used as calibration site. Additional testing should be done in other Mediterranean regions for operational use. The index was computed every day with weather observation taken at noon. Moisture content was expressed as percent of dry weight.

The meteorological data to compute the index were extracted from the MARS database maintained at the JRC. The spatial resolution of this database is 50x50 km^2. The index was computed daily and transferred to the Internet mapserver developed for the semi-operational testing of the summer of 2004.

Figure 4 shows the spatial distribution of FMC estimated from meteorological variables for the same period as for the figure 3 (in this case, just a single day, instead of an 8-day period). As it can be observed, the spatial patterns are similar in the two figures , in spite of being generated from two very different sources

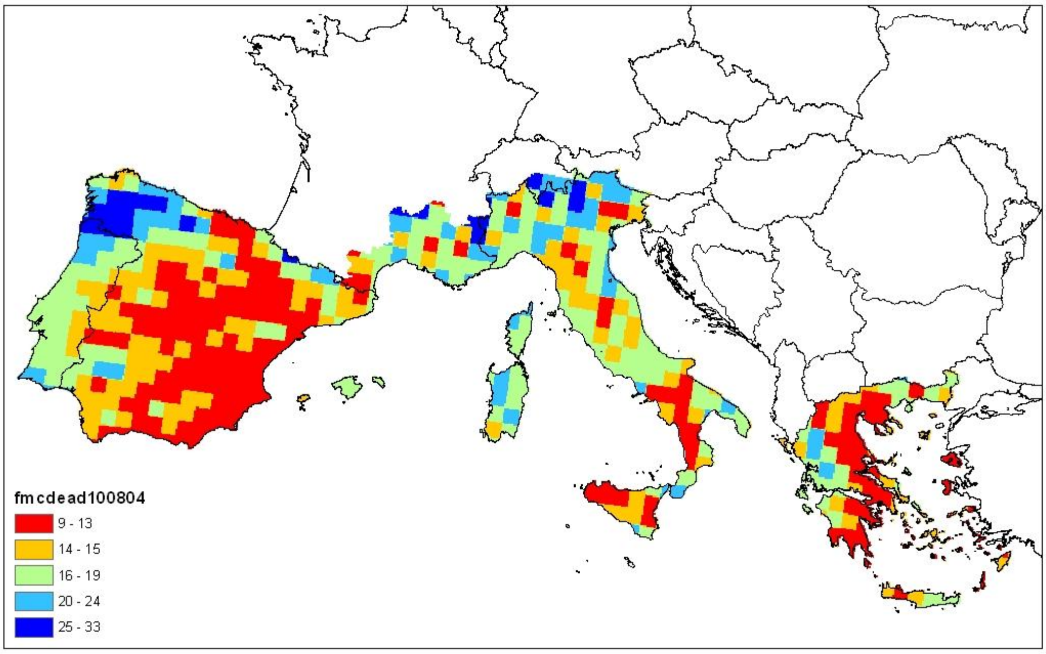

Figure 4: Estimation of FMC for dead fuels. Map from 10th August 2004

2.4. Probability of Ignition (PI) related to the FMC

This index was derived from a combination of the two previous products. Both dead and live FMC were converted first to probability of ignition, based on average values of moisture of extinction ME (Chuvieco et al. 2004a). The values of ME are dependent on the fuel complex, and therefore a fuel type map with a ME parameter defined for each fuel type is required to derive this index. Since no fuel map of Europe with such a specification is yet available, an estimation of fuel type distribution was extracted from the CORINE land cover and a ME value assigned to each fuel type. Once the FMC of dead and live fuels and their respective PI were obtained, a global PI for each pixel was computed following:

$PI_f = PI_{live}$ * Live proportion + PI_{death} * Death proportion

Live and Dead proportion express the fraction of live and dead fuel particles in each pixel, which is also dependent on the fuel type. As a first approach, this map was again generated from the CORINE land cover map.

