HIGHFIRE RISK PROJECT STAKEHOLDER'S RESEARCH REPORT

EVIDENCE-BASED POLICY FOR FIRE RISK MANAGEMENT IN AND AROUND AUSTRALIA'S HIGH COUNTRY.

BUSHFIRE COOPERATIVE RESEARCH CENTRE

HIGHFIRE RISK PROJECT

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This is a photograph from a line-scanning aircraft at 10,000ft. Major channeling events are drawing fire in from either side (McIntyres Hut Fire on the left, Bendora Fire on the right). Violent pyro-convection is the result. In the lead up to this situation mountain wind waves and nocturnal low-level jets played a role. The lightning ignitions were, as expected, at sites along the rugged spine, and the fires were, ultimately, largely constrained within rugged landforms. Photograph courtesy of Target Air Services Pty Ltd.

FRONT COVER: Downloading of data from a portable automatic weather station on top of the Tidbinbilla Range. The data indicate that winds on main ridges such as this are dominated by terrain-steered winds and lee-slope eddies.

This report contains the results of research into the key drivers of bushfire risk in the High country. It is intended to inform a wide range of stakeholders – fire managers, emergency managers, land managers and water catchment managers.

A key goal of the HighFire project is to support evidence-based policy development. It is recommended that fire management policies be reviewed in the light of the findings presented here.

Until any research findings have been assessed during actual fires there will always be a limit to the confidence that can be placed on them. However, the established knowledge base in the high country has been found seriously deficient during the very large fire events of recent years.

It is strongly recommended that IMTs establish a means of monitoring the situation they face with a view to early detection of any of the events that can seriously jeopardize crew safety, detailed within this report. Expert advice may be needed, and if so should be sought. Bureau of Meteorology fire weather forecasters may often be surprisingly familiar with the events described through other work, such as pollution dispersal or aviation forecasting.

ACKNOWLEDGEMENTS

The project team would like to thank:

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- ACT Territory and Municipal Services
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- Geoscience Australia

Unless otherwise credited, all photographs, figures and diagrams are by the HighFire Risk project.

The authors of this report have taken all practical steps to validate the research findings and other material presented in this report. Users of this material are cautioned to ensure both that they are competent in its correct use and that they have organizational approval to do so.

CONTENTS

INTRODUCTION

The alpine fires of January 2003 and December 2006 burnt vast tracts of forested country in Victoria, New South Wales and the ACT. Much of the prior basis for bushfire risk management was found insufficient for understanding these events (as seen in the lists of recommendations in Esplin *et al.* 2003 and House of Representatives Select Committee on the Recent Australian Bushfires 2003). Lessons must be learnt from these events to ensure future safety of threatened communities and assets.

Many inquiries were held, or indeed still are being held, into the 2003 event. The House of Representatives held one of these. Arising from it, the Federal Government gave the BushfireCRC funding for the *HighFire Project*. One of the research projects within HighFire is a bushfire risk study. Developed in co-operation with land- and fire-managers, its research outputs will provide a scientific evidence-base to support decisions made regarding policy and practical issues for land- and fire-management.

Bushfire risk studies began in earnest in Australia in the early ‘90s with projects in Western Australia, the Victorian Country Fire Authority and the ACT Bush Fire Council. Many elements of these were common, and were also taken up by later projects, such as that in New Zealand (NRFA 2002). All studies have recognised the complexity of the problems faced. The development of spatial tools has greatly facilitated the application of processes to risk modelling.

However, there were always “To Do” lists in these projects, aimed at filling-in gaps in knowledge of processes or in the fundamental datasets that drive such modelling. When the extreme events of January 2003 came along, many of the knowledge gaps were still real. The intense collection of real-time data during the fires has proven both how complex the processes can be and how real the knowledge gaps were.

One of the key goals of HighFire is that of evidence-based policy setting. Thus the only way that we can achieve validated policies for bushfire risk mitigation is to address the knowledge gaps. In many ways the restriction of HighFire to “the high country” has facilitated the goal, by allowing an intense focus on specific issues.

THE RESEARCH

A decision was made to use the bushfire risk framework used across the ACT. This is a foundation of the ACT Government's Strategic Bushfire Management Plan (ACT ESA 2005), and has been designed in a modular fashion to cover both scale-dependent issues and all aspects of the fire problem. Where it overlaps frameworks used in other jurisdictions it is equivalent in all respects.

The latest revisions of the model address the transitions between scales as fires escalate or decay. This gives valuable insights into setting operational strategies and to prior mitigation measures. It is a process model, and considers transition probabilities.

The project addressed all aspects of the process model and methodically analysed shortfalls in the understanding that should underpin it. Some of these are already evident from material collected during the recent alpine fires, while some had to be researched. A multi-disciplinary approach has been applied, spanning field data collection, modelling, analysis of fire data and risk methodologies. While much of the initial effort was of necessity meteorological, many aspects of fire management have been integrated.

A key innovation has been the use of transects of portable automatic weather stations across the terrain. This on-going research has revealed major gaps in our knowledge[1] and has also proved valuable for validating hypotheses.

Figure 1. Installation of a portable automatic weather station on a very steep, fire-affected slope of the Tidbinbilla Range. This is one of a dozen stations, that carry sensors for a wide range of weather parameters, and which require no site disturbance to install.

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[1] The reader is referred to Whiteman (2000) for a review of mountain meteorology.

RISK

Risk is the combination of likelihood and consequences, but must be expressed in terms of risk to what, from what and over what time frame.

The policies that drive the management of government lands and assets in the high country (if not those in private ownership) are, in part, in conflict. These conflicts arise most sharply in matters such as fire fuel management. We claim that, in many ways, these policies are driven by overly-simplistic assumptions about how fires behave. This claim is based what we now know about the existence of a set of different fire size classes, each reflecting different processes. Further, each size class produces a different risk exposure to threatened assets.

While small fires are common and rarely cause damage, large ones are less common but do cause damage. When applied to a risk matrix, such as defined in the Australian Standard for Risk Management (Standards Australia 2004), the resulting risks for each size class may differ, but are in general equivalent.

Most fire managers have very little experience with catastrophic fires, and are required to extrapolate upwards from their experiences with the smaller size classes. The result of this may be an erroneous perception of risk.

