ASSESSING AND MONITORING FIRE RISK IN MEDITERRANEAN ENVIRONMENT BY AIRBORNE REMOTE SENSING AND GIS. A CASE STUDY IN FRENCH PYRENEES

Jean-François GALTIÉ, Franck VIDAL, Jacques HUBSCHMAN

GEODE / UMR 5602 CNRS
Maison de la Recherche
Université de Toulouse-Le Mirail
5, allée Antonio Machado
31058 TOULOUSE CEDEX
Phone : (33) 61-50-36-26 Fax : (33) 61-50-42-75
E-Mail : galtie@CICT.fr

INTRODUCTION

In the Mediterranean area of Southern France, vegetation can be regarded as a serious threat, and forests regularly burst into flames : between 3000 and 4000 fire startings for an average of 30 000 to 40 000 hectares which vanish every year (about 1% of the total surface and 3 % of the so called "red zone"), sometimes like catastrophic fires (less than 1 % of fires are responsible for 2/3 of burnt areas). Despite of large efforts made to find a final and relevant solution, the way this one is nowadays involved, outlines the limitations of the actions which have partially been embarked upon and the necessity to tackle the problem at the earliest stage. This approach goes through the definition of a new fire hazard assessment relying on (1) a global assessment in terms of the attention given to it as well as the interaction of different factors involved in the outbreak and the spread of fire, and in terms of management of fire hazard (prevention, prevision, fire-fighting). This approach includes as well (2) the aspect of evolution both in time and space which feature this hazard through its origins and occurrences (anticipation).

For the last decade, advances in data processing with GIS development and in remote sensing technics permit now analyzing and assessing dynamic phenomena over a broad range of space-time scales. Using these technologies, wildland fire can be considered in a global perspective and its spatial and temporal dimensions.

To achieve this aim a comprehensive examination has been embarked upon with the fire-fighting authorities of the department of Pyrénées-Orientales (France) in order to design and to test out a decision support system in the management of forest fires hazards (SADFEU).

This presentation deals with its general directions as well as its first applications.

STRUCTURE OF SADFEU

SADFEU combines a number of hazard indicators coming from a ground based cartography, meteorological data provided by the data network and remote sensed parameters. Based on operation criteria (operational flexibility, real-time working ...) this system falls into two main structures (figure 1) :

- Airborne remote sensing and data processing environment

Integrating remote sensing meets a thematic and technical target at the same time: the

