# Fire hazard mapping : towards dynamic GIS

**D. Alexandrian**

Agence MTDA, 298 avenue du Club Hippique, F-13100 AIX-EN-PROVENCE
Tél. (33) 42.20.12.57 - Fax (33) 42.20.16.35

**ABSTRACT**

Among the numerous applications of satellite technology and GIS for fire management, some of them are not very widely used: for example, wind maps (for firebreak location) or "visible area" maps (for lookout network optimisation).

For the last three years, the company MTDA has been developing a set of tools in the field of fire hazard mapping. Particular focus has been placed on:

1. burnt area mapping,

2. fire hazard mapping with traditional GIS,

3. forest fire simulation.

From experiences gained from this work, it can be concluded that the use of dynamic GIS (the next generation of GIS technology) is essential for an efficient fire management tool.

## 1. INTRODUCTION

For some years, satellite technology and GIS have been used more and more for fire management. Some techniques are already well known for burnt area mapping or fire hazard mapping (parts 2 and 3 of this paper). Others techniques are still not very widely used, for example, wind maps (for firebreak location) or visible area maps (for lookout network optimisation).

In any case, an efficient fire management tool needs a dynamic component in order to be able to estimate the spread of a fire starting in any stand of a forest, given the burning conditions.

For this purpose, a research programme on "Forest fires modelling" was initiated at the end of 1991. At the same time, software was developed in collaboration with the company GEOIMAGE (part 4 of this paper).

## 2. BURNT AREA MAPPING

### 2.1. Introduction: use of satellite technology to make a map over an 18 year period

In most Mediterranean countries, a data base on wildfires already exists, including information on the date, time, location, area and cause of the fire.

The French Department of Agriculture and Forests wished to augment this database with a map of burnt areas, in order to see which regions suffer from high frequency of fire events.

Landsat images were used to make this map for an 18 year period (1973-1990).

### 2.2. Materials and methods

The study area is located in south-east France, mainly the three regions Provence-Alpes-Côte d'Azur, Languedoc-Roussillon and Corse.

This area is covered by approximately 8 Landsat full scenes, every scene being about 180 x 180 km. The images were chosen from the periods when it is easier to distinguish the burnt area (i.e. generally between 15 September and 30 October). Only one image per year was bought, in order to limit the total cost of the map.

Since the aim of this study was a map (and not a precise statistical analysis), colour composites of Landsat MSS

(Multi Spectral Scanner) images were "photomapped", which also decreased the cost of such a temporal analysis.

The outline of each burnt area was plotted on a small scale map (1:500.000), and marked with a special pattern when two burnt areas occurred at the same location (1).

Three main difficulties were encountered:

1. It was impossible to detect scars from small fires (i.e. less than 10 ha for forest fires and less than 20 ha for bush fires),
2. Images for 1982 were not available,
3. It was sometimes difficult to find an image for the right period, especially for the early (March) and late fires (October) in mountainous regions.

### 2.3. Results

Fires which burned more than 10 ha represented 5 % of the total number of fires and 90 % of the total burned area. Those which burned more than 100 ha represented 1 % of the total number of fires and 75 % of the total burned area. When comparing our results with the data base, it appeared that Landsat-derived map showed approximately 80 % of the recorded fire events. **Figure 1** shows an extract of the map produced (Northern Corsica).

Several extensions to this work are considered:

- To complete the data with records made in the field by foresters,
- To regularly up-date this inventory,
- To link these geographic data with the fire data base, in a GIS.

## 3. FIRE DANGER MAPPING

### 3.1. Introduction: production of a fire danger map for an entire French region, using a GIS

The Limousin – a non Mediterranean region – belongs to the "medium risk zone" according to the EEC classification (EEC 2158-92), but, the high economic value of recent commercial conifer plantations significantly increases the fire damage. Moreover, the annual area burnt increases with the reduction of the cultivated area.

