# WILDLAND FIRE RISK MAPPING USING A GEOGRAPHIC INFORMATION SYSTEM AND INCLUDING SATELLITE DATA

## EXAMPLE OF "LES MAURES" FOREST, SOUTH EAST OF FRANCE

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**ABSTRACT**

The French Mediterranean region regularly suffers a large number of fires : 4.5 million hectares (10.8 million acres) of natural space risk fires. Because of summer droughts, 10,000 to 60,000 hectares (24,000 to 144,000 acres) burn each year. The French Agriculture and Environment Ministries are trying to develop effective methods to prevent forest fires and to lessen their consequences. The risk of forest fires depends on human, ecological and climatic factors such as slope, exposure, vegetation (its composition and water content), wind, housing and vulnerable installations.

There are two complementary methods for assessing fire risks:

- a time-based approach which involves defining the high-risk periods using biological and meteorological parameters (inflammability and combustibility indexes).

- a spatial approach which involves defining and mapping out the main high-risk zones.

The second methodology has been developed by the CEMAGREF of Aix-en-Provence and tested on the Maures mountains in the Var département in south-east France.

The final product resulting from this study will be four 1/50 000 maps:

* a map showing the risk of fire outbreaks
* a map showing the risk of spreading
* a map of the dangers to human and natural life
* a map of prevention and means of protection.

These different maps are in the process of being drawn up. They are the result of a combination of several theme-based maps on human, ecological and climatic factors. At this stage of the study, only the thematic maps have been drawn up. They are presented in this article. All these data are brought together and analyzed in a Geographical Information System (Arc Info). An analysis of the correlations between the different factors studied is being carried out and the results will be published at the end of the year. The four consolidated maps will form a support for consideration and decision-making for the people in charge of regional planning. They will be particularly useful in negotiations involving land owners, managers, elected representatives and fire-fighting services.

## A. INTRODUCTION

The French Mediterranean region regularly suffers a large number of fires : 4.5 million hectares (10.8 million acres) of natural landscape risk fires and 10,000 to 60,000 hectares (24,000 to 144,000 acres) burn each year.

As the prevention of forest fires is certainly the best way to protect the forests, various methods have been developed to assess fire risk using different factors such as the type of vegetation, its water content, the relief, wind speed and potential sources of fire outbreak (electricity lines, roads, houses) etc.

These methods are based on either meteorological data or biological data. There are two complementary methods for assessing fire risk:

- a time-based approach which involves defining the high-risk periods using biological and meteorological parameters (inflammability and combustibility indexes): Drouet 1982, Valette 1988 et Carrega 1991

- a spatial approach which involves defining and mapping out the high-risk zones.

A few years ago, remote sensing first appeared as an interesting technique for assessing forest fire risks both in time and spatially (Vidal et al 1993, 1994, 1995).

The CEMAGREF of Aix-en-Provence is developing a spatial forest fire risk assessment methodology, which is at the same time being tested in "the Maures", in the Var département in the south-east of France.

This study lays the groundwork for the Plans for the Prevention of Risks (PPR) created by legislation and decree in 1995.

The analysis of forest fire risk can be broken down into three parts:

- the frequency and intensity of the risk,
- the scope of the dangers to human and natural existence (life, human installations, landscape, flora and fauna, etc.),
- the quality and quantity of prevention and protection means.

The aim of this study is to determine and to map the risk zones in the whole Maures mountain chain using the different human and natural parameters.

We shall present in this article the methodology and data base which have been used in the G.I.S.: only the maps of outbreak and spreading risks will be developed here.

## B. METHODOLOGY

### ❶ *Field of study*

The field of study is the Maures mountain chain, covering an area of about 100,000 hectares (240,000 acres). It is located in the south-east of France, between Toulon and Saint-Raphaël (Maillet 1991).

