HAZARD NOTE

bushfire&natural HAZARDS CRC

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TOPICS IN THIS EDITION | FIRE WEATHER | FIRE SEVERITY | FIRE IMPACTS

FIRE ESCALATION BY DOWNSLOPE WINDS

ABOUT THIS PROJECT

This research is part of the *Improved prediction of severe weather to reduce community impact* project, and builds on work described in *Hazard Note* 22.

AUTHORS

Dr Jeff Kepert, Dr Kevin Tory, Dr Will Thurston, Simon Ching, Dr Robert Fawcett and Claire Yeo, Bureau of Meteorology. Contact jeff.kepert@bom.gov.au

Above: THE STATE MINE FIRE IN THE BLUE MOUNTAINS, OCTOBER 2013, SPREAD ABNORMALLY FAST FOR THE WEATHER CONDITIONS DUE TO A WEATHER PHENOMENON KNOWN AS A MOUNTAIN WAVE. PHOTO: GARY P HAYES, PROVIDED BY THE NSW RURAL FIRE SERVICE.

SUMMARY

One of the most challenging situations in fire management is when relatively benign weather conditions are expected, but a severe fire eventuates. These situations can result in significant loss of property or even life. Identifying the cause of such incorrect expectations can help to prevent them from recurring in the future. Analysis of the meteorology of recent bushfires has now uncovered three cases (the State Mine fire, New South Wales, 2013, the Margaret River fire, Western Australia, 2011, and the Aberfeldy fire, Victoria, 2013) where a weather phenomenon known as mountain waves has contributed to the severe fire behaviour. Mountain waves are atmospheric oscillations that occur due to air flowing over hills or mountains. They can arise in several different ways, some more predictable than others. Often they cause strong downslope winds on the lee slope of the hill or mountain. If a fire is present, it may become unexpectedly severe as a result.

CONTEXT

This project has investigated the meteorology of several recent cases where unexpectedly severe fire behaviour has occurred. In the three bushfires discussed, mountain wave activity seems to be at least part of the cause.

BACKGROUND

Mountain waves are oscillations that can occur when the wind blows across a mountain or hill. They are somewhat similar to water flowing over a rock in a stream, but are much more complex because their existence and amplitude is sensitive to the atmospheric temperature structure (stability) and vertical variation of the wind (wind shear). They often lead to strongly accelerated flow attached to the lee slope of the mountain or hill, known as downslope winds, as seen for example in Adelaide's famous gully winds and the analogous scarp winds in Perth. While some have suggested that these strong winds could affect a fire (Sharples, 2009), there has been little direct evidence of this actually happening, either in Australia or overseas.