As a consequence, MTDA has been ordered by the forest service to carry out the following (2):

- A technical study of more than a thousand fires that have been registered since 1976 (fire location, burnt areas, meteorological conditions, fire seasons, flammability of each type of fuel, main causes, action time,...),
- A fire hazardous areas map (600.000 ha) based on results from the previous technical study,
- To determine new fire prevention policies, based both on the technical study and the fire danger map.

Only the procedures for making the fire hazardous areas map are detailed in this paper.

### 3.2. Materials and methods

This application was developed using the GRASS software (Geographical Resource Analysis Support System), a freeware from the US Army (Construction Engineering Research Laboratory), which is very powerful for raster data treatment.

In order to be able to produce a map at a 1:250.000 scale, a 20 metre resolution was chosen.

Three main cartographic principles were adopted:

1. To determine the "ignition risk" and the "spreading risk". The former expresses the probability of the phenomena (hazard). The latter expresses the foreseeable consequences of a fire, if it starts (damage). The "fire risk" is the combination of the "ignition risk" and the "spreading risk".
2. To express each parameter in a quantitative way, to allow objective and easy use for comparisons.
3. To combine all the available data in a logical way (i.e. using results obtained from the technical study) to correctly estimate the fire risk.

### 3.3. Results

The 13 basic maps and their various combinations in the production of the final fire hazardous areas map are listed in **Table 1**, **Table 2** and shown in **Figure 2**.