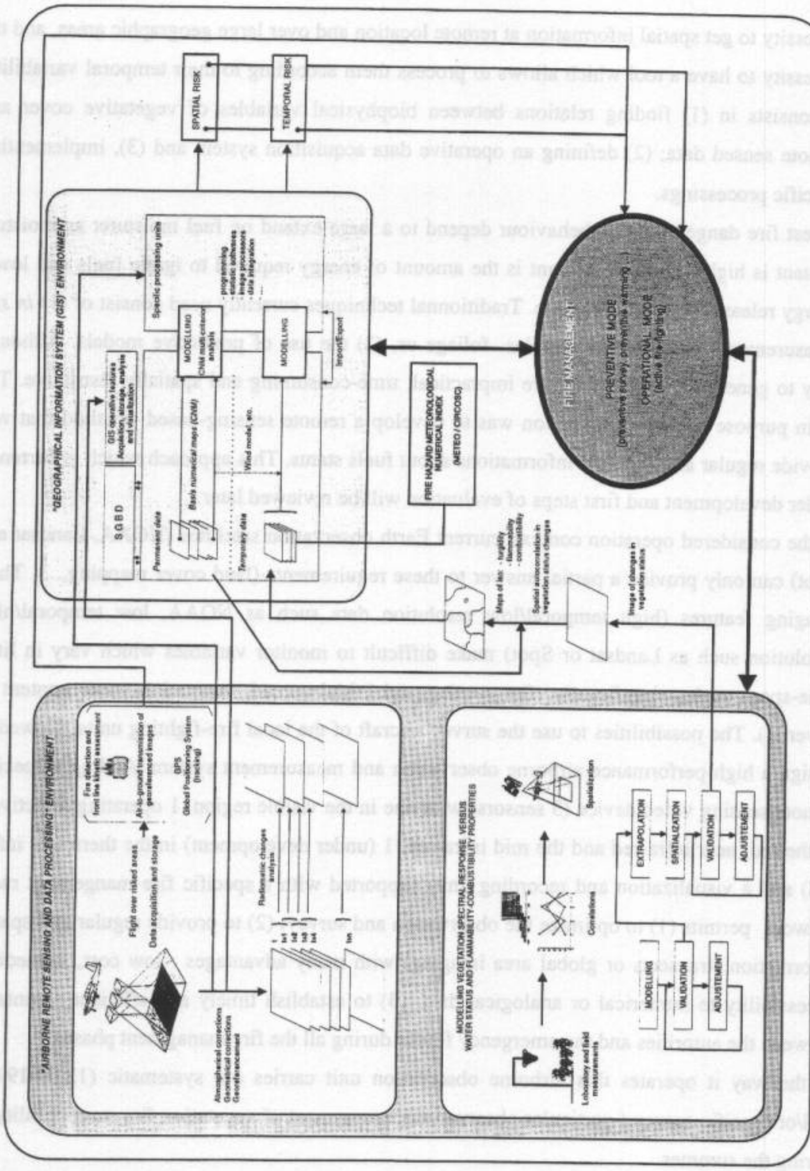

Fig 1 : Structure and functioning of SADFEU necessity to get spatial information at remote location and over large geographic areas, and the necessity to have a tool which allows to process them according to their temporal variability. It consists in (1) finding relations between biophysical variables of vegetative cover and remote sensed data; (2) defining an operative data acquisition system and (3), implementing specific processings.

Forest fire danger and fire behaviour depend to a large extend on fuel moisture: as moisture content is higher, more important is the amount of energy required to ignite fuels and lower energy release and fire spread are. Traditionnal techniques currently used consist of (1) *in situ* measurements on collected samples foliage or, (2) the use of predictive models. Although easy to generate, both of them are impractical, time-consuming and spatially restrictive. The main purpose of this investigation was to develop a remote sensing-based method that will provide regular and accurate informations about fuels status. This approach which is currently under development and first steps of evaluation will be reviewed later.

In the considered operation context, current Earth observation satellites (NOAA, Landsat and Spot) can only provide a partial answer to these requirements (land cover mapping,...). Their imaging features (high temporal/low resolution data such as NOAA, low temporal/high resolution such as Landsat or Spot) make difficult to monitor variables which vary in little time-space scales significantly (fire starting and initial spread, vegetation water content of cover,...). The possibilities to use the survey aircraft of the local fire-fighting units allowed to design a high-performance airborne observation and measurement system. Adding a specific remote sensing video device (3 sensors (with one in the visible region, 1 operating selectively in the red, near infra-red and the mid infra-red, 1 (under development) in the thermical infra-red) and a visualization and recording unit) supported with a specific fire mangement radio network permits (1) to optimize the observation and survey; (2) to provide regular and spatial information (transects or global area imaging) with many advantages : low cost, immediate accessibility to numerical or analogical data; (3) to establish timely and efficiently contacts between the autorities and the emergency forces during all the fire managment phases.

In the way it operates this airborne observation unit carries out systematic (13.00-19.00) and/or specific survey (particular observations, assessment of vegetation fire susceptibility...) during the summer.

This first configuration was validated during the summer 1995 and is currently under development : real-time georeferencement (GPS-Global Positioning System) and air-to-ground transmission, on ground real-time tracking (on a topographic map) the position of the airplane. This new experimental configuration will be effective during the campaign of the 1996 forest fire fighting.

According to the objectives of data acquisition (vegetation fire risk determination, preventive survey,...) airborne video data processing system consists in two specific processings : direct visual interpretation (spot of fires ...) or numerical data processsing which can be made on board (real-time) or on ground (real-time or differed-time). Numerical data processing consist of four kinds of traitment: analogical/numerical data conversion, atmospherical and geometrical (distorsion and referencement) corrections, enhacement and thematic analysis.

