EXPERT KNOWLEDGE AND QUANTITATIVE WIND MODELLING FOR SPATIAL DECISION SUPPORT DEDICATED TO WILDLAND FIRE PREVENTION

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ABSTRACT

The objective of this study, carried out as part of an European Union contract, has considered in elaborating an aid package that enables "automatic" and "real time" identification of the instantaneous wind situation during seasons with high forest fire hazard.

INTRODUCTION

Meteorology is one of the major components of wildland fire behaviour. In order to provide a better forecast of the wind field and thus to have a more realistic wildland fire behaviour prediction, we present a new approach for wind modelling.

Traditionally, wind behaviour modelling tends to use **quantitative models**.We use such a model, called Nuatmos (Ross & al., 1988). After simulations with real data, several insufficiencies were noted. We decided to use **expert knowledge on meteorological situations** to improve quality of results. Thus it was agreed that **the link of a quantitative model** with an **expert analysis** is an alternative to make up for the lack of satisfactory results.

Three research teams are involved in this project. The mathematical wind model study is leaded by the Cermics, the expert analysis is provided by P.Carrega (topoclimatological specialist), and finally, the knowledge-based system design, implementation and its integration in a Spatial Decision Support System dedicated to wildland fire prevention are done by Ecole des Mines.

QUANTITATIVE AND QUALITATIVE APPROACHES IN THE WIND MODELLING CONTEXT

Research Background

The problem of wind modelling is basically related to the need of having an estimation of the wind field in different geographical locations and for different weather conditions. Meteorological parameters have a decisive role in the outbreak and spread of wildland fires. Wind, relative humidity and air temperature are, in particular, directly measurable and can be studied individually or collectively. In our case, they are combined in order to generate meteorological hazard indices and inputs for fire behaviour models. They can be also used to give to managers the essential information concerning the wind speed and direction in a region of interest.

Located in southeastern France and exposed to a Mediterranean climate, the Alpes-Maritimes Department is an area of mountainous relief with a relatively dense network of weather sensors. This area is covered by 21 meteorologic sensors. They record temperature (°C), relative humidity (%) and wind (the direction from 0° to 360° and the speed in m/s). The sensors are questionned by modem three times per day or more if needed during high risk periods in summer. All the data acquired are stored and managed by a Relational Data Base Management System (R-DBMS) and and maps of the different fields are computed and stored in a Geographical Information System (GIS) in order to have a spatial distribution of the phenomena.

Usefulness Of A Mathematical Wind Model

The wind behaviour study is based on data measured in several points (the sensor network).This discrete spatial data is often insufficient. A global wind field estimation for the total geographical area is needed. For this, we must use more or less sophisticated models which allow a reconstitution, in all points of the space, of the wind intensity from some point data. This problem recovers from the interpolation values. It is solved using mathematical models.

In this context, we use such a model. The diagnostic model NUATMOS produces a three-dimensional mass-consistent wind field in complex terrain based on wind observations (velocity and direction).

First, an interpolation of observed data is performed to produce an "initial" wind field over the whole domain of interest. Measurements at 10 meters provided by the sensor network are used. In a second step, the resulting wind field is ajusted to satisfy mass-conservation by minimun possible modification. Mathematically, the problem is to minimize the functional

$$\int_D \left[\alpha_1{}^2(u - u_o)^2 + \alpha_1{}^2(v - v_o)^2 + \alpha_2{}^2(w - w_o)^2 + \lambda\, \vec{\nabla}.\vec{U}\right] dV \quad (1)$$

where (x, y, z) are the terrain-following coordinates, $\vec{U} = (u, v, w)$ is the velocity, $\overrightarrow{U_o} = (u_o, v_o, w_o)$ is the initial interpolated wind field, α_1 and α_2 are positive parameters (Gauss precision moduli) and λ is the Lagrange multiplier of the constraint of mass conservation $\nabla .\vec{U} = 0$.