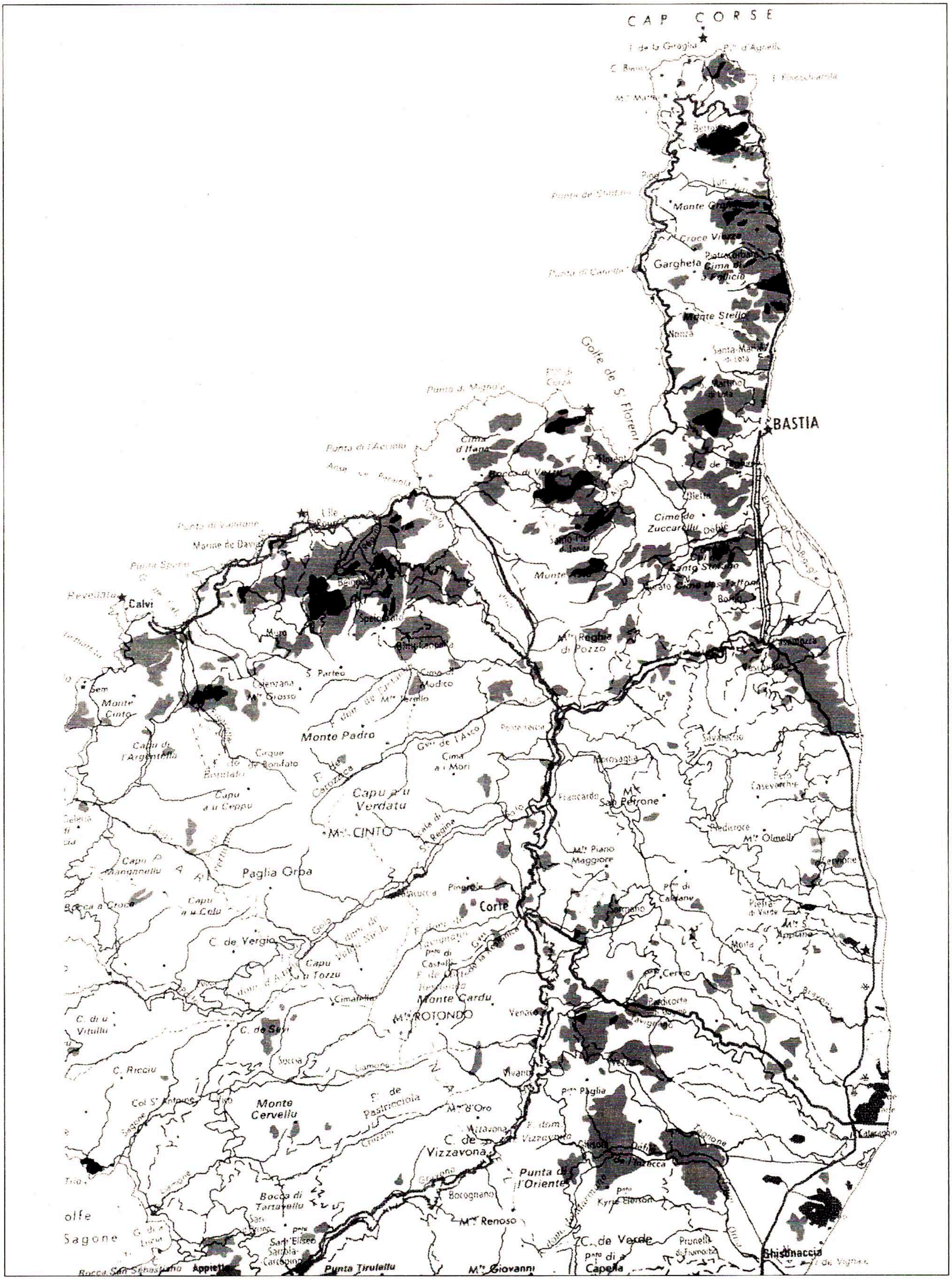


*Figure 1 - burnt area mapping in northern Corsica (scale 1:500.000).*
*In pink, the areas burnt once, in red the areas burnt twice (or more)*

**Table 1 - Type of data used in the GIS**

| Type of data | Map name | Sources |
|---|---|---|
| Climate | DROUGHT INDEX | Atlas agro-climatique |
| | SPRING EARLINESS | Atlas agro-climatique |
| Demography | DENSITY OF POPULATION | Institut National de la Statistique et des Etudes Economiques |
| | DENSITY OF FARMING | Recensement Général de l'Agriculture |
| | CULTIVATED LANDS REDUCTION | Recensement Général de l'Agriculture |
| Action | DISPATCH CENTER DISTANCE | Service Départemental d'Incendie et de Secours |
| | CONTROL FORCES | Service Départemental d'Incendie et de Secours |
| Statistics | FIRE CONCENTRATION | Archives |
| | FIRE OCCURRENCE | Archives |
| Fuel | FUEL FLAMMABILITY | Inventaire Forestier National + Archives |
| | INTERFACES LENGTH | Inventaire Forestier National |
| | FUEL COMBUSTIBILITY | Inventaire Forestier National + Archives |
| | CLUMPS AREA | Inventaire Forestier National |

**Table 2 - The 13 basic maps of the GIS**

| BASIC MAPS | Data | What does it mean ? | Values (min/max) |
|---|---|---|---|
| DROUGHT INDEX | The number of sequences of 3 consecutive days without rain (from 20 April to 10 June). | The peak fire season probability at the end of winter. | 5/9 |
| SPRING EARLINESS | The date of the last spring frost. | The duration of fire season. | 21 April/ 1st June |
| FUEL FLAMMABILITY | The number of fires/year/ 1000 $km^2$ of each fuel type. | The relative ease with which each kind of fuel ignites. | 0,9/4,7 |
| DENSITY OF POPULATION | The number of people/$km^2$ of each commune (the trend 1982-1990 has been continued until 2000). | The "urban" man-caused risk. | 2/1638 |
| DENSITY OF FARMING | The amount of farming/$km^2$ of each commune (the trend 1982-1990 has been continued until 2000). | The "farming" man-caused risk. | 42/334 |
| INTERFACES LENGTH | The perimeter of forest areas of each commune. | The parcelling out of forest areas. | 0/160 km |
| FIRE CONCENTRATION | The number of fires/year/ 1000 $km^2$ of each commune (1976-1992). | The situations in which numerous fires have been burning. | 0/99 |
| CLUMPS AREA | The area of each forest area. | The area potentially threatened. | 0/78000 ha |
| CULTIVATED LANDS REDUCTION | The ratio of cultivated land likely to return to wasteland in 2000 (in continuing the trend 1979-1988). | The probability of expansion of forest areas. | -34/+115 % |
| FUEL COMBUSTIBILITY | The average burned area per fire (ha) of each fuel type. | The difficulty of control of fires for each kind of fuel. | 4,4/17,2 ha |
| DISPATCH CENTER DISTANCE | The distance of the fire fighting forces, within the fire district. | The estimated action time. | 1/22 km |
| CONTROL FORCES | The total volume of apparatus (tankers) of the fire district. | The strike team available for the first action. | 1/37 $m^3$ |
| FIRE OCCURRENCE | The burned area/year/1000 $km^2$ of each commune (1976-1992). | The situations in which large fires have been burning. | 0/2357 ha |