This chain is mainly covered by cork oak (*Quercus suber*) together with green oak (*Quercus ilex*) and pine trees (*Pinus halepensis*, *Pinus maritimus* and *Pinus pinea*). The altitude varies from sea level to 780 meters and the different slopes are covered by more or less inflammable vegetation.

In this zone, forest fires are made more likely by intense summer droughts and violent winds (particularly by the north-west wind or the Mistral).

### ❷ *Forest fire risk analysis*

First, the methodology was based on a statistical approach (Maillet, 1993) which involved large fire areas (more than 200 ha). Those fires were systematically drawn on maps since 1959 by the departement of French Ministry of Agriculture (Direction Départementale de l'Agriculture et de la Forêt - DDAF).

Fire occurrence was compared with different natural and human factors, such as the slope, the exposure, the vegetation, its structure and its water status, the human lives and installations. (Trabaud, 1989). It appeared that fire risk intensity is not only due to summer rainfall deficit or windy episodes, but also to spatial changes with other variables. This underscores some significant factors as regards fire risk : for example, slope, vegetation structure, water stress etc. (Maillet, 1991). It must be carried on with multivariate and spatial analysis by integrating data in a GIS.

### 2.1 Risk of fire outbreak

The "PROMETHEE" forest fires data base for the French Mediterranean area was created in 1972 on the initiative of the Prefect of the "la zone de Défense Sud" area. This data base concerns fifteen regions in the south of France. It is an inventory of all the forest fires which gives information about causes, meteorological conditions, relief, fire-fighting conditions etc.