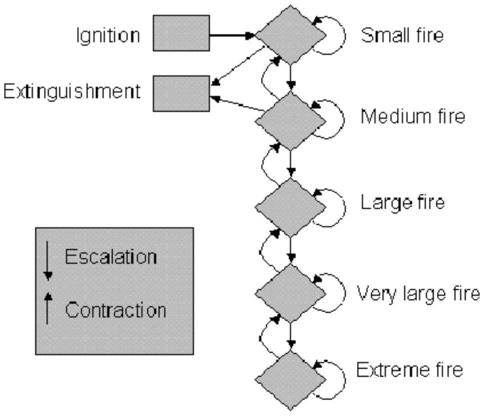

Figure 2. Simplified flow chart for the transition model.

By methodically studying the bushfire risk process in the high country (McRae *et al*, 2006), we have:

- Formalised the basis of risk assessment for the largest fires
- Allowed better understanding of the relative risks from each fire size class in the high country
- Identified options for risk mitigation and for incident management.
- Developed and provided material to pass these findings on across the industry (for example, this report).

KNOWLEDGE GAPS

We undertook analyses of large fire events, such as:

- the ACT fires of 2003
- the NSW alpine fire of 2003
- the Victorian alpine fire of 2006
- historical fires, such as the Tumut Valley Fire of 1965
- significant historical US fires, such as the 1949 Mann Gulch Fire (Rothermel 1993) and the 1994 Storm King Mountain Fire (Butler *et al* 1998, Butler *et al* 2006)

In many cases there was clear corroborated evidence for the processes described below. In other cases these were strong indications that these same processes occurred. From the perspective of the transition model it was possible to link all of these together and explain many salient features of these fires.

Field weather observations were taken at non-standard sites. For climatological reasons most AWS data are from ridgetops or plains. This pattern of placement has caused most of the key patterns for fire work to be overlooked. We were able to go to mid-slope sites because of a once-in-a-lifetime opportunity to do so after the 2003 fires removed the forest canopy from much of the landscape. Normally AWS placement guidelines force placement in non-forested areas. (We did of course assess the effects of the residual dead canopy on wind speed, but wind speed was not a key concern for us.)

Numerical modeling at BMRC (see Mills 2005 and Mills 2007 for examples) confirmed that these processes were present and were occurring often enough to be significant risk drivers. Armed with these insights, monitoring of real-time weather has seen these events occurring.

It is possible to take standard fire behaviour explanations and massage them sufficiently to replicate what was observed. However doing so usually requires setting artificial inputs and provides no insight or predictability.

What was lacking was a depth of technical literature to provide a basis for end-user education. Some overseas papers had indicated what might occur, but much of the literature was written for other purposes, such pollutant dispersal, civil aviation or agriculture.

We are in the process of writing a number of papers to fill-in the gaps – see the reference list at the end of this report. While what is in this report may preempt peer reviewed publication, it is all backed up by solid data or modeling.

Time is of the essence. Vast tracts of forest in the high country are basically of the same age. They will return to a “hazardous condition” as a single cohort – unless active management strategies are implemented. The effort to break up this cohort must be spread over a number of years, and must focus on those years suitable for safe burning. This is a clear imperative to make these findings known as early as possible to support this challenging goal.

REFERENCES

Butler, B.W., Bartlette, R.A., Bradshaw, L.S., Cohen, J.D., Andrews, P.L., Putnam, T., Mangan, R.J. (1998) Fire behaviour associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado. *Research Paper RMRS-RP-9*. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Butler, B.W., Bartlette, R.A., Bradshaw, L.S., Cohen, J.D., Andrews, P.L., Putnam, T., Mangan, R.J., Brown, H. (2003) The South Canyon fire revisited: lessons in fire behaviour. *Fire Management Today*, **61(1)**, 14-26.

McRae, RHD, Weber, RO & Sharples, JJ (2006). Lessons from the January 2003 fires – advancing bushfire risk management in the high country. *Proceedings, Bushfire Conference 2006*, Brisbane.

Rothermel, R.C. (1993) Mann Gulch Fire: A race that couldn't be won. United States Department of Agriculture. Forest Service. *General Technical Report* **INT-299**. Intermountain Research Station.

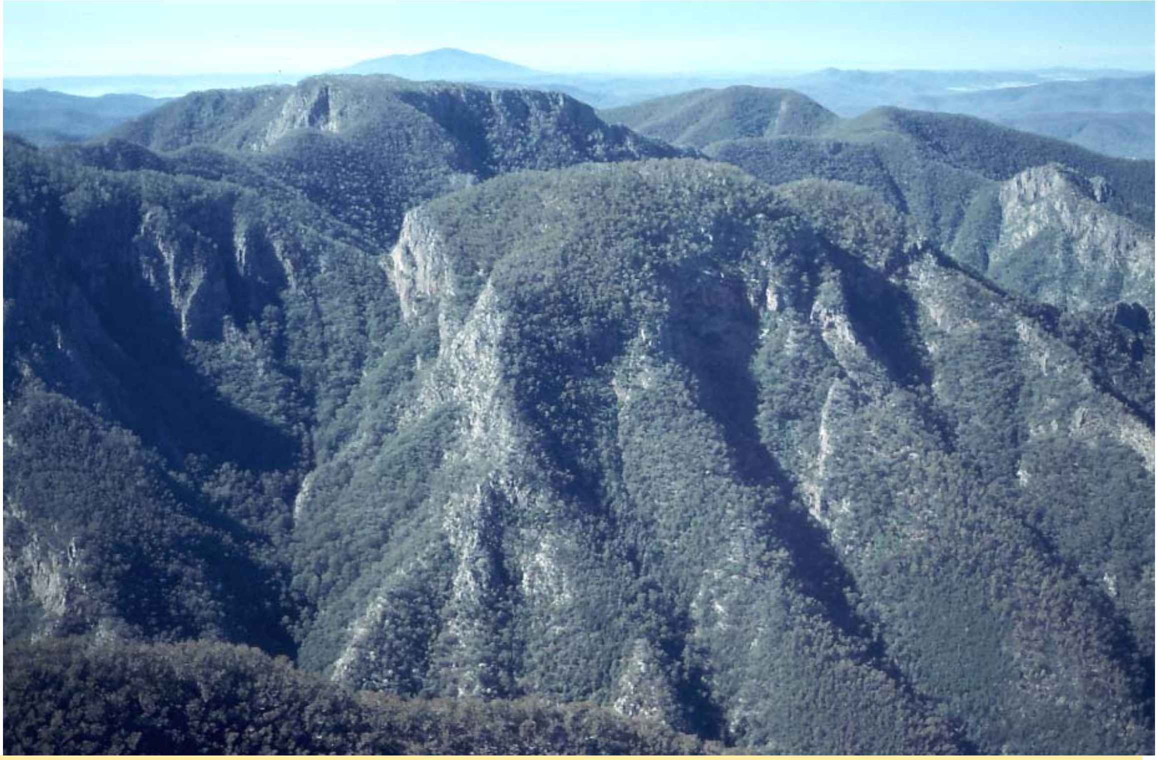

Figure 3. Rugged landforms on the coastal escarpment will experience some of the same processes as do alpine areas. [Mother Woila, Deua National Park]