Comments:

- The availability of data is a very important consideration when the map has to be produced in a short time.
- The colours used for mapping the data are always "green to red through yellow", representing low to high risk levels, respectively.
- The fire danger map provides a very useful risk scale, similar to those used in other French or European regions. We have chosen the "Annual Medium Risk" **(Table 3)**, which is expressed as the area (in ha) burned every year within a 1000 km² forest area.

**Table 3 - The thresholds of each risk level**

| Colour | Annual Medium Risk | The fire risk is |
|---|---|---|
| Green | Less than 10 ha/year/1000 km² | Very low |
| Yellow | 10 to 100 ha/year/1000 km² | Low |
| Orange | 100 to 1000 ha/year/1000 km² | Moderate |
| Red | More than 1000 ha/year/1000 km² | High |

## 4. Forest fire modelling

It was shown previously that the fire risk must involve both the "ignition risk" and the "spreading risk". But, with traditional GIS, we do not take into account the dynamic characteristics of the phenomena: when a fire starts at a point in an area, it is able to spread to some other points of the area, especially when strong winds are blowing.

So, for a true fire danger map, the following questions should be considered:

- the "suffered risk": what is the probability for a stand to be reached by a fire started "upstream"?
- the "induced risk": what likely damage is caused by a fire to the stands "downstream"?

As a consequence, it is necessary to be able to estimate the spread of a fire starting in any stand of a forest area, given the burning conditions.

For this purpose, a research program on "Forest fires modelling", funded by the E.E.C. at the end of 1991 (Contract n° EV5V-CT91-0015) was undertaken. The aim of this study was to develop behavioural models of vegetation fires adapted to European conditions.

In fact, the North American BEHAVE model, designed in the early 70's, is currently the most frequently used model world-wide. Its main limitations are:

- specific to North American conditions,
- based on restrictive hypotheses,
- built on a "semi-empirical" approach to the phenomena.

However, it is now possible to enhance the model due to the evolution over the last ten years in various domains:

- fluid mechanics (aerology),
- thermodynamics (combustion, heat transfer),
- mathematical models (numerical simulation),
- artificial intelligence (integration of knowledge and skill),
- information management (databases, GIS, remote sensing).

This project involves 10 of the most experienced teams in Europe in the different domains of modelling. It is essential for the success of the project to link all skill domains needed to encompass all phenomena (i.e. physics, biology) involved in forest fire propagation.

The methodology we used is summarised in **Table 4**. It can be separated into 6 main parts: identification of the situations, fuel modelling, combustion modelling, wind modelling, validation of the results, integration of results.

Each part is broken down into elementary tasks (16 in all), which have been shared among the 10 teams.

The work programme has been running for one year and some interesting results have been obtained. They are described in detail in the reports drawn up by each contractor (3).

The set of information and the results obtained by the contractors in this project (data on fuel, propagation models, information management architecture, etc.) must be integrated in such a way as to create a common tool for the validation of the results.