After derivation, the Euler-Lagrange equations to be solved are then:

$$\left|\begin{array}{l} 2\,\alpha_1{}^2\,(u - u_o) = \dfrac{\partial\lambda}{\partial x},\ 2\,\alpha_1{}^2\,(v - v_o) = \dfrac{\partial\lambda}{\partial y},\ \ 2\,\alpha_2{}^2\,(w - w_o) = \dfrac{\partial\lambda}{\partial z} \quad (2) \\[2ex] \qquad\qquad\qquad\qquad\qquad\qquad \dfrac{\partial u}{\partial x} + \dfrac{\partial v}{\partial y} + \dfrac{\partial w}{\partial z} = 0 \end{array}\right.$$

which can be manipuled to give:

$$\frac{\partial^2\lambda}{\partial x^2} + \frac{\partial^2\lambda}{\partial y^2} + \frac{\partial^2\lambda}{\partial z^2} = -2\,\nabla.\overrightarrow{U_o} \quad (3)$$

The following coordinate transformation is made

$$\overline{x} = x,\ \overline{y} = y,\ \sigma = \frac{z_\iota - z}{z_\iota - z_s} \quad (4)$$

where the subscript ι denotes the top of the solution domain and s the terrain surface. The equation (3) is written in these new coordinates and the obtained Poisson equation is solved iteratively using a tridiagonal solver and an elaborate differencing scheme. A Multi-Grid method which employs more than one nested grid is used in order to speed up the convergence.

Days representing typical meteorologic situations were selected in order to compare three main features (Carrega P. & al., 1994):

- the general behaviour of the wind field on the studied domain,

- at each sensor, the deviation between the measured value and the value given by the models, for the velocity and the direction,
- the variation over all sensors of the directions and velocities estimated by the model.

For typical situations when the wind field is locally strongly influenced by the topography (as in a valley for instance), the behaviour of the computed wind field is acceptable only if sensors by their location are representative of the meteorologic situation. This is not the case, in particular, for valleys, where an "upstream" flow takes place during the day: without a sensor inside the valley, this flow is completely ignored by the model (the error reaches in certain cases 90° for the wind direction).

Wind Types Identification And Expert Analysis

To improve the behaviour of the computed wind field, we decided to add virtual sensors in several valleys. The values of the direction and the velocity were estimated for **different identified meteorological situations** following the method provided by a topoclimatological expert.

Four months (February 1991, February 1992, July and August, 1992) were chosen for the treatment of the data provided by the network of meteorological sensors. Two sets of measurements, taken at 03:00 H and 15:00H GMT, and representing respectively the nocturnal and diurnal regimes, composed the bulk data retained for analysis.

The main problem consists, on one hand, in establishing a typology of the situations; the parameter combinations which are adapted to the issue (which is not the case of the usually elaborated climatologic typologies) and on the other hand, in being able to automatically identify the actual weather, exclusively from the weather sensors data.

The wind types are defined on the basis of discrimination between breeze and synoptic regimes (Carrega P., 1994). A combination of inductive and deductive procedures, partly used a verified existing model and sought to define their local applications. The situations and the behaviour of the stations have been analysed from a succession of steps of reasoning involving the crossing of several type of information:

- detection of types of situation from Principal Component Analysis's of wind speed,
- analysis of the dealy weather situation for day from synoptic charts and collection of all available weather parameters,
- complete, individual and fine analysis of each situation allows to associate wind direction and speed with each representative sensor.

A total of 6 wind types were defined for each season. To each type corresponds an expected effect at each sensor, that is a wind behaviour type depending on the type of situation and the type of local topography. For each type, the expert elaborated a set of rules in order to identify automatically the wind type, already classified for its specific behaviour.

We give an example with rules proposed by the topoclimatologist in order to identify a general breeze regime (at 15:00 GMT):

. If at Ascros, the wind has a directional range of 100°-170° with a speed of 4-7 m/s; and if at Mandelieu, 70°-120° or 210°-230°, with 3-6 m/s; and if at Breil, 160°-200°, 2-7 m/s; and if at Caussols, 120°, with 1-6 m/s; and if at Menton, 130°-160°, with 0-2 m/s; and if at Levens, 180°-260°, 1-2 m/s; and if St Roman, 160°-190°, with a speed of 1-4 m/s, then general breeze regime.

. If no breeze detected at Mandelieu, and wind speed ≤ 6 m/s and ≤ 4 m/s at Tanneron, and breeze elsewhere, then general breeze regime.

. If no breeze detected by a maximun of four out of seven sensors, but wind speed < rule (especially if ≤ 2m/s), then general breeze regime.

Soundings made out of the sampling context confirm the validity of the types adopted in this study. We must note that the construction of the rules pursued two phases: they were first made over one month only, summer and winter alike, and night and day alike. The second month is used as verification, and showed that only a few minor modifications had to be made.

At the end of this step, the idea to use virtual sensors in order to improve the results calculated by the mathematical model occured. Our objective is to add to the set of initial data (the sensor network) several virtual sensors with data provided by the topoclimatologist. For each wind type previously identified, the expert is able to indicate the better location for several virtual sensor and to give their probable values.

