P3.1 A FIRE INDEX FOR MEDITERRANEAN VEGETATION

BASED ON MICROMETEOROLOGICAL AND ECOPHYSIOLOGICAL MEASUREMENTS

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1. INTRODUCTION

Many fire risk models have been developed for various temporal and spatial scales and application purposes. Forest fire risk is being evaluated from several perspectives, which take into account the variability of the input parameters in time. Those indices that are derived from factors that do not change in a short lapse of time are referred to as static or structural indices.

On the contrary, the dynamic indices are derived from factors that vary in short period of time, such as the vegetation status or the meteorological conditions. Indices that include structural and dynamic variables can also be computed and they are called integrated or advanced indices.

In this paper an integrated fire index specific for Mediterranean ecosystems (Ichnussa Fire Index, IFI) is presented. This integrated forest fire index, which utilizes micrometeorological inputs, was developed to be included into an operational early warning system managed by the Regional Weather Service of Sardinia, Italy.

2. PHILOSOPHY and STRUCTURE of the INDEX

The present form of the index is practically based on micrometeorological and eco-physiological observations considered along with some topological data related to local environmental conditions and vegetation type and structure.

In this new approach, involving micrometeorological inputs in alternative to the most commonly used meteorological observations, it is implicit a change in the basic philosophy of the Index utilization.

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Because of these peculiar properties, a micrometeorological based index can be usefully utilized to represent and forecast conditions for complex terrain structures and textures as well as for early warning systems and operations (i.e. potential fire spreads for channeling conditions between adjacent hills with different kind of vegetative coverage).

To assure a *continuum* between meso- and micro-scale representation the developed micrometeorological form of the index was compared, for some case studies, to the meteorological form.

The IFI index accounts for four components or relative numerical ratings which take into account individual and combined factors determining the level of fire risk. In specific, IFI includes: (i) a Drought Code describing the water status of vegetation (DC); (ii) a Fuel Code related to the fuel type and vegetation structure (FC); (iii) a Meteo (micro- or meteorological) Code which includes turbulence field data or weather data (MC); (iv) a Topological Code that is a descriptor of site topography and the prevailing synoptic conditions (TC).

Both representation of the IFI Index are normalized over a 1 to 5 range (Table I) that is a very common representation of the danger level.

5 extreme danger
4 high danger
3 surveillance condition
2 low danger
1 very low danger

Table I. Danger levels associated to the IFI meteorological and micrometeorological index forms.

3. PARAMETERIZATIONS AND ALGORITHMS

The IFI Index computation is based on the assumption that the total result produced by each single effect of the various danger components is additive:

$$IFI = DC + FC + MC + TC$$

It is well known that concomitant effects are not simply additive because the non-linearity of the processes, but they sinergically contribute in producing the wildfire event. However, at the present stage it is not possible to represent the real event with an 'holistic' approach because of the huge amount of parameters involved in the danger potential as the result of the interaction of the three environmental compartments: atmosphere, vegetation and topography.

Specific coefficients, determined on-site, have been utilized to normalize the total result leading to the application of a 'simple' approach.

3.1 Drought Code

The drought parameterization DC can be easily related to the ratio between evapotranspiration and precipitation. Considering the average texture value of soil along with the characteristic retention capacity, the meteorological risk factor related to drought has been parameterized as:

$$DC = \frac{e^{(0.061\frac{RgT}{\lambda})}}{1+\sqrt{P_a}+\sqrt[3]{P_{c100}}}$$

where P_a is the actual precipitation value and P_{c100} is the cumulative value in the last 100 hours (mm), λ the latent heat of evaporation, R_g the global radiation and T the air temperature.

The micrometeorological form is determined considering the saturation deficit δe and the sensible heat flux measured by a sonic anemometer.

From the sensible heat flux directly measured by eddy-covariance dT (temperature difference between air and soil) is obtainable. dT and δe lead to the determination of the drought stress utilizing a parameterization based on the Crop Water Stress Index (Idso, 1981; Jackson, 1981) proposed for the irrigation scheduling of agricultural crops. Figure 1 and 2 report the basic steps of the drought stress determination with this methodology where the index is expressed as:

$$CWSI = (dT - dT_l) / (dT_u - dT_l)$$

dT_u and dT_l are respectively the difference between the upper limit and the lower limit of crop temperature and the air temperature.

