

# FIRE NOTE

## TOPICS IN THIS EDITION

- RISK
- TECHNOLOGY
- NATURAL ENVIRONMENT

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## MODEL PINPOINTS FACTORS DRIVING EXTREME BUSHFIRE BEHAVIOUR



▲ Researchers used the WRF-Fire coupled atmosphere-fire model to examine dynamic fire spread observed in the ACT 2003 bushfires.

### SUMMARY

In the 2003 Canberra bushfires, a number of unusual fires were observed in which bushfire spread sideways in a diagonal or crosswise direction to background winds. It occurred alongside rapid and intense downwind fire spread due to spotting. The atypical fire occurrence was on steep leeward slopes (a sheltered slope facing away from the wind) where background wind was mostly perpendicular to the terrain.

The WRF-Fire coupled atmosphere-fire model was used extensively to examine both the physical mechanism driving the atypical lateral fire spread, as well as its sensitivity to the fire environment conditions. The numerical simulations qualitatively match the fire spread seen in the 2003 Canberra bushfires, and provide new insights into dynamic modes of fire spread in rugged terrain. The results have important implications for firefighter safety and fire management.

### ABOUT THIS PROJECT

This research originated from a Bushfire CRC funded PhD project entitled 'Dynamic interactions between wildland fires and the surrounding atmosphere'. Dr Simpson continues to research this topic in his new position as a postdoctoral fellow at the University of New South Wales.

### AUTHOR

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### CONTEXT

The WRF-Fire coupled atmosphere-fire model was used to investigate physical interactions between bushfire, local terrain and atmosphere, that drive lateral fire spread across steep leeward slopes. This dynamic mode of fire spread was observed in the 2003 Canberra bushfires and can result in extreme fire behaviour.

### BACKGROUND

On 18 January 2003, bushfires in and around the Australian Capital Territory exhibited some of the most extreme fire behaviour ever witnessed in Australia. Using remote-sensing technology, including thermal and multispectral linescans, satellite imagery and aerial photographs, McRae (2004) presented evidence of extreme fire behaviour during the 2003 Canberra bushfires. He included a description of an "asymmetric wind-terrain interaction event" that occurred in a number of bushfires. In those events, the fire advanced rapidly across a leeward slope in a direction approximately transverse to the background winds. In addition to this atypical lateral fire spread, embers were launched by atmospheric eddies and travelled downwind, resulting in a rapid and intense downwind propagation of the fire.

The atypical lateral and downwind fire spread observed in the 2003 Canberra bushfires was subsequently studied by Sharples *et al.* (2012), who termed the phenomenon "fire channelling". Sharples *et al.* (2012) ruled out several possible physical mechanisms as the driver of the atypical lateral fire spread. In addition, they discovered that the phenomenon was sensitive to the terrain slope and background wind direction relative to the terrain orientation. Based on the lateral fire spread events in the Canberra bushfires, they estimated that a leeward slope of around 26-30° or higher, and a wind direction within around 40° of the terrain aspect (i.e. winds approximately perpendicular to the terrain)

was required for the lateral fire spread to occur.

This atypical fire spread challenges the assumption commonly made in operational fire spread prediction tools that the rate and direction of forward fire spread remains constant for non-varying fire environment conditions. If the appropriate fire environment thresholds are met, it is possible for a fire on a leeward slope to exhibit asymmetric and extreme fire behaviour with little or no change in the local fire environment required. It is this non quasi-steady state nature of the atypical fire spread, which can occur at a rapid rate, that makes the phenomenon a potential danger to firefighters.

