Use of remote sensing data in a forest fire simulation software – GEOfeu

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ABSTRACT

Geoimage and MTDA Agency[1] have in cooperation developed a forest fire simulation software package based on a propagation model. A friendly graphic interface has been developed, taking into account the needs and the requirements of the people who may use this software.

Besides the propagation model, our software relies on a data base built on a series of geo-referenced plans: the active data and the passive data. The active data are relative to three types of physical parameters included in the propagation: the land cover, the relief, the wind. Passive data consist of all the plans which are used as a reference for analysis and decision making: existing maps, georefenced images from SPOT, LANDSAT or aerial images.

Our paper deals with the way we use the different remote sensing data in a propagation model which follows the relief variations closely and takes into account information such as wind and ground cover.

1. INTRODUCTION

The size and importance of several past forests fires in the Mediterranean area raised the need to improve the fire fighting and prevention means. Despite the work done for a better supervision of the forests and for quick interventions, some fires get through the fire-fighting net only under severe but quite frequent meteorological conditions. The usefulness of computers to improve, combat and prevent fires is more and more obvious (Chevrou 92). The availability of forest fire simulation tools seems to be essential nowadays to facilitate decision-making in prevention and fire fighting.

On the other hand, the progress made in digital mapping software and satellite imagery enables us to envisage computerised propagation simulation of forest fires fed by ever more precise data. The evolution of prevention and fire fighting techniques will certainly make use of such tools.

The main interest of remote sensing in the matter of forest fires is also the regular availability of satellite data over most regions of the Earth allowing the execution of maps necessary for the simulation of forest fires.

Geoimage and the MTDA Agency have worked together for the last two years to create a forest fire simulation program. A man/machine friendly interface has been developed in close collaboration with the people who may use this software package, and who have experience and knowledge about forest fires. The three domains of application of this software package are: prevention, training and fire fighting.

Concerning prevention, this tool will be used to acquire a better knowledge of the sensitive areas (a set of simulations will identify the particularly endangered zones) and to manage the modification of the fuel nature in some strategic places (installation of fire-breaks which are positioned with the help of simulations).

The understanding and the control of the propagation of a fire will also enable the rescue teams to be better prepared. The training in actual situations being difficult to achieve, part of the training can be carried out using computer simulation with the mobilisation of the fighting crews on hypothetical situations or past real fires.

In the long term, the usefulness of such a tool is obviously to be able to use it in an operational mode: that is to say, the possibility, in case of fire, of anticipating the behaviour of a fire in order to quantify and position the necessary fighting and rescue means.

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2. A FOREST FIRE SIMULATION SOFTWARE: "GEOFEU"

The GEOfeu software package relies on a data base containing a series of geo-referenced data planes. They are divided into two groups: the active data and the passive data. The active data concern three types of physical parameters which are part of the propagation:

- land cover (location of the different types of vegetation),
- relief (relief map, slope map, exposure map),
- wind (wind vector map).

All the planes which are used for consulting purposes, for helping analysis and decision making constitute the passive data:

- existing maps of the zone under study (maps from National authorities (Institut Géographique National IGN), maps from National Forest Inventory (IFN), maps from firemen),
- SPOT, LANDSAT or aerial data.

GEOfeu can be considered as a GIS specialised in Forest Fire with fire simulation processing in order to provide a well adapted tool to help in decision making.

The interface functions are used to simulate one or several fire outbreaks and to visualize the various stages of propagation. Some parameters can be set directly, in particular the direction and the global force of the wind, the relative percentage of dampness in the air and the time unit between the different stages of the propagation. The ground cover can be modified to introduce one or several firebreaks, for example. Moreover, a module is used to display certain stages of the propagation on a perspective view image.

The Geoimage company and the MTDA Agency are participating in the European research programme n°EV5V-CT91-0015 for modelling forest fires. From this work some models of fire propagation should eventually be developed which will be included in the simulator. For this reason, the present fire propagation model was implemented in a modular way. It will thus be possible to test easily various propagation models.

In the following, we present the remote sensing data which we handle and the manner in which they are used by the software package.