FINDINGS

The study has produced a series of research papers, some published, some submitted for publication, and some under preparation for submission. In order the facilitate end-users accessing the findings, they are presented below in a thematic manner. The themes are:

1. Risk Transition Model
2. High Country Rugged landscapes
3. Thermal Belt
4. Lightning Ignition-Prone Lands
5. Nighttime Dew Point Depression Events
6. Daytime Dew Point Depression Events
7. Low Level Jets
8. Dynamic Channelling
9. Violent Pyro-convection
10. Foehn Winds
11. Mountain Wind Waves
12. Fire in Rugged Landscapes
13. Unusual combustion

For access to the detailed research, see the Bibliography at the end of this report. Additionally all material is available on the web at www.highfirerisk.com.au

Operational users are reminded that:

While this material is not yet part of national training competencies, much of it identifies gaps in the established knowledge set available to fire managers. If in doubt, or if this material is not clear to you, apply the fundamental principles of AIIMS ICS: request suitable skilled or expert personnel be assigned to work in the Planning Section during your shift.

Techniques must not be applied unless they are endorsed by the lead agency at an incident.

RISK TRANSITION MODEL

The transition model, introduced above, primarily looks at the source of risk. It starts with the assumption that all fires start small. Modelling of ignition densities from lightning and of anthropogenic fires is useful here, although in much of the high country lightning is the principle source.

If certain conditions occur, then the small fire is able to grow into a medium fire that spreads around the point-of-origin. If yet more conditions occur it can escalate into a large fire, which leaves the area of origin and moves around within a landform element.

For every size class the drivers differ. For small, medium and large fires the traditional fire triangle approach is valid, and models such as the McArthur model may be valid.

If yet another set of conditions occur, then an escalation into a very large fire may result. Such a fire responds to different environmental cues – for example, a small fire may respond to the micro-climate on a knoll, while a very large fire may respond to conditions arising from being on the windward face of a mountain range.

With the passage of time – or the changing of shifts for an IMT – there may be times when fires de-escalate and break down into a number of smaller components. There may, of course, be future opportunities for further escalation.

With a final set of conditions an ultimate escalation to a plume-driven or extreme fire may occur. These are discussed later, under violent pyro-convection.

The model is now supported by a formal technical framework, which will not be discussed in this report. However it is worth covering one element of it.

On an average day, as a default starting point, there may be a minimal likelihood of a large fire escalating to a very large fire in a given remote area. However, if there was already a large fire present in the landscape we can use that fact to estimate the likelihood of that same transition – and would expect a far high probability. Work is on-going on providing reliable estimates, but just stating the problem clearly gives useful insight. This is the guidance that Incident Controllers have long been seeking to allow better setting of incident objectives.

We can say for any size class of fire, different approaches to fire behaviour modeling are needed, and different drivers are important. This allows better tasking for field observers, especially for identifying watch-out situations.

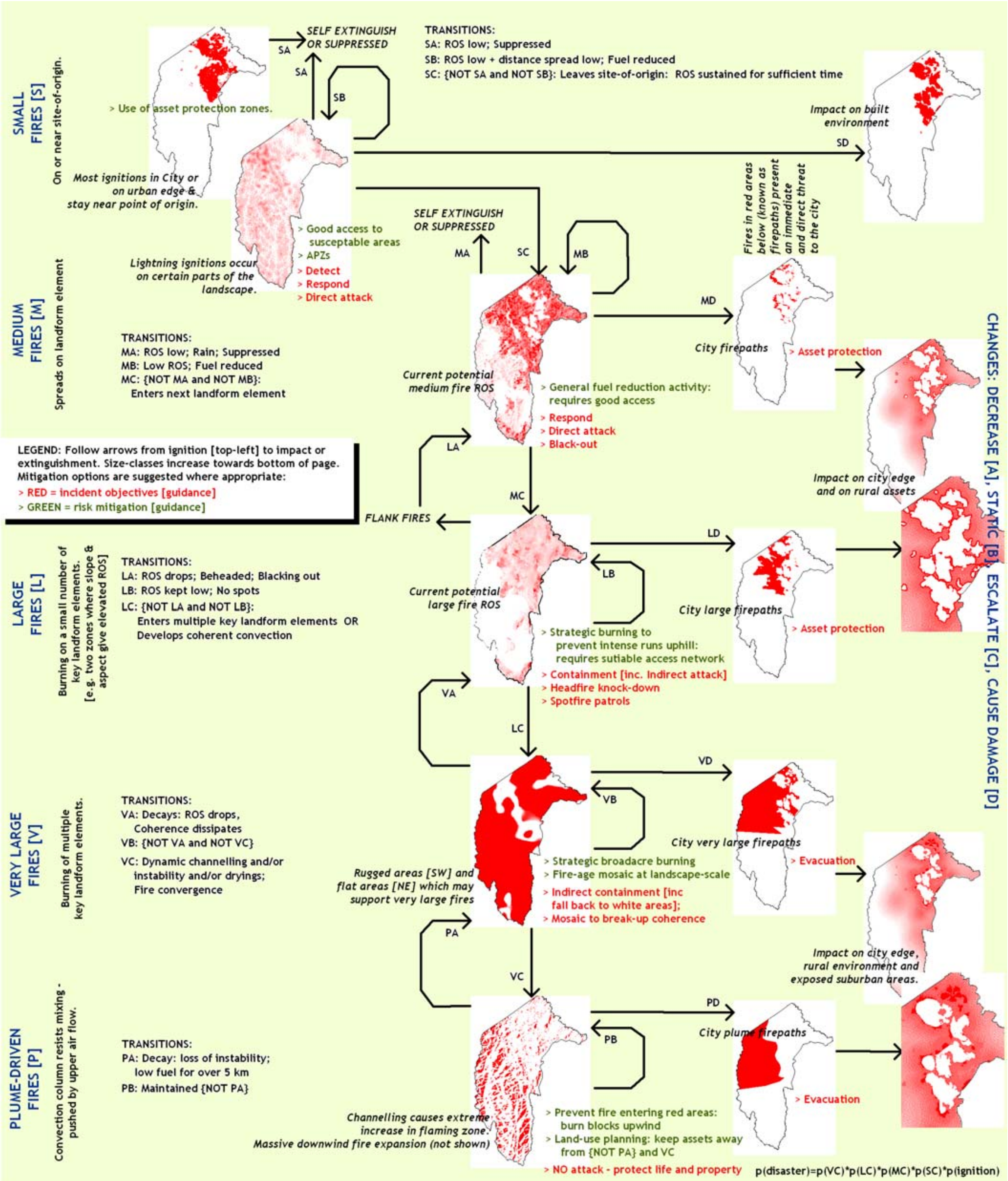

Figure 4. Detailed flow chart for the transition model.

