Background briefings on emerging issues for fire managers from AFAC and Bushfire CRC.

FIRE NOTE

ISSUE 61 MAY 2010

WIND-TERRAIN INTERACTION AND BUSHFIRE PROPAGATION OVER RUGGED TERRAIN

SUMMARY

The interaction of wind, terrain and a fire burning in a landscape can produce a variety of unusual yet significant effects on fire propagation. This note discusses one such example, where a fire exhibits rapid lateral spread in addition to the usual downwind direction. This type of fire spread is characterised by intense lateral and downwind spotting and production of extensive flaming zones.

The dependence of this atypical fire spread on wind and terrain was analysed using wind, terrain and multispectral fire data collected during the January 2003 alpine fires over southeastern Australia. The research confirmed a quantitative link between instances of the atypical spread and parts of the terrain that are sufficiently steep and lee-facing. A number of processes that could produce the atypical fire spread were considered and discounted using the available evidence. Based on the processes that could not be discounted, a likely mechanism for the atypical spread was hypothesised.

ABOUT THIS PROJECT

Project B6.3 Managing the risk of fire in the high-country (HighFire Risk).

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in collaboration with Mr Stephen Wilkes, ACT Parks, Conservation and Lands.

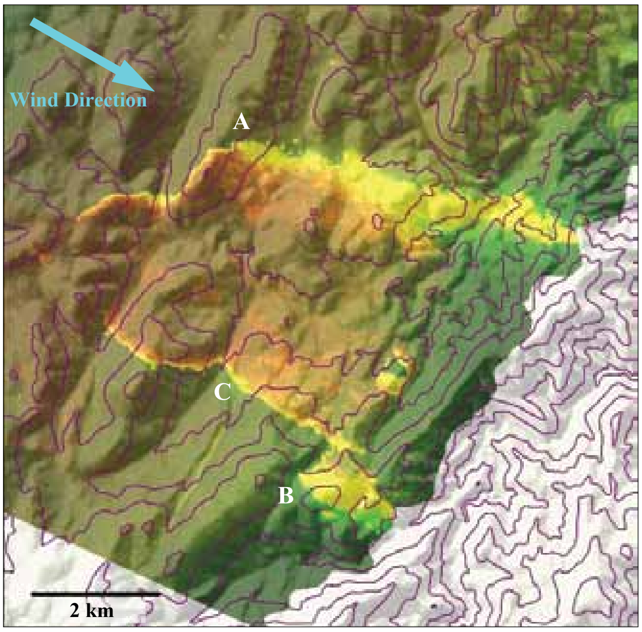


Figure 1: Multispectral line-scan data for the Broken Cart Fire captured at 15:09 on 18 January 2003, overlayed on elevation data (100m contours). Feature A indicates lateral spread and spot fire development with an extensive flaming zone downwind, as does feature B. By contrast, feature C indicates typical flank fire behaviour.

CONTEXT

The research aims to provide a better understanding of the processes that can affect the development of wildfires in the high-country. A particular aim is to catalogue and understand processes that can result in the rapid escalation of a wildfire burning in rugged terrain.

BACKGROUND

The January 2003 alpine fires in southeastern Australia were notable in many ways. In particular, the firestorm that impacted Canberra on 18 January claimed four lives and destroyed hundreds of houses within a few hours. The Canberra fires also stand out as some of the best documented wildfires in Australia, namely, through airborne and land-based photographs and video, satellite data and multispectral line-scans. These data sources permit analyses of the extreme fire behaviour experienced during the event. Moreover, as controlled experiments at the scale of the fire behaviour experienced on 18 January are not possible, these data sources provide rare opportunities to gain insight into the mechanisms driving the spread of large wildfires. The line-scan imagery and photographic accounts of the fires on 18 January, in particular, revealed a number of unusual features, which could be consistently characterised by rapid lateral fire spread, intense lateral and downwind spotting and the formation of extensive flaming zones. Given the rugged terrain in which the fires burnt and the strong winds that occurred, it was natural to consider the influence of wind-terrain interaction on the fire spread.

BUSHFIRE CRC RESEARCH

The HighFire Risk project team utilised wind data recorded by the Bureau of Meteorology and the ACT Emergency Services Agency, 90m resolution terrain data from the Shuttle Radar Topography Mission (rescaled to 250m), and photographic evidence

DEFINITIONS/KEY TERMS

Forced channelling – The mechanical deflection of winds by terrain features such as valley side-walls.

Pressure-driven channelling – The formation of winds within valleys and other terrain features, driven by broad-scale pressure gradients.