HOW CAN QUANTITATIVE AND QUALITATIVE MODELS BE USED TOGETHER IN A SPATIAL DECISION CONTEXT?

Toward A Mixed Approach

The coupling of qualitative and quantitative models is now widely recognized to be an effective means of addressing many computing problems in science, engineering, business and environment.

There are several factors that are generally involved in the choice between a qualitative and a quantitative model (Hulthage, 1988). Some reasons to choose a qualitative model are based on the non satisfactory results of existing quantitative models, on the insufficiency of input data in order to use such models and on their computational difficulties. Some reasons to choose a quantitative model are based on the fact that it can give sufficient accuracy and it is known that it is fast enough and applicable in all relevant cases.

Therefore, it is clear that qualitative reasoning cannot replace quantitative reasoning or vice versa, but rather they complement each other.

How The WILFRIED System Deals With This Original Approach Of wind Modelling?

The WILFRIED system (Guarnieri, 1995) is an integrated SDSS (Spatial Decision Support System) designed to fit the requirements of managers in charge of wildland fire prevention and fighting. In the same computer software, the system proposes a relevant set of tools (Data Base System, Geographic Information System, Simulation models, User Interface). In order to help the user in his decision-making job, the system offers several functions allowing him to manipulate and visualize geographical data and to make WHAT-IF analyses on fire behaviour or on danger assessment for a critical meteorological situation using models for simulations.

We describe the way how the WILFRIED system provides a better prediction of the wildland fire behaviour or danger assessment by mixing the quantitative and the qualitative approaches of the wind modelling.

We describe the mixed approach:

- Firstly, meteorological data are collected by a modem. They are stored and managed by a R-DBMS and a GIS.
- Then, the system triggers the knowledge base "Pierrot" in order to identify the wind type and to locate the virtual sensors.
- Finally, the system triggers the Nuatmos model with all the collected data (real and virtual). The results (a wind speed map and a wind direction map) are stored in the GIS. At this time, the WILFRIED system is able to compute the other parameters needed for the prevention support. The steps are repeated for each set of new weather data.

Knowledge-Based System

In this part, we explain how we have formalized the expert knowledge using the knowledge-based system approach.

An knowledge-based system can generally be divided in two parts: the knowledge base composed of facts and rules, and a program intended to apply the rules to the facts according to a given context. This program called inference engine is independant of the knowledge base. The initial prototype was implemented starting from the expert analysis (see § 1.3) and several other documents (texts of the interviews) which detail:

- the facts: describe the state of the problem,
- the rules: fixing the logical inferences.

We use a classical formalism called "production rules" :

IF <condition1> <condition2> ... <conditionN>
THEN <assumption1> <assumption2> ... <assumptionN>

This expression may be translated by:

IF condition1 is true and condition2 is true and ... and conditionN is true

THEN we may deduce that assumption1 is true and assumption2 is true and ... and ... assumptionN is true.

We give an example with a rule proposed by the expert:

IF Mandelieu 220°, ≥ 5m/s and if Saint Roman 130°-160°, 3-6m/s and if Antibes 190°-220°, 3-6m/s and if Mont Agel 240°-290°, 2-6m/s and if Sophia-Antipolis 160°-210°, 2-5m/s
THEN **Synoptic type S.**

Thus, programming with rules consists in defining all the knowledge bricks allowing the solution of the problem without any concern of the initial arrangement of these different bricks. The inference engine, acting as a bricklayer, selects the bricks and sets them to the best to solve the submitted problem.

The knowledge base "Pierrot" contains all the knowledge accessed by the system at a given time of the processing in order to continue it. This knowledge is formalized by situation descriptors (assumptions, corresponding to the conclusive (i.e., THEN) part of the rule and the data, corresponding to the rule premiss (i.e., IF) and by production rules. The fact and the rule bases constitute the knowledge base grouping the knowledge set of the studied domain. The fact base is constituted of declarative knowledge, static and descriptive, characterizing the concepts properties or the objects and their relations. This base must contain all the facts that the system has to deduce at a given time (example of facts in the base "Pierrot": the wind direction and the wind speed). The rule base contains the different operating knowledge types. It indicates the way to use the facts, roughly simulating a reasoning fragment or a way to act. It is the part of the system in charge of bearing all the studied domain knowledge.