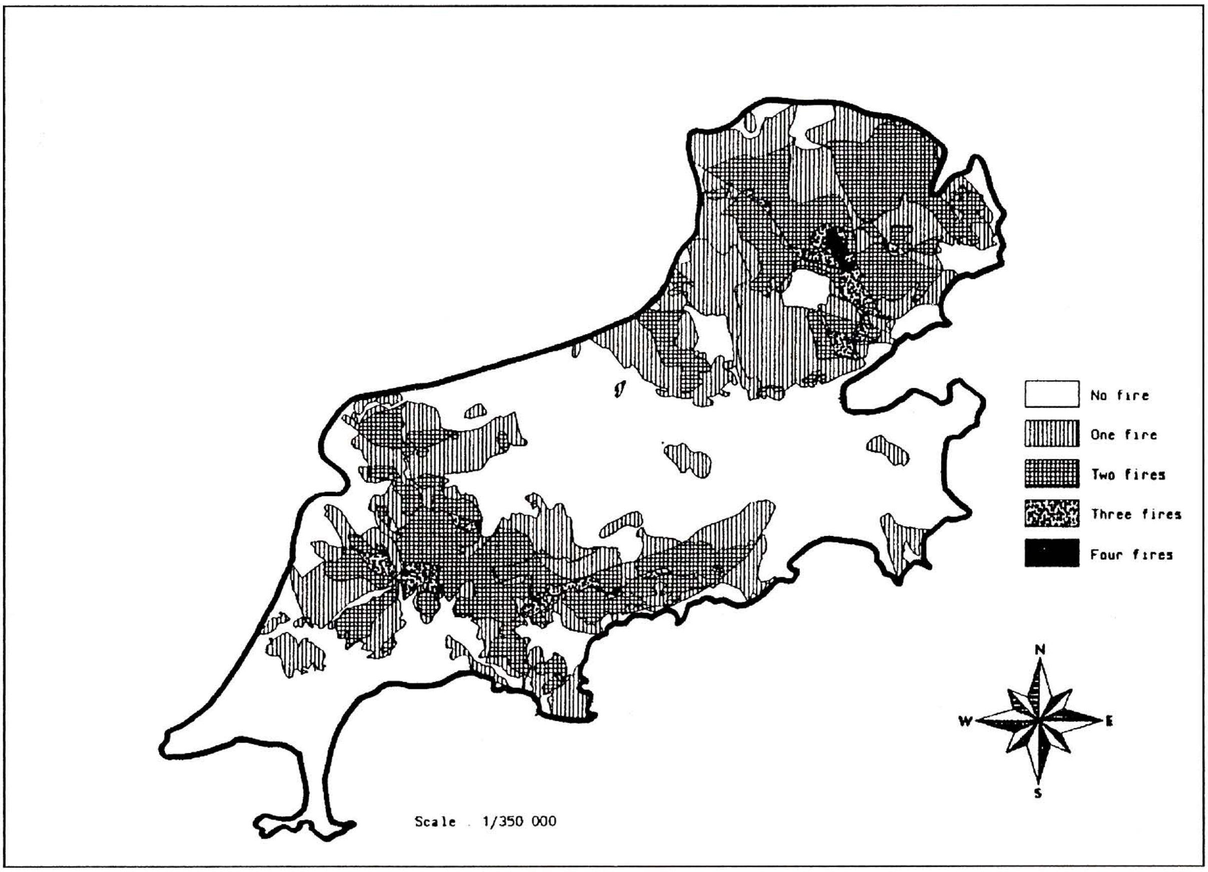


*Figure 1 - Past forest fires map (> 200 ha) : 1959-1994*

This information is supplied by the different partners : foresters (Service forestier de la DDAF), fire-fighters (Direction Départementale des Services d'Incendie et de Secours - DDSIS), police officers, Meteorological Office (Centre météorologique régional de Marignane) and air base for Civil Security (Base aérienne de la Sécurité Civile). Reference : Opération Prométhée.

The forest fire statistics have been studied and a map of outbreak points has been created. This map shows the usual outbreak areas (figure 1).

## 2.2- Propagation risk

The different parameters playing an important part in forest fire propagation are the slope, the wind, the exposure, the vegetation and its water status. (Trabaud, 1989, De Montgolfier, 1990 and Maillet, 1991). The principle of the analysis is to superpose the > 200 ha fires map since 1959 on the different maps of slope, wind and vegetation in order to find some possible correlations.

### *2.2.1 Slope and illumination*

The slope modifies the flaming front angle in relation to the soil.

Elevation Contours were digitised from the National Geographic Institute 1/50.000 maps and a Digital Elevation Model (DEM) was generated in the TIN software unit (Triangular Irregular Network). The Digital Elevation Model allows slope to be calculated on all the points of the area (figure 2).

Slope has been classified in three classes : 0 to 10%, 10% to 30% and more than 30%.
The overlay with the burnt and unburnt areas gives the results shown in figure 3.