Thermal winds – Differences in insolation across rugged terrain can result in temperature differences across the landscape. These temperature differences cause local circulations over a range of spatial scales.

Downward momentum transport of upper winds – In many circumstances it is possible for the upper winds to be mixed down to the surface (e.g. through convective effects). When this occurs, conservation of momentum dictates that the surface winds will inherit the upper wind direction, which might be quite different to the ambient surface wind direction.

Lee-slope channelling – Results when a lee-slope eddy develops an across-slope component. For example, when the ambient winds are not quite perpendicular to a ridge the eddy can inherit an across-slope component through conservation of momentum. Alternatively, it is possible that the flow within the separation eddy could acquire an across-slope component due to the influence of thermally-driven winds or the emergence of local pressure gradients. The net effect in either case is for the air to follow a helical pattern about a horizontal axis aligned approximately parallel to the ridgeline.

Multispectral Line-Scanner – An instrument that measures radiance in a number of discrete spectral bands (in this case covering the visible and infrared parts of the spectrum).

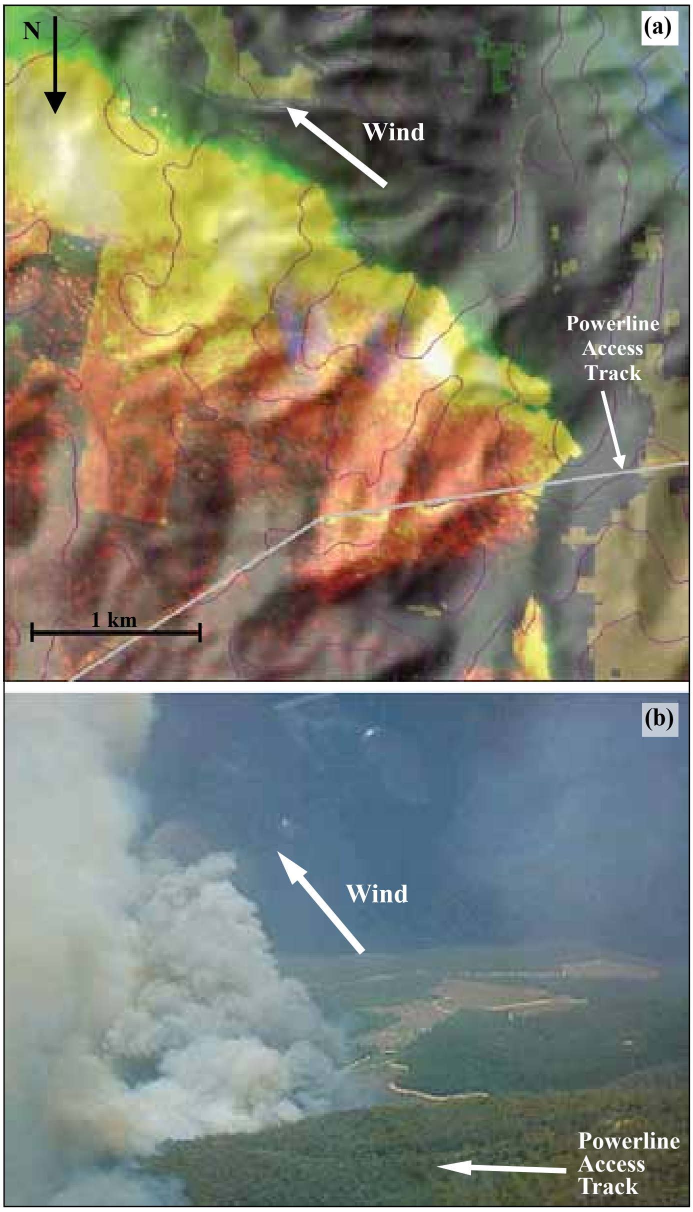


Figure 2: (a) Line-scan image at 15:03, 18 January 2003 [Run 3] of the atypical spread at Blue Range, ACT. (b) Photograph of the Blue Range event (taken by Stephen Wilkes). A powerline access track, indicated in each panel, can be used to assist in matching locations in the images.

and multispectral line-scan imagery. The multispectral line-scan imagery was captured by a Cessna fitted with line-scanning instrumentation, which flew several missions over fire-affected regions.

Of particular interest were features in the line-scan imagery indicating atypical spread, such as can be seen in Fig. 1. These features included: a distinct angular 'kink' in the fire perimeter; lateral spot fire development and fire spread; constraint of the upwind edge by a major break in topographic slope; and the formation of extensive flaming zones downwind.