• Geographical information system (GIS) environment

The system core includes software Excel 7.0 and MapInfo 3.0 interfaced to analysis units and specific processings (image processing and statistics softwares, ...), to hardware (printers,...) and, in its summer 1996 configuration, to a GPS (tracking). Remote sensing and conventional data are integrated and archived in a GIS data bank structure and are organised in (1) fixed data (data varying few in time : relief, past fires, ...) and data requiring, in operation mode, a very frequent updating (flammability map, wind map...); (2) active data which are used in the model building of fire hazards and passive data, which are editable but not taken in account in model building. The implemented methodology relies on a multi-criteria analysis combining description, examination and a hierarchy of factors having an effect upon the fire hazard. After defining variables to be considered and weighing each of these ones, the approach consists in defining two models of fires hazard and to generate the time-space distribution by using multi-parameters deterministic combinations.

METHODOLOGY AND OBJECTIVES

SADFEU has been imagined to support the decision-makers during all the three phases of fire management : before (prevention and prevision), during (active fire-fighting) and after fire (damage assessment).

Hazard prevision and preventive survey phase

The assessment of the fire hazard relies on a double approach : (1) assessment of the temporal variability of hazard through dynamic information such as vegetation status (water content, flammability and combustibility properties, ...) or climatic factors (wind, ..); (2) assessment of the spatial variability of fire hazard using time-static information such as topography, vegetation types, road networks, ...

The fire hazard includes several factors which have been grouped in three categories : fire occurence, fire spread and intensity and resistance to control. Each of these factors is characterized by four space-times indicators :

- vegetation conditions performed with field data collection, high resolution data of remote sensing linked to physionomical and biological data
- topographic conditions derived from a digital elevation model (DEM) computed from the topographic map at 1/25 000 and with a resolution of 40m x 40 m
- meteorological conditions carried out from the French Fire hazard Meteorological Numerical Index refined through more accurate located data (ponctual measurements)
- human factors estimated from fire data provided by the French database Prométhée

Vegetation status (water content, flammability and combustibility) related to meteorological data (rainfall, temperature, wind) and man-induced ignition factor are used to assess daily fire hazard while fuel characteristics (height, abundance, structure), topomorphology conditions (elevation, gradient (declivity and slopebreaks) and slope aspect), anthropogenization degree (potential fire occurence area, planimetry) and fire fighting conditions (accessibility to vehicles, penetrability to human, water supplies nearness) define static hazard components. Fire assessment results from the combination of these fire components according to their impact on increasing the fire hazard. It is represented with the definition of two hazard indexes, the sensibility index and the vulnerability index, corresponding respectively to the occurrence hazard and initial spreading and, to the fire behaviour and difficulties of fire-fighting.

Detailed methodology will not be reviewed here, only the most original part about vegetation condition will be outlined. This approach relies on a static component (structural risk) and a dynamic component (conjonctural risk). Using the method developed by Trabaud (Galtié and Trabaud, 1993), a vegetation mapping which identifie homogeneous fire risk areas according to the species composition (kind of major vegetation, sensibility to fire,...) and the horizontal/vertical structure (overlap ratio, biovolum,...). It has been computed using IRC aerial photographies, airborne video data and a field survey.

The second approach is based on the integration of biological parameters and remote sensed data. It aims at relating fuel water content to flammability and combustibility properties. Results allowed (1) to classify the plant species according to their susceptibility in relation to fire; (2) to define, from the turgor level to the relative dryness of the plant, several strategic thresholds in its fire sensibility (ignition delay time) according to water status (figure 2).