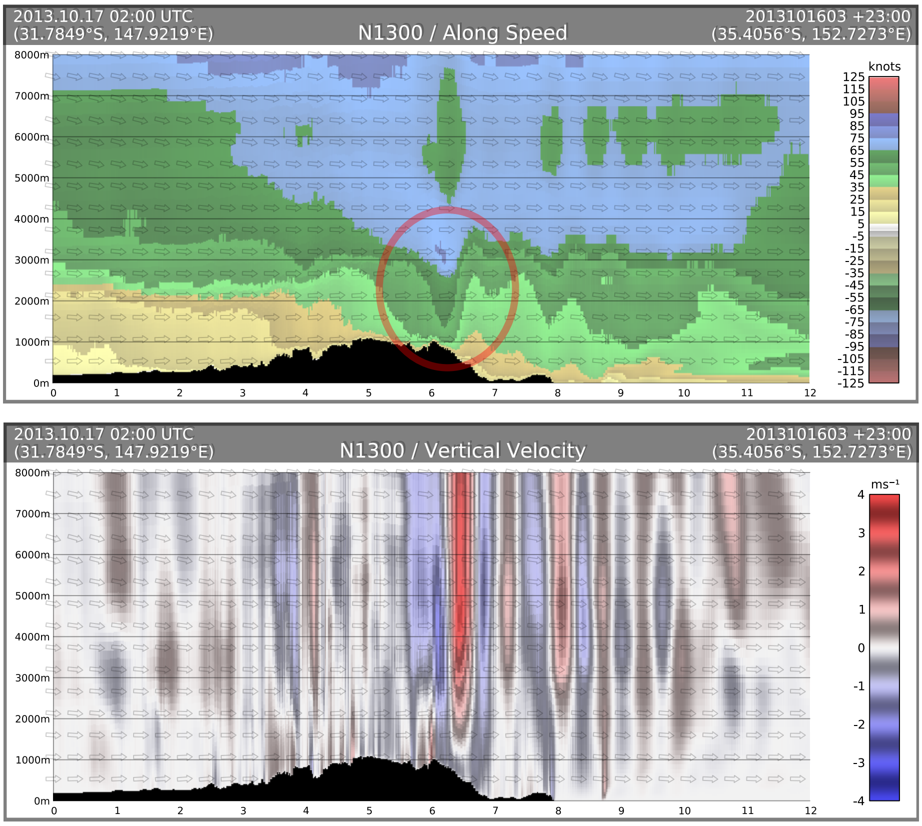
RESEARCH ACTIVITY

The Bureau of Meteorology's operational numerical weather prediction system, ACCESS, has been used to conduct the case studies into severe fire weather. ACCESS can simulate the weather of the event at very high resolution (a grid spacing of around 440 metres). This compares with the highest operational grid spacing of four kilometres at the time of the case study fires. Sub-kilometre resolutions are currently impractical for operational forecasting because the computer runtime becomes very long (by a factor of up to 1,000 times), although they can be very instructive in research mode. After running the model, the simulation is verified against the observed weather, and

DEFINITIONS

Mountain waves: Atmospheric oscillations that occur due to air flowing over hills or mountains. There are several causes, some more predictable than others. Often mountain waves cause strong downslope winds on the lee slope of the hill or mountain. If a fire is present, it may become unexpectedly severe as a result.

Dry slot: In the context of fire weather, a relatively long narrow band of dry air, often associated with a wind change, which can cause sudden drops in humidity and increases in wind speed if it mixes down to the surface. The onset of dry air can reduce fine-fuel moisture and thereby elevate fire risk.



▲ **Above:** FIGURE 1: A NORTH WEST – SOUTH EAST CROSS-SECTION THROUGH THE VICINITY OF THE STATE MINE FIRE AT 1PM ON 17 OCTOBER 2013. THE TOP PANEL SHOWS WIND COMPONENT ALONG THE CROSS-SECTION PLANE, WITH STRONG HORIZONTAL DOWN WINDS CIRCLED, AND THE LOWER PANEL SHOWS VERTICAL VELOCITY (RED = UP, BLUE = DOWN). THE FIREGROUND WAS NEAR THE NUMBER 6 ON THE X AXIS. THE FLOW DIRECTION IS LEFT TO RIGHT.

if it proves to be sufficiently accurate, it can be assumed it is a good representation of what actually occurred. In many cases, the team have been able to uncover fine-scale meteorology, too small in scale to be resolved by the operational models or captured by available observations, which would have contributed to more severe fire behaviour. However, these features would either not have been depicted in the traditional fire danger parameters of surface temperature, humidity and wind, or would have been filtered out in a broader-scale depiction of the data.

Such numerical weather prediction-based case studies have been widely used in meteorology and have significant benefits. While observations sample only a few points, the model contains information on the conditions throughout the area of interest, including above the surface. The model data are coherent in space and time, making it easier to interpret what is happening, and less likely to have something of importance fall in the gaps between the observations. These studies also help shape future numerical weather predictions, using high-impact events to test the models under demanding conditions and demonstrate the value of upgraded computers.

In the course of this research, a number of significant bushfires have been analysed. It has been discovered that mountain waves were a factor in three of these fires, enough to suggest that mountain wave impact on fire is a reasonably common problem.