Overall we identified 14 instances on 18 January where the line-scan data indicated atypical spread of the type described above. In some instances the atypical spread indicated in the line-scan data was confirmed by photographs. For example Fig. 2 shows line-scan imagery (a) and a contemporary photograph (b) of the event at Blue Range, ACT. Similarly considering line-scan data collected on 26 January 2003, another nine instances were identified. A cursory examination of all of the instances of atypical spread identified, suggested a connection with steep slopes that are approximately lee-facing. To investigate this apparent connection in a more quantitative manner the researchers developed a simple terrain-filter model. The terrain-filter was defined by two parameters: the first describes a critical value of topographic slope, while the second describes the maximum allowable discrepancy between the topographic aspect and the direction the wind was blowing towards (this is the usual wind direction plus 180°). The model identifies those parts of the landscape that have topographic slope above the critical slope value, and that have aspects within the aspect discrepancy.

The model was calibrated on a subset of five of the instances identified. The calibration procedure involved manual variation of the parameter values until the smallest subset of the landscape containing the locations of the five calibration events was obtained. The calibrated terrain-filter model identified those parts of the landscape with topographic slope above 25° and with aspects within about 30° of the direction the wind is blowing. The relationship between the output of the calibrated terrain-filter model and the regions of atypical spread identified in the Broken Cart Fire can be seen in Fig. 3.

To explain the atypical spread evident in the data the researchers considered a number of processes that could result in lateral fire spread. These included: forced channelling; pressure-driven channelling; thermal winds; downward momentum transport of upper winds; lee-slope channelling; and interactions between the wind, the terrain and the fire. By appealing to the available evidence a number of these processes were ruled out as factors driving the atypical spread.

RESEARCH OUTCOMES

As detailed in Sharples et al. (2010a), the researchers were able to rule out pressure-driven channelling, thermal winds and downward momentum transport of upper winds as mechanisms driving the atypical fire spread. For example, downward momentum transport could be confidently ruled out for the following reasons:

- downward momentum transport would tend to drive the spread in only one direction, i.e. the direction of the upper winds. This is at odds with what was observed
- downward momentum transport would be expected to occur wherever the fire was able to produce sufficient vertical mixing. This is difficult to reconcile with the fact that the atypical lateral spread only occurred in connection with steep, lee-facing slopes.
- the wind profile at Wagga Wagga indicated that winds were from the west throughout the vertical extent of the atmosphere on 18 January.

By combining the terrain-filter analyses with the probabilistic analyses of Sharples et al. (2010b), the hypothetical mechanism that best fits with all of the evidence can be illustrated as in Fig 4. An eddy-like structure forms due to separation of the ambient flow from the terrain surface. Once a fire enters a region prone to eddy formation, the fire can act to intensify the vortical flow and the increased turbulence can facilitate more efficient production of embers, which are then circulated with the eddy. These embers move in a lateral direction, igniting spot fires in a direction transverse to the main wind direction. The lateral spread could occur through a number of processes: the eddy circulation could inherit an across-slope component from the momentum of the ambient winds, the presence of the fire could induce across-slope thermal or pressure gradients within the separated flow, or the eddy could interact with lateral winds caused by forced channelling. As noted by Byron-Scott (1990), vigorous lee-slope eddies can contribute momentum to the main airflow (through buoyant enhancement) as well as burning embers. Thus, in addition to their advection by the lateral flow, a proportion of the embers can be 'peeled off' from the top of the eddy by the ambient winds and deposited downwind where they ignite further spot fires that grow and amalgamate. The bidirectional nature of the process, with embers advected both laterally within the separated flow and downwind by the ambient flow, means that it can rapidly and efficiently spread a fire across a landscape. The result of the process is an extensive region of active flame. In the case of the McIntyre's Hut fire the process has been directly linked to the formation of a large pyro-cumulonimbus (a firestorm) – see Fig. 5.

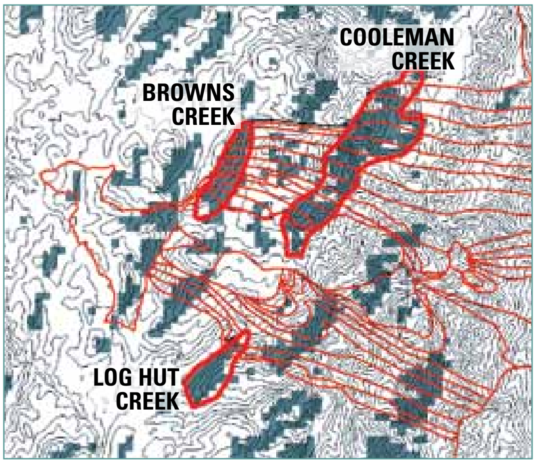


Figure 3: Output from the terrain-filter model calibration.
Grey pixels are the parts of the landscape identified by the terrain-filter. The thick red lines enclose the three instances of atypical spread observed at Log Hut Creek, Browns Creek and Cooleman Creek (Broken Cart fire).
Thin red lines are 10-minute isochrones estimated from the available evidence, which indicate the lateral spread during the events.
The calibrated model was applied assuming a west-northwesterly wind direction.

