From the Vegetation to the Inputs of a Fire Model: Fuel Modelling for WUI Management

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Abstract

As a growing number of inhabitants settle next to or inside wildland areas, the management of the wildland–urban interfaces (WUI) becomes one of the key-points of wildland fire prevention in the Mediterranean Regions of Europe. To test and deliver accurate and efficient fuel management rules in such areas, a behaviour model of wildland fire based on the complete physical and multiphase approach has been developed (Morvan & Dupuy, 2001) thanks to the European funded project Fire Star (EVG1-CT-2001-00041). In order to build up inputs for such a model, a fuel distribution model has been developed with cellular automata.

1. Requirements of the Fire Star fire behaviour model

The fire behaviour model is currently running in 2 dimensions (x, z). This had to be taken into account in the fuel modelling process. The x axis represents the direction of fire propagation and the z axis represents the local vertical. To satisfy these requirements, the fuel model is also based on a grid in 2 dimensions and made of 25 x 25 cm elementary cells. The dimension of an elementary cell comes from a compromise between the ability to describe fuel on the field and the calculation time needed to simulate a fire in a long resolution domain (approximatively 200 m long which represents the usual width of a fuel-break).

The multiphase approach used in the model of fire behaviour consists in solving conservation equations (mass, momentum, energy). In this approach, several fuel families describe vegetation. A fuel family represents all the solid particles of vegetation, which have the same properties concerning physical, chemical and thermal processes involved in a wildland fire. We distinguished here several kinds: needles or leaves, twigs of several diameters (very fine twigs between 0 and 2 mm, fine twigs from 2 to 6 mm, medium twigs from 6 to 25 mm and coarse twigs, with a diameter bigger than 25 mm). Volume fraction is one of the properties of the particles that are used as input parameter in the fire behaviour model.

These requirements exposed, it is now possible to precise what kind of data on fuel that were needed to provide inputs into the fire behaviour model. We distinguished 3 scales in the fuel description. On the one hand, we modelled the spatial distribution (in 2D) of the species in the selected experimental plots or in another WUI whose effectiveness has to be assessed. These data at the plot scale constitute the first kind of inputs into the cellular automaton. On the other hand, we also had to take into account the particle distribution within each clump of vegetation and thus to be able to give the value of the volume fraction of each particle in any 25 cm by 25 cm elementary volume of a shrub or tree. The fuel family distribution at the clump scale is the second kind of inputs of the fuel model. Finally, we went down to the particle scale, to provide data on the physical and chemical characteristics of fuel particles that were also needed by the fire model. We present successively in the following parts of this paper the methods used to get and model these 3 kinds of data.

2. Modelling the spatial distribution of fuel

The idea was to build up on the whole width of a fuel-break, a vegetation vertical profile (x, z) based on descriptive data collected on elementary field squares. We wanted to find a compromise between time-consuming field measurements and a satisfactory average representation of the fuel-break vegetation profile. In this perspective, cellular automata seemed to constitute a perfectly adapted tool. We used the CORMAS simulation platform (Bousquet et al., 1998), and the procedure was coded with the object-oriented language Small-Talk under the VisualWork© environment. The modelling work developed an automatic procedure to perform a randomised transformation of non localised data from experimental plots into the spatial grid made of the 25 cm x 25 cm elementary cells required by the fire behaviour model.

First, non destructive measurements on vegetation were made on some selected sites that are part of the Fire Star catalogue and that have been chosen in order to be representative of the major ecosystems of the Mediterranean Region (Cohen & Valette, 2003). The field description used here was quite similar to approaches used in the cartography of vegetation (Etienne & Rigolot, 2001). It aims to give an average representation of the fuel distribution. It was made thanks to a transect constituted of several 25 m x 25 m elementary squares placed perpendicular to the main fuel-break direction. In such places, we measured total height and estimated cover and aggregation of the 3 dominant species in each strata (litter, grass, shrubs and trees), assessed on several 25 m x 25 m elementary squares (Cohen et al, 2002). Data were completed by estimates of the average distance between tree canopies, average height of the lower level of tree foliage and average distance between trees and shrubs. All these non-destructive field measurements were used in the fuel distribution model which runs thanks to the cellular-automata.

Each grid built up by the cellular-automaton covered the profile of an elementary square (25 m long and maximal height of the tree layer). The last 2 lines at the bottom of the grid were devoted to the litter layer and the herbaceous layer. They are the only ones that do not represent real fuel heights.
The transformation to get from the (x, y, z) field description to a (x, z) plan, corresponded to a run of the average image of the structure and the composition of the vegetation from the field data. This run represented one possible event among all those that are defined by general distribution constraints implemented in the model and was

not a classical projection. Distribution rules to construct the runs were deduced from the 3 parameters measured on the field.

