

SIGRI PROJECT: THE DEVELOPMENT OF THE FIRE VULNERABILITY INDEX

LANEVE Giovanni^{a,*}, JAHJAH Munzer^a, FERRUCCI Fabrizio^b, BATTAZZA Fabrizio^c

^aUniversità di Roma "La Sapienza" – CRPSM, Rome, Italy – (laneve, jahjah)@psm.uniroma1.it

^bUniversità della Calabria, Cosenza, Italy -

^cAgenzia Spaziale Italiana, Rome, Italy -

Abstract - The SIGRI (Sistema Integrato per la Gestione del Rischio Incendi) pilot project, funded by ASI (the Italian Space Agency), aims at developing an Integrated System for the Management of the Wild Fire Events. The system should provide satellite based products capable of assisting all the phases of the fire contrasting activities: prevision, detection, and damage assessment/recovering. This paper concerns the development of a fire vulnerability index based on the Fire Probability Index (FPI) introduced by Burgan et al.. The original index takes into account mainly the status of the died vegetation by means of the extinction moisture and the relative greenness. The green vegetation water content is also considered in order to improve the performances on the Mediterranean area. Furthermore, the evapotranspiration parameter has been introduced to take into account the effect of the solar illumination in determining the humidity existing in the died vegetation.

Keywords: remote sensing, fire, evapotranspiration, satellite, fire probability index.

1. INTRODUCTION

The SIGRI (Sistema Integrato per la Gestione del Rischio Incendi) pilot project, funded by ASI (the Italian Space Agency), aims at developing an Integrated System for the Management of the Wild Fire Events. The system should provide satellite based products capable to help fire contrasting activities during all the phases: prevision, detection, and damage assessment/recovering. In particular, the paper concerns the development of a Fire Risk Index to be produced daily with the objective of showing the risk total level for the area of interest and the zones of major concern within such area.

In the European Community the member countries interested by forest fires are at least six: Portugal, Spain, France, Germany, Italy, and Greece. The higher number of wild fires occurs in the western part of Spain and Portugal, in southern Italy and in the Mediterranean islands. The idea to develop maps able to show the fire risk all over the Italian territory is based on the observation that there is a tight relationship between the fire and the characteristics of the fuel (vegetation type, density, humidity content), of the topography (slope, altitude, solar aspect angle) and the meteorological conditions (rainfall, wind direction and speed, air humidity, surface and air temperature). These parameters directly impact the proneness of a given area to the fire ignition and propagation. Since these quantities can be measured, notwithstanding the cause of the fire ignition could be unpredictable (mainly due to human actions - more than 90% of the ignitions is intentional or accidental), the behaviour of the fire can be considered strictly dependent from these parameters it can be foreseen when such parameters are known.

* Corresponding author

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According to the model, the methods of fire risk estimate exploit different information and can be distinguished as follow: Statistical Methods or Structural (*long-term fire risk index*) defining forecast models based on the utilization of slowly changing parameters like topography or other variables that can be considered constant along the year and statistical information on the frequency of the phenomenon.

Dynamical Methods (*short-term fire risk index*) based on data measured continuously (i. e. daily), on characteristics territorial data (orography and vegetation) and on forecast models of the meteorological parameters.

Indices like: the *Fire Probability Index* and the *Likely Damage Index* belong to the first category. The *Fire Probability Index* defines the fire probability taking into account three parameters: the fuel available, the topography and a socio-economical variable. The *Likely Damage Index* provides an estimate of the possible damage that a fire can cause in a given area. This index can be evaluated taking into account: soil erosion proneness, slope and rainfall amount, protection level based on the environmental interest and distance from houses that allows to consider the risk for human live and his properties. On the other side, the *short-term fire indices* are, in general, able to provide information on the danger of the event defining: areas of possible ignition, propagation direction and speed, irradiated energy, etc. In its simplest form these models provide risk index. Such an index represents the probability of the ignition and propagation of the forest fire. According to this index, a daily level of risk can be defined. The different indices used for generating maps of fire risk are, in general, based on the following meteorological parameters: air temperature and humidity, wind speed, rainfall in the previous 24 hours, cloudiness, solar radiation during the previous 24 hours, averaged monthly temperature, maximum and , minimum temperature during the previous 24 hours. By combining this daily fire risk index with the information typical of the Likely Probability Index (infrastructures, protected areas, etc.) we can compute the Fire Vulnerability Index that would be one of the products provided by the SIGRI project.