For this purpose, two tasks have been outlined in the work programme:

1. the data bases necessary for the chosen pilot wild land areas (Belgium, France, Greece) must be developed

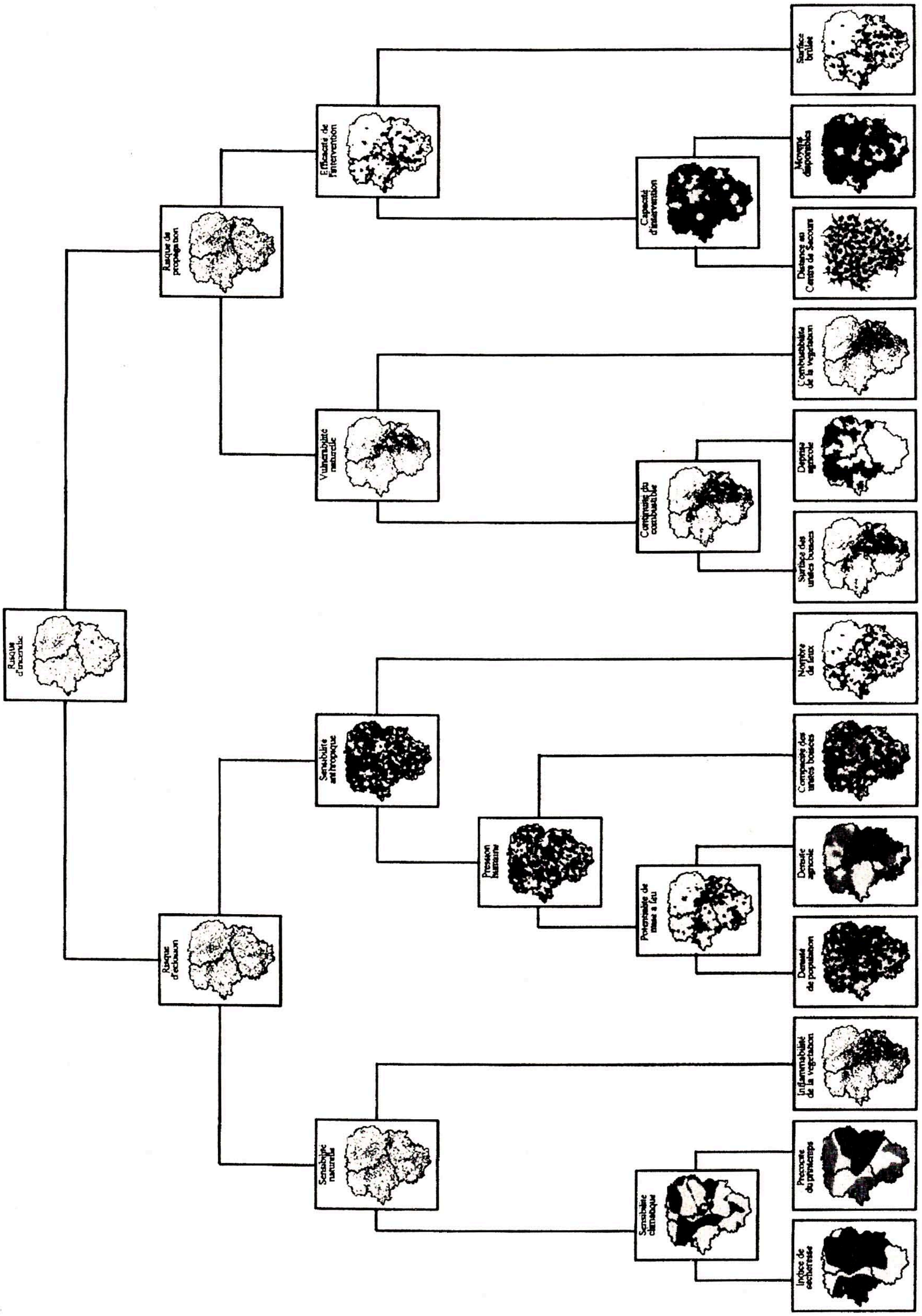

*Figure 2 - the structure of the GIS (see tables 2 and 3 for key).*

**Table 4 - methodology used in the research program**

| Part | Task | Work to make | Observations | Teams |
|---|---|---|---|---|
| Identification of situations | 1 | Collection and organisation of knowledge | Identification of situations (vegetation, terrain, climate) | ARMINES,AAS, INRA,UL |
| | | | Association of the physical phenomena to situations | ARMINES |
| | | | Association of the numerical models to the physical phenomena | ARMINES |
| | 2 | Development of a methodology | Breaking down a situation into known elementary situations | ARMINES,ASS |
| | | | Assembly of the corresponding numerical models to enable a given situation to be processed | ARMINES |
| Fuel modelling | 3 | Common protocol | Examination of the various methods already in existence | MAICH,MTDA,UL |
| | | | Establishment of a common protocol | MAICH,MTDA,UL |
| | 4 | Land sampling | Taking into account of the evolution in time of the vegetation | UL |
| | | | Methodological research for the recognition of the various situations | MAICH |
| | | | Use of recent simulation models of plant growth | MTDA |
| | 5 | Typology | Multivariable statistical analysis | MAICH,MTDA,UL |
| Combustion modelling | 6 | Analysis of existing models | Physical models, hypotheses and the ensuing systems of mathematical equations, numerical methods | CERMICS,DIFT |
| | 7 | Development of new mathematical models | Based on existing models and on the experimental data | CERMICS,DIFT |
| Wind modelling | 8 | State of the art (existing models and codes) | Simulation of the atmospheric flows over complex terrain in the absence of fire | CERMICS,FISBAT |
| | | | Possibility of linking these models to geographical data bases | CERMICS,FISBAT |