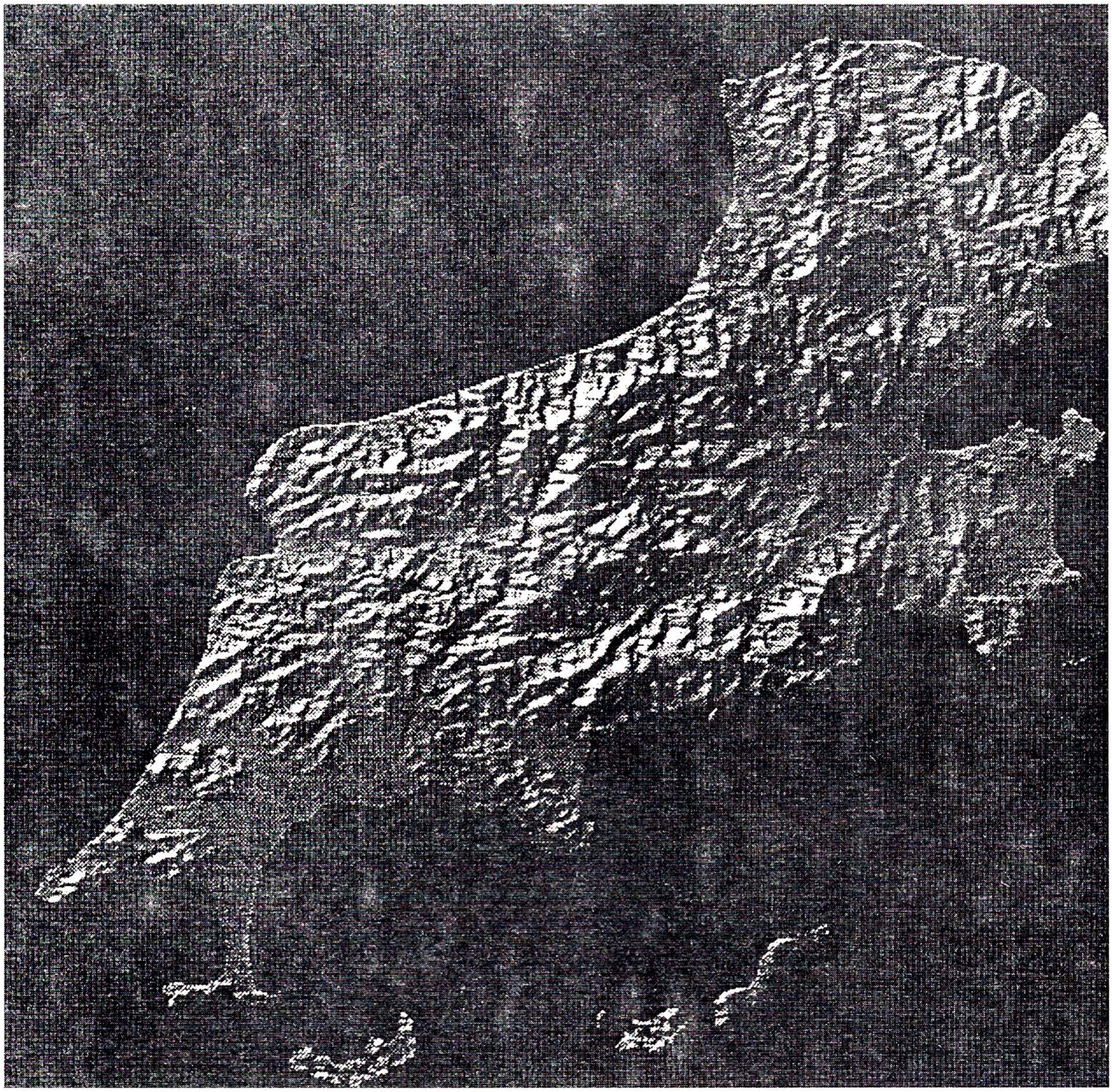

*Figure 2 - Illumination map*

I = 255 (cos (s) cos (S) + sin (s) sin (S) cos (a - A) )
s and a = local slope and azimuth angles at a cell.
S and A = altitude and azimuth angles of the light source

Class 2 is more important on burnt areas : the flaming front is nearer the canopy and the fire propagation is easier. The low percentage for class 3 is hardly significant.

The illumination map is generated from a special function that integrates exposure, slope and relief for an average solar elevation at south position. Sunny and shady areas are individualised. They express local bioclimatic conditions. Salas and Chuvieco (1994) have also used such solar radiation models.

*2.2.2- Wind*

A large experimental water channel has been operated at METEO FRANCE in the "Centre de Recherches Météorologiques" Laboratory (Butet and Perrier, 1995). This facility can simulate the