2. FIRE RISK INDICES

The European Commission funded the development of the EFFIS (European Forest Fires Information System) system (San-Miguel Ayanza, 2003). This system, developed by JRC (Joint Research Centre), provides, apart from a structural risk index already re-called above, a three days forecast based on a daily updated risk index of risk. For several years the forecast has been based on 7 different indices (6 of them represent an evolution of indices developed for national application and they are basically meteorological indices). Satellite data are used for the computation of only one of these 7 indices. After this test period, the JRC has selected as index useful for describing the fire risk for the European region the FWI (Canadian Fire Weather Index) among the following 7 indices [(INMG, 1988), (ICONA; 1993), (Drouet, 1993), (Ventura, 2001), (Heidorn, 1998), (Rothermel, 1986), (Burgan 1993), (Burgan, 1998)]: the Portuguese index, the ICONA Method, the numerical risk Drouet-Sol, the Italian index of risk, the Canadian Fire Weather Index, the BEHAVE Model, the Fire Potential Index (FPI).

The present paper aims at presenting the results obtained by applying at the Italian territory and more specifically to the three test areas of the SIGRI project (Figure 1) a modified version of the FPI (Usa/JRC). The FPI consists in the estimate of the fuel conditions by means of a separation of the dead and green vegetation. This estimate is carried out by using maps of the vegetation index NDVI (Normalized Digital Vegetation Index) obtained with space-borne sensor like, for instance, MODIS (on board of the Terra and AQUA satellites). To carry out the computation, a map of the fuel distribution on the area of interest is needed. Other needed quantities are the air temperature and humidity, cloudiness and rainfall. This index, commonly called *integrated* or *advanced*, is based on the FPI derived by Burgan (Burgan, 1998) for U.S. and successfully validated in California. Its validation in the European context has not yet completed. The model requires the NDVI to compute the *Relative Greenness*, meteorological data (air temperature, relative humidity, cloudiness and rainfall) for estimating the Ten Hours Time Lag Fuel Moisture (FM10hr) and a fuel map to estimate the percentage of dead vegetation. The relative greenness (RG) or vegetation stress index represents how much green is a pixel, with reference to the range of historical observation of the NDVI used (Burgan, 1993). This quantity allows the estimate of the percentage of green fuel, as function of the fuel model assigned to each pixel. The *Ten Hours Time Lag Fuel Moisture* has been selected as the quantity representative of the humidity available in the dead vegetation (Nelson, 2000). Such a quantity can be computed by using the meteorological parameters and the relationship described by Lopez (Lopez, 2002).

The fuel map can be compiled by using, as first approximation, the CORINE Land Cover (CLC) map that gives European

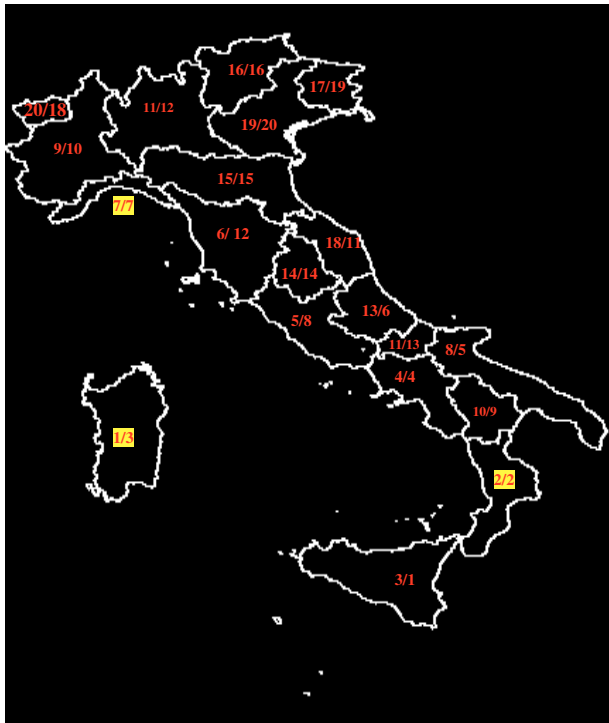


Figure 1. The figure shows the position of each Italian region in the special rating of the number of fire events and amount of burned areas during the quadrennial period 2004-2007. The yellow boxes corresponds to the test regions of the SIGRI project.

countries vegetation maps with a spatial resolution of 100 m. These maps should be converted in the NFDRS (National Fire Danger Rating System) fuel models. The modified formula for computing FPI is given by Burgan (Burgan, 2000). The FPI,

having a value in the range 0 to 100, results inversely proportional to the percentage of green fuel and to the humidity content of the dead vegetation.