RESEARCH OUTCOMES

Blue Mountains fire

A detailed case study of the Blue Mountains (NSW) fires of October 2013 was undertaken, focusing on 17 October when some 200 houses were destroyed. On this day, the State Mine fire, one of several fires in the Blue Mountains, grew from 1,036 to 12,436 hectares in around 10 hours. While antecedent conditions had been dry, this was severe fire behaviour by any definition, especially occurring so early in the fire season.

Figure 1 (above) shows a cross-section of the horizontal wind speed and vertical motion along a section passing north west – south east through the fireground. Notice the region of strong horizontal winds (circled) extending downwards towards the surface in the vicinity of the fire. Elsewhere, much weaker winds prevailed at these levels. Notice also the oscillations downwind of this feature. Looking at vertical motion along the same cross-section, alternating bands of ascent and descent are apparent. Together, these bands are the characteristic features of mountain waves.

The modelling also showed that a marked 'dry slot' of drier air passed over the fireground during the day (see definitions box, above left), further contributing to the fire danger.

Margaret River fire

The Margaret River fire in November 2011 was a prescribed burn that escaped overnight. Strong winds the following day drove it south into the communities of Prevelly and Gnarabup, where 39 houses were lost. While the fire activity was reasonably consistent with the fuels and weather on the day, the behaviour overnight was not. For the days preceding the escape, the fuels had been reluctant to burn, to the extent that it was decided to leave the fire overnight. Early the following morning, crews returned to find the fire had dramatically intensified and was in the process of crossing the control lines. They were unable to contain it and it proceeded through inaccessible terrain to impact those communities.

The prescribed burn area included the southern slopes of a small hill about 200m in height. Modelling has shown that overnight, as the wind tended northerly, strong downslope winds developed on this slope, reinvigorating the fire and pushing it towards the containment line. In this particular case, and in contrast to the State Mine fire, strong near-surface atmospheric stability due to a nocturnal temperature inversion was important for the development of the mountain waves. In fact, the meteorology appears similar to Adelaide's gully winds,