RESEARCH SUMMARY

- The ACT bushfire risk model has been evolving since 1990 (McRae 1991, McRae *et al*, 2006).
- The project is investigating two key enhancements, through literature review and discussions with practitioners):
  - Use of Bayesian statistics or a Markov Chain to examine the temporal variations in transition probabilities with circumstances.
  - Implementation as a spatial model, where the transition probabilities vary spatially with the context.
- The work has been discussed at conferences (Bushfire Research Conference Brisbane 2006) and forums (GeoScience Australia Seminar, Bushfire CRC internal events & BushfireCRC public HighFire forums) to allow feedback.

REFERENCES

McRae, R. (1991). ACT Fire Hazard Assessment. Proceedings of Eighth AARFA National Conference. Australian Association of Rural fire Authorities, Victoria.

McRae, RHD, Weber, RO & Sharples, JJ (2006). Lessons from the January 2003 fires – advancing bushfire risk management in the high country. *Proceedings, Bushfire Conference 2006*, Brisbane.

HIGH COUNTRY – RUGGED LANDSCAPES

Fire managers in the high country must understand the landscape, as many key drivers of elevated fire danger occur only on some identifiable parts of the landscape.

There is no agreed definition of “the high country”. We can use elevation, ecosystem, landform or economic setting.

The HighFire research into bushfire risk in the high country has repeatedly identified the need to identify rugged landforms. This is an important distinction because, firstly, not all high country is rugged, and, secondly, there are rugged landscapes outside the high country that may benefit from the results of this research. Examples of the latter include the Blue Mountains, the coastal escarpment of NSW, the Grampians, much of Tasmania, the Adelaide Hills and the Darling Escarpment behind Perth. It will be noted that many of these areas feature prominently in the register of historically significant “bad fire seasons”.

RUGGED LANDFORMS

Ruggedness is a way of describing local relief. Local relief is the range of elevation in the local area. Thus a local relief of 400m could mean a range from 100m ASL to 500m ASL or a range of 1200m ASL to 1600m ASL.

To analyse ruggedness we first average the elevation in the local area. This average is then subtracted from the actual. The remainder is called the meso-scale elevation residual or MSER. We go down this path because MSER is critical for analyzing areas prone to lightning ignitions and for wind – terrain interactions. Here, the local area is defined as a circle around a point of radius 1500m.

For any point the local relief is the difference between the maximum and minimum MSER in the same local area.

The highest LR in the high country is about 600m.

For convenience we can categorise LR into three categories:

- Flat country has LR below 150m
- Undulating country has LR between 150 and 300m
- Rugged country has LR over 300m

This has been modeled for the entire HighFire research area, shown in Figure 5.

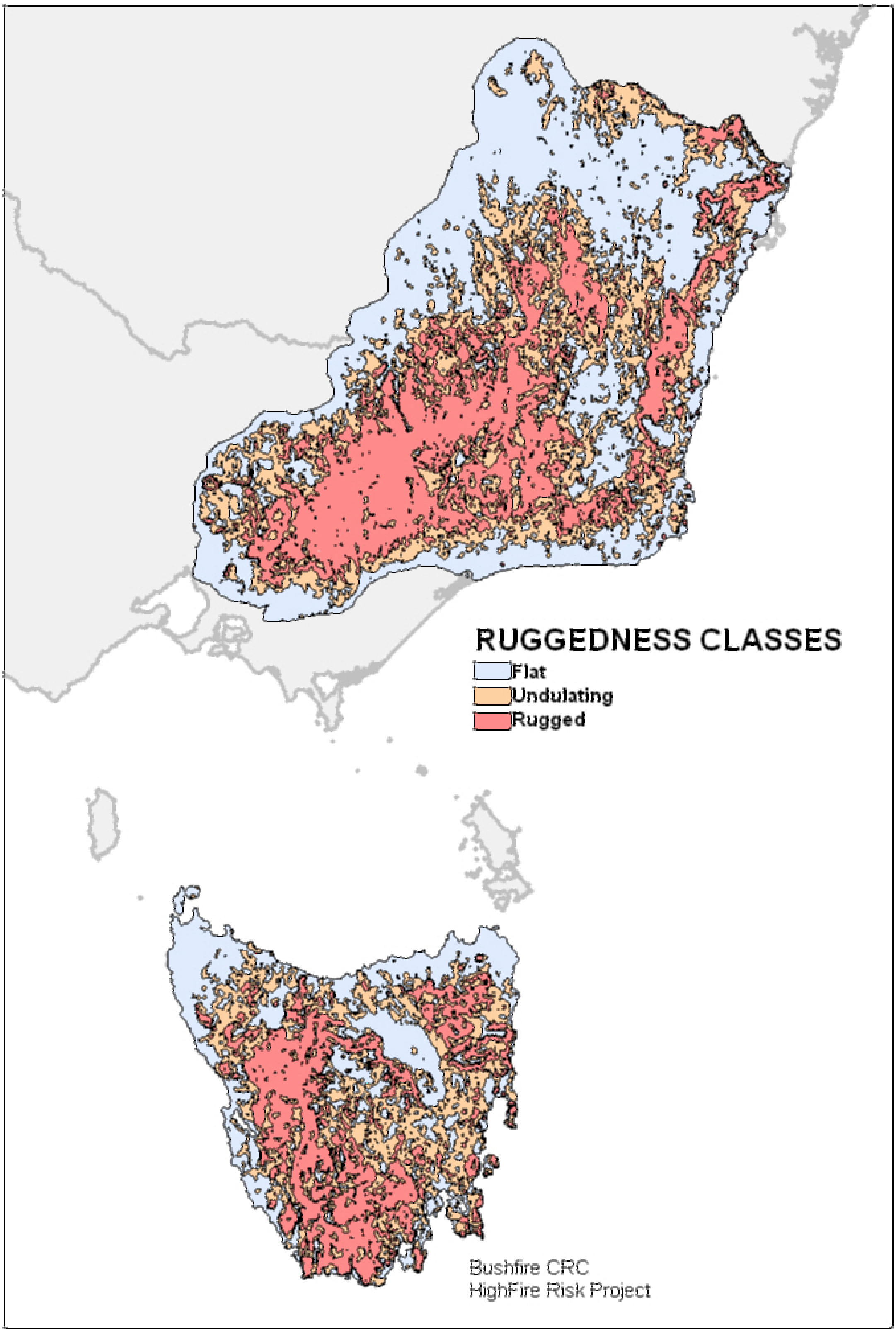

Figure 5. Map of ruggedness classes for the High Country.