Its computation needs a fuel map that, at the present time, can limit its application to the Italian territory.

The classic definition of FPI does not allow to take into account the effect of solar illumination conditions in determining the humidity present in the dead vegetation therefore its proneness to burn. In order to introduce such parameter we suggest to apply the formulas used for estimating the vegetation evapotranspiration rate, ET_0 , and to use the computed values as a sort of weight for obtaining the *FM10hr* term for similar vegetation types characterized by a different solar *aspect angle*. ET_0 has been computed by using the Penman-Monteith formula, modified according with FAO:

$$ET_0 = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T} \cdot u_2 (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad (1)$$

where ET_0 is the reference evapotranspiration [mm day^{-1}], R_n the net radiation available at the vegetation [$\text{MJ m}^{-2} \text{day}^{-1}$], G the heat flux [$\text{MJ m}^{-2} \text{day}^{-1}$], T the daily mean temperature at 2 m [K], u_2 the wind velocity at 2 m [m s^{-1}], e_s water vapour saturation pressure [kPa], e_a actual vapour pressure [kPa], $e_s - e_a$ the deficit of saturation pressure [kPa], Δ the slope of the vapour pressure curve [$\text{kPa } ^\circ\text{C}^{-1}$], γ psychometric constant [$\text{kPa } ^\circ\text{C}^{-1}$]. Therefore the needed meteo data are: the mean temperature and humidity, the wind speed, the net solar radiation computed, in our case by using slope and aspect angle retrieved from a DEM of the area of interest. However, the whole process to obtain the quantities needed can be found in (Maidment, 1992). Anyway others relationship, like these of Hargreaves (Hargreaves, 2003) and Thornthwaite (Thornthwaite, 1948), can be used for computing the same quantity.

Since also the presence of water in the alive vegetation can be considered relevant in determining the fire regime, the problem of estimating the vegetation water content, by using satellite images, has been dealt with. This estimate is made through an index called the *Equivalent Water Thickness* (EWT). We adopted the expression given by Ceccato (Ceccato, 2002) which allows to estimate the value of EWT as a function of GVMI (Global Vegetation Moisture Index), although this index is defined for the sensor SPOT/VEGETATION.

In particular, the relationship between EWT and GVMI can be written as:

$$EWT = \frac{-(a \cdot d + c - d \cdot GMVI) + \sqrt{(a \cdot d + c - d \cdot GMVI)^2 - 4 \cdot c \cdot d(a + b - GMVI)}}{2 \cdot d \cdot c} \quad (2)$$

a , b , c and d coefficients determined on the basis of a statistical regression of experimental measurements (for example, measures of land conducted in a typical African vegetation: shrubs, savanna, provide, if the index is calculated from SPOT images, the following values: $a = 1.53$, $b = -1.4$, $c = -0.000099$, $d = 0.000517$). It should be noted that the parameter EWT is not related to the Fuel Moisture Content (FMC) that is commonly used in the derivation of indices of risk of fire. In fact, the dry matter is of prominent importance in determining the flammability of the vegetation therefore it should be developed a method to estimate this parameter. Actually, it could be more useful the knowledge of the FMC index for the estimation of the likelihood that a certain vegetated area burns. In fact, it was shown that when this index takes values above 100% the risk of ignition is very limited. This index, however, is not, in general, easily estimated from satellite by measuring the variations induced by it on the spectral reflectance of vegetation, unlike what happens for the index EWT.

The expression for GVMI is as follows:

$$GVMI = \frac{(NIR_{cor} + 0.1) - (SWIR + 0.02)}{(NIR_{cor} + 0.1) + (SWIR + 0.02)} \quad (3)$$

with SWIR reflectance of the channel to 1.6 μ and NIR_{cor} , near-infrared reflectance corrected for atmospheric effect through the relationship suggested by Gobron et al. (Gobron, 2000):

$$NIR_{cor} = \frac{-1.12 \cdot (BLU + 2.169)^2 + 0.2929 \cdot (NIR + 4.2614)^2 + 65.13 \cdot BLU \cdot NIR}{-204.3 \cdot (BLU - 0.132)^2 + 0.0109 \cdot (NIR + 23.81)^2 + 5.593 \cdot BLU \cdot NIR} \quad (4)$$

where BLUE and NIR represent the reflectance in channels 1 and 3 of the sensor SPOT- VEGETATION, respectively. The validity of the EWT index to capture the state of the vegetation has been largely demonstrated. For example, the overall decline in the EWT index, as shown in Figure 2 qualitatively corresponds rather well to the official start of fire season. Therefore, the traditional/ bureaucratic choice of the fire season starting day, fixed at June 15 (for Italy) is well reflected in the actual physical state of the vegetation.