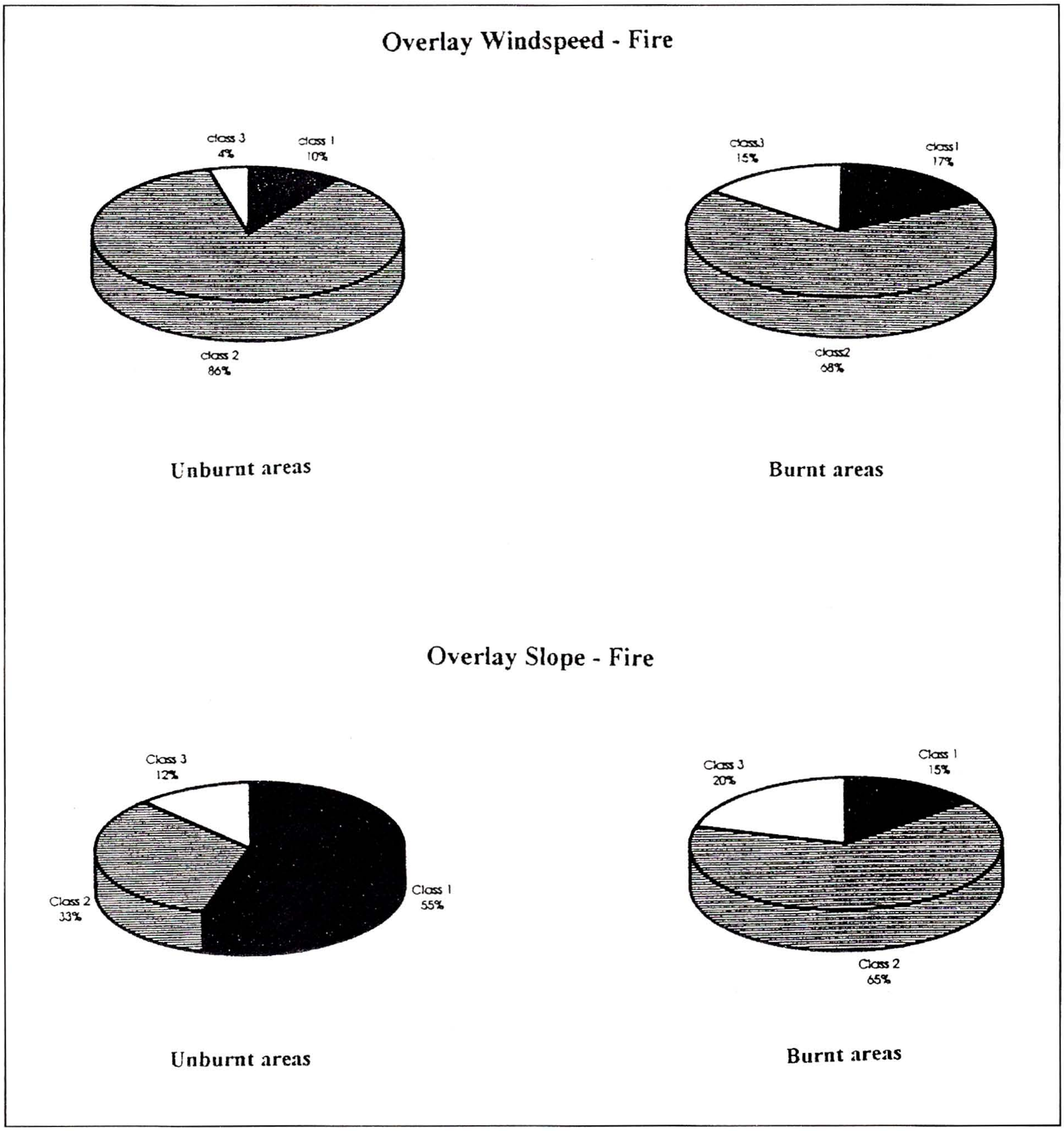


*Figure 3 - Overlays of Windspeed-Fire and Slope-Fire*

atmospheric boundary layer to study flow fields over topographic models in neutral conditions.

The apparatus is a loop-closed water channel 30 m long, 3 m wide and 1 m deep (figure 4).

The whole channel was filled with fresh water to simulate neutral atmosphere with an adiabatic vertical temperature gradient. The test section is located in the last third of the channel : for the "Maures" experiment, a 3 dimension model at a 1/10.000 scale was constructed.