RESEARCH SUMMARY

- We acquired a Digital Elevation Model (DEM) for the entire high country – the Shuttle Radar Terrain Mission product with 90m resolution.
- We modelled ruggedness for the whole domain, in MapInfo using Vertical Mapper for analyses.
- The work has been discussed at conferences (AFAC/Bushfire CRC conferences at Auckland 2007 and Bushfire Research Conference, Brisbane 2006) and forums (Bushfire CRC internal events & BushfireCRC public HighFire forums) to allow feedback.

REFERENCES

McRae, R. (1992). Prediction of areas prone to lightning ignition. *Int. J. Wildland Fire* **2(3)**: 123-130.

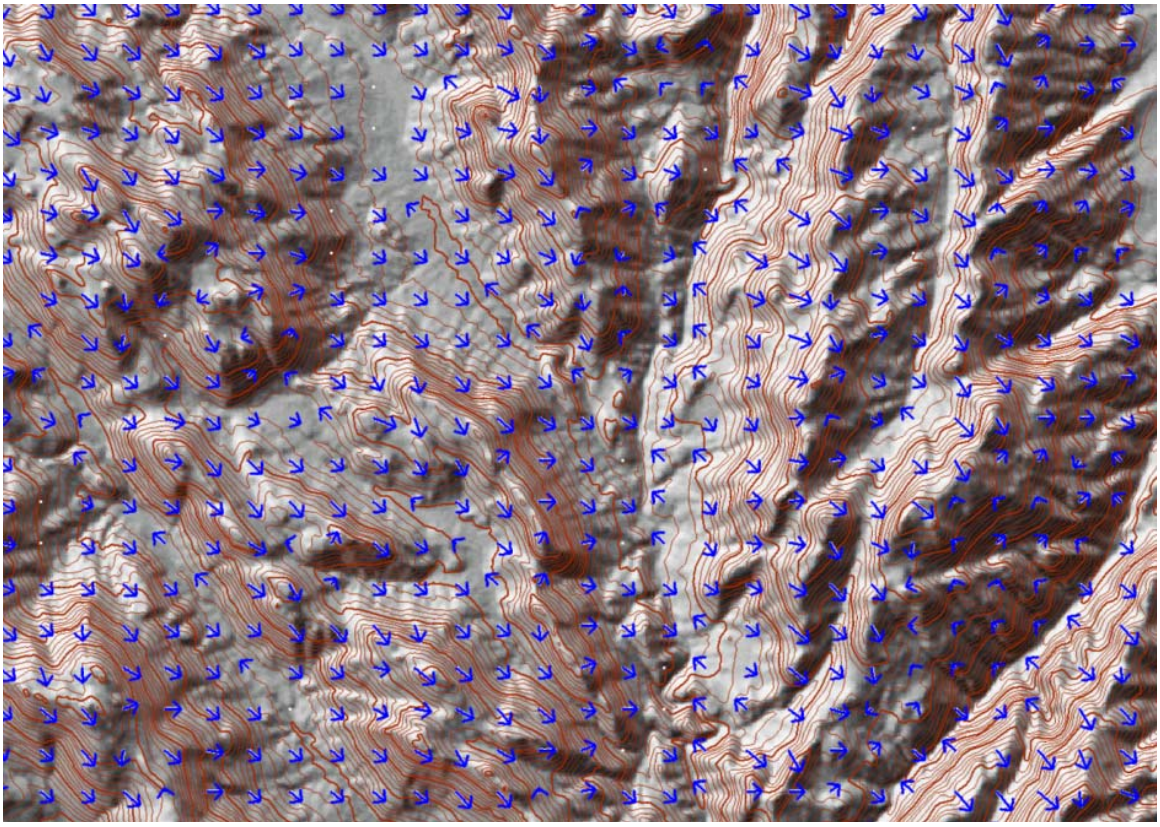

Figure 6. Wind – terrain interaction modelling output for the Gudgenby area, soutghern ACT.

THERMAL BELT

Linescan data has shown how the high country has a significant warm band some way up valley sides. These are predictable, and are significant for fire tactics.

Many have seen training material that refers to thermal belts or to nighttime inversions in mountain valleys. However, there has never been much detail on this. Old hands often have anecdotes about fires on valley sides being surprisingly intense overnight.

The use of thermal linescanning technology during major fires, such as the ACT fires, has given us much insight into processes such as this. Thermal linescans overnight give, in effect, a map of the temperature of the ground. Calibration of the data tells us what the patterns are.

Perhaps the strongest pattern reflects different vegetation types or landuses. Let us now focus solely on eucalypt forests and woodlands and see what the pattern is.