These limits can be determined experimentally (Fig.s 1 and 2) determining the two constants which regulate:

$$dT_l = k\delta e + \beta$$

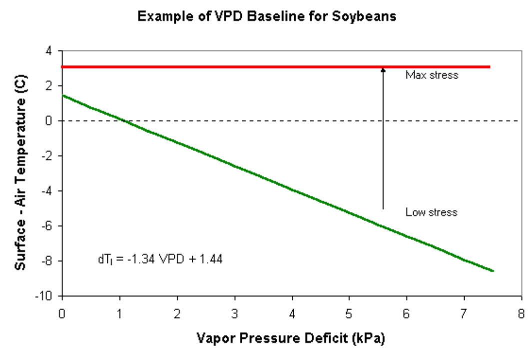

Figure 1. Determination of the maximum and minimum stress for soybeans (Idso, 1981).

Baseline parameters for various crops - sunlit conditions (from Idso, 1982).		
Crop	**Intercept**	**Slope**
Alfalfa	.51	-1.92
Barley (pre-heading)	2.01	-2.25
Barley (post-heading)	1.72	-1.23
Bean	2.91	-2.35
Beet	5.16	-2.30
Corn (no tassels)	3.11	-1.97
Cotton	1.49	-2.09
Cowpea	1.32	-1.84
Cucumber	4.88	-2.52
Lettuce, leaf	4.18	-2.96
Potato	1.17	-1.83
Soybean	1.44	-1.34
Tomato	2.86	-1.96
Wheat (pre-heading)	3.38	-3.25
Wheat (post-heading)	2.88	-2.11

Figure 2. Baseline parameters for various crops.

For the determination of DC, representative values for the Mediterranean macchia of the two const ants have been evaluated as: k = -1.5 and β = 3.6

3.2 Fuel Code

The fuel code has been simply numerically determined (but utilizing time consuming techniques) as:

$$FC = LAD * LAI_c * DW$$

where LAD is the leaf area density, LAI_c the leaf area index of the canopy and DW the dry weight of the vegetation in %.

This code has been created to synthesize the structural properties of the local vegetation.

3.3 Meteo Code

The meteorological form of MC is based on previous studies conducted by Palmieri et al. (1983, 1992) in Sardinia. These studies led to the formulation of the Italian Fire Index that is an exponential relationship in which air temperature and humidity and wind speed contribute to the overall risk.

The formulation experimentally determined during this study is:

$$MC = .14 * \exp(.05\,T + .1\,V - .062\,(RH-50))$$

where T is the air temperature, V the wind speed and RH the relative humidity.

The micrometeorological form defines with much more accuracy the interaction between the atmosphere and the surface directly determining the momentum exchange, the stability conditions and the surface heat fluxes.

The overall micrometeorological risk determined in this way is expressed by the following formulation:

$$MC = \exp(.5u^{*} + \cos^{-1}(z/3L) + T^{*}/(.8\,R_n - H)$$

Even if this equation appears much more complex of the meteorological one with the only exception of R_n (net solar radiation, that must be determined with a specific instrumentation), the other parameters are directly obtainable by sonic measurements and are: the friction velocity u^{*}, the Monin-Obhukov length L, the scale temperature T^{*} and the sensible heat flux H.

3.4 Topological Code

The TC code is formed by a scheme of empirical coefficients taking into account: the terrain slope S, the angle between the wind direction and the terrain maximum slope Vp, the global radiation Rg and East-West orientation VE:

$$TC = S * Vp * Rg * VE$$

In case of micrometeorological measurements it appears more convenient to utilize net radiation Rn, in spite of global radiation Rg, with the inclusion of a different empirical scheme.

4. FIELD TEST and COMPARISON

The IFI index, in its meteorological form, was evaluated analyzing its performance for several fire events occurred in Sardinia (Fig. 3).