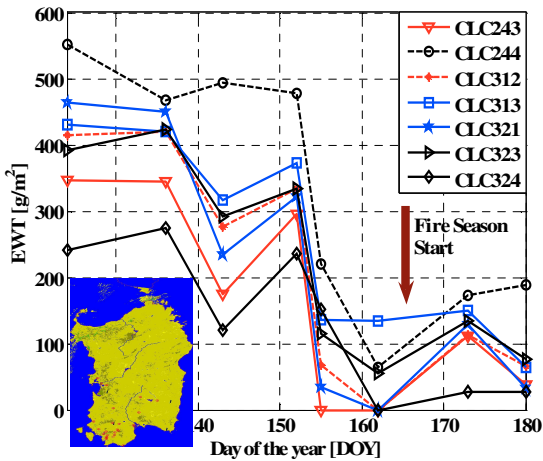


Figure 2. EWT behaviour versus the day of the year computed by using MODIS images for year 2008. The plots refer to the sites indicate by red circles in the small image of the Sardinia region, corresponding to different CORINE classes.

3. DATA

The historical minimum and maximum values of the NDVI have been computed by using the NDVI averaged values provided by the MODIS sensor image for the years 2006 to 2010. The daily NDVI values, used to estimate the RG has been computed by using MODIS images and the IMAPP software. The fuel maps have been constructed by using the 2006 CLC maps, the Forest Map of Europe and visually comparing the photos showing examples of the NDFRS fuel types (Anderson, 1982) with these representing the CORINE classes. The 90 m spatial resolution SRTM-DEM has been used for computing the illumination conditions and the evapotranspiration rates. The fires data, used for validating the FPI maps, have been obtained by using MODIS and SEVIRI/MSG satellite sensors based hot spots. Unfortunately, due to the difficulties to obtain atmospheric data for the regions of interest, the analysis has been limited to the year 2007. The atmospheric data acquired at 16 ground stations in Calabria have been downloaded from the ARPACal website. The interpolation needed to compute the humidity and air temperature maps has been performed by using Matlab functions.

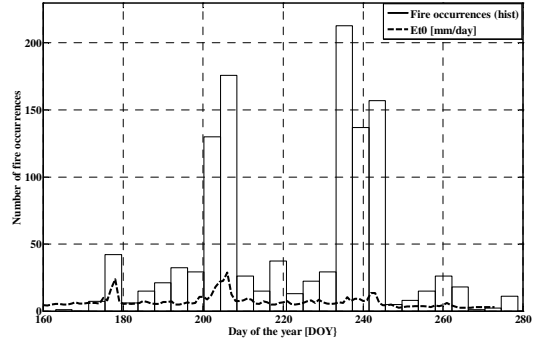


Figure 3. Daily distribution of fire events in Calabria during the 2007 summer season. The peaks occurrence correspond well to the ET peaks.

4. RESULTS

In Figure 1 the two numbers given for each region represent the position occupied by each one of these in the ranking of the number of fire events and the extent of burnt areas in the period 2004-2007. In other words, the values 2/2 indicates that the Calabria region, in the given period of four years, results as the second in the number of fires occurrences (after Sardinia, with 5665 events in the 4 years period) and also second for the extent of burnt areas (first Sicily).

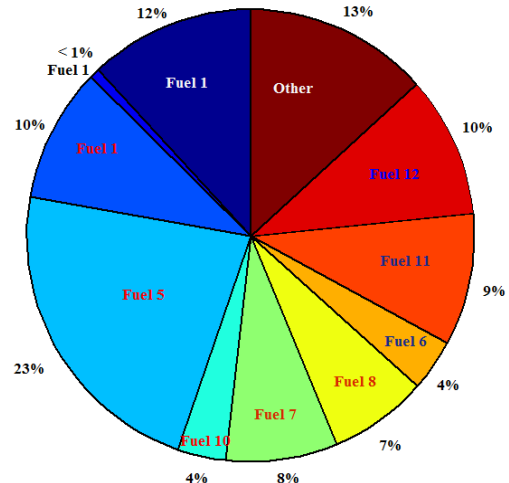


Figure 4. Distribution of the fire events (in percentage) as function of the fuel type of the interested area.