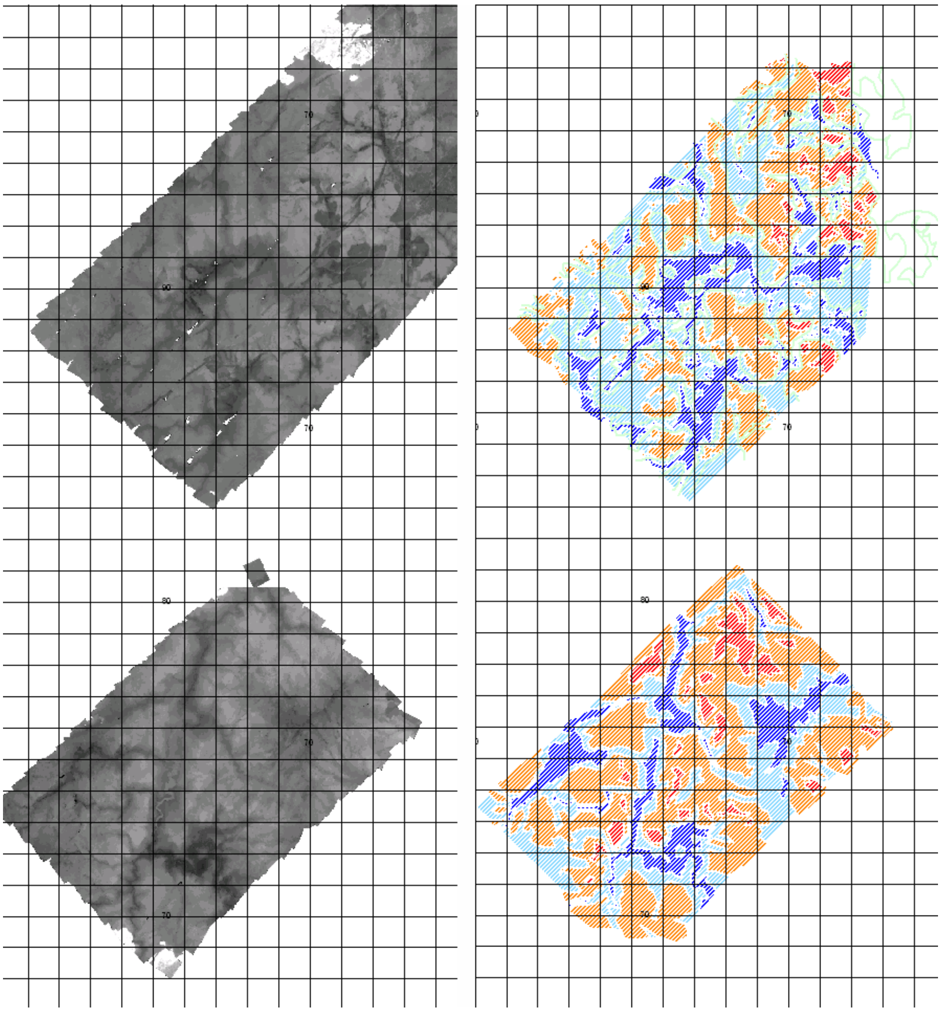

Figure 7. Thermal linescan images and their interpretation. Blue is coldest, red warmest and the gird are at 1 km spacing. Linescan data courtesy of Firesearch Pty Ltd.

There is a process to consider in order to understand the thermal belt. It starts on a clear night with the ground losing heat, as thermal infrared radiation, to space. Note that air is a poor absorber of the wavelengths involved, and is effectively transparent.

Radiative cooling appears to be about 1.5°C per hour given clear skies.

Air in contact with the ground will cool. Being cooler, it is denser and flows downslope under the influence of gravity. Even at 1 metre above ground the air temperature can be a number of degrees warmer.

At any point on the side of a mountain top, we can consider the geometry of the slopes. On a convex slope[2] such as a spur, the key influence is turbulent mixing with the surrounding air. This disperses the coolest air in contact with the ground, and prevents the formation of a density gradient.. On a concave slope such as a gully, there is protection from the turbulence, the density gradient develops and a localized inversion forms and further protects the flow.

Before continuing, let's revisit what an inversion is. Normally if you increase your height, the air pressure drops and as a direct result of that the temperature drops, all other things being equal[3]. This is rarely the case, as there are always converging or diverging air flows and air masses. These changes can, and often do, produce zones where the temperature increases with height[4]. When cold air flows into low points on the landscape, it is cooler than the air above it – thus we have a localized inversion, and this inversion is embedded within the landscape. The literature shows that while the subsiding air warms adiabatically, the gullies are also loosing heat radiatively, keeping the air cooler than expected. Overseas research indicates it can easily be up to 8°C cooler.

We need to think about the passage of time as air flows down a gully. it is losing heat radiatively, it is passing through an ever cooler landscape, and it is descending and warming adiabatically. It takes time for the concentration of the density flow into the gullies to arrive at any point down the gully, and the timing reflects the length and gradient of the streamline.

When the density flow reaches the lowest point of the local landscape it begins to pool. Valley floors and some major side valleys or gullies are where this normally happens. Here the inversion reaches its deepest extent. It is critical to realize here that these sites are where most roads are built and where the cleared areas suitable for locating Control Centres are found.

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[2] Consider four directions: upslope, downslope and two across slopes. If three of those are downhill we have a convex slope; if three are uphill we have a concave slope.

[3] This is called the adiabatic lapse rate. For dry air it is 1°C per 100m, for moist air it is roughly half that.

[4] The resulting complex profile is called the environmental lapse rate.

With time the cold air drainage pool will thicken, until after sunrise when the heat of the sun breaks down the inversion and this pattern is replaced by daytime patterns. Remember that many mountainous valleys do not see the sun until well after official sunrise times. Additionally light regional winds blowing towards the higher areas may act to force cool, moist air back into the valleys.

Until sunrise occurs there will be a continuing radiative heat loss and cooling through general mixing. The other limiter to this is the dew point temperature. If cooling reaches the dew point, dew, frost and fogs occur, with the latter especially putting a local brake on the cooling process.

Now let’s think about walking up a spurline from the valley to the top at midnight. We start in the cold air pool. Being significantly cooled, it may well be below the dew point temperature, producing a fog. As we walk uphill the temperature rises until we reach the inversion level, when we have the maximum slope temperature. From here the temperature drops with the lapse rate until we reach another minimum at the top. Assuming conditions suitable for a very large fire, we might find fuel moisture contents of 16% where the temperatures are minimal, but of 8% on the inversion level. A broad band of elevated temperatures and lower fuel moisture content on mid-slope is what we call the thermal zone.