Figure 5 shows an example of the PI_f map computed for the same days as shown in previous figures. It should be considered as an integration of the fuel moisture status of dead and live fuels. The spatial resolution of the AVHRR data improves the resolution provided by the MARS meteorological database, and therefore, geographical patterns are more evident in the final product

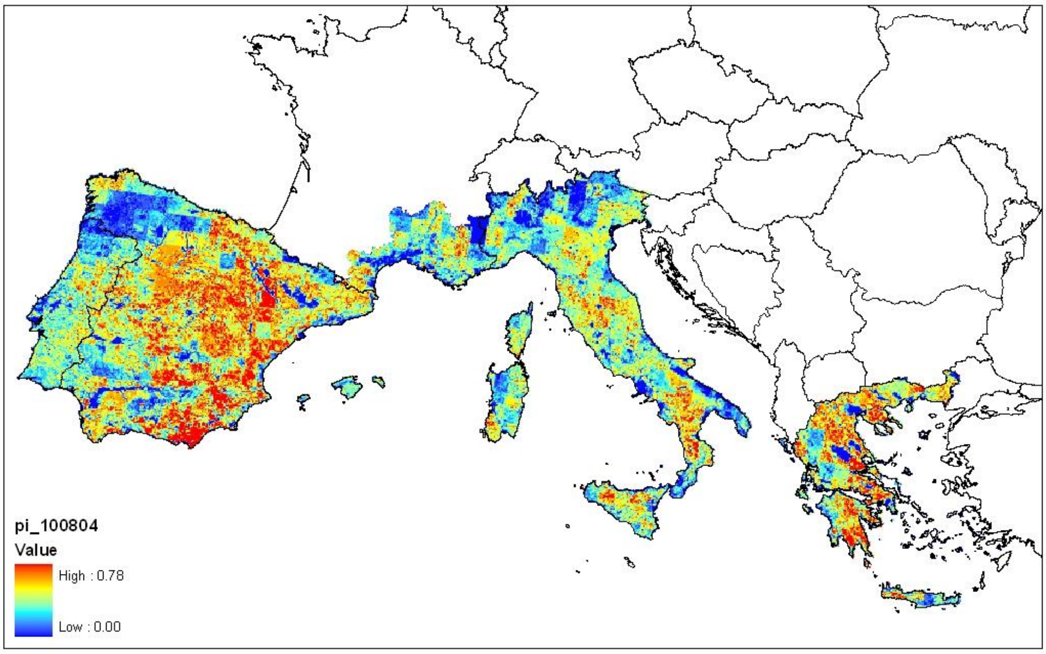

Figure 5: Probability of ignition from FMC of 10th August 2004

2.5.Average rate of spread (RoS) and Flame Length (FL)

In order to obtain a global view of risk associated to fuel loads, terrain characteristics and wind flows, a global simulation analysis was performed. This analysis tried to obtain average values of rate of spread and flame length, considering different wind and topographic conditions for the estimated fuel maps of the whole EUMed area. This attempt should be considered as a general overview of average expected fire behaviour at global scale, in order to rank different danger levels according to the combination of fuel and terrain spatial patterns. The estimation of the average RoS was based on several simulations performed by the Autonomous University of Barcelona for different fuel types, slope ranges and wind flows.

As a simulation kernel the wildland simulator proposed by Collins D. Bevins, which is based on the fireLib library (Collins, 1996) were used. **fireLib** is a library that encapsulates the BEHAVE fire behaviour algorithm (Morgan et al., 2001). In particular, this simulator uses a cell automata approach to evaluate fire spread. The terrain is divided into square cells and a neighbourhood relationship is used to evaluate whether a cell will be burnt and at what time the fire will reach the burnt cells. As inputs, this simulator accepts maps of the terrain, vegetation characteristics, wind and the initial ignition map. The output generated by the simulator consists of two maps of the terrain. In the first one, each cell is labelled with its ignition time; in the second one, each cell is labelled with its flame height. This information must be used to calculate the rate of spread and an average from among all flame heights.

To calculate the rate of spread, the distance between the ignition point and each particular cell in the terrain is divided by the ignition time of that particular cell. This calculation is repeated for each cell in the terrain to determine the maximum value of the rate of spread. This maximum value is used as the rate of spread for that particular situation.

To provide the propagation danger map, a set of prototype plots was created, considering all the fuel models from Rothermel classification and a certain slope percentage (from 0 to 100%, with a step of 5%). The total number of plots was therefore 273. Each plot consists of a grid of cells with 11 columns x 11 rows (each cell measured 328.083 x 328.083 feet). The ignition point was located in the middle of plot. For each plot, many input parameter combinations were used to simulate the wildland fire behaviour and the average rate of spread and flame height were also calculated. The parameters considered for variation were: 1-hr dead fuel moisture, 10-hr dead fuel moisture, 100-hr dead fuel moisture, live herbaceous moisture and wind speed and direction.