This equipment allows whirlwinds to be viewed and located and allows to calculate the wind speed.

We can give here the result of a crossing between the >200 ha fires map and the wind map. Wind speed is ranges from 3 to 35 m/s. Highest values are located on the plain, northerly, and over the ridges. Over the whole area, values are globally lower than at the reference point.

We defined 3 classes : 0 to 10m/s, 10 to 20m/s and more than 20m/s and we overlaid these classes with burnt and unburned areas. The result is shown in figure 3.

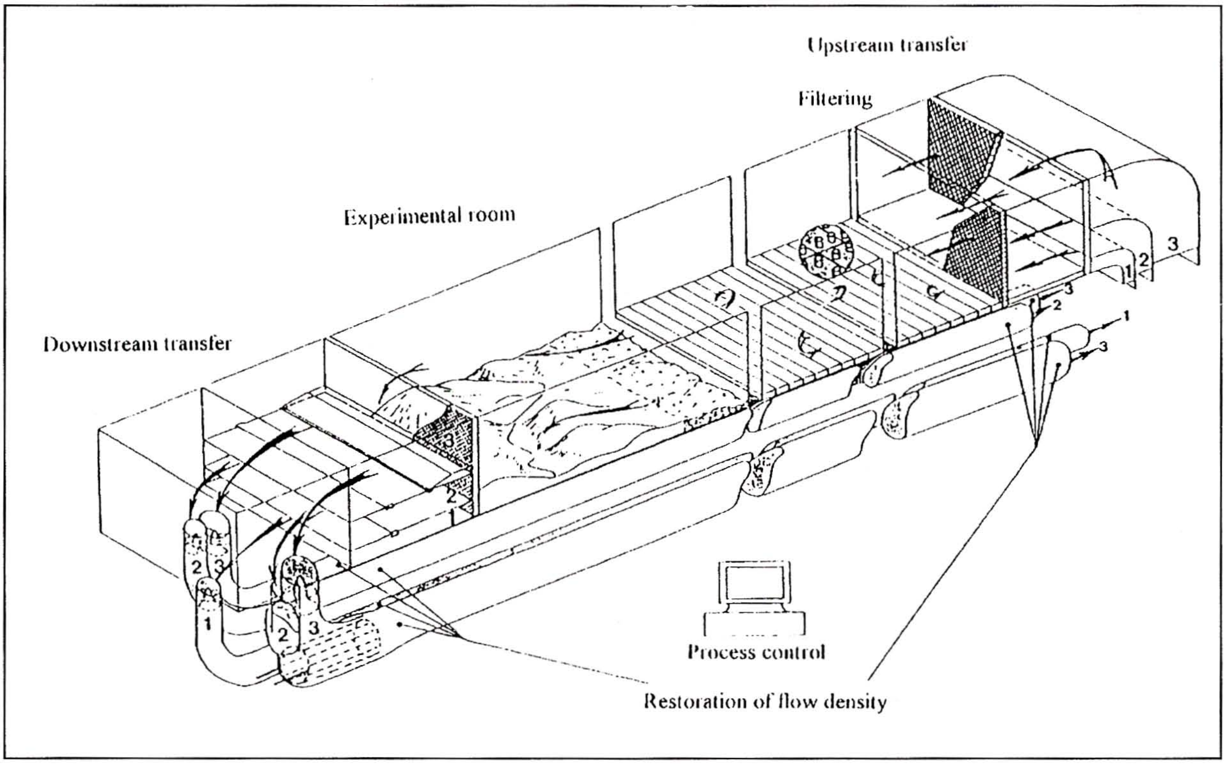


*Figure 4 - Experimental Water Channel - Meteo France « Centre de Recherches Météorologiques » Laboratory*

Class 1 and especially class 3 are more important on burnt areas. Highest wind speeds make propagation easier. Lower wind speeds are associated with the presence of whirlwinds which make propagation variable.