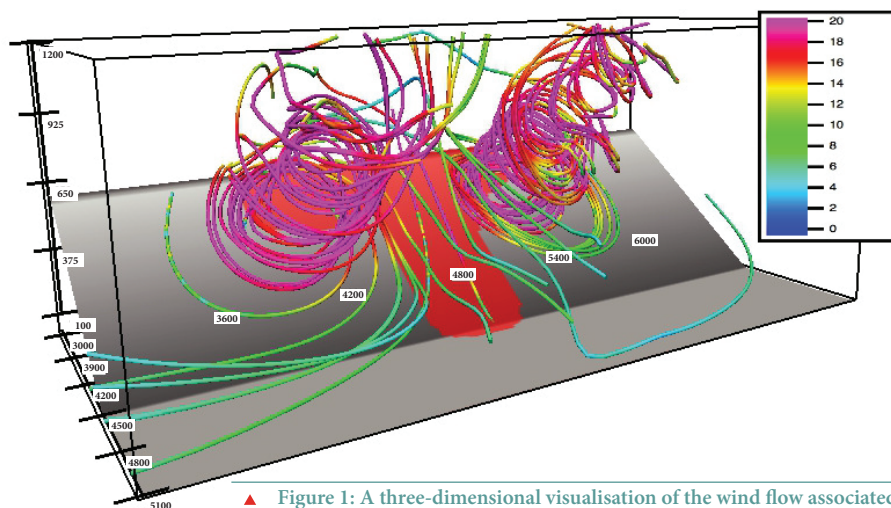
## BUSHFIRE CRC RESEARCH

Following the studies by McRae (2004) and Sharples *et al.* (2012), two important questions about the atypical fire spread events observed in the 2003 Canberra bushfires remained. The first asked what physical mechanism drove the lateral fire spread? The second was what was the relationship between the atypical fire spread and fire environment conditions, in particular the terrain slope, the fuel properties, and the background wind speed and direction?

Initially part of a Bushfire CRC funded PhD project investigating the dynamic interactions between wildland fire and the atmosphere, the research discussed in this *fire note* was undertaken to address those two questions. More broadly, the research fitted into Bushfire CRC research into fire behaviour modelling and the physical mechanisms responsible for extreme fire behaviour.

## RESEARCH OUTCOMES

Simpson *et al.* (2013, 2014) and Sharples *et al.* (2013) used the WRF-Fire coupled atmosphere-fire model, described below, to perform idealised numerical simulations of the two-dimensional fire spread following the ignition of a fire on a leeward slope. They



▲ Figure 1: A three-dimensional visualisation of the wind flow associated with the fire whirls that drive the atypical lateral fire spread across steep leeward slopes. The red surface colour shows the extent of the fire line starting from a circular ignition towards the bottom of the leeward slope, which has advanced upslope and then spread laterally close to the ridge. The flow streamlines show the spatial extent of the fire whirls and the corresponding wind speeds (m/s, as shown in colour scale).

demonstrated that WRF-Fire could simulate atypical lateral fire spread across steep leeward slopes in a qualitatively similar manner to that observed in the 2003 Canberra bushfires. However, the rapid and intense downwind propagation of the fire discussed by McRae (2004) was not reproduced, most likely due to the absence of a spotting model in WRF-Fire.

WRF-Fire is one of a small number of models that can directly model the dynamic interactions between a wildland fire and the atmosphere. It combines the Weather Research and Forecasting (WRF) numerical weather prediction model with a two-dimensional implementation of Rothermel's semi-empirical fire spread model. The rate of spread is calculated at sub-second intervals at multiple points along the fire line, and is dependent on the local fuel properties, the terrain slope and the mid-flame height winds. The mid-flame height winds are calculated using the atmospheric model, hence providing the atmosphere to fire coupling. Combustion

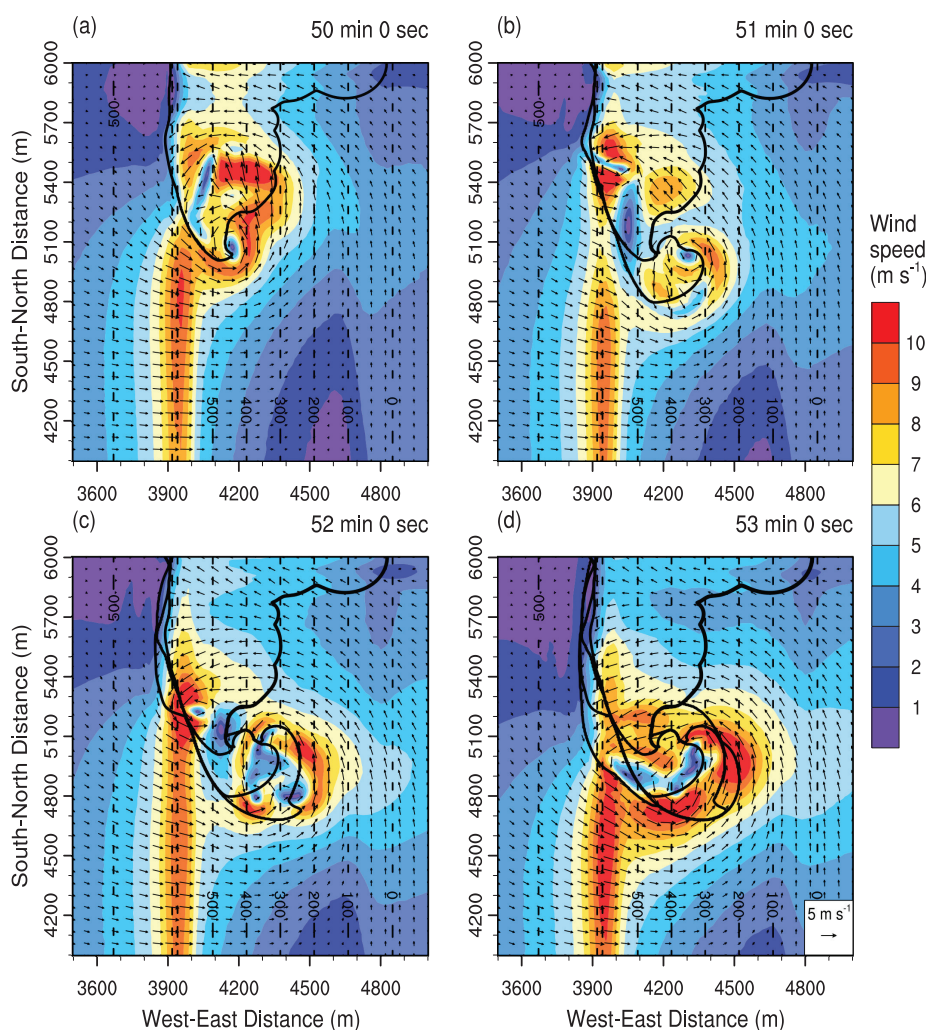
of ignited fuel in the fire model produces sensible and latent heat, which is then injected back into the atmospheric model, and can therefore affect the local atmospheric dynamics and subsequently the fire spread, hence providing the fire to atmosphere coupling.