This figure explains immediately the choice of Sardinia and Calabria regions as test areas for this project. The choice of Liguria resides on the particular situation of this region affected by winter fires. The usefulness of including in the computation of the modified FPI the solar insolation/evapotranspiration effect is well demonstrated by Figure 3 where the behavior of the evapotranspiration index has been compared with the fire events distribution. It could be observed as, even if most of the fires (more than 90%) are due to the human intervention (intentional or accidental), their daily distribution clearly follows the evapotranspiration behavior. The number of fire events, obtained by the MODIS Fire Mapper website, for the year 2007 are 1080. Their distribution in terms of the fuel type of the burned areas are given in Figure 4. It is interesting to observe as only the 13% of such events are, apparently, involving areas not classified as fuel in accordance with the available NDFRS vegetation fuel models. However, this result

arises some concern on the possible presence of false alarms among the hot spots detected by using the MODIS sensor. This problem will be solved by improving the information on the hot spots by using data based on the SEVIRI images and the ground data provided by DPC.

Regarding the behaviour of FPI index, Figure 5 shows two maps of such index computed for the days 1st and 25th of June 2007. As it can be observed the 25th June FPI values result in

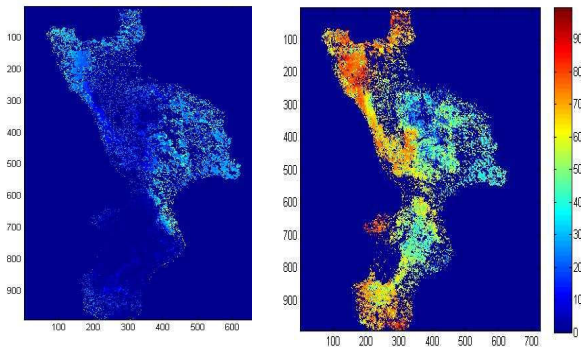


Figure 5. Maps of FPI computed (by using Burgan relationship) on the Calabria region for the days 1st and 25th of June 2007.

general higher. This agrees with the fire occurrences behaviour which, as shown in Figure 3, exhibits around such date the first seasonal peak. Figure 6 shows the behaviour of the FPI index for a couple of pixels corresponding to two different NDFRS fuel types. The FPI behaviour, for both pixels, confirms the capability of such index to reproduce the daily variability of the fire risk. The FPI index has been preliminarily computed by using three slightly different relationships. They are defined as FPI98, described in (Burgan, 1998), FPI00 described in (Burgan, 2000) and FPIJRC described in (San-Miguel-Ayanz, 2003). The FPI98 values are given in Figure 5 and 6. Usually, for the FPI values an error estimate has not provided. Therefore, an assessment of FPI quality is mostly obtained by means of a statistical comparison with the time and spatial distribution of the fires.

5. CONCLUSIONS

In the paper preliminary results of the performances of the MFPI (Modified Fire Probability Index) have been described. The additional information (evapotranspiration and EWT) used to compute the new index with respect to these involved in the computation of the FPI index seems to be able to capture other terms relevant in determining the proneness of the vegetation to burn. Such index has been developed in the framework of the SIGRI pilot project and aims at producing daily maps of the spatial distribution of the fire risk to be used for prevision and resources management purposes.

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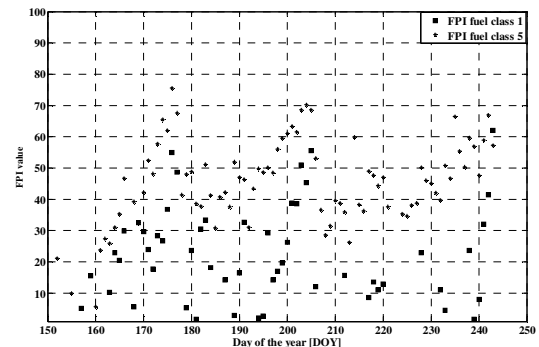


Figure 6. FPI behaviour during the June, July and August 2007 period. The index has been computed for two different pixels corresponding to two different types of fuel.

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