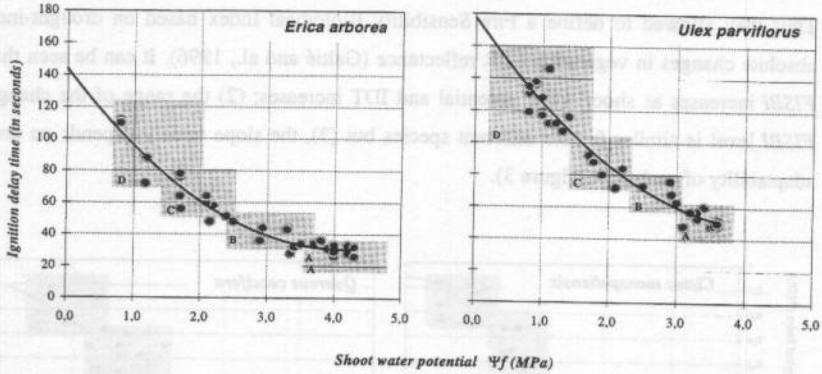

Fig 2: Relationships between ingnition delay time (IDT) and shoot water potential (ψ_f)
Determination of thresholds of fire sensitivity: samples very flammable (A), moderately flammable (B), little flammable (C) and very little flammable (D)

The knowledge of occurrence time and stress duration allows to define different intermediate stages between stage of full turgidity and very last dryness stage, then to recognize the different phases of risk. Assessing the vegetation participation (Vs) to the sensibility index (fire occurrence and initial spreading) can be performed by integrating these two components.

$$Vs = \sum (i), ((j \times k)^o)_H, ((l \times m)^o)_s$$

where (i) refers to the risk-induced cover structure

(j)-(k) and (k)-(l), to the fire sensibility features (structural and conjonctural) of the main species from herbaceous (H) and shrubby (S) layer

(o), to overlap index

Experiments led both in laboratory and outdoor conditions allowed to collect a large number of data about major Mediterranean species water content and spectral kinetic linked to their inflammability and combustibilty status. The results from field measurements conducted in summers 1994-1995 provide interesting possibilities of detection and monitoring of water stress through spectral kinetic (specially in the mid-infrared region) of the studied vegetation. Thus they allowed to define a Fire Sensibility Biological Index based on drought-induced absolute changes in vegetation MIR reflectance (Galtié and al., 1996). It can be seen that (1) *FISBI* increases as shoot water potential and IDT increases; (2) the range of the changes in *FISBI* level is similar for the different species but (3), the slope widely depends on drought adaptability of each ones (figure 3).

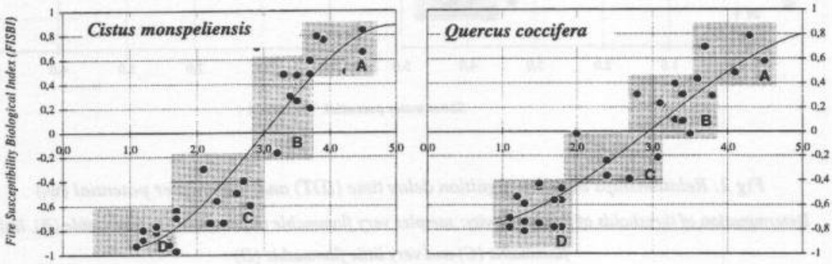

Fig 3: Relationships between Leaf Water Potential, fire sensibility thresholds (A,B,C and D) and FISBI. Observed points and computed trend

The assessment of fire hazard and the definition of areas at risk allow to optimize resources deployment for control and prevention actions and lead to set up the airborne preventive survey system in a selective way, in addition to traditional means (lookout tower, patrols). This system having mobility and flexibility features belongs totally to the global plan of action for preventive mobilization and is systematically implemented during fire seasons. By flying regularly over the risked areas, it facilitates both a deterrent survey and outbreaks of fires detection (detection or recognition of fires). A quick and accurate detection allows to make the reaction times of fire-fighting brigades (time of operation / intervention times) much shorter and to contain the fire in most cases in acceptable proportions. The addition of the remote sensing device to the airborne observation unit helps to upgrade this phase of observation and survey. Contributions of airborne imagery can be noticed at two quite different levels : (1) fire ignition and/or starting point location (MIR sensor) and (2), knowledge of the environment of fire spread (sensor in the visible). Results of investigations led in summer 1995 showed that MIR (1.45.2.0) video imagery could be a real-time useful support in detecting burning wood coals. The flexibility of the system (low, middle and high flying) allows a detection of small fire starting points and a fire synoptical imagering at the same time.