3. REMOTE SENSING DATA HANDLING

Whatever the fire propagation model used, three essential parameters must appear in the data plane list: relief, land cover, and wind. They are acknowledged as being the factors which mainly govern fire propagation. At present, remote sensing techniques are used as the easiest way to gather information on relief and land cover.

3.1 The GEOfeu propagation model

The GEOFEU forest fire simulation software package uses a propagation model (Demagistri 92) which takes into account variations in relief.

The fire front is described by a list of points in real coordinates which represent its contour.

- For each of these fronts, the points are propagated through a "propagation speed" (V) computed by the fire model.
- At any point on the front, the V vector is included in the plan which is tangent to the relief at this point. It is obtained through a weighted sum of the vectors relative to the relief, the wind and the normal direction on the front, given by the following formula:

$$V = \alpha \, . \, f_c \, \{ \, V_c + (f_v\text{-}1)V_v + (f_p\text{-}1)V_p \, \}$$

where:

V_c, V_v, V_p are unitary vectors showing the normal direction at the fire front (V_c), the wind direction (V_v), the slope direction (V_p).

f_c is the fuel related propagation factor.

f_v is a wind and dampness related propagation factor

f_p is a slope related propagation factor;

α is a model adjustment ratio

dt being the time unit for the propagation, the points of the fronts are projected in the direction of the motion vector for a distance of V.dt.

The V_c, V_v and V_p vectors result in a projection on the relief tangent plane, thus ensuring a parallel propagation to it. Their coordinates are computed through the elementary trigonometrical relationships between the slope and exposure angles, the orientation of the normal to the front (for the V_c vector), the wind direction (for the V_v vector). The values which are used for the f_c, f_v and f_p parameters are explained in the following paragraph and in **Tables 1, 3 and 4**.

This model has been developed from well-known models in literature (Dupuy 1991). In particular, the Rothermel's model or the Canadian one (the "Fire Behavior Predicting System") which have been studied for many years. Our model is a simplification which allows us to represent, in a rather realistic way, the average evolution of a fire using a simple combination of the physical parameters.

The propagation method consists of considering the different points of the fire front line separately and applying the model to them in order to obtain a new line of fire front. This method is also used in Knight & Coleman (Knight 93). In this paper, the model relies on an elliptical propagation from each point of the fire front.

One of the problems with this propagation method is the occurrence, along the new outline, of loops and intersections that cannot be easily dealt with. As a consequence, we are also working on other propagation methods and particularly on pixel contagion processes. These consist of spreading the fire from a burning pixel to its nearest neighbours and repeating the phenomenon. Some teams have already been working on this topic (Kientz & Lenco 1992) and the basic algorithms are recalled in French *et al.* (French 1990).

3.2 The Data

3.2.1 Relief

The relief is obtained from a digital elevation model. A digital elevation model can be obtained in various ways. It can be acquired by digitizing the contour lines or by image processing techniques applied to remote sensing data. In this case, it is computed by automatic restitution method from a pair of satellite or aerial stereoscopic images, i.e. two images of the same area taken from different view angles (obtained by two different passages of the sensor over the scene). For the SPOT images, the ideal conditions are obtained through a maximum angle range and a minimum date range. Sub-products of the digital elevation model such as the slope map or the exposure map can be derived. For each point of the map, the slope and the orientation of the face are computed by analysing the tangent surface to a particular point. The values of the slope and of the exposure cannot be dissociated: a steep slope can contribute either to accelerate or to slow down the progression of a fire according to whether the orientation coincides or not with the propagation direction.

As the equation in the previous paragraph shows, the influence of the slope on the propagation model is expressed by a component of a vectorial sum characterized by:

- a unitary vector representing the direction in which the slope tends to affect the fire,
- a "slope" propagation factor obtained as a function of the angle of the slope incidence as shown in **Table 1**.

Table 1 - Slope related propagation ratio (fp)

Slope (°)	0	6	11	17	22	27	31	35
fp	1.00	1.25	1.67	2.30	3.24	4.65	6.78	10.00

The DEM, the computed exposure, and the slope image from a part of the "Alpes-Maritimes"district in France are presented in **Figure 1**.

