HAZARD NOTE

bushfire&natural HAZARDSCRC

ISSUE 113 FEBRUARY 2022
TOPICS IN THIS EDITION | FIRE | FIRE IMPACTS | FIRE SEVERITY

UNDERSTANDING WHAT HAPPENS WHEN BUSHFIRES MERGE

ABOUT THIS PROJECT

The *Threshold conditions for extreme fire behaviour* project investigated which processes cause bushfires to change behaviour and the conditions in which these major transitions occur. Merging bushfires are known for their dynamic behaviour, which might create catastrophic fires. Fire behaviour models need to account for merging fires to accurately reflect the potential spread and impact of extreme fires. The results of this project provide the ability to better predict the behaviour of extreme fires, which can help fire managers plan firefighting efforts more effectively, reducing impacts and keeping people safe.

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SUMMARY

Catastrophic bushfires are often caused by dynamic or extreme fire behaviours, such as when two fire fronts merge together to create one larger fire that is much more dangerous, especially for emergency personnel on the ground.

To date, there have been few studies that have adequately measured the characteristics of merging fire behaviours outside the laboratory. This study developed a simple, fast and accurate way to track the spread of a fire front (also known as fire front propagation) at the field scale, using emerging technologies to understand the physical characteristics of fires about to merge.

Researchers conducted medium-scale field experiments with fire during April 2019 on harvested wheat fields in western Victoria, using drones to capture high-definition videos of fire spread. The footage showed two types of merging fire behaviour: junction fire fronts and inward parallel fire fronts. Junction fire fronts were found to spread 60 per cent faster, some with increasing speeds at the end of merging.

These results contrast with previously published work regarding the physics of merging fires and highlight the importance of further investigation. The approach that this study used to detect and track the spread of fire fronts, with drones at field scale, can be used to reduce the time it takes to process data and obtain a fire perimeter in real time. Utilisation of this research used the same approach, focusing on creating educational modules and operational tools, including improved fire behaviour models. The data collected during this project can be incorporated into other technology that tracks fire spread and notifies firefighters and fire operational managers of its current location in real time.

The data and new tools provide operational and management personnel with a better understanding of the dynamic nature of merging fire fronts. These outcomes can be used to better support decision making around ignition methods during planned burning operations, as well as maximising the information available to support firefighter training and further research and development.

Above: THIS RESEARCH USED FIELD-SCALE EXPERIMENTS AND DRONES TO TRACK THE WAY THAT MERGING FIRE FRONTS BEHAVE. PHOTO: BRETT CIRULIS.

Merging fire fronts = the convergence of multiple fire fronts from a single fire (e.g. junction fire fronts or parallel fire fronts) or separate individual fires into larger fires (fire coalescence).

Junction fire = one type of merging fires (also known as a junction fire fronts, junction zones or jump fires), when two fire fronts merge at an oblique angle. Junction fires can produce very high rates of spread with the potential to generate fire whirls and massive spotting.

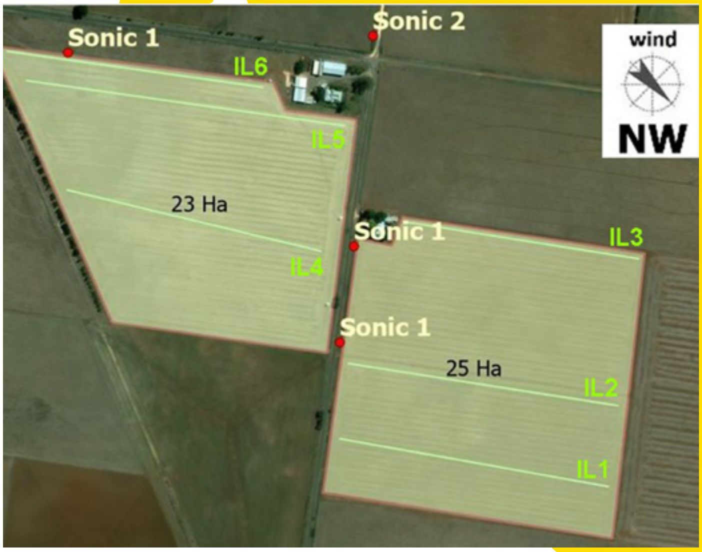


Figure 1: LOCATION OF EXPERIMENTAL PLOTS. GREEN LINES AND RED DOTS REPRESENT IGNITION LINES AND SONIC SENSORS, RESPECTIVELY.