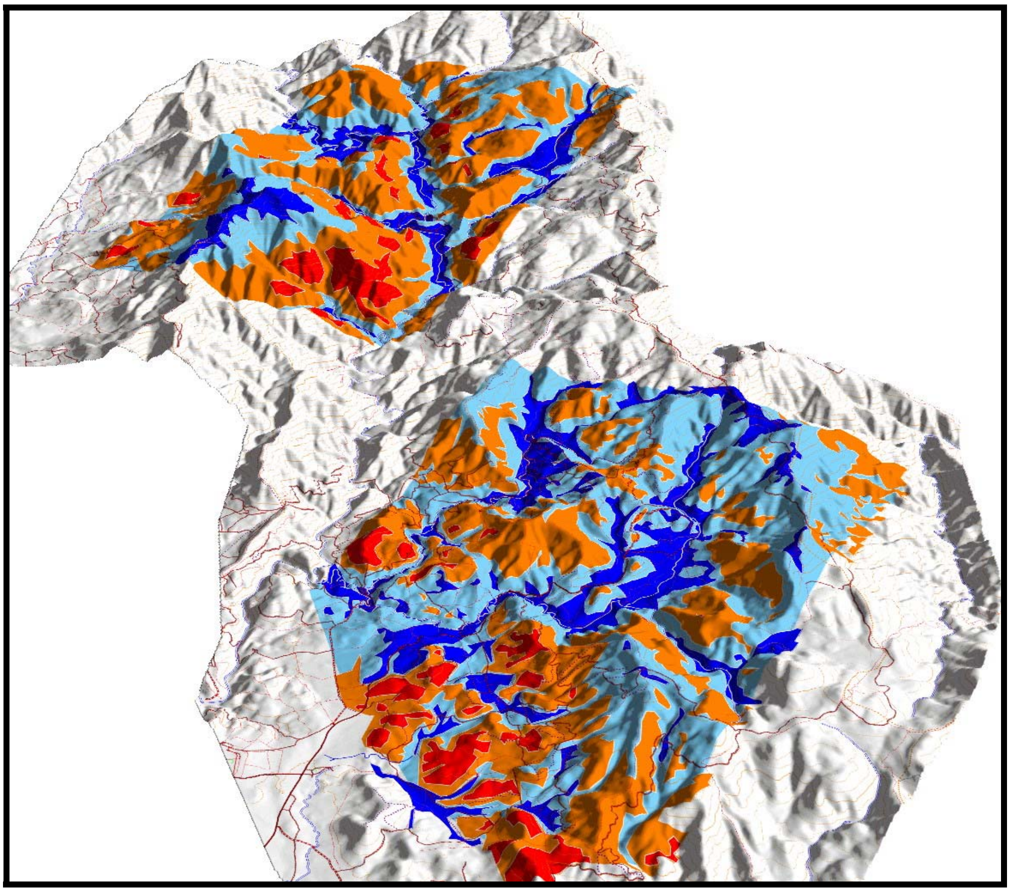


Figure 8. Visualisation of thermal data overlaid of terrain. This is the lower Cotter River valley, seen from the north.

The inversion height is often between 200 and 400m above the valley floor. It may be higher in winter than in summer. There may be some aspect differences. Note that around the ACT, for example, the main diurnal inversion is often around 1200m ASL, and this is broadly equivalent to these depths in valleys. This may produce a reinforcement effect. If the ridgetops are below the inversion level, a thermal zone will not occur.

Now let's walk uphill along a creek. Here we stay in concave slopes and thus stay under an inversion. The temperature stays roughly the same, and the fuel moisture contents stay elevated. The thermal zone is broken up by gully lines.

For the radiative heat loss to drive this process we need a clear sky overnight. Note that areas prone to sea breezes may start with clear skies, but eventually a stratocumulus overcast of 6 to 8 octas will settle in. We would expect the thermal zone to abate when the clouds settle in.

Also for the turbulence breakdown of the gradient flow on exposed slopes we need to have overall light winds. Strong winds will disperse the gradient flow even in gullies. Note that winds may be channeled into valleys producing stronger winds than might otherwise be expected – see the discussion on channeling elsewhere in this report.

OPERATIONAL WATCH-OUTS

When planning overnight operations in mountainous valleys always consider a thermal zone. When assessing the timing for implementing assigned tactics never rely solely on observations on ridgetops or in valleys. Observations from convex mid-slopes are essential. This may be difficult to achieve safely. Observers should always to able to leave safely and rapidly.

Always estimate fuel moisture content and fire behaviour at both extremes. Remember to assess **spotting potential**.

Remember also that if the cold air pool becomes saturated you may **lose air ops** (noting of course that this would be instrument rated aircraft only – linescanners, aeromedical helicopters and some observer machines).

PRESCRIPTION BURNING

The way that creeks break up the thermal belt may provide opportunities for burning remote areas without built containment lines. Good weather forecasting is vital. Note the potnetial time delays for asrrival of moist air in gully lines.

RISK MODELLING

Normal risk modeling will not pick up the effects of the thermal belt.

