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Comparing rate of fire spread measurement methods

Many methods are available to measure the time and distance of travel of a fire front and thus determine its speed. The choice depends on measurement objectives, scale, location (in the laboratory or field), desired accuracy and availability of resources. The performance of three common methods were quantitatively compared using fires burning in eucalypt litter in the CSIRO Pyrotron.

Determining rate of fire spread

Precise and accurate measurement of the speed of a bushfire presents significant problems for the measurer. Determining the precise location of the flame front and its time of arrival are often difficult. The flame front pulsates and surges and releases showers of burning particles that complicate the flame front position. Thick smoke may obscure vision and the intense heat release can overheat or saturate instruments (Gill and Knight 1991, Fig. 1).

A fire's rate of spread may be determined by measuring the position of the fire front at predetermined times or by measuring the time taken for the fire to travel a given distance, then dividing the distance travelled by the time taken. The accuracy and precision with which rate of spread is determined depends on the scale of the fire and the accuracy with which time and distance are measured. In the open where fire progression can be rapid, an error of tens or even hundreds of metres in distance may be acceptable. However, in a laboratory with a 5 m fuel bed the measurement of spread distance needs to be within a few centimetres to provide the same level of precision.

Ocular (i.e. by eye) observation of fire arrival or the interpretation of visible spectrum or infrared photography of the fire at known times may be used to estimate distance travelled. Time taken can be measured directly or inferred from differences in time of imagery. However, such observations may be subject to human reaction time, perspective or parallax error, observer error or bias, particularly in regard to determining fire front position.

Alternatively, fire spread measurement devices, such as thermocouples, mercury switches, radiometers or photocells, placed at known locations ahead of the fire and connected to data loggers can provide more precise measures of fire arrival time. Such measurement systems can minimise subjectivity and bias and improve reliability but must be set up well before the arrival of the fire and require additional processing to be useful.

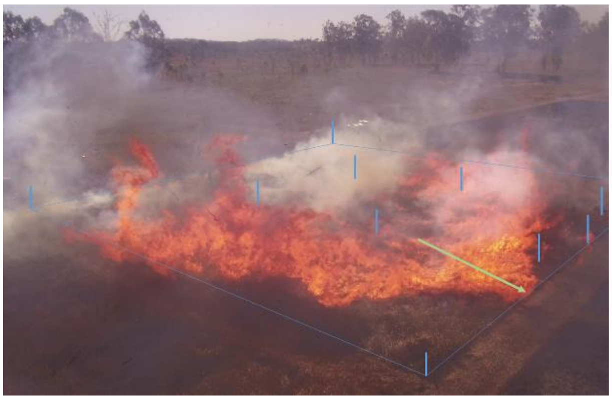

Figure 1. An experimental grassfire view from a video camera mounted on a 10 m tower. Determining rate of fire spread of a free-moving fire is difficult under the best of circumstances.

Methodology

The performance of three methods of determining fire rate of spread—ocular, thermocouple and video-based analysis--were quantified using experiments carried out in the CSIRO Pyrotron combustion wind tunnel (Sullivan et al. 2013) at two wind speeds (1.25 and 2.0 m/s) and three ignition line widths (point ignition, 400 and 800 mm). The fuel was fine (<6 mm diameter) eucalyptus forest litter with a dry load of 1.2 kg/m^2 and dried to 5.0 or 7.0% moisture content.

Fire progression was measured as follows:

Ocular: The time the base of the leading section of flame front was observed to reach predefined measurement intervals of 0.5 m from the ignition line was taken using a stop watch, to the nearest 0.1s.

Thermocouple array: Temperature data from ten rows of K-type 0.51 mm thermocouples 0.5 m apart in the floor of the Pyrotron perpendicular to the air flow were recorded at 100 Hz. The time of arrival of the fire front at each row was determined by the first thermocouple in that row that recorded five consecutive measurements (i.e. 0.05 s) of at least 250°C or when there was a rapid rise in measured thermocouple temperature (Fig.2).

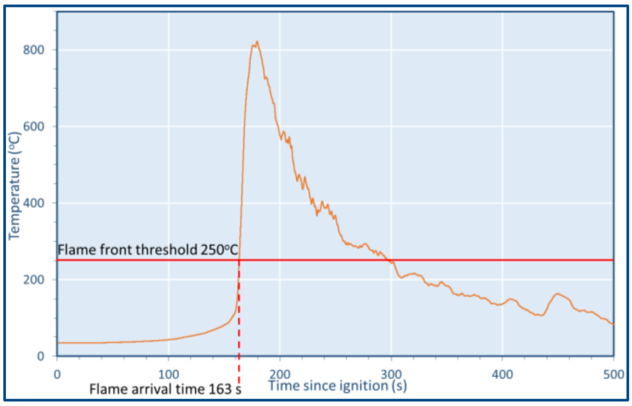

Figure 2. Example of thermocouple trace from a fast moving fire in the Pyrotron. Time of fire arrival at the thermocouple is assumed to occur at a temperature of 250°C.

Video: Fire progression was recorded using a high definition video camera positioned in the Pyrotron ceiling looking straight down and imagery rectified to remove lens distortion (Fig. 2). The time of the video frame at the arrival of the flame front at each 0.5-m interval was recorded and converted to a travel time by subtracting the time of the video frame at ignition.

The rate of spread for each method was then calculated for each spread interval as 0.5 m divided by the recorded travel time for that interval. The cumulative rate of spread at each interval was calculated as the cumulative distance travelled from ignition divided by time since ignition. A total of 58 experimental fires were carried out.

Figure 3. Rectified overhead video frames of an experimental fire. From left to right: 2, 4 and 6 minutes since ignition from a 400-mm-wide line, wind speed 2 m/s, FMC 5%.

Results

Analysis of the results showed that there was a significant difference between the mean rates of spread determined by the three methods, depending on the burning conditions. When fire spread was relatively slow (lower wind speed, higher moisture content) there was no significant difference between the means of the recorded time or calculated rate of spread of the three methods.

However, as the speed of the fire increased and flames became longer, significant differences became apparent. Generally, mean rates of spread determined by overhead video-based measurement were significantly lower than those determined by either ocular or thermocouple methods. This suggests difficulties in determining the precise arrival time of the flame front from overhead that led to estimates of slower overall rate of spread.

Implications

The time and effort to deploy, process and produce results for the ocular, thermocouple array and video techniques varied significantly, and the results, while not substantially different, did depend on the burning conditions with faster fires with larger flames being less consistent across methods. The suitability of any method depends on the objective and resources available.

Ocular methods are relatively quick to obtain useful time and rate of spread estimates if distances are known but are difficult to do remote from the fire. Thermocouples are very precise but take time to deploy and are open to choice of threshold value for flame arrival. Overhead video imagery provides more detail on fire behaviour but on fast moving fires determination of precise arrival time can be difficult. Both thermocouples and video require extra effort in data analysis to produce results.

Further reading

Gould JS, Sullivan AL, Hurley R, Koul V (2017) Comparison of three methods to quantify the fire spread rate in laboratory experiments. *International Journal of Wildland Fire* 26, 877–883.

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Gill AM, Knight IK (1991) Fire measurement. In: Cheney N, Gill A (eds) ‘Proceedings of Conference on Bushfire Modelling and Fire Danger Rating Systems’, pp 137–146.

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

FOR FURTHER INFORMATION

CSIRO Land and Water
Dr Andrew Sullivan
t +61 2 6246 4051
e Andrew.Sullivan@csiro.au
w www.csiro.au/en/Research/LWF

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