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Fire spread experiment across Mediterranean shrub: Influence of wind on flame front properties

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Abstract

A fire spread experiment was conducted in the field under wind-blown conditions. The fuel consists of tall and dense Mediterranean shrub vegetation. The plot area was about 30 m wide and 80 m long. This experiment was conducted not only in order to increase the knowledge and understanding of the fire behaviour in the field but to provide data for the validation of physics based models of fire spread. In particular, the effects of wind on the geometric and thermal properties of the flame front in the field were investigated. The flame temperature along the vertical direction and the radiation emitted ahead of the flame front, were measured. The methodology employed in this experiment and some quantitative measurements of wind velocity and direction, flame geometric properties, are also presented and discussed. The measurements and observations exhibit that the behaviour of the fire and the flame structure character are very different from the one encountered at laboratory scale. These preliminary results show that large scale turbulence influence fire spread and affects the flame shape, temperature and radiation emission.

Keyword: Fire experiment; Field scale; Shrub; Wind; Temperature; Radiant heat flux

1. Introduction

In forest fire research, the experimental studies of the fire spread across vegetal fuels are of great interest for understanding and modelling of the fire behaviour. The fire spread experiments across beds of fuel at laboratory scale have generated an abundant and miscellaneous literature over the last fifty years [1–3]. At present time, there is a need for valuable data on fire spread at a scale larger than the laboratory one. Few experimental studies at field scale were conducted in this way up to now [4–6]. The major part of these studies only provides observations or measurements of the macroscopic characteristics of the flame front (rate of spread, flame length, flame tilt angle, residence time, etc.) because instrumentation in the field is more difficult. The data on the spread of real-size fires are thus quite rare and experiments in the field have to be conducted to improve the knowledge of the mechanisms of forest fire spread. For instance, contradictory assumptions can be found in the literature concerning the nature of the dominant heat transfer mechanism under wind blown conditions. Only quantitative measurements will allow to answer to the question of knowing which process contributes for the major part of the heat required to fire spread. Data collection in the field appears to be the best alternative for the understanding of real fire behaviour and improve and validate the fire spread models. Although much progress has been made, more remains to be accomplished for the development of physical model that account for the behaviour of a forest fire. Moreover, the field scale predictions of the fire spread models, which have been validated against laboratory experiments data, must be considered with caution. Indeed, the fire front intensity, the magnitude of heat transfers and the turbulence effects (which play a significant role on fire spread and in particular on the combustion processes) involved at laboratory scale are not the same in the field. The

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development of sub-models (thermal degradation of the vegetation, etc.) from laboratory scale data, under conditions which are not representative of the one encountered in the field (small samples, low rate of temperature increase, etc.), should also be carefully considered.

These considerations have provided the main motivation for the present work to generate valuable data on the fire at field scale. A fire spread experiment was conducted across Mediterranean shrub and data were collected following the method detailed in [7]. Only, one run has been conducted; but the aim of this short communication is to propose a set of processes of data collected in the field. In particular, the effects of wind on the geometric and thermal properties of the flame front are investigated. The study of the wind effects on the fire is of great interest since buoyant flames in the open space, are nearly always exposed to a cross-wind. The effects of wind turbulence on the flame front are not frequently described as mentioned by Pitts [8]. Nevertheless, the fully developed turbulence is an essential character of wind flowing on a natural ground and significantly affects the fire spread as well as the flame shape, temperature and radiation emission.

2. Experimental procedure

The fire-spread experiment was conducted in the field on July 2004. The study area was located in south Corsica (France) on a varying slope facing northwest. The plot area was about 30 m wide and 80 m long. The fuel consisted of tall (about 2.5 m high) and dense Mediterranean shrub vegetation in which the dominant species were *Olea europea, Quercus ilex, arbustus unedo, Cistus monspeliensis,* and *Cytisus triflorus.* The site description and the properties of the vegetal cover are fully detailed in [7].