CONTEXT

Extreme and catastrophic bushfires have become more common around the world. They create enormous risks to safety and the environment and can result in many lives or homes being lost. In most cases, the catastrophic fires are the result of dynamic fire behaviours, such as fire whirls, pyro-convective events or merging fire fronts, which can lead to rapid increases in fire intensity and rate of spread. Merging fire fronts have been recorded in several significant bushfires, including the 2019–20 Black Summer fires. In the 2003 Canberra fires, the McIntyre's Hut and Bendora fires merged in the early afternoon. The merging fire apex spread rapidly and developed into an extremely destructive junction fire which resulted in four deaths, many injuries and property losses valued between $600 million to $1 billion.

BACKGROUND

Junction fires have generally been studied experimentally at the metre scale (see Viegas et al. 2013, Raposo et al. 2018 and Sullivan et al. 2019 in Further Reading, page 4). Their results reveal discrepancies between characteristics of merging fires, likely due to varying scales, amount of vegetation, type of vegetation and wind conditions.

Physics-based modelling can be a powerful instrument to uncover physical phenomena beyond experimental limitations. Thomas et al. (2017) tested junction fires using a physics-based model at a kilometre scale. They found some quantitative differences in the acceleration of junction fires with existing experimental data and assumed that it could be attributed to the scaling problem.

Although physics-based models are the best instrument to provide insights into different fire phenomena, they are too slow and complex for operational purposes. Hilton et al. (2017) developed a simplified 'pyrogenic' potential model, which can replicate basic wildfire interaction effects, including fire line attraction, the shape of fire fronts and the enhanced coalescence of spot fires. However, the model assumes that the plume is not significantly affected by the wind and requires further validation at field conditions.

To fully understand how a given fire will merge and spread, and implement this knowledge into operational practices and existing models, extensive high temporal and spatial experimental data at larger scales are required. This project used drones to obtain these measurements. Owing to their flexibility, low cost and high-resolution data collection, drone remote sensing can fill data gaps about how different fire phenomena behave.

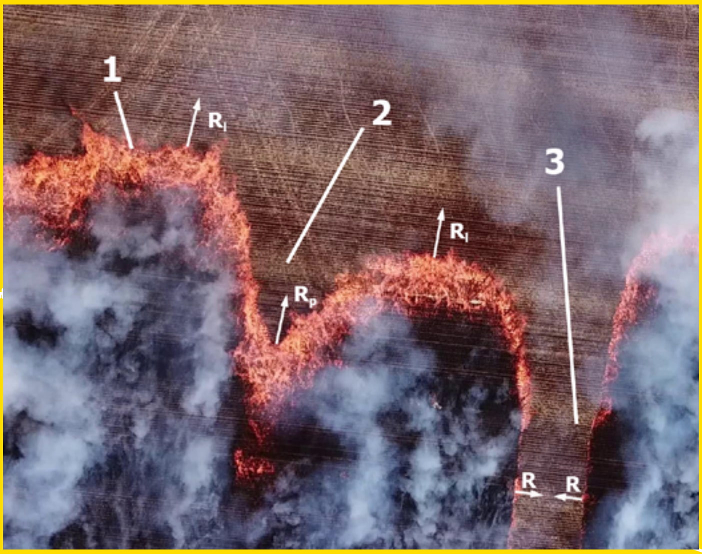
BUSHFIRE AND NATURAL HAZARDS CRC RESEARCH

For this study, researchers conducted several preliminary small – and medium-scale field experiments, igniting fires on harvested wheat fields near Kingston, 110 km west of Melbourne, to characterise and analyse merging fire behaviour using emerging technologies (Figure 1).

