

Development of a method to transform Life Fuel Moisture Content into ignition probability

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Abstract – This study aims to explore several methodologies concerning ignition probability (IP) modeling for grassland and shrubland located on the Mediterranean region of Spain. This research has been performed based on Live Fuel Moisture Content (LFMC) product developed by García et al. (2008) from an Advanced Very High Resolution Radiometer (AVHRR) time series. Fire occurrence has been determined by the MODIS Thermal Anomalies product (MOD14) for the years between 2001 and 2007. The results show that the methodology applied for this study helps to transform LFMC cartography into an IP index. This index, integrated with other variables, is likely to be a strategic indicator useful to prevent and manage forest fires.

Keywords: Fuel Moisture Content, Forest fire, Ignition Probability, MODIS, Logistic Regression.

1. INTRODUCTION

Forest fires can become a danger not only for their ecological damage but also for their associated economical and social impact. Plants moisture plays a great role in the ignition probability (IP) (Schroeder 1969) since is being considered as the major factor for forecasting fire occurrence and severity (Mutch 1970; Schroeder 1969) and also one of the most important factors of fuel flammability (Carlson and Burgan 2003; Chandler et al. 1983; Chuvieco et al. 2004; Van Wagner 1977).

Vegetation moisture is frequently defined as fuel moisture content (FMC) which is usually expressed as the amount of water per dry mass of fuel. It is formulated as:

$$FMC = \left(\frac{W_w - W_d}{W_d} \right) \times 100$$

Where W_w = wet weight
 W_d = dry weight of the same sample, usually after oven drying at 60 °C–100 °C for 24–48 h (Viegas et al. 1992).

Considering Mediterranean fire frequency and importance, many authors have focused their studies on estimating forest fires IP from Live FMC (LFMC) in these areas (Chuvieco et al. 2009; Xanthopoulos and Wakimoto 1992). Some of these studies are based on the concept of moisture of extinction (ME) (Rothermel 1972). Rothermel (1972) defined this threshold as the FMC above which fire cannot be sustained. On the other hand, other authors use a gradual scale that correlates IP increments and LFMC decrements (Green 1981). Recently, classification trees and logistic regression models have been applied (Chuvieco et al. 2009; Dimitrakopoulos et al. 2010).

Despite several methods have been developed, not many studies have research the relationship between LFMC derived from LFMC cartography and fire occurrence for the Mediterranean Spanish region. The aim of this study is to present this information and to offer an IP cartography in order to allow decision makers to further enhance fire prevention.

2. METODOLOGY

2.1 Data description

The LFMC cartography used in this study is based on empirical equations that relate field measurements of LFMC with image data, using vegetation indices, surface temperature and a function of the year rainfall trend. A vegetation stratification of this product into grassland and shrubland has been performed according to the Corine Land Cover 2000 (www.eea.europa.eu). In addition, a climatic stratification into Mediterranean and Atlantic regions has been also done based on Rivas-Martínez biogeographic classification (Rivas Martínez 1983). Due to the differential LFMC behavior depending on the day of the year, this study is focused not only on all fires registered from April to October (fire season) from 2001 to 2007, but also, on the relationship between LFMC and fire occurrence at three temporal stages: spring (30th March–17th June), early summer (18th June–28th August) and late summer (29th August–31st October).

The MODIS Thermal Anomalies product (MOD14) has been selected as the source of information for burned pixels (<http://maps.geog.umd.edu/firms/>). A sampling method based on drawing random points located near the MODIS hotspots has been applied to construct the spatial database for those areas that had no fire. Variograms were computed to estimate the threshold distance up to which un-burned spots are not autocorrelated to the burned spots.

2.2 LFMC variables description

Table 1 shows the five variables, related to LFMC, that have been designed in order to assess their ability to predict IP.

Variable	Description
LFMC t-1	LFMC corresponding to the 8 days period prior to the fire event.
LFMC t-2	LFMC corresponding to the 16 days period prior to the studied event.
Difference	Moisture variation just before the studied event ((LFMC t-1)-(LFMC t-2))
Slope	Moisture decrement since maximum LFMC recorded in spring until the studied event.
Anomaly	Studied event LFMC variation in relation to the LFMC mean corresponding to the rest of the years considered in the analysis.

Table 1. Variables based on LFMC designed as predictors of fire occurrence for a specific pixel.

2.3 Analysis description

A Mann-Whitney test has been first applied in order to know whether there were or not significant differences between burned and un-burned pixels for the proposed variables. Afterwards, two methodologies have been developed in order to perform IP modeling from LFMC (i) the design of IP classes according to the cumulative proportion of fires above certain LFMC t-1 values. It has been built accumulating fires frequency as LFMC t-1 decreases and assigning the results to IP. For instance, if the total of fires is 1000 and 10 of them register a LFMC between 290-310 %, then, the proportion of fires for this interval would be 0.01. If 50 of them occur at a LFMC between 270-290 %, then the proportion of fires would be 0.05. When the cumulative frequency is represented, this interval would show a proportion of 0.06 (0.05+0.01) what indicate that from this value the 6% of fires take place. In this case the IP would be is insignificant.