3.2.2 Land Cover

The land cover map is obtained by supervised classification from multispectral image of the area under study. This technique consists of re-grouping the pixels of an image into different classes according to their spectral information. In order to easily distinguish between zones with close spectral responses, it is sometimes necessary to use a second multispectral image taken during a different season. Current practice, in vegetation studies, uses two images which are respectively taken in summer and in winter. Knowledge of the area under study, represented by training plots, is integrated into the system to describe the land cover types to be classified.

The land cover map produced for this application is a location map of the various types of vegetation defined by a typology customised for the field of forestry **(Figure 2)**.

In order to obtain a more accurate definition between the various species, a cross-comparison between data planes such as altitude and exposure is used. Some species are found only below or above some precise altitude thresholds, or on faces having a specific exposure. Some results of a study carried out in the Alpes-Maritimes district (France) are presented in **Table 2**. This table results from a detailed study of forest inventory in Mediterranean zones performed by the MTDA agency (MTDA 1992).

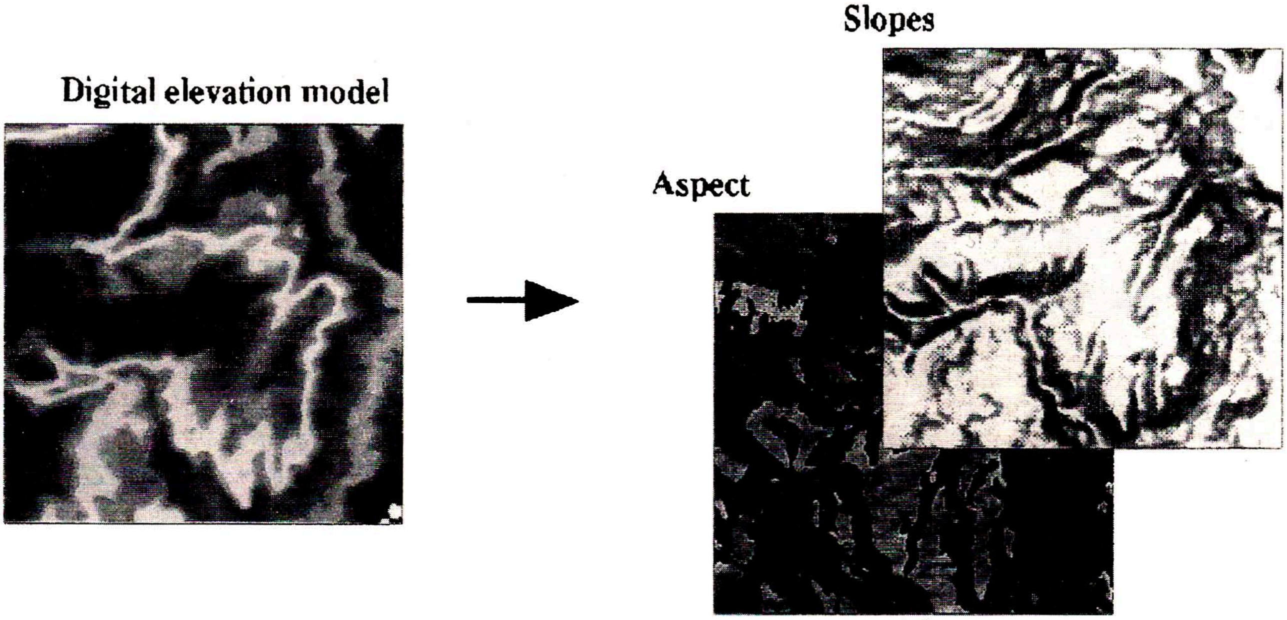

Figure 1 - Digital Elevation Model on a part of the Alpes Maritimes area, computed exposure, and slope map

