

A method for incipient wildland fires profile analysis: PROFIRE application

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ABSTRACT: Experience has shown that success in wildland fire suppression is most likely to happen during initial stage but sometimes incipient fires are much more aggressive than expected and the deployed fighting forces fail in tackling their extinction. A new method and analysis tool for the expected progress of an initial fire along a given terrain cross-section or “profile” is presented. The outcome is used in a catalogue of initial fires that should help enormously to conduct appropriate fighting response in a region. A first approach of the solution-space conceptual representation is given in the form of a “profile line”, described by the initial point and a second one set by analyzers. Besides a number of “transversal profiles”, profiles are analyzed on a strap of a certain width. A primary graph is obtained by plotting the resulting values of rate of spread (ROS) and linear intensity (I) for each analysis point, together with terrain profile as well. In the interpretation of the resulting curves, attention will be paid to the increase or decrease of linear intensity and rate of spread from point to point. According to this analysis, recommendations about the place and type of containment and extinction operations are obtained. Final analysis is done by combining the results in every point regarding longitudinal and transversal profiles. The presented procedure is used to obtain a risk value for a point according to its ability to bring fire which consolidates rapidly instead of just its intrinsic values.

1 INTRODUCTION

Many fires in the wildland have an initial stage in which fire fighting can be successful. After this initial stage, a consolidated fire demands much more resources and effort to be effectively contained and suppressed. But required fighting forces are not always available in the immediate vicinity of fire, thus their presence in the area before this consolidation takes place is not always possible.

Besides, successful fire fighting of initial fires entails the consideration, among others, of four main factors: the type of fire developed when the first fire fighting units arrive; the time of access of such fighting units to fire area; the type and number of forces reaching the fire, given that they operate appropriately for the fire they are facing; and the local conditions in which the fighting takes place, such as slope-steepness, vegetation coverage and water availability.

The first factor can be modified to some extent through forest fuel treatments in pre-suppression activities, thus pre-setting the type of initial fire the fighting forces will face; in the other hand, access time to fire area depends largely on the topography and the road network, which can be also improved by adapting or creating new roads, together with helispots for aerial transport. Third,

each fire fighting unit reaching the fire has an specific (not infinite) capacity of fire containment and extinction, which has been tabulated for some types [...]. Finally, mobility within fire area and accessibility to suitable water points in the nearby can be improved as well by modifying vegetation coverage and adapting water points.

In light of the above, preventive planning and pre-suppression deployment of forces is a multi-faceted task that has to be orchestrated encompassedly beforehand (Caballero, 2001) and that has noticeably more effect in the aim of tackling initial fires.

As mentioned, experience has shown that success in wildland fire suppression is most likely to happen during initial stage [...] but sometimes incipient fires are much more aggressive than expected and the deployed fighting forces fail in completing their containment and extinction. And then, the fire escapes.

But, what is the meaning of the word “aggressive” in this context? In the history of wildland fire fighting in Europe [...] it is well-known that aggressive fires consolidate quickly, sometimes in terms of minutes, developing large fronts of flames, big flame lengths and high linear intensity and rate of spread. In the worst cases, surface fires jump to overstory canopy and derive into crown-fire episodes. This cases are directly and strongly associated with severe weather and wind conditions.

Given a certain region, the combination of factors that potentially could develop an aggressive initial fire can be identified and plotted in synthetic maps thanks to the existing Geographical Information System (GIS) platforms. From this, a number of initial fire types can be characterized beforehand, hence deriving specific prescriptions for prevention and extinction operations that could lead, after proper training, to successful, efficient and safe fire suppressions.

Although fire spread models have been used world-wide [...] to predict the most likely fire propagation of an incipient fire, these systems base the evolution of a fire front in subsequent, simulated steps, giving each step as true to project the next one, hence unavoidably accumulating errors in most of cases and progressively deviating predictions from real world, making them useless. This effect is much more evident in the simulation of long periods of time (i.e. more than 3 hours), but it could be corrected by intercalating real monitoring (by remote sensing, airborne reconnaissance, etc.) of flame front interpreting it as actual border conditions, and then projecting its propagation just one, two or three hours ahead each time.

A new approach is presented in this paper. Instead of simulating the propagation of a surface fire, a new tool of analysis of the expected progress of an initial fire along a given terrain cross-section or “profile” is presented. Hereinafter it will be addressed as “incipient fire profile” or simply “profile” to the set of components and factors taking place in the initial stage of a wildland fire along a terrain profile.

Based on the key points exposed above, the author strongly believes that a catalogue of initial fires, including pictures, commentaries on them according previous experiences, characterization of fire progress and recommended fire fighting tactics and observations, should help enormously to conduct appropriate response to fires developing in a region. Besides, actual field training on such tactics should improve the productivity and safety of fire-fighters in the real extinction operations.