(ii) the logistic regression (LR) has been the final IP modeling method.

3. RESULTS

As it is shown in Figure 1, there are significant differences for the majority of the derived LFMC variables in most of the spatial and temporal strata. Among all the variables analyzed, LFMC t-1 and LFMC t-2 present the most significant differences, Slope and Anomaly are also important whereas Difference has got less impact.

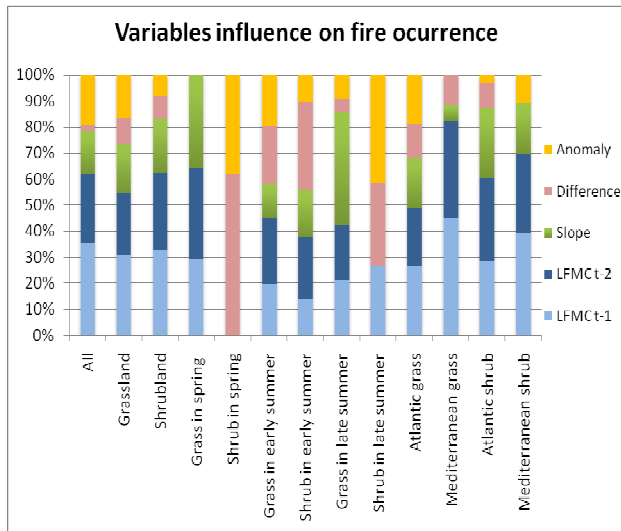


Figure 1. Variables that present significant differences (p-value: 0.05) between burned and un-burned areas. Z value has been the criteria to build the percentages. Variables without significant differences have not been considered.

Taking into account that LFMC t-1 is the most influential variable, it has been represented with the cumulative proportion of burned and un-burned pixels above different LFMC intervals (Figure 3). The columns could be converted in an IP indicator. If it is considered that the 30-50% LFMC t-1 threshold has the highest IP and that it is equal to 1, then the IP would decrease whilst LFMC t-1 increases.

Figure 3 show that burned pixels abound in the lower LFMC intervals. In both cases, it is observed that the maximal IP is registered in the lowest LFMC t-1 intervals.

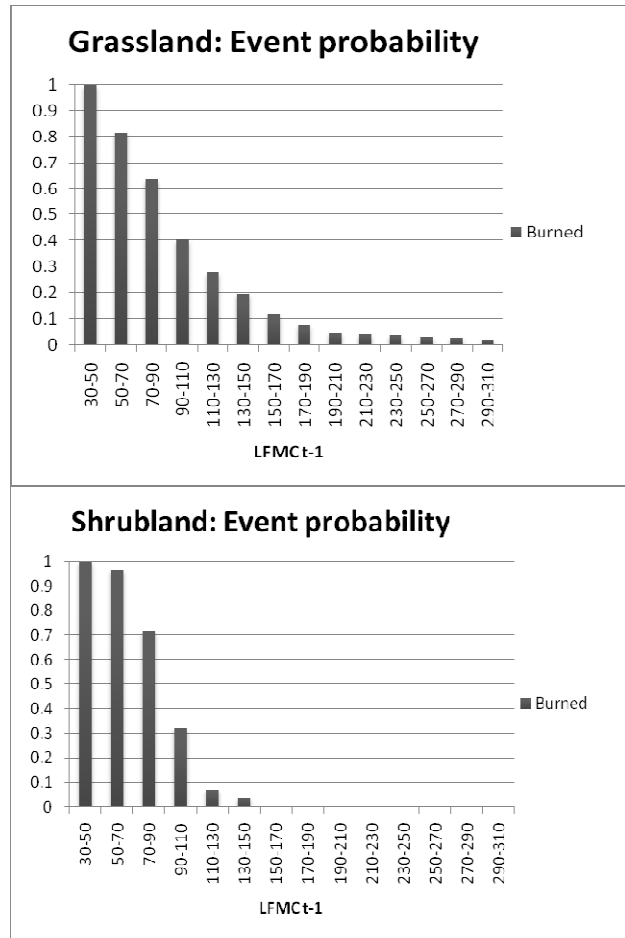


Figure 3. Cumulative proportion of burned and un-burned pixels above different LFMC intervals for Grassland (on the top) and Shrubland (on the bottom).

Finally, a logistic regression has been used for the IP modeling as it is a valuable predicting fire tool. All data were analyzed using SPSS 15.0.

	Logistic Regression Equation
Grassland	$(-0.006 * LFMC t-1) + (-0.006 * Difference) - 2.553$
Shrubland	$(-0.379 * Slope) + (-0.017 * LFMC t-2) - 1.479$

Table 2. Equations obtained by the LR method. The results have been assessed by the Area Under the ROC (grassland: 0.616; shrubland: 0.664).