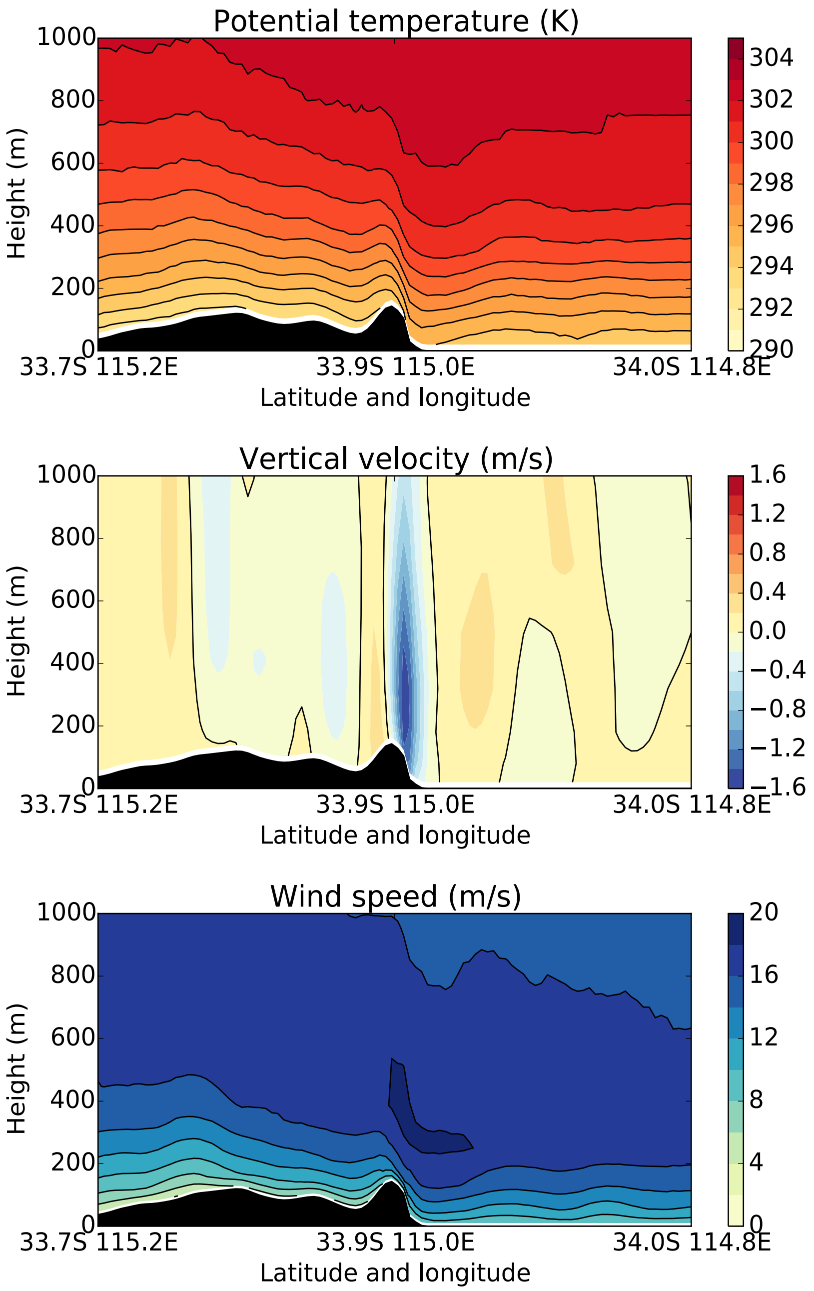
END USER STATEMENT

This research has drawn attention to an important but hitherto neglected weather phenomenon that can cause bushfires to behave with unexpected severity on downslope terrain in the lee of a mountain range. An interesting finding from the work is that, under some conditions, mountain wave phenomena may occur in areas where the local relief is as small as one or two hundred metres. High resolution numerical weather modelling has contributed to improved understanding of the factors associated with strong downslope winds. Having the ability to identify situations where strong downslope winds are likely to occur would allow better planning of fire suppression operations, reducing risks to firefighters and the community in affected areas. Further work is required to develop weather products that can convey information about the location of areas prone to downslope winds and the likelihood of wind speeds exceeding specified thresholds.

– Lachlan McCaw, Principal Research Scientist, Department of Parks and Wildlife Western Australia

or the similar scarp winds that occur off the Darling Escarpment east and south of Perth. Figure 2 (right) shows a cross-section through the fireground, aligned along the wind direction. The strong low-level inversion, marked descent and wind acceleration on the lee slope are all clearly visible.

A further meteorological contributor to the unexpected fire behaviour in this case was that dry continental air moved over the fire earlier in the night, making the fuels more flammable. For further details on this case study see Kepert and Fawcett, 2013.



Above: FIGURE 2: CROSS-SECTIONS OF POTENTIAL TEMPERATURE (TOP), VERTICAL VELOCITY (MIDDLE, BLUE IS DOWN) AND WIND SPEED (BOTTOM) THROUGH THE FIREGROUND OF THE MARGARET RIVER FIRE. THE OVERNIGHT INTENSIFICATION AND ESCAPE OF THE FIRE OCCURRED ON THE LEE OF THE SMALL HILL NEAR THE CENTRE OF THE DOMAIN. THE FLOW DIRECTION IS LEFT TO RIGHT.

Aberfeldy fire

In the Aberfeldy fire, the unexpected fire activity occurred on the night of 17 January 2013. Like the Margaret River fire, this was against the usual diurnal trend. The main difference with the Margaret River fire was that the fireground was much more elevated, being on the southern slopes of the Great Divide overlooking the Latrobe Valley. Modelling has shown clear evidence that mountain waves and strong downslope winds developed overnight. These winds would have directly increased the fire intensity and spread, as well as contributed to firebrand transport. However, it is likely that other factors also contributed. One influence was the steep and rugged topography, while another was that the fireground, being elevated, was in the warm dry air above the nocturnal inversion, which would have limited overnight recovery of the fuel moisture. More details on this analysis can be found in Wells *et al.* (2014).