Simpson *et al.* (2014) noted that for those WRF-Fire simulations that exhibited atypical lateral fire spread, three distinct stages of fire spread were evident. First, the fire advanced upslope due to the combined effects of wind reversal along the leeward slope and the positive upslope contribution to the rate of spread. Second, a thermal, or pyrogenic, wind developed along the leeward slope that increased the upslope rate of spread and could trigger the formation of fire whirls over the fire region. A fire whirl is a rotating column of air above the fire region and is pyro-convectively driven, which distinguishes it from atmospheric vortices such as dust devils. Third, if a fire whirl moves across the fire line,

► WRF-Fire is one of a small number of models that can model dynamic interactions between a bushfire and the atmosphere.







▲ Figure 2: Plan view of a fire whirl driving the lateral fire spread between a time of 50 and 53 min in one of the WRF-Fire simulations. The wind vectors and colours show the mid-flame height winds across the leeward slope. It is evident from the black lines, which depict the changing position of the fire line at 1 min intervals, that rotating winds are responsible for driving lateral and diagonally downslope fire spread during this three minute period.

thereby providing a local wind that is aligned approximately transverse to the background winds, this can drive the lateral fire spread. The numerically simulated fire whirls that drive the lateral fire spread typically have a diameter less than several hundred metres, with an upward vertical motion on the near-side of the fire region and a corresponding downward vertical motion on the far side, as shown in Figure 1, page 2.

The lateral fire spread stage seen in the WRF-Fire simulations is broadly consistent with the description of fire whirls in the lee of a ridge by Countryman (1971). He noted that fire whirls develop frequently in the lee of a ridge, due to wind shear where the hot upslope flow driven by the fire meets the cooler opposing background winds. This wind shear intensifies the eddies that are formed naturally due to the mechanical obstruction of the background winds in the lee of the ridge. He also noted that fire whirls can drive fire spread along the ridge

when they move laterally along the slope or diagonally downslope. It seems likely that the process driving the lateral fire spread described by Countryman (1971) is the same as that seen in both the WRF-Fire simulations and the events discussed by McRae (2004) and Sharples *et al.* (2012) in the 2003 Canberra bushfires. However, the downwind extension of the fire due to spotting was not discussed by Countryman (1971), although he did note that fire whirls can lead to increased rates of spotting.

Sharples *et al.* (2012) demonstrated that the atypical fire spread in the 2003 Canberra bushfires was sensitive to the local fire environment conditions, in particular the background wind direction relative to the terrain orientation, and the terrain slope. The WRF-Fire simulations presented by Sharples *et al.* (2013) demonstrated that the numerically simulated lateral fire spread is sensitive to the background wind speed, with no lateral fire spread occurring for a

## END USER STATEMENT

A major impetus for research into wildfire dynamics was observations from the January 2003 alpine fires. With rapid advances still being made in physical drivers of fires, it remains crucial to make detailed observations of fires to support research. The long-term benefits to fire agencies are immense, but require the collection of detailed field and airborne data, as well as weather and satellite data.