LR results confirmed that LFMC one or two weeks before the fires is the most influential variable on fire occurrence. Since there is a large seasonal variation on grasslands LFMC as is more sensitive to weather conditions, it is affected by an immediate decrease on LFMC. Hence, LFMC t-1 and

Difference, are the variables included in the LR equation. In the case of shrubland, its strategies developed to moderate drought (deeper root system, thicker leaves, etc.) help them to preserve their moisture. Therefore, more importantly are changes which imply a temporal tendency in moisture reduction and they increase the vegetation susceptibility to be burnt. Consequently the explicative variables in the LR for shrubland are Slope and LFMC t-2. For both vegetations types, the area under the ROC is above 0.6, which means that the equations are appropriate although it should be considered that the results are not precise enough to take them as accurate IP predictors.

4. CONCLUSIONS

This study proves that LFMC is a key variable to be considered in forest fires prevention plans. While other studies have investigated the difference in LFMC between burn and unburned pixels taken the LFMC values in the same date as the fire happened, this research aimed to relate fire occurrence with LFMC before fire starts, its seasonal tendency and its annual variation. In this sense, the five LFMC variables developed helped to understand that both vegetation types studied are affected by LFMC decrement differently.

Two methods have been followed to convert the LFMC cartography in an IP index. The first of them was based just in one of the variables studied taken into account that LFMC t-1 was the variable which most significant difference between burned and un-burned pixels showed. For both cases studied (grassland and shrubland), an approximation of IP was given by the cumulative hotspots registered in the LFMC intervals considered. In addition, the LR tool has been explored obtaining the respective equations where different variables combination allows obtaining an IP cartography. However several are the limitations of this study. First of all, the LFMC cartography and the MOD14 product have their own error degree. Secondly LFMC is not the unique variable to predict forest fires. Hence, the influence of another several factors makes IP estimation more complex. Finally, a deeper effort should be done in order to study some other prediction tools and to improve the strategies shown.

5. REFERENCES

Carlson, J.D., & Burgan, R.E. (2003). Review of users' needs in operational fire danger estimation: the Oklahoma example. *International Journal of Remote Sensing*, 24, 1601-1620

Chandler, C., Cheney, P., Thomas, P., Trabaud, L., & Williams, D. (1983). *Fire in Forestry. Forest Fire behavior and effects*. Nueva York: John Wiley and Sons

Chuvieco, E., Aguado, I., & Dimitrakopoulos, A. (2004). Conversion of fuel moisture content values to ignition potential

for integrated fire danger assessment. *Canadian Journal of Forest Research-Revue Canadienne de Recherche Forestiere*, 34 (11), 2284-2293

Chuvieco, E., González, I., Verdú, F., Aguado, I., & Yebra, M. (2009). Prediction of fire occurrence from live fuel moisture content measurements in a Mediterranean ecosystem. *International Journal of Wildland Fire*, 18

Dimitrakopoulos, A.P., Mitsopoulos, I.D., & Gatoulas, K. (2010). Assessing ignition probability and moisture of extinction in a Mediterranean grass fuel. *International Journal of Wildland Fire*, 19

European Environment Agency (EEA). Corine Land Cover 2000 cartography. www.eea.europa.eu

FIRMS: Fire Information for Resource Management System. University of Maryland. <http://maps.geog.umd.edu/firms/>.

Garcia, M., Aguado, I., & Chuvieco, E. (2008). Combining AVHRR and meteorological data for estimating live fuel moisture content in forest fire danger rating. *Remote Sensing of Environment. Remote Sensing of Environment.*, 112, 3618-3627

Green, L.R. (1981). Burning by prescription in chaparral. USDA Forest Service, Pacific Southwest Forest and Range Experiment Station, PSW-51. General Technical Report 51. In. Berkeley, CA

Mutch, R.W. (1970). Wildland fires and ecosystems - a hypothesis. *Ecology*, 51, 1046-1051

Rivas Martinez, S. (1983). Pisos bioclimáticos de España. *Lazaroa*, 5, 33-43

Rothermel, R.C. (1972). A Mathematical Model for Predicting Fire Spread in Wildland Fuels. In. Ogden, Utah: USDA, Forest Service

Schroeder, M.J. (1969). Ignition probability. In (p. 26): Unpublished report on file at: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO.

Van Wagner, C.E. (1977). Conditions for the start and spread of crown fire. *Canadian Journal of Forest Research*, 7, 23-34

Viegas, D.X., Viegas, T.P., & Ferreira, A.D. (1992). Moisture content of fine forest fuels and fire occurrence in central Portugal. *The International Journal of Wildland Fire*, 2, 69-85

Xanthopoulos, G., & Wakimoto, R.H. (1992). A time to ignition-temperature-moisture relationship for branches of three western conifers. *Canadian Journal of Forest Research*, 23, 253-258

6. ACKNOWLEDGEMENTS

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