END USER STATEMENT

Many experienced fire fighters have, at some point in their careers, witnessed fire behaviour they cannot explain. It is pleasing to see researchers developing detailed explanations for some of these events. It is evident from the research that channelling-driven fires were a major component of the catastrophic fires here in the ACT and surrounding alpine areas during and after January 2003.

By understanding some of the reasons that such fires become catastrophic we can reassure the community that there are targeted ways to mitigate the risks that arise from these fires. This research is of necessity very technical. Clearly it will not be an easy path to explain the concepts involved to the wide range of stakeholders involved, but the effort is essential. This research will also underpin improvements to wildfire models by providing more accurate predictions of rate of spread, particularly as fires become affected by this very dangerous form of wind – terrain interaction.

– Andrew Stark, Chief Officer
ACT Rural Fire Service
ACT Emergency Services Agency.

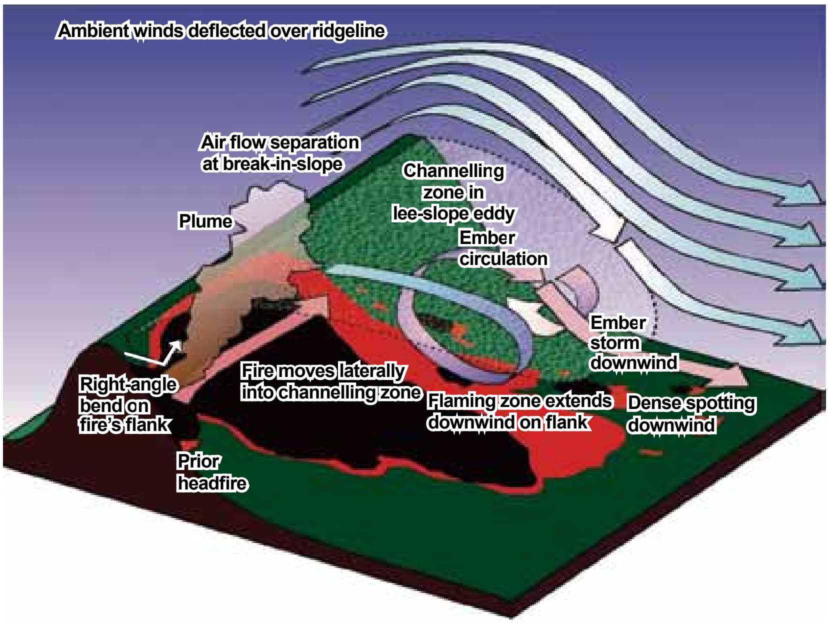
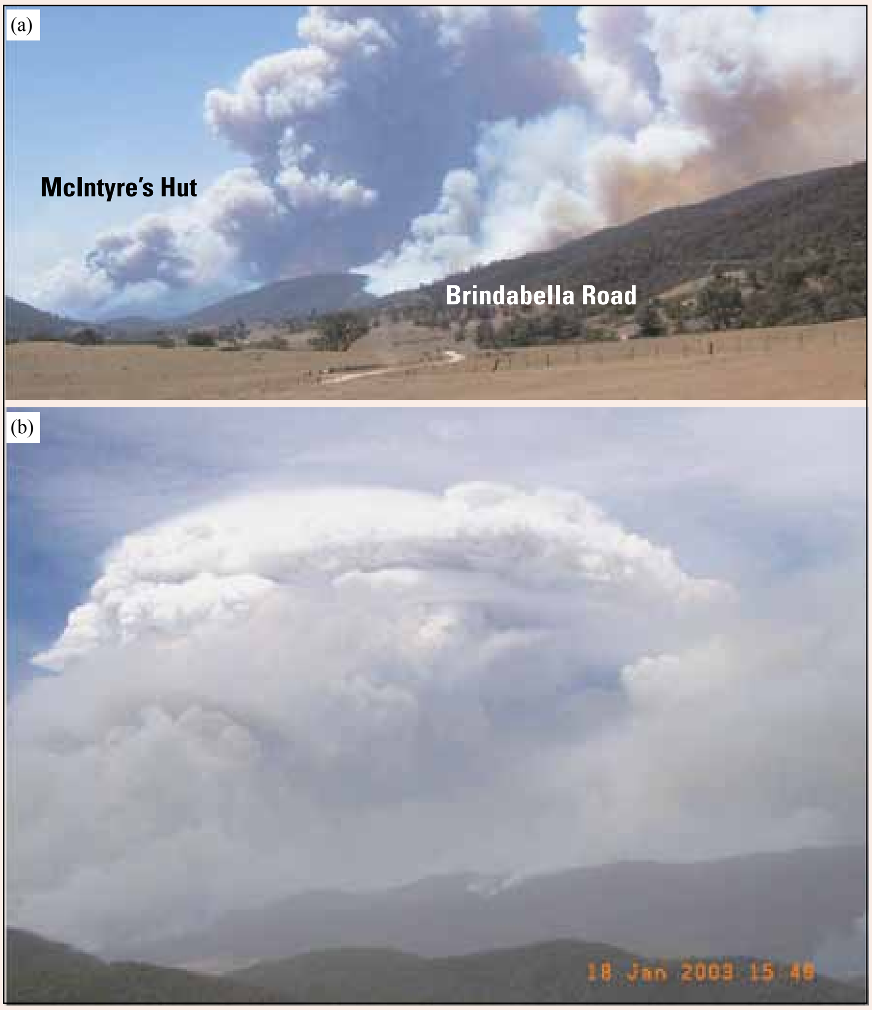