Cover and aggregation were used to generate and localise each shrub or tree on the x axis (in the fire propagation direction) and to define their width. Namely, all the covers collected on field were totally reproduced on the profile. Once the number of clumps of a species in one stratum had been calculated thanks to the aggregation mark, it was possible to define an average width for clumps, taking into account each species cover. In addition, some variability in the distance between each clump and in width of each clump was added. But a minimum width of tree canopy was defined to avoid unrealistic representation. Other rules had to be added to account for biological and ecological behaviour of each species in its ecosystem. In this respect, rules of exclusion of species were implemented based on incompatibility between species. For example, individual knowledge or expertise about *Quercus ilex* (holm oak) behaviour in Mediterranean wildland led us to exclude the possibility to have some shrubs below a clump of *Quercus ilex*. We also used direct relationships existing between layers: it is a well-known fact that litter is mainly found below ligneous species. So, in the model, cells with the biggest amount of litter were distributed in priority below zones where trees or shrubs are overlapping. Once each clump was localised, heights measurements were used to define the maximum and minimum height of individual crown within a stratum on the z axis. Thus, trees and shrubs are represented only thanks to their crown, as it can be seen on figure 1 below. It was no worth taking into account trunks because they are not significantly involved into fire propagation.

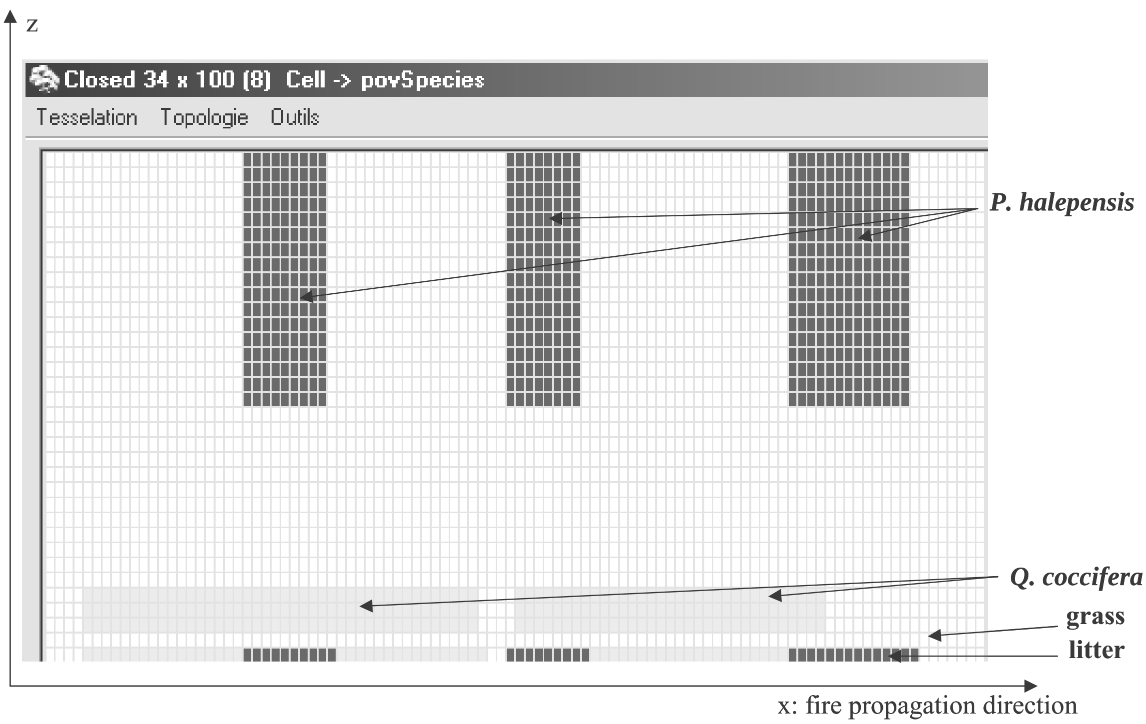

Figure 1: an example of run from the cellular automaton on a 25 m long *Pinus halepensis* & *Quercus coccifera* plot

3. Modelling the distribution of particles within each clump of vegetation

3.1 Principles

The main goal of the following methods were to determine the volume fraction value for all families studied in Fire Star within the clumps designed on the 2D grid by the cellular automaton. The hypothesis we made was that the volume fraction of particles varies significantly within a tree or a shrub crown.
As reality is in 3 dimensions (y = perpendicular to x and z), to each elementary cell of the grid corresponds an elementary volume in the field. All the cells with the same volume fraction for a type of fuel particle define a zone in the canopy. In a first approximation, we distinguished only three zones to totally represent fuel distribution within the shrub: bottom, centre and top. We stated that the edges of a shrub had the same characteristics as its top. Therefore the description of only 3 types of cubes (those that constitute the vertical column) enables to model a whole shrub. For example, the shrub of the picture below is modelled in Fire Star like shown in figure 2 i.e. with a combination of several types cubes.