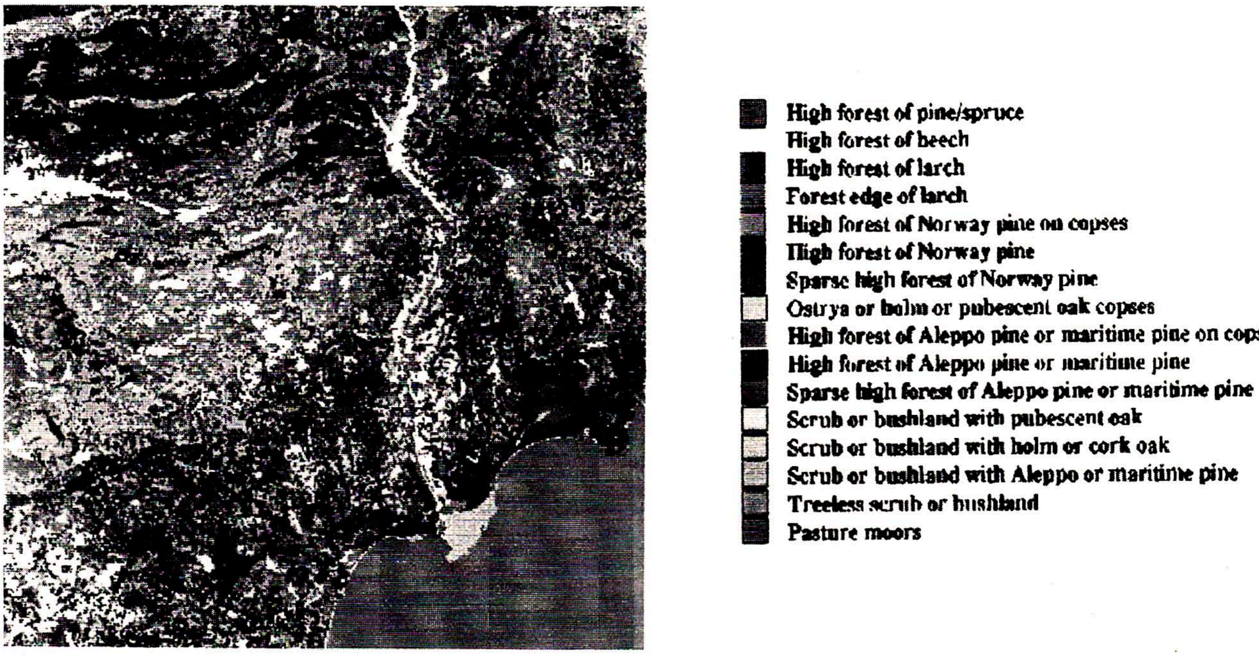

Figure 2 - Land cover map of the Alpes Maritimes area

The full characteristics necessary for input into the fire propagation model corresponds to each of the listed species in the land cover image.

In our model, the fuel is taken into account by connecting each species of the land cover map to a list of characteristics necessary at the input stage. These characteristics can be summarized into two parameters: the fuel related propagation ratio(fc) and the fuel load (C). These are shown below in **Table 3** for the typology defined in the Alpes-Maritimes area.

One of the main advantages in using remote sensing to describe land cover is the ability to obtain heterogeneous classes of fuel, including several plant species. In fact, according to the distribution of these species and their respective percentages, the spectral response which is obtained by satellite or aerial imagery will be different. It will, thus, be possible to distinguish between two types of environment, made up of identical species, with slightly different proportions.

Table 2 - Cross comparison between the result of a supervised classification and the exposure and altitude maps in order to obtain the several species in the Alpes Maritimes area

Class	Altitude (m)	Exposure	Most frequent (IFN) type
Conifer high forest	> = 1200	SE-SW	Sparse Norway pine high forest
Conifer high forest	1200-1500	NE	Pine/spruce high forest
Conifer high forest	1200/1500	NW	Norway pine high forest
Conifer high forest	< 1200	SE-SW	*Aleppo* or Maritime pine high forest
Conifer high forest	< 1200	NE-NW	Aleppo or maritime pine high forest on copse
Broadleaf high forest	> = 1200	All	Beech high forest
Broadleaf high forest	< 1200	All	*Ostrya* or *ilex* or pubescent oak copse
Mixed high forest	> = 1200	All	Norway pine high forest on copse
Mixed high forest	< 1200	All	*Aleppo* or maritime pine high forest on copse
Scrubland/bushland	< 1200	All	Treeless scrubland or bushland
Scrubland/bushland	> =1200	All	Pasture land