2 CONCEPTUAL REPRESENTATION

To accomplish the proposed analysis adequately, a solution-space conceptual representation has to be given, a profile line is described by two points, the initial point A and a second one B at the end of a straight line placed at a distance defined by the analyst (Fig. 1). The mentioned initial point A coincides with the starting location of the incipient fire, although this can be also applied to any point in the front of a developed fire.

This A-B line will be addressed as “longitudinal profile” along which the analysis will take place and that forms an azimuth angle θ with the north-south axis. The angle θ is freely defined by the user, but a good recommendation could be to take such angle equal to dominant wind direction.

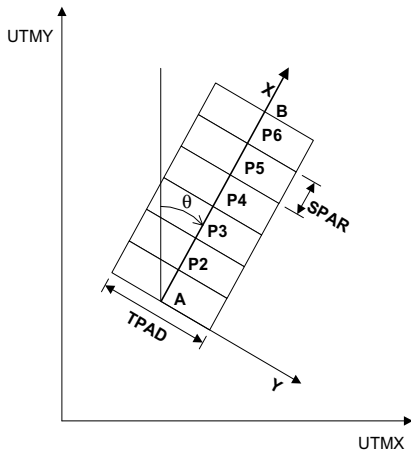


Fig. 1

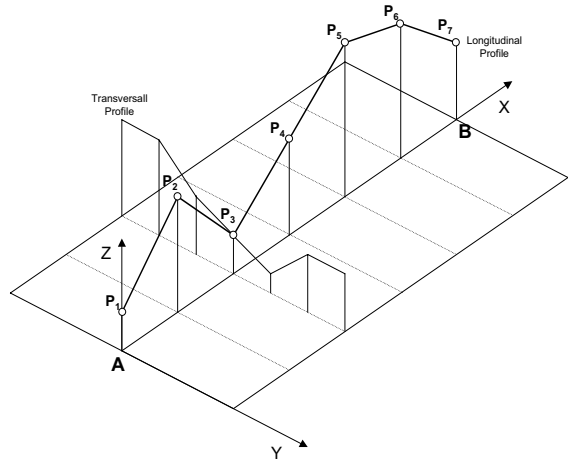


Fig. 2

Along the longitudinal profile a number of “transversal profiles”, perpendicular to the longitudinal profile, are obtained separated by a distance equal to the spatial resolution of analysis (SPAR). Transversal profiles are analyzed along a definite distance, the transversal profile analysis distance (TPAD) which is also defined by the analyzer, and typically ranges from 100 to 500 meters. Analysis of transversal profiles are useful to identify the potential appearance and progress of canyon effect downstream the fire front of the developing fire.

In order to systematize calculations, a local axis system is considered in which the X axis follows the longitudinal profile direction, the Y axis the transversal profile and the Z axis the vertical direction.

Coinciding with the intersection between transversal and longitudinal profiles, a number of nodes (P1, ..., Pn, in Fig.1 and Fig.2) are obtained conforming the basic set of analysis points.

2.1 Longitudinal profile analysis

For each analysis point P1, ... Pn, basic data is requested, such as terrain height, slope in the θ direction, aspect, fuel type, wind vector in the θ direction, dead and live fuel moisture content together with data about the overstory such as crown base height, crown bulk density and foliage moisture content.

A set of calculations is done to obtain information about the type of surface fire potentially developed in each point. Thus, rate of spread in the θ direction, maximum rate of spread, direction of maximum spread, deviation with such direction with θ angle, fire linear intensity in the θ direction and flame length are obtained. Fire access time can be obtained as well combining the values of rate of spread $ROS_{\theta i}$ in the given θ direction and the X distance d_i from the origin (A) to the P_i analysis point considered.

To systematize the interpretation of the resulting curves, thus deriving recommendations on fire containment and extinction, a set of ranges of values have to be described. Instead of pointing to the absolute obtained values, and given that the interest of this method is to obtain information on the fire progress, attention will be paid to the increase or decrease of linear intensity and rate of spread from point to point by calculating the differences $I_{\theta i} - I_{\theta i-1}$ and $ROS_{\theta i} - ROS_{\theta i-1}$, which resulting values will be assigned to the intermediate segments separating pairs (P_{i-1}, P_i) .