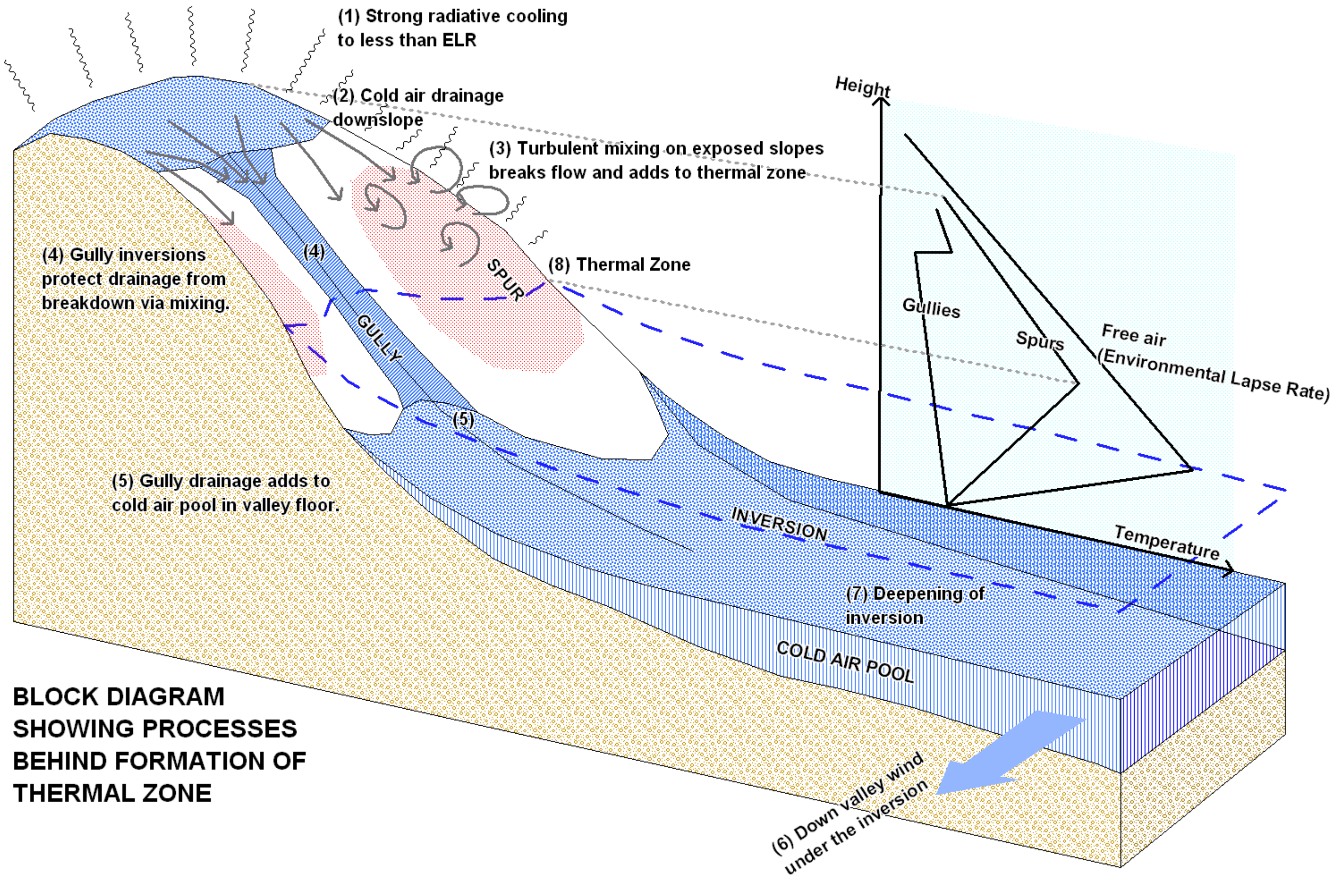


Figure 9. Diagram of thermal belt formation.

RESEARCH SUMMARY

- An initial detailed interpretation operational linescan data showed the process was imaged.
- This was them matched to the SRTM DEM.
- A literature review was undertaken, showing detialed knowledge of the process for agricultural and air pollution purposes.
- The linescan data were seen to be compatible with predictions from the literature.
- This allowed the process model to be developed.
- A paper is under consideration, pending field test of the model.

REFERENCES

Yeo and Bannister (unpublished). Fire weather notes. Fire Behaviour Analyst Training Material.

McRae, RHD, Sharples, JJ, ??Wilkes, SR & Weber, RO. (in prepn). The Thermal Belt in an Australian Bushfire Context.

LIGHTNING IGNITION-PRONE LANDS

Identifiable parts of the landscape are prone to lightning-ignitions. These are primarily the most rugged landforms, and are mapped. Certain types of fire behaviour arise from these locations.

There has long been confusion around the question of where on the landscape do lightning ignited fires tend to start. The sight of a smoke plume coming straight over the top of a ridge has caused the impression that ridgetops are where these fire start. Research in the ACT in 1992 showed that these fire actually tend to start off the side of the ridgetops.

Here's what you need to do to understand this. At any point, average the elevation within a 1500m radius. Subtract that average, the macro-scale elevation, from the actual elevation to give the meso-scale elevation residual (MSER). Lightning fires start where the MSER is zero. All lightning fires with a detailed point-of-origin on record in and around the ACT fit this model.

Additionally, the more rugged the landform, the more likely it is that lightning ignitions will occur. This is best addressed by the slope of the macro-scale elevation surface.

These can be combined into a single index, below.

MODEL = (([MSER] - 30)^2 + 1)^-0.5 * [Macro-scale Slope] / 22

This has been mapped for the entire HighFire study area.

The implications of this are significant.

In the absence of strong winds, a lightning ignition in rugged forested lands will make an initial rapid uphill run for about 300m to 500m, but sometimes up to 2km, depending on the landform. (You need to know the drainage network type and its orientation to the prevailing fire winds to get a deeper insight.) At that point the fire will generally slow to nearly stationary due to reversed slope and recurved winds. As these sites are primarily convex landforms, flanks will often also tend to be backing downslope, and may be less of a problem for containment that they would otherwise be. The major challenge for fire crews is if the uphill run causes spotfires past the adjacent downslope.

Strong winds may act to amplify or reduce the intensity of the uphill run, depending on their orientation relative to the aspect. Backing or veering of the winds may cause flanks to flare up occasionally, which also creates new spotting risks. Lee-slope channeling may cause the fire to turn when it crosses onto the lee-slope.

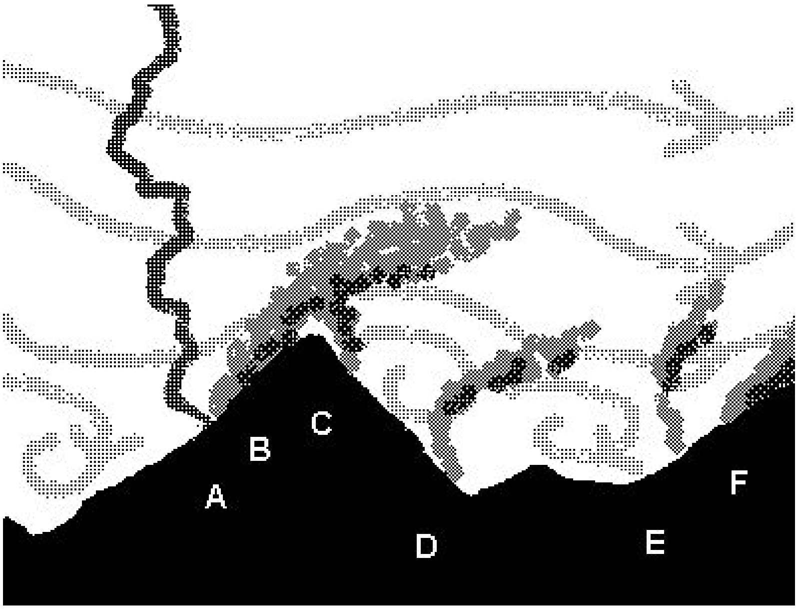


Figure 10. A = lightning ignition; B = Initial run up to hill top; C = Short distance spot onto lee slope burns back up hill, as does a longer range one at D; E = medium range spot still in irregular winds; and F = long-range spot gets uphill run with wind in support.

OPERATIONAL WATCH OUTS

Crew safety can be threatened if they are between a lightning ignition and the ridgetop, or if a spotfire occurs below them. Knowledge of the hazardous parts of the landscape helps to ensure safety during reconnaissance to locate lightning ignitions. Spotting risk eases once the headfire's uphill run ends. Knowledge of when fuel moisture contents fall below 5% is vital