*2.2.3- Water status*

Water status appears to be a major factor in forest fire risk definition. Spatial variability of forest water stress status can be assessed from Landsat TM images (Vidal *et al*, 1994). Canopy surface temperature that can be estimated using Landsat TM thermal infra red data with a 120 m resolution is related to canopy evapotranspiration (LE) through the surface energy balance equation. Vidal *et al* (1993) have shown that the ratio LE/LEp was a good index for fire prediction, as it represents the canopy water stress.

However, the estimation of this ratio from satellite with high resolution on a hilly forest requires a precise evaluation of net radiation that strongly depends on slope and orientation.

In the definition of the CWSI (Crop Water Stress Index), Jackson *et al.*(1981) have shown that the ratio LE/LEp only depends on the difference between surface and air temperature and on maximal and minimal surface temperature of the canopy.

Perrier (1975) has shown that these relationships do not depend on net radiation anymore, but only depend on canopy aerodynamic resistance. Though this resistance varies a great deal from one day to another, it can be assumed that it does not vary spatially on a homogeneous forest.

Therefore for the assessment of forest water status spatial variability on a precise day, we can use the surface minus air temperature difference derived from Landsat TM thermal infra red data and meteorological data corrected with a DEM, instead of the ratio LE/LEp whose estimation is complex and may induce additional errors.

Air temperature is obtained from the meteorological station of le Ruscas, located in the centre of the area and corrected from topographic effects using a 120 m resolution digital elevation model.

A map of the surface minus air temperature (Ts - Tair) is derived from both Landsat and meteorological data and is compared to fire events registered in PROMETHEE data base.

It appears that 86 % of fire events began in areas where the maximal value of Ts - Tair was higher than 9° C and 50 % for Ts - Tair > 15° C, whereas the mean value for the whole area is 5,5 °C.

Ts - Tair thus appears to be a rather good fire risk index.

For our study, we have used these results on water status assessment.

Two Landsat TM images (precision within the range of 120 m - 16 days repetitivity) in July and in August are used in order to define the strongly stressed areas, i.e. in situation of high water stress from the beginning and throughout the season and the areas which, on the contrary, hardly endure any stress.

*Remark :*

This approach has been completed with the study of the vegetation :

- the vegetation composition for which we have used the data of the National Forester Inventory (Inventaire Forestier National).
- and the vegetation structure : the interpretation of aerial photographs and ground measurements gave a detailed vegetation structure map, including density and height class.

## CONCLUSION

Given the state of progress of the work, it is not possible to present the results of the map combination nor, therefore, the four consolidated maps (risk of outbreaks, risk of spreading, sites to protect and means of prevention and protection). It is important to point out that the creation of the data base has been very long and that it presented a certain number of problems (a legal vacuum in the field of ownership of information and of its exchange, cost of digitisation work, data acquisition costs).
Concerning methodology, the analytical principle chosen involves defining qualitatively the zones which have the most frequently suffered substantial damage in the past .

However, certain factors in the natural and the human environment change with time. We can mention vegetation, for example, which has been shaped by past fires, or urban development in the forest or in contact with it which has dramatically modified the problem of fires.

It is therefore difficult to take this change into account in our analysis.

We find the same problem in updating the consolidated maps which will be drawn up. In fact, these maps, which are the result of the combination of thematic maps (some of which change with time) will be dynamic maps.

The final point concerns the follow up to such a study. The scale which we are working with is 1/25 000. However, at this scale, we cannot determine constructible and non-constructible zones as defined in government regulations (law and decree concerning Plans for the Prevention of Risks). We must therefore carry out a feasibility study for a change of scale (from 1/25 000 to 1/5 000 for example), with all the possible consequences this may produce for the methodology and the data. This is sure to be the subject of new study on just a part of the Maures mountains.

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