Average values of rate of spread (RoS, in m/min) have been computed for the different fuel types. Finally, the RoS values were scaled into a 0-1 range, by normalizing the values between the maximum and minimum values. Fuel types were derived from the Corine land cover, as explained before. This map is considered static, since no specific conditions are simulated (wind or FMC), but only general patterns of propagation rates.

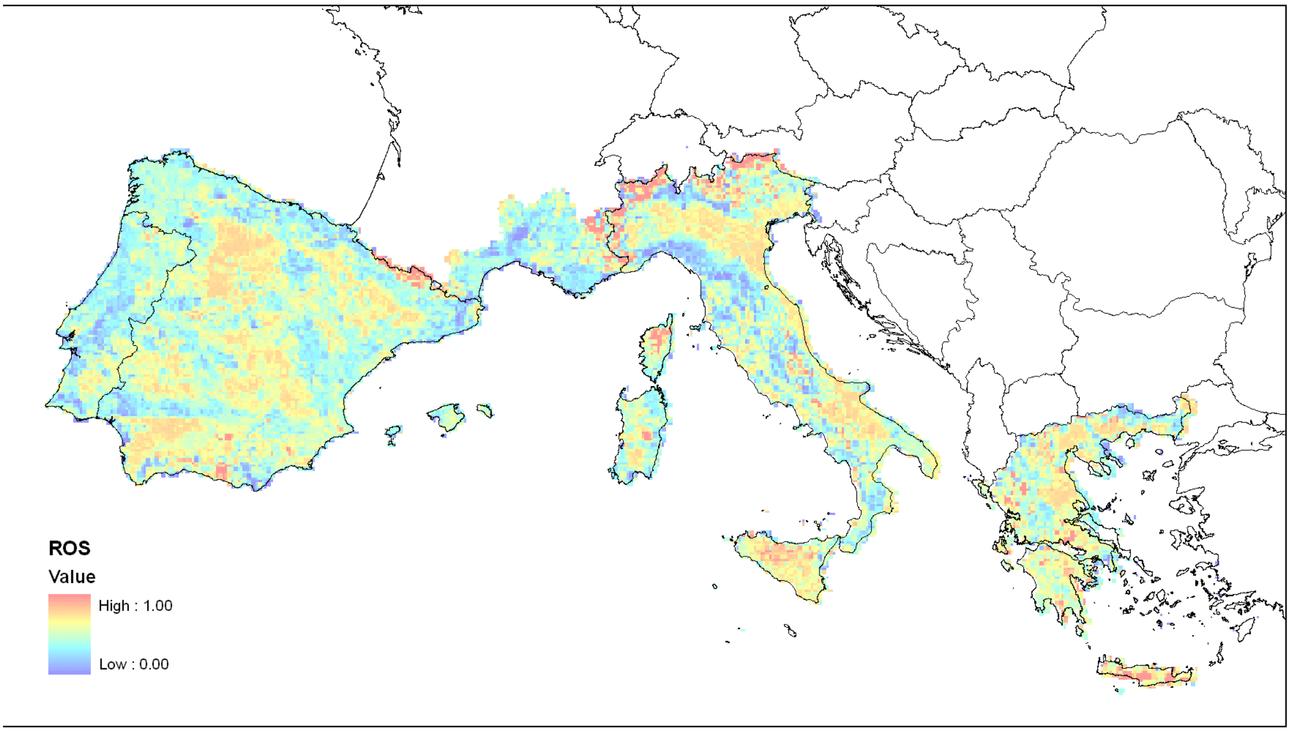

Figure 6: Estimated average Rate of Spread (normalized values from 0 to 1)