HOW COULD THE RESEARCH BE USED?

This research has found strong evidence in three cases of mountain waves and downslope winds contributing to unexpectedly severe fire behaviour. So what does this mean for fire management?

Obviously, it would help to be able to forecast such activity. In cases such as the Margaret River fire, the ingredients that led to similar events such as the Adelaide gully winds and its Perth counterpart are well known (nocturnal cooling, reasonable strong synoptic flow, gentle upwind slope and steeper downwind). Other mountain wave forecasting cases are more difficult – forecasters could be reasonably confident of some activity, but is it strong enough to cause a serious problem?

Mountain wave activity is sensitive to the atmospheric wind and temperature structure, to the shape of the particular hill, and to all the hills upwind of that. Theory helps in some cases, but attempts to fit the Blue Mountains case study into one of the existing theoretical paradigms were not successful. On the other hand, sufficiently high resolution modelling is well established as being capable of capturing at least some of these events, and the Bureau of Meteorology's new 'city domain' versions of ACCESS have a grid spacing of 1.5 km, which should suffice in many circumstances. However, these are only available in those regions covered by those models (in most cases, a roughly 1,000 km square centred on the state capitals). They have been enabled by the new supercomputer, and will be operational in 2017.

A further problem is that the area affected by mountain waves is often comparatively small – only a few kilometres across in the case of the Margaret River fire. District-level forecasts may be too broad-scale to capture the effect, as will forecasts based on anything but the finest resolution numerical weather prediction.

Even if numerical weather prediction that reasonably correctly resolves the occurrence and amplitude of the mountain waves is available, it is still necessary to get the information to the fire manager. A request for a spot forecast from the fire manager, mentioning the precise location and perhaps the possible concern regarding mountain waves, might be necessary. But this approach could rapidly become impractical when there are many fires, and fire managers might be reluctant to request a spot forecast when they expect the fire behaviour to be benign. It may be necessary to train both meteorologists and fire managers in the potential impacts of mountain waves on fires.

These studies show the utility of high-resolution numerical weather prediction in diagnosing the cause of unexpectedly severe bushfires, and this utility should translate into skill in the forecast situation. But high-resolution numerical weather prediction contains a wealth of fine-scale three-dimensional detail, only a small part of which will be relevant to a particular situation. Teasing out the useful information, and avoiding swamping the user with unnecessary detail, are challenges that will become harder as forecast capabilities increase.

▲ **Above:** A MOUNTAIN WAVE CAUSED THE ESCAPE OF THE PRESCRIBED BURN NEAR MARGARET RIVER IN NOVEMBER 2011, EVEN THOUGH THE HILL THAT RESULTED IN THE DOWNSLOPE WINDS WAS ONLY AROUND 200M HIGH. 39 HOUSES WERE LOST. PHOTO: DEPARTMENT OF FIRE AND EMERGENCY SERVICES, WESTERN AUSTRALIA.

FUTURE DIRECTIONS

Mountain waves are also a hazard through wind damage and to aviation, and so a substantial body of research exists. Their formation and amplitude is sensitive to the topography, and to upwind conditions through the depth of the troposphere, and accurate forecasting of strong events is known to be a difficult problem. Where there is sufficient model resolution to resolve them, better means of detecting mountain wave occurrence in the model will help. But downscaling methods need to be improved for use with coarser resolution models.

The three events that have been identified to date are each quite different. It would be optimistic to assume that these cover the full range of the phenomenon. Further case studies will likely reveal other examples of mountain waves adversely affecting fires, perhaps in quite different situations to those discussed here.

FURTHER READING

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The Bushfire and Natural Hazards CRC is a national research centre funded by the Australian Government Cooperative Research Centre Program. It was formed in 2013 for an eight-year program to undertake end-user focused research for Australia and New Zealand.

Bushfire and Natural Hazards CRC
Level 1/340
Albert Street
East Melbourne
VIC 3002
www.bnhcrc.com.au