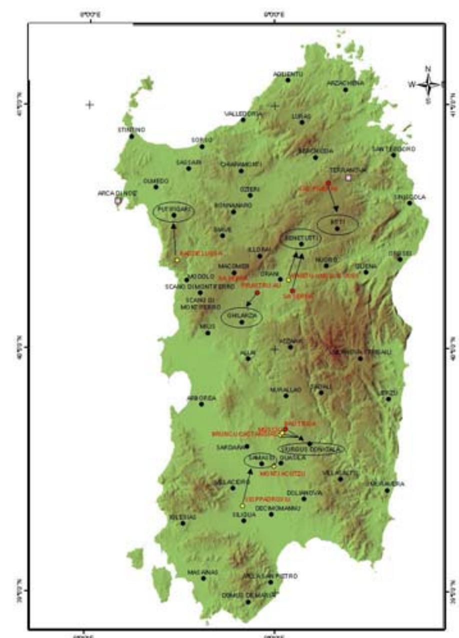

Figure 3. Map of Sardinia with the locations of the different wildfires events considered in this study (circles).

The nine episodes analyzed were characterized by time durations ranging between 2 and 8 hours. A wide variety of meteorological and topographic conditions was encountered allowing firm confidence on the dynamics of the MC and TC codes. Much more critical is the analysis of the confidence of FC and DC because in some cases representative values of parameters had to be assumed on the basis of the 'field report' produced by the local Fire Department, lacking of effective measurements.

In order to check how the IFI dynamics can be considered reliable in terms of spatial-scale, the obtained index values were compared with those derived from different forest fire risk indices commonly applied.

The comparison was performed utilizing the European Forest Fire Risk Forecast System (DG-JRC, Ispra). The System is able to provide different fire indices, for the whole Europe, with a spatial scale of a national province. The determination of the specific index can be performed directly *via* world wide web at the URL:

http://natural-hazards.jrc.it

The results of the comparison are reported in Table II. The IFI appears to match the better results with the Behave fire danger index.

Date (2001)	**IFI**	**Beh**	**FWI**	**Ital**	**Port**	**Span**
17 June	**3**	**3**	**2**	**1**	**1**	**3**
23 June	**3**	**3**	**2**	**2**	**1**	**3**
24 June	**3**	**3**	**2**	**-**	**1**	**3**
28 June	**3**	**3**	**3**	**2**	**1**	**3**
03 July	**2**	**2**	**2**	**2**	**1**	**3**
18 July	**4**	**3**	**4**	**2**	**2**	**3**
22 August	**3**	**3**	**4**	**3**	**4**	**3**
24 August	**3**	**3**	**3**	**2**	**3**	**2**
21 September	**3**	**1**	**3**	**3**	**4**	**2**

Table II. Comparison of the IFI Index for the different wildfire episodes analyzed with other Danger Indices: Beh (Behave), FWI (Fire Weather Index), Ital (Italian Fire Index), Port (Portuguese Index) and Span (Spanish Index) as provided by the Joint Research Centre (Ispra).

5. CONCLUSIONS

The last step of the study is to utilize a mass consistent model in order to derive the surface fields of micrometeorological quantities and a GIS to up-scale the applicability of the Ichnussa Fire Index to the whole region to create an early warning system for the prevention of wildfires.

6. ACKNOWLEDGEMENTS

This study was grated by ‘MURST – Ministero dell’Universita’ e della Ricerca Scientifica e Tecnologica’ within the project ‘Sviluppo, verifica e messa a punto operativa di un sistema di supporto decisionale e di valutazione del rischio di incendi boschivi, volto al potenziamento delle attivita’ del Servizio Agrometeorologico Regionale della Sardegna – Programma Operativo del Piano *Ambiente terrestre* – Cluster C11/B’.

The authors wish to acknowledge Ms. Nicoletta Zar of Abdus Salam International Centre of Theoretical Physics for having provided fundamental bibliographic support.

The European Forest Fire Risk Forecast System (part of the European Forest Fire Information System) coordinated by DG-JRC/Institute for Environment (DG-ENV), and in particular Giorgio Liberta’ for his strong assistance.

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