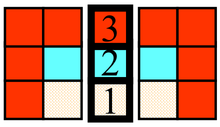

Figure 2 : Diagram (side view) of a 75 cm shrub modelled thanks to the description of only 3 types of elementary cubes of the vertical column
("bottom" in orange, "centre" in blue, "top" in red).

3.2 First method: field sampling campaign

Two steps are necessary to calculate the volume fraction thanks to this method.
a) calculation of the ratio of:
- the oven-dry biomass (kg) of each family which is in the cube,
- to the mass to volume ratio (kg m^{-3}) of the particle family,

to obtain the volume really occupied in the elementary cube (expressed in m^3)

b) then calculation of the ratio of this volume to the volume of the elementary cube, to obtain the volume fraction (a-dimensional number).
The protocol that follows only aims to the measurements of dry-oven biomass of fuel particle in several 25 cm cubes of a shrub.

To define each elementary volume in a shrub, a column made of 4 vertical rods of 2m (and many clips to link them together) was used (see figure 3) on the field.
By convention, the cube representing the "top" was always taken at the very top of the clump and on the last 25 cm where there is the maximum density of leaves (so, new sprouts have usually to be neglected). Therefore, it was possible to insert the column in the ground thanks to a hammer or to take it off of a few cm. Then the column is replaced on the ground to sample the other cubes.
The type "bottom" was taken from the cube which touches the ground, and if possible outside the zone where there was the trunk.

When the shrub is taller than 75 cm, many cubes can represent the type "centre" (as instance 4 if the shrub is 150 cm high). For this reason, we suggested a standard height of sampling: the third cube starting from the ground (i.e. the cube between 50 and 75 cm).

For each species, shrubs of 4 different total heights had to be found. These 4 heights were selected in order to use the same classification as those used to describe the strata used in Fire Star:

Stratum 1	max height 25 cm
Stratum 2	max height 50 cm
Stratum 3	max height 75 cm
Stratum 4	max height 150 cm

Moreover to include the variability encountered between shrubs, which is function of several factors like the plot location, the tree canopy cover, the vegetation treatment on the fuel-break, grazing pressure … shrubs of a given species and a given height were sampled on 8 different stands. Finally, 32 samples were taken for a given species & height. We sampled the material during the winter, before the period of growth of the shrubs.

The steps during the sampling were the following:

We inserted the 4 rods in the shrub and linked themselves with the clips in order to constitute the vertical column in the clump. We cut roughly everything around the column in order to facilitate the sampling of the cubes. The observation of the internal structure of the shrub revealed to be useful for the modelling step. We sampled the material within each cube, taking care of the 6 faces of the cube. We put the vegetal material in the identified container (paper bag, box) corresponding to the cube which was currently sampled. A container was identified by a stand, a species name, a height, the position in the clump (Top, Centre or Bottom), and the number of the shrub (number of repetition).

Figure 3: the INRA device used in the sampling of "cubes" in the shrubs

In the lab, we put the samples in the drying-oven at 60°C for 4 days in order to help the sorting.
Container by container, each type of particle was sorted between the 4 major particle families that are:

- leaves (or needles)
- twigs 0 to 2 mm,
- twigs 2 to 6 mm,
- twigs 6 to 25 mm.

Dead material, in case of shrubs like *Ulex* sp., was considered as another family.

We then determined the mass of the oven-dried material (around 24h at 60°C) for each family of each container. Finally we used the mass to volume ratio previously determined through a common procedure to calculate each volume fraction.

3.3 Second method: use of some outputs of architecture models

Information was also given by the plant architecture method developed by our partners in Cirad, Montpellier (France). It aims at simulating architecture of plant by characterising growth and ramification and knowing its edification mechanism. Many typical Mediterranean plants (*Pinus halepensis, Quercus ilex, Q. coccifera, Cistus albidus, Rosmarinus officinalis,…*) had already been described that way and were thus available in “a catalogue” (Caraglio *et al*., 1996). The fuel family distribution among the cells of each clump could be extracted from the outputs of these models and designed according to the current knowledge on every species architecture.

3.4 Modelling work

Experimental work was done on *Quercus coccife*ra shrubs for 3 height classes (25, 50 and 75 cm). The data on particle distribution have not been analysed yet statistically. After this analysis, data will be stored in a specific database organized at this specific level (tree or shrub level). The data will be used to propose various models of fuel distribution in clumps, by species and height classes.