After starting the ignition line, the fire front produced 'fire tongues' (as seen in Figure 2). When the fire lines of two neighbouring tongues naturally merged, it was identified as junction fire fronts. Parallel fire fronts were identified as two fire tongues burning parallel to each other. Researchers also measured rate of spread of junction fire fronts, parallel fire fronts and an angle between junction fire fronts.

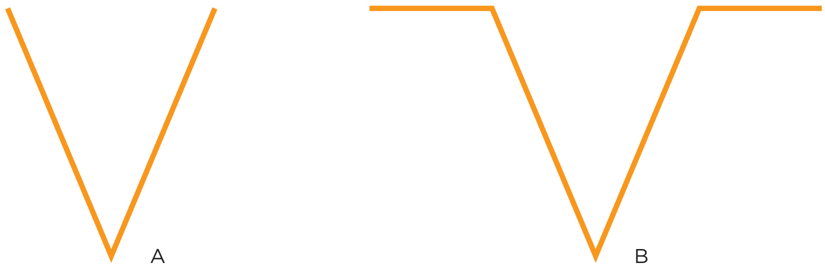
Georeferencing this data using drone software

A drone was used to capture high-definition video imagery of fire propagation, while



▲ **Figure 2:** THE FIRES (WITH THEIR FIRE TONGUES) PRODUCED THREE TYPES OF FIRE FRONTS: 1) LINEAR FIRE FRONTS; 2) JUNCTION FIRE FRONTS; 3) PARALLEL FIRE FRONTS. R_l IS THE RATE OF SPREAD OF THE LINEAR FIRE FRONT, R_p IS THE RATE OF SPREAD OF THE JUNCTION FIRE FRONTS INTERSECTION AND R IS THE RATE OF SPREAD OF THE PARALLEL FIRE FRONTS.

▲ **Figure 3:** STILLS OF VIDEO FOOTAGE. EACH RECTANGLE REPRESENTS SEPARATE GEOREFERENCED FOOTAGE.



▲ **Figure 4:** CONTOUR OF JUNCTION FIRE FRONTS: A) CONSIDERED IN ALL PREVIOUS STUDIES, B) OBSERVED IN THE FIELD EXPERIMENTS.

the Global Positioning System (GPS) and Inertial Measurement Unit (IMU) onboard the drone captured the platform/camera orientation and position in space to be aligned with the video footage. This process is called georeferencing.

The post-processing phase was completed for each video and sensor files using the Full Motion Video (FMV) toolbox within the ArcGIS Pro software. The sensor files were combined with the video file in a process called ‘multiplexing’ – combining multiple signals into one shared format. The result is a video file with each frame georeferenced.

Once it is multiplexed, the georeferenced frame of the filmed area appears on a map (Figure 3). The multiplexed video file was then used to identify and spatially define fire fronts at set time intervals.

RESEARCH FINDINGS

Researchers identified 21 junction fire fronts and five inward parallel fire fronts during the experiments. The rate of spread of junction fire fronts was significantly different and higher than the rate of spread of linear fire fronts, which is consistent with previous studies.
Using the data from these fires, researchers deduced some other key findings:

- Junction fire fronts presented more than 60 per cent increase in rate of spread compared to linear fire fronts.
- All junction fires behaved differently – some only decelerated in rate of spread, some only accelerated their rate of spread, while others did both, which differs from previous studies.
- The length of junction fire fronts (ranging from 3.6–22m) did not affect the rate of spread, in contrast to previous studies.
- 38 per cent of junction fire fronts had an increase of rate of spread at the final stage of merging, in contrast to a decrease or no change in the rate of spread in previous research.
- The rate of spread of junction fires was three to six times the rate of spread of linear fire fronts when the angle between junction fire fronts was < 14°.
- Analysis of video footage with merging fire fronts revealed that, in all cases, junction fire fronts have a different shape to previous studies (Figure 4). It is hypothesised that the left and right shoulder (Figure 4b) create complex convective structures and cause changes in the rate of spread, e.g. acceleration at the end of merging.