The flame temperature along the vertical direction was measured with three sets of K-type ungrounded thermocouples with 50 μm wire diameter. The insulated supporting rods (6.1 m high) were prepared to hold ten thermocouples. Three rows of three sets of heat flux sensors, spaced 5 m apart, were located ahead of the vegetation to measure the radiation emitted ahead of the flame front. The sampling rate for the thermocouples and heat flux sensors was 100 measurements per second. Three two-dimensional ultra-sonic anemometers were placed around the plot to measure the wind fluctuations. The fire spread was recorded thanks to three digital video cameras and an infrared camera. Thermal fuses located inside the vegetation were also used to determine accurately the fire front location during spread.

3. Results and discussion

3.1. Wind characteristics

The instantaneous components of the wind, namely the velocity, u and the direction, θ, recorded by each anemometer, can be decomposed into averaged and fluctuating components (Table 1). The measurements exhibit spatial and temporal variation of wind characteristics over the plot since the wind is influenced by the topography of the terrain, the vegetation and the fire itself. The autocorrelation functions S_{xx} and S_{yy}, associated to fluctuating longitudinal and transverse components of the velocity, reveals the nature of turbulence in the surface layer. These quantities represent the components of turbulent kinetic energy, namely the kinetic energy of wind fluctuations. The spectral densities of the velocities fluctuations E_{xx} and E_{yy}, as a ratio to the local mean speed squared are provided in Fig. 1 against reduced frequency $f_{\mathrm{red}} = f(z/U(z))$. These spectra are computed for the fire spread duration using a Fast Fourier Transform, for a sampling frequency F_s equal to 1 Hz. These spectra are close to those found in the literature [9] and behave as $f^{-\alpha}$, with α positive. In the present study two values of α can be fitted, each of them defining a different region. In the first region, found between the frequency range from 6×10^{-4} to 10^{-1} Hz, α is about 0.6. In the second region, the determination of α is more difficult because of the lack of data close to the upper frequency limit $F_\mathrm{s}/2$ imposed by the Shannon theorem. However, α seems to fit a value larger than $\frac{5}{3}$, the Kolmogorov exponent. The frequencies in this second range sign phenomena dominated by strongly dissipative processes of turbulent kinetic energy [10]. This dissipation is mainly due to the drag induced by

Table 1
Wind characteristics measured during fire spread

	Average wind velocity (standard deviation)	Average wind direction (standard deviation)
Anemometer 1	3.80 m/s (1.78)	267° (27)
Anemometer 2	4.36 m/s (1.60)	266° (20)
Anemometer 3	4.04 m/s (1.74)	271° (23)

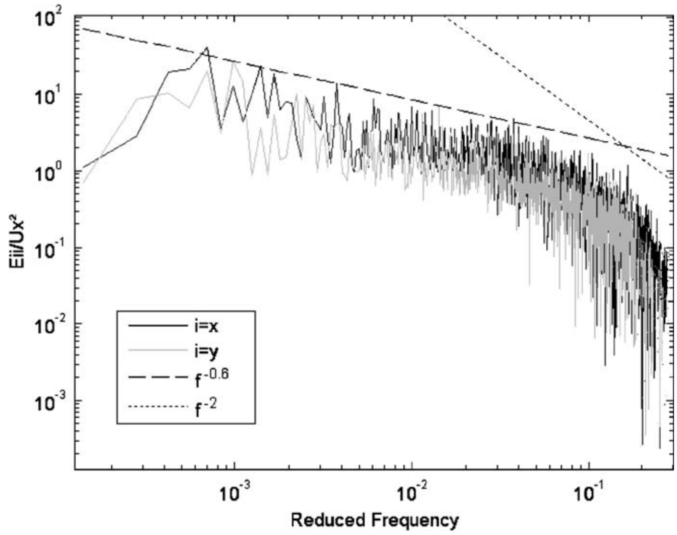

Fig. 1. Two-component turbulence spectra at a height of 2 m.