4. Adding the physical and chemical characteristics of the particles

To complete the requirements of the fire model, other destructive measurements on fuel were made to complete a database on particles designed to gather all the available information on fuel particles of each country belonging to Fire Star consortium. The database includes parameters like surface to volume ratio (m^2/m^3), mass to volume ratio (kg/m^3), high calorific value (kJ/kg) or ash content (g/g) that were calculated or measured through a standardized procedure. Moisture content (expressed in % over oven-dry weight) is also entered as input of the fire model. For the Fire Star simulations, the fuel moisture content was the value characterising the most severe conditions. All this information was collected directly in the field following a common method that is presented in one of the deliverable written in the framework of Fire Star project (Guijarro & Valette, 2002).

Close this chapter

Finally, the outputs of cellular automata were linked with this database on particles so that each cell of the grid was informed with the required physical and chemical parameters for each fuel family which is in the cell. Such files constituted inputs for the fire behaviour model. The following scheme (fig. 6) summaries the steps to go from the vegetation to the inputs of the fire behaviour model.

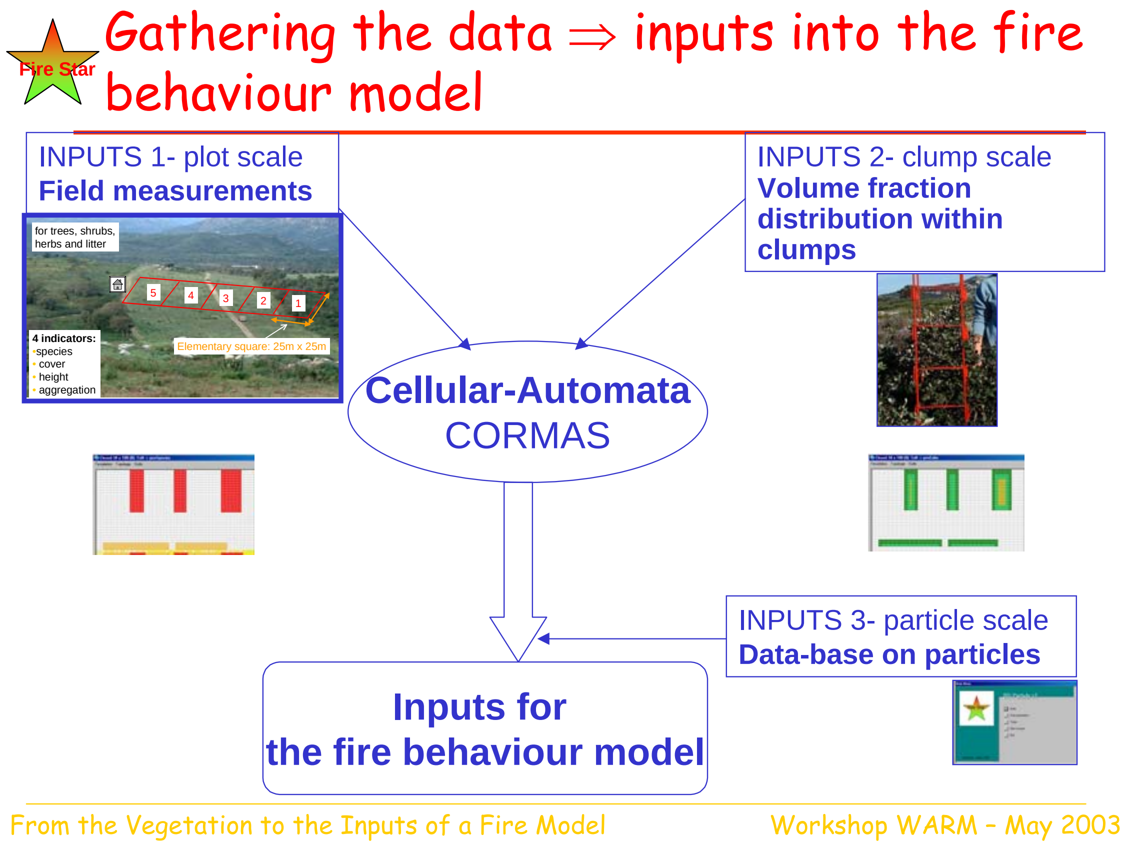

Figure 6: general scheme describing the steps to end up with the inputs of the fire behaviour model

5. Conclusion and perspectives

We developed a new way to model fuel distribution at the fuel-break scale by using a cellular automata, in order to take into account more accurately specificity of fuel-breaks. This coupling between fuel and fire behavior modelling is a promissory approach to test management rules to improve fire prevention efficiency in WUI. This method is currently used and tested on contrasting woodland and shrubland stands of Mediterranean Region with different modalities of fuel treatment. It aims in the long run at developing a decision-making system that will help land-managers to elaborate fuel-breaks or interfaces. In the French context of forest fire risk prevention plans it will be useful to enhance the quality of fire prevention.

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