HOW COULD THIS RESEARCH BE USED?

Previous research has largely focused on conducting small-scale laboratory experiments to capture the rate of spread of fire fronts, and there are no clear descriptions of the driving mechanisms of merging fires. These results serve to prioritise the further examination of extreme fire behaviours in Australia.

Extensive experimental data at larger scales is required to fully understand how a given fire will merge and spread. Using cutting-edge measurement technologies in field-scale experiments, this project provides high-resolution data that illustrates some of the key mechanisms of merging fires. More sophisticated models are required to inform decision makers about the potential behaviour of extreme fires.

The quantification of captured video and photo imagery has traditionally been challenging and requires significant pre-experiment set up time or a complex post-processing workflow. The approach used in this study has the benefit of minimal set up time (hours) with the resulting data being highly accurate. With further development and testing, it shows promise to be a valuable tool for fire behaviour research, operational and management applications.

Application to prescribed burning

These results can also be used to inform more effective prescribed burning strategies. Prescribed burning is critical in reducing bushfire behaviour and thereby increasing the likelihood of suppression. However, there is a lack of understanding of merging fire mechanisms in prescribed burning, and the impact of merging fires on fire intensity, escalation and progression.

To assist with prescribed burning strategies, this project was extended to combine the knowledge and expertise it developed with the results of the *Fire coalescence and mass spotfire dynamics* project at the University of New South Wales.

Researchers developed materials that provide operational and management personnel with a better understanding of the dynamic nature of fire line merging – including educational material, operational tools (including improved models), and protocols for maximising data collection and processing during prescribed burning operations.

These outcomes can be used to better support decision making around ignition methods during planned burning operations, as well as maximising the information available to support firefighter training and further research and development.

FUTURE DIRECTIONS

Future research can also focus on examining the discrepancies that previous studies have found when measuring the rate of spread, including the following basic questions for investigation:

- Scaling: does the size of merging fires change the rate of spread?
- Fuel load and structure: do the structural properties of the vegetation fuel (bulk density, porosity, surface to volume ratio, heterogeneity, etc.) change the rate of spread of merging fires?
- Wind speed: how does the change in wind speed modify the rate of spread?
- Experimental design: how realistic is the V shape contour? This study's observations showed that junction fire fronts in the field have always shoulders on the top of V, which could result in different fire behaviour compared to "classical" V shape contour. This might result in acute angles and increased rate of spread at the final stage of merging.

Existing studies on merging fires are disconnected. Future research needs to conduct experiments with similar initial conditions and measurements of convective and radiative energy.

END-USER STATEMENT

Predicting the spread and behaviour of fires that differ from typical parabolic head fires is challenging for fire managers, whether for prescribed burns ignited with multiple lines or for merging bushfires in the worst fire danger conditions. Models derived from simpler fires are a starting point but do not capture the complexity of merging fire lines. Because fire merging involves complex convective interaction between fires and the atmosphere, understanding these processes requires studying them across a range of scales using different methods. This project has made important steps forward in using field scale fires and drones to better understand fire merging at a real-world scale. I look forward to future work that will build on these experimental results along with modelling to help understand fire line merging and lead to better predictions and fire management decisions.

Dr Stuart Matthews, Principal Project Officer at NSW Rural Fire Service

FURTHER READING

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The Bushfire and Natural Hazards CRC has been incorporated into Natural Hazards Research Australia, the new national centre for natural hazard resilience and disaster risk reduction. The new Centre is funded by the Australian Government.