The knowledge base "Pierrot" deduces the wind type and can give to the user a commentary explaining the wind behaviour. Once the weather type has been determined by the knowledge-based system, it is necessary to give a value at the virtual sensors (wind direction and speed). The expert analyses the daily data and deduces the values which will be assigned to the different sensors. This knowledge forms a second knowledge base.

After the identification of a breeze situation, three virtual sensors are added (see fig 1 and 2) in three valleys. The values of the direction and the velocity are estimated. The system runs the Nuatmos models with added data. Figure 2 shows the inportant role of these virtual sensors for this meteorologic situation. Now, the wind flows throught the valleys, taking into account the topography.

CONCLUSION

This project gathered people from universities (Nice-Sophia-Antipolis) and research centers (Cermics and Ecole des Mines), having very different approaches of the wind phenomena modelling. The first one, in this case P.Carrega, is acquainted with the studied area and of the topoclimatologic phenomena. The second (Cermics) are numerical modelling specialists. Encountering with insufficiencies of the Nuatmos model, combined with the lack of sensors in characteristic locations, the idea to use the expert's work on wind type identification was retained. Realizing validation tests on the Nuatmos model, the hypothesis to use virtual sensors was put forward. Thus, it was agreed that the link of a quantitative model with expert knowledge was the solution to obtain satisfactory results. Tests and validation simulations are realized in order to verify these hypothesis.

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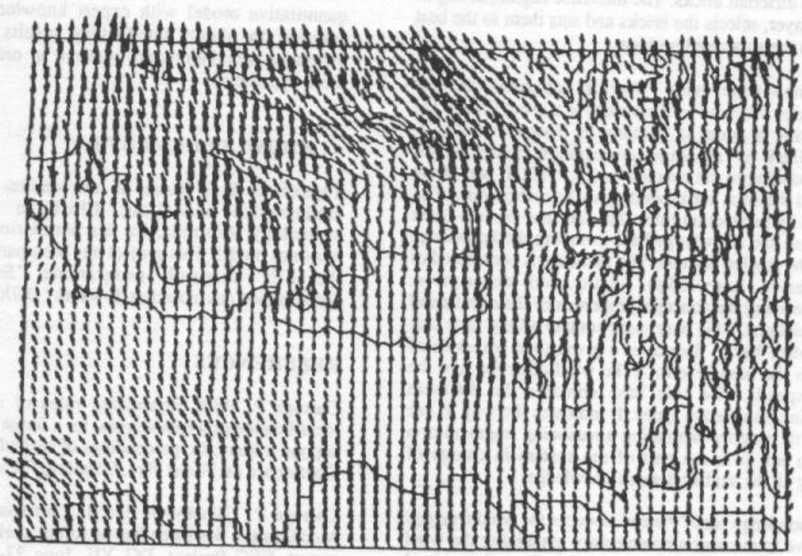

Figure 1: Wind field computation without the three virtual sensors

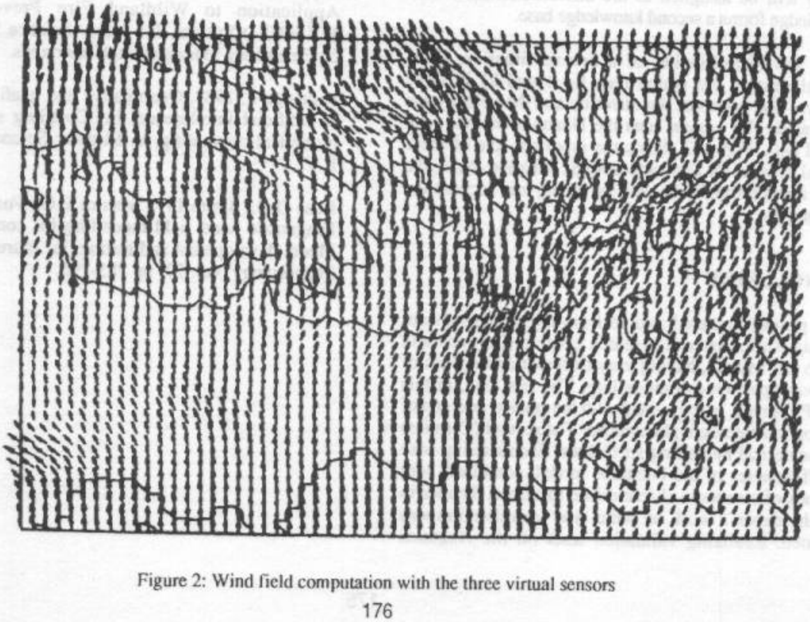

Figure 2: Wind field computation with the three virtual sensors