As knowledge of dynamic modes of fire spread improves, fire agencies will be better placed to provide researchers with rich data on a broad range of fire events. This could potentially lead to improved operational predictability and management of bushfires. It is worth noting that there have been a number of incidents in recent decades where firefighters have been injured or killed when fires in rugged terrain suddenly became more severe. This has been largely due to unexpected changes in local wind conditions or through some dynamic interaction between the fire and its local environment. This specific work on VDLS improves our understanding of extreme fire behaviour, and in turn could help reduce the risk to firefighters working in extreme bushfire conditions.

– Rick McRae, ACT Emergency Services Agencies

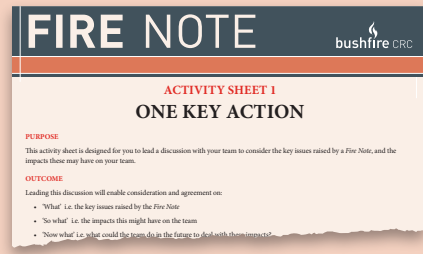
background wind speed of around 5 m/s or lower. More recent WRF-Fire simulations, which will be published in due course, also suggest that the simulated lateral fire spread is also sensitive to the background wind direction, the terrain slope, and the fuel load. The lateral fire spread is only simulated if the wind direction is within around 30° of the terrain aspect, and the terrain slope is around 25° or higher. These results are qualitatively and quantitatively consistent with those presented by Sharples *et al.* (2012). In addition, the simulations suggest that a moderate to high fuel load is also required for the lateral fire spread to occur, as a sufficient quantity of heat is required to sustain the development of the fire whirls.

## HOW IS THE RESEARCH BEING USED?

Countryman (1971) appears to have provided the first description of lateral fire spread driven by fire whirls on leeward slopes. However, his brief description of the phenomenon seems to have been largely overlooked within both the fire science and fire management communities until recently. As a result, there is limited knowledge within fire agencies in

## NOW WHAT?

What three things stand out for you about the research covered in this *Fire Note*? What information can you actively use, and how? Tools are available at [www.bushfirecrc.com/firenotes](http://www.bushfirecrc.com/firenotes) to help, along with activities you can run within your team.



Australia and worldwide of this dynamic mode of fire propagation. This represents a risk to firefighters for several reasons:

- The lateral fire spread can occur at a high peak rate and result in extensive lateral and downwind spotting. These events therefore have the potential to outpace firefighters in rugged terrain or ignited spot fires ahead of them.
- The lateral fire spread can occur under fairly benign fire environment conditions as measured on the leeward slope. For example, the wind speed on the leeward slope is typically much lower than the background wind speed, and the threshold wind conditions required for the lateral fire spread to occur may be exceeded with little or no change in the winds across the leeward slope, turning a previously non-threatening situation into a dangerous one. The research to date suggests that careful monitoring of the surrounding fire environment, particularly the upwind conditions, will be required to successfully predict the occurrence of the atypical fire spread.
- The intense pyro-convection associated with the rapid lateral and downwind fire spread could have secondary effects on the larger-scale atmospheric dynamics

and subsequently affect the behaviour of nearby fires. However, this theory has not yet been studied in any detail.

One of the main aims of our current research is to determine environmental thresholds for the occurrence of the atypical lateral and downwind fire spread. The intention is for these thresholds to be translated into improved guidelines for monitoring the weather conditions in rugged terrain, and provide new watchout situations for firefighters. It may also be possible to incorporate these environmental thresholds into operational fire behaviour prediction tools, and to parameterise the dynamic fire behaviour in fire spread models that do not utilise atmosphere-fire coupling. However, the environmental thresholds will need to be evaluated carefully before they can be used in an operational context.

## FUTURE DIRECTIONS

There are several main future directions for this research:

1. Confirm that WRF-Fire has correctly identified the physical mechanism driving the lateral fire spread. This can be achieved through a comparison with laboratory-scale experiments and landscape-scale fires that exhibit atypical lateral fire spread.
2. Provide better constraints on the fire environment thresholds required for the occurrence of the atypical lateral fire spread. Recent WRF-Fire simulations suggest that there is an interdependency between the various fire environment thresholds, and it may not be possible to determine a single set of thresholds that work for all situations.
3. The WRF-Fire model has limitations that must be addressed, including the lack of a mid to long-range spotting model. In addition, further validation of the effects of atmospheric turbulence on the two-dimensional fire spread is required. Additional validation studies and planned improvements to the WRF-Fire model will begin to address these issues.

## REFERENCES/ FURTHER READING

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AFAC is the peak body for Australasian fire, land management and emergency services, creating synergy across the industry. AFAC was established in 1993.