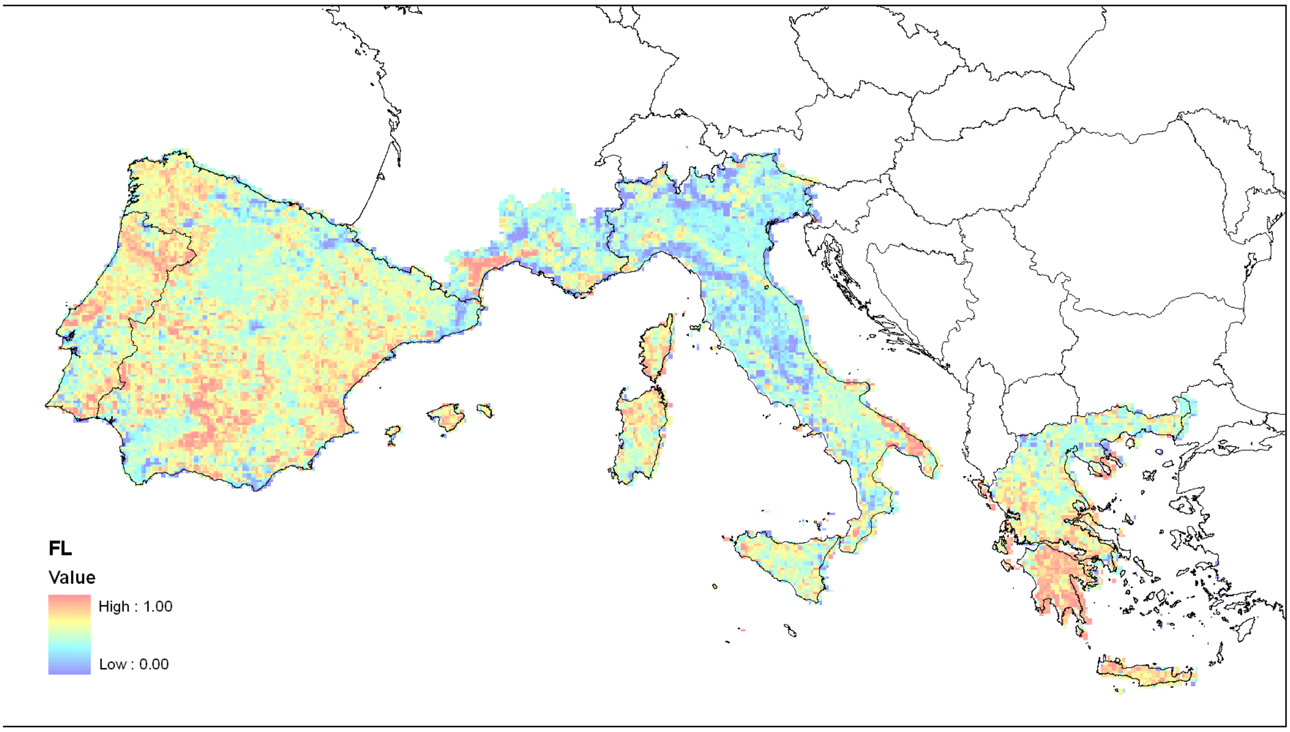

Figure 7: Estimated average Flame Length. (normalized values from 0 to 1)

2.6. Propagation danger (PD)

It derives from the combination of the two intermediate products previously described: RoS and FL. The results of the simulations were mapped at EUmed scale using CORINE land cover (reclassified into fuel models) and slope maps

The maps of FL and RoS were then normalized using linear fitting and multiplied to produce PD:

$$PD = [(RoS_i – RoS_{min})/(RoS_{max} - RoS_{min})+0.001] * [(FL_i – FL_{min})/(FL_{max} - FL_{min})+0.001]$$

A small constant (0.001) was added to avoid zero multiplication in case of minimum values. RoS and FL were considered in this formula of equal importance, although this could be tuned up in future improvements, according to further experience or suggestions. This map is taken as static, i.e. it will not change throughout the fire season.

3. Wildland Fire Danger Assessment (WFDA)

The index of Wildland Fire Danger Assessment integrates the three components previously described, the human danger index (HDI), the probability of ignition associated to fuel Status (PI_f) and the Propagation Danger (PD), as follows:

$$WFDA = (HDI+c) * (PI_f+c) * (PD+c)$$

HDI and PD are static, they do not change throughout the season, c is a constant to avoid multiplying by zeros (0.001 is used), PI_f changes every 8 days with respect to live fuels and every day with respect to dead fuels. Therefore the resulting map of WFDA has to be updated daily. An example is shown in Figure 9, derived using the maps depicted in Figures 2, 5 and 8 for August 10th 2004..