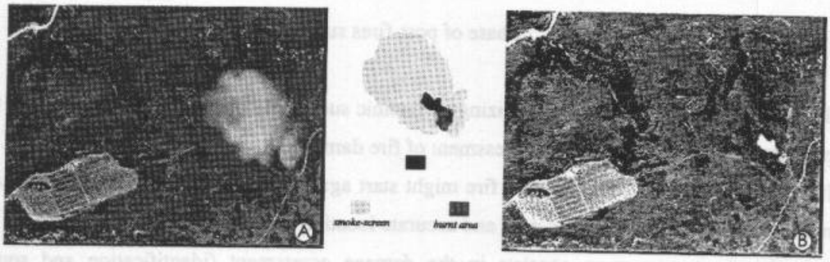

Fig 4: Visible (A) and middle-infrared (B) images of a burning area
In the MIR image (B), active part of fire is clearly delineated whereas, in (A), due to a thick smoke-screen, fire location and identification appears limited

Phase to help to lead operations

Visualizing images on board helps to make the initial diagnosis, to anticipate the fire occurrence (initial burnt area and direction and progress of the very edge of fire) as well as the fire fighting strategy to involve. On the ground, information from aircraft linked to the real-time plane tracking permit to locate precisely the different starting points of fires over which the plane flies, and to outline strategies of intervention (to set up a hierarchy of starting points, to invest supplementary means ..) by considering the level of risk at this location (accessibility, water supplies nearness ...). It represents an important stage in which the fire is controlled or not. In the second case, defining a coherent and efficient fire fighting policy is needed. In addition to existing structure, decision can be assisted through:
- real-time transmission of georeferenced images (visible or infrared wavelenght) from

airplane flying over the fire to a ground station

- acquisition, from airborne tracking and GIS operative features, of accurate data about fire front line (location, lenght), burnt area (surface) and therefore about fire kinetic
- reviewing
- editing and processing of data from databank maps (information about location, land cover, roads and water sources from distant sites ...)

This approach could facilitate fire management operations : troops repositioning, people evacuation, definition of strategic places of action ...)

Phase of post-fires survey

The postfire phase consists in organizing a systemic survey of burnt area (and principally, fire perimeter line) ; (2) an objective assessment of fire damage.

It is a very important stage because fire might start again (wind ...). Airplane monitoring can make a relevant support in detection and accurate location of residual ignition points.

An other important stage consists in the damage assessment (identification and square measure of burnt area) because, on a day-scale (number of fires, location ...) or for specific fires (fire kinetic, fire-fighting report,...) it permits to have a retrospective view which can enable to anticipate in a better way the risk for the following days and to benefit from the past fires.

CONCLUSION

Supporting the decision enables not to replace the human decision making but enables to make it more reliable in critical situations. It provides fires managers with information about strategy and methods which allows to assess the hazard in the whole dimensions and to define a specific plan of action according to the more appropriate decision. Being aware of fire hazard should allow to anticipate critical situations (preventive survey, management of outbreaks of fires at the very early stage, ...) and represents a very useful support in the decision making. The system in its final version must above all be designed as a support to logistics of fire managers.

This approach however stands only at an experimental stage, and before thinking about its use or development in operational mode, we must consider the different aspects ranging from technical (data processing,...), human, economical (investment and operating costs) or organizational aspects. Therefore the experimental stage of development will be followed by an assessment of usefulness and technical viability of such a device related to fires management and the conditions of implementation and integration in the current conditions of operation (summer 1996).

REFERENCES

GALTIE (J.-F.) and TRABAUD (L.), 1993.- Evaluation des risques d'incendies dans une zone sensible: le massif des Aspres (Pyrénées-orientales)-. Revue Géographique des Pyrénées et du Sud-Ouest, 63(1), pp33-51

GALTIE (J.-F.), VIDAL (F.) and HUBSCHMAN (J.), 1994.- SIG et incendie de forêt: vers un système d'aide à la décision à référence spatio-temporelle-. GEOPOINT 1994, pp121-123

GALTIE (J.-F.), HUBSCHMAN (J.), TRABAUD (L.), VIGNE (D.) and TOSCA (C.), 1996.- An initial evaluation of visible-infrared video data to characterize fire susceptibility of mediterranean shrubs-. in press