Table 3 - Some values of the fuel related propagation ratio and fuel load depending on the kind of species

IFN type	fc(m/s)	C(g/m^2)
Sparse Norway pine high pine	0.17	2000
Pine/spruce high forest	0.01	500
Larch high forest	0.06	500
Aleppo or Maritime pine high forest	0.31	2000
Larch pre-forest	0.08	1000
Beech high forest	0.03	500
Ostrya or *Ilex* or pubescent oak copse	0.19	2000
Scrubland or bushland with pubescent oak	0.36	2000
Treeless scrubland or bushland	0.42	3000
Pasture land	0.45	1000

3.2.3 Wind

The wind is a parameter which cannot be fully and precisely understood at present. Numerical models can be found in the literature (Sol 1990) but they are not satisfactory because of their resolution.

Some partners in the European programme mentioned above are working on this problem at the moment. A wind model computing the deformation of a wind profile on relief has been carried out by the FISBAT Institute (Bologna, Italy). This kind of model can be used to obtain wind fields in synoptical situations. However, its hypotheses on the studied relief are too restrictive (FISBAT 1994). Images of wind direction have been computed from the Digital Elevation Model of the Alpes-Maritimes (**Figure 3**). To take into account more local effects such as thermal winds, it seems necessary to work with a combination of models at different scales.

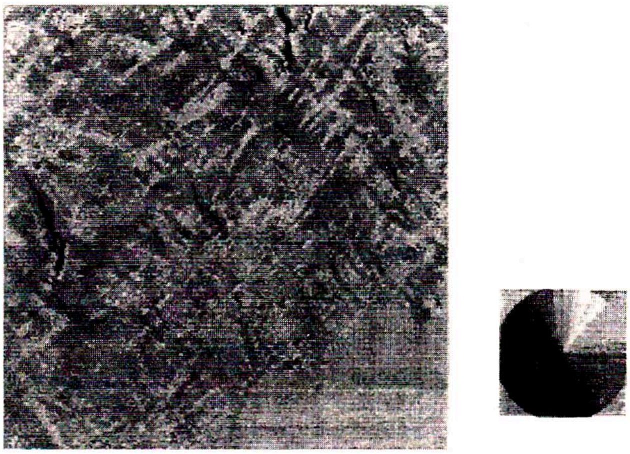

Figure 3 - Wind Direction image on the relief of the Alpes Maritimes. The synopic wind blows from West. The color is related to the wind direction

In our model, the wind direction and force are directly taken into account.

The wind related propagation ratio (obtained from **Table 4**) which takes into account the speed of the wind and the dampness level in the air.

Table 4 - Wind related (U in km/h) and dampness related (H in %) propagation ratio (fv)

H/U	8 to 16	17 to 24	25 to 32	33 to 40	41 to 48
41 to 45	1.0	2.0	2.8	3.2	3.4
31 to 40	1.4	2.8	3.9	4.5	4.8
26 to 30	2.0	4.0	5.6	6.4	6.8
16 to 25	2.8	5.6	7.8	9.0	9.5
< 15	3.2	6.4	9.0	10.2	10.9

In the following section, some illustrations of the use of the GEOFEU simulator are described.

4. EXAMPLES OF SIMULATIONS WITH GEOFEU

The simulations which are described below have been carried out using the Alpes-Maritimes data base.

In the first instance, an initial fire digitized using the interface functions has been allowed to propagate itself. Since the software is able to manage an unlimited number of fire fronts, after a certain lapse of time, a secondary fire has been lit at the fore of the front. Then, the simulation has been continued until the two fronts met (**Figure 4**).

In order to demonstrate the effects of the modification of the land cover map during a simulation (a method which is presently used to simulate an intervention on the fire), two fire simulations have been carried out under identical conditions. During one of them, a fire-break has been positioned across the front. The setting of the fire-break corresponds to the local modification of the land cover map. The zone in question is then transformed into a non-combustible or low-combustible area. The fire is then stopped alongside the fire-break and it starts to go round it (**Figure 5**).