Figure 4: Schematic diagram illustrating the hypothetical mechanism suggested by the research. The channelling zone referred to in the above figure is the region within the lee-slope eddy where lateral advection of fire and embers can take place..

As far as the researchers are aware, this was the first study into this dangerous type of fire spread.

HOW THE RESEARCH COULD BE USED

The research has highlighted a hitherto undocumented, yet very dangerous form of fire propagation that has important implications for fire management and fire-fighter safety. The atypical spread was shown to be a very efficient mechanism for spreading a fire across a landscape, and the intense fire behaviour associated with it increases the likelihood of a fire escalating to catastrophic levels. Furthermore the rapid escalation of a small fire due to incidence of the atypical



▲ **Figure 5** (a) The McIntyre's Hut and Brindabella Road fires exhibiting extreme fire behaviour in association with two incidences of the atypical spread (Photo taken by local resident).
(b) Photograph of a well developed pyro-cumulonimbus over the McIntyre's Hut fire 24 minutes after the line-scan imagery indicated atypical spread and the production of an extensive flaming zone (Photo taken by Stephen Wilkes).

spread can result in a catastrophic decay in fire-fighter safety that is counter-intuitive. This may have been a factor in past fire-fighter fatalities.

The distinguishing characteristics of the atypical spread provide a clear set of indicators. For lookouts posted to monitor fire development, the appearance of darker smoke and vigorous convection on the flank of a fire burning on a lee-slope or in an incised valley should trigger an immediate message to incident controllers, warning them of the potential for rapid escalation of the fire.

Although the terrain-filter model was used primarily as a diagnostic tool, it could also be used in a predictive capacity. The terrain-filter identifies regions that possess some of the characteristics necessary for the occurrence of the atypical spread, and so combining the model output with information from lookouts and other sources can provide more accurate information on how a fire might develop, should the atypical spread occur.

Knowledge of the parts of the landscape most prone to the atypical spread can also be used to better inform fire managers on where to safely place personnel (especially lookouts) and can be used in longer-term planning. For example, the terrain-filter model could be used to better inform fuel management strategies outside of the fire season. The model, which is easily implemented in a GIS platform, could be used to better identify regions prone to the atypical spread and thereby assist in prioritising fuel reduction treatments, including prescribed burning. Careful management of fuel in regions prone to the atypical spread could significantly reduce the chances of fire escalation, and hence the overall risk posed by a bushfire burning in rugged terrain and montane fuels.The researchers are eager to engage with end-users to pursue these ideas further.

FUTURE DIRECTIONS

While the terrain-filter model was able to identify regions or terrain conditions that were necessary for the atypical spread to occur, these terrain conditions were not sufficient. The capability of the atypical spread to rapidly propagate a fire across a landscape is dependent upon the rate at which spot fires ignite, spread and amalgamate, and so conditions of sufficiency are also likely to include factors such as low fuel moisture and fuel structure conducive to ember formation (e.g. stringy bark). The strength of the ambient winds and local atmospheric stability characteristics will also be important factors in determining whether the atypical spread will occur. Separation eddies are much more likely to form in a locally unstable atmosphere and when ambient wind speeds are high.

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