| | 9 | Development of new mathematical models | Establish wind prediction and fields of turbulence models on a small scale | CERMICS,FISBAT |
| | | | Test the advanced models | CERMICS,FISBAT |
| Validation | 10 | Organisation of the experiments necessary for the modelling | Determination of the parameters | DIFT |
| | 11 | Laboratory validation | Test of the different variables of the model FIRE 1 | DIFT,INRA |
| | 12 | Climatic validation | Validation of the topo-climatic variables | AAS |
| | 13 | Validation on past fires | Collection of information available | MAICH,MTDA,UL |
| | 14 | Validation on controlled fires | Depending on the authorisations obtained | MAICH,MTDA, INRA,UL |
| | 15 | Validation on real fires | Collection of the maximum of data on the fires that break out in the pilot wildland areas | MAICH,MTDA,UL |
| Integration | 16 | Creation of a common tool | Data bases and simulation | ARMINES, GEOIMAGE |

from satellite images, especially for information on relief and land use.

2. the processing of all this information must be carried out on the screen in such a way as to enable the necessary simulations during the validation of the models, and their comparison with the recorded data.

From this experience, we can conclude that the use of dynamic GIS (the next generation of GIS technology) is essential for an efficient fire management tool.

## REFERENCES

(1) Agence MTDA (1992). Cartographie des feux de forêts par télédétection satellitaire. Ministère de l'Agriculture et de la Forêt. Affiche 120 x 80 cm.

(2) Agence MTDA (1993). Instructions régionales de référence en vue de l'établissement de plans départementaux d'aménagement des forêts contre l'incendie. Conseil Régional du Limousin, Service Régional de la Forêt et du Bois. 97 p.

(3) Commission of the European Communities (1993). Forest fires modelling: periodic progress report. Agence MTDA, ARMINES, CERMICS, DIFT, FISBAT, MAICH, AAS, GEOIMAGE, INRA, UL. 11 reports.