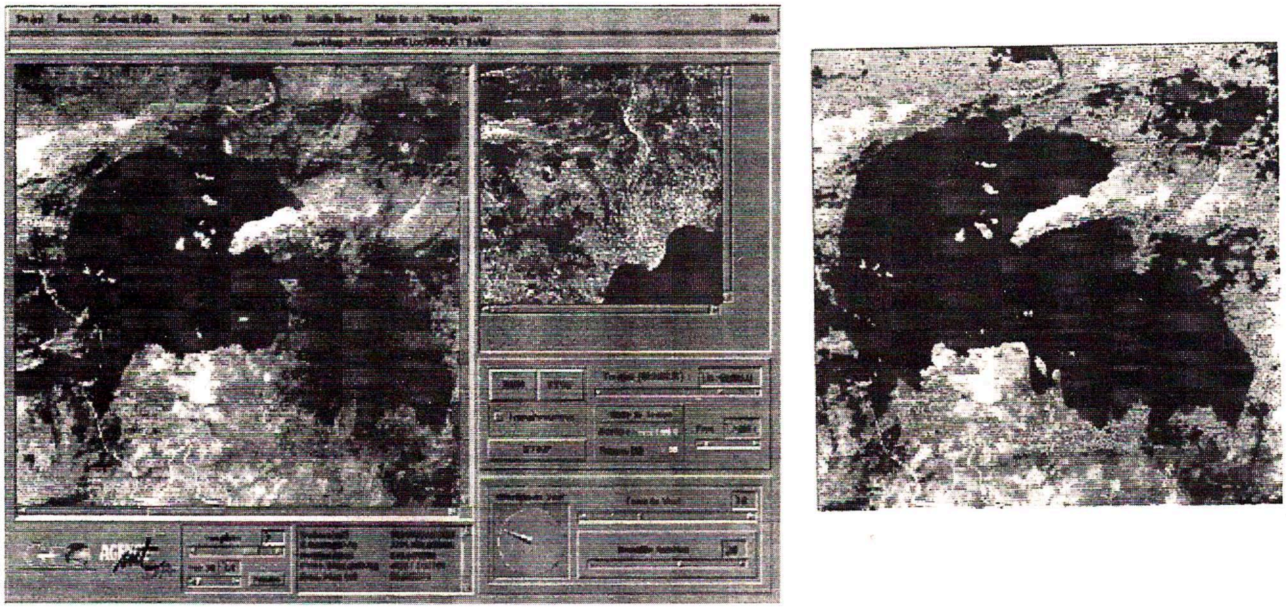

Figure 4 - Simulation of two fires. Two stages of propagation are presented

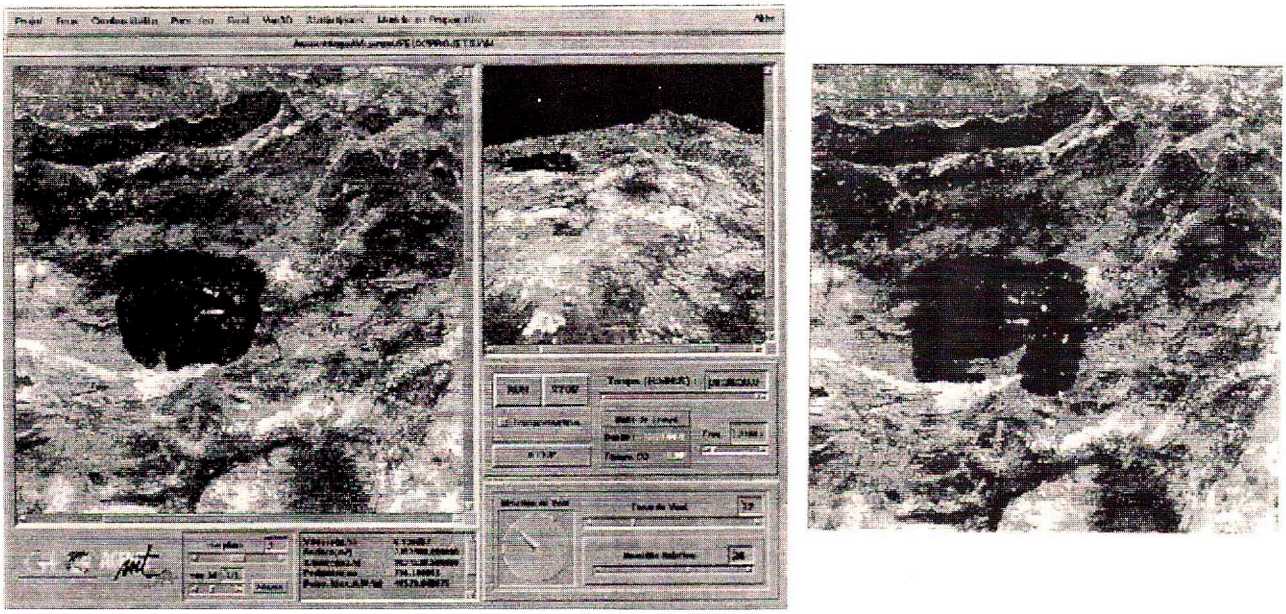

Figure 5 - Modification of the land cover map during a simulation

Using information about past fires, several simulations give interesting results according to the shape of the burnt area. For example, in the case of a fire close to Gattières (a village in the Alpes-Maritimes area): the fire climbed up the mountain and was stopped at the top by firemen. According to experts (from National Forest Office ONF) the simulation achieved with fire simulation software gives almost identical burnt areas to that of the real ones. **(Figure 6)**.

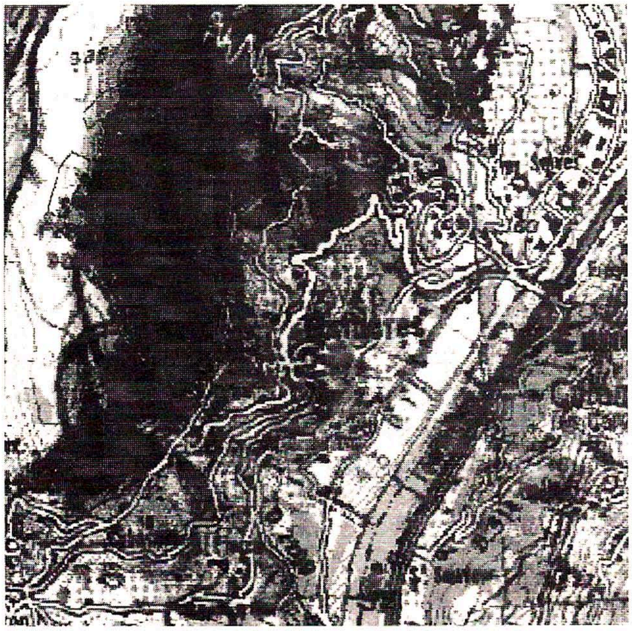

Figure 6 - Simulation of the real fire on "Gattière" according to the information of experts

5. CONCLUSION

The simulations which are obtained through the interface are quite satisfactory. The behaviour of the fire according to the slope, to the wind and to the fuel nature is quite realistic. It is possible to test the influence of one or the other parameter separately: in actual fact, the fire accelerates both in the direction of the steeper slope and of the wind. However, a calibration phase of this model is necessary in order to modify the various ratios in order to adjust the simulations to the data which were gathered on previous fires. In order to do this, and to validate and adjust the model in real conditions, cooperation been established between the DDSIS of the Alpes-Maritimes (the Alpes Maritimes area management for fire services and assistance) and the partners of the EEC project. Using a water spraying helicopter from the Civilian Security, it is planned to carry out a recording campaign of outlines and characteristics of the fires throughout their development, during all of the 1994 summer season. This information transmitted in real time could constitute an initial front from which the fires' behaviour can be simulated and anticipated.

The list of the parameters which are likely to play an important role in the propagation of a fire and therefore to intervene in a fire model, is not exhaustive. The data bases to be established in order to use the forest fire simulation software package, will have to be completed as the fire models evolve. Remote sensing will certainly help to obtain some of the parameters which appear to be missing. Among these important parameters still missing are ground temperature, the percentage of air moisture and the percentage of ground moisture. All three of them appear as factors which will have to be taken into account in the accurate modelling of fire propagation.

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