The mentioned changes are classified according the following table (Table 1):

Table 1

Growth code	Intensity Change kW/m	Rate Change m/min
--	<-1000	<-20
-	-1000 to -100	-20 to -5
0	-100 to 100	-5 to 5
+	100 to 1000	5 to 20
++	>1000	>20

<i>(1) Fire consolidation zones</i>					
Intensity growth	ROS growth				
	--	-	0	+	++
--	-3	-2	-1	+1	+1
-	-2	-2	-1	+1	+1
0	-1	-1	-1	+1	+2
+	+1	+1	+1	+2	+2
++	+1	+1	+2	+2	+3

Using these ranges, a table of recommendations is proposed (Table 2):

Table 2

2.2 Zone	Description
-3	Fighting operation recommended. Dimension forces according fire scale
-2	Fighting recommended, but caution about fire progress
-1	Caution. Fighting recommended if all other factors are favourable
+1	Fighting is dangerous, consolidation of fire is incipient
+2	Noticeable fire consolidation, fire fighting is dangerous
+3	Very high consolidation, no fire fighting is recommended

According to this table, the segments between points can be classified as well and plotted in the same graph, and recommendations about the place and type of containment and extinction operations can be derived for such segments of longitudinal profile.

This analysis can be easily coupled with an estimation of jump to crown fire probability by combining obtained linear intensity with critical intensity according foliage moisture content and crown base height (Van Wagner,), including such probability in the same graph for the corresponding segments.

2.3 *Transversal profiles analysis*

To analyze transversal profiles, a second conceptual representation has to be defined. For each point P_1, \dots, P_n in the longitudinal profile, a transversal section is obtained by intersecting a vertical plane perpendicular to the longitudinal profile to the terrain. Two regions are considered, one at the left side of the analyzing point along Y axis (LEFT) and other at the right side (RIGHT). Be the angle, either positive or negative, formed by the average slope at the right part with the horizontal plane, and the same for the left part.

In determining the severity of canyon effect, a final judgement has to be done also in every analysis point regarding the direction of maximum propagation. In determining the accessibility, it is also needed to consider the slope in every analysis point P_i along the longitudinal profile.

The interpretation of the analyzed done over transversal profiles is based in the graph, in which the evolution of canyon effect is depicted along the longitudinal profile, by comparing left and right angles. This analysis shows in which segments canyon effect will be noticeable and if it will be progression positive or negatively along the longitudinal profile axis.

2.4 *Final analysis*

The final analysis of the incipient fire profile is done by combining the results in every point P_i regarding longitudinal and transversal profiles, hence a set of recommendations is obtained accordingly.

This is a method that can be applied to a single starting point (A) following a single linear profile (A-B) as mentioned; but this analysis can be easily be extended thanks to GIS platforms.

Most of fire risk-indexes which are implemented in GIS platforms are point-driven analysis, meaning that the resulting value for a point (raster cell) depends solely on the variables and parameter found for that specific point, ignoring the surrounding ones. Instead, in the presented procedure, the profile analysis concept can be used to obtain a risk value for a point according to its ability to bring a fire which consolidates rapidly along a terrain profile, which can also show canyon effect and difficulty of accessibility for fire fighting forces.

To accomplish this task, a procedure is proposed. For each point (raster cell) a number of analysis directions θ_i are considered, i.e. one every 45 degrees clockwise from north, and the previous explained method is applied. A ranking of the point is done according to the obtained results for the θ_i directions, that is the presence of a consolidating fire along the profile, the appearance of canyon effect and the difficulty of access to the fire area.

Alternatively, a single direction θ of analysis can be considered, that of the wind vector, or in a more complex version a polygonal line A-B (Fig. 8), built following the directions of maximum spread for each point, can be considered as analysis profile. In this case the procedure ensures that the conditions of "most aggressive" part of the predicted fire front is what is analyzed.

In terms of territory analysis for planning, it is proposed to apply this method to those points which are certainly well-known causes of fires and which can be pin-pointed in a map, such as waste disposal sites, recreational areas with rustic-barbecues, roads in the nearby of populated areas, surroundings of urban-interface, railroads etc.

3 CONCLUSIONS

A set of conclusions regarding this method is listed below:

- There is a clear need to concentrate efforts in characterizing and study the behavior of incipient fires.
- It is strongly believed that catalogues of incipient fires for each region could entail a great benefit in the improvement of fire prevention plans and fire extinction operations
- Analysis along terrain profiles points to be a practical alternative to fire spread simulation engines

- Ranging increases and decreases of rate of spread and linear intensity, instead of absolute values, help to understand the aggressivity or degree of potential consolidation of an incipient fire
- Recommendations regarding the feasibility of successful operations can be derived from incipient fire profile analysis
- Transversal profiles give an approximation of canyon effect and accessibility to the fire area
- Fire risk maps can make use of the presented method to show the ability of points to bring aggressive, consolidated fires under certain meteorological and wind conditions.
- Maximum spread path can be obtained as analysis base profile by selecting points following maximum direction of spread.
- All the presented procedures have been implemented in a GIS-based, practical stand-alone application named PROFIRE.
- Profile analysis can be directly applied to planning of forest fuel and the adaptation of wild-land fire fighting infrastructures.

REFERENCES

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