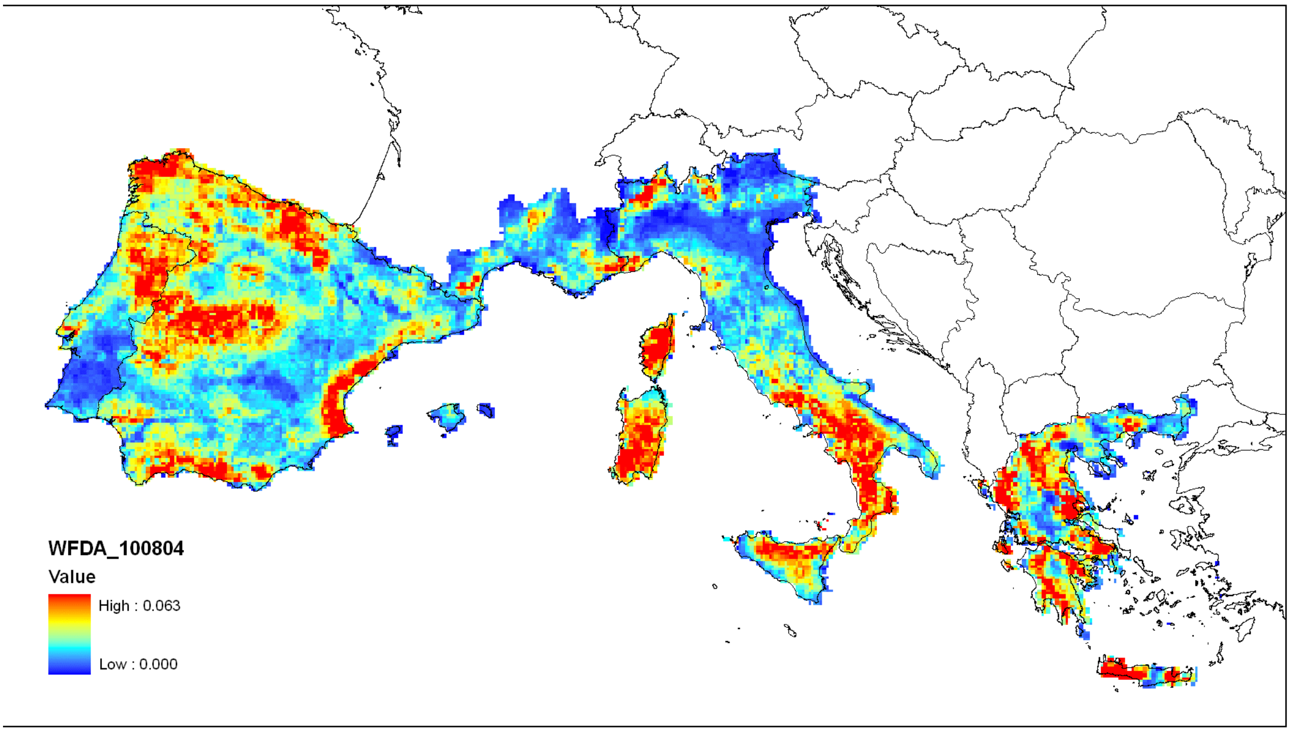

Figure 9: Wildland Fire Danger Assessment for the 10th August, 2004.

All the EUMed maps mentioned so far were made available as a demo product in quasi-real time (with 2-3 days delay) within the demo of the Spread Project web based services. During the demo, that lasted 1 month, the intermediate dynamic maps and the final WFDA map were produced daily at JRC, transferred to Algosystems S.A. through FTP, that published them in the Spread map server application (http://www.spread-dss.org/).

4. Conclusions

A prototype of a fire danger assessment system has been presented in this paper. This index combines different variables associated to the probability of fire ignition and propagation. All input variables are spatially distributed, and therefore, a geographical analysis of fire danger and fire danger factors may be undertaken. This approach would greatly help the spatial planning of fire suppression resources, as well as risk reduction through prescribed burning or controlled grazing. Future improvements of the fire risk index will include the consideration of fire vulnerability, as well as a more detail analysis of fuel type distribution.

Acknowledgements

This work was funded by the EC project 'Forest Fire Spread and Mitigation (SPREAD), EC-Contract Nr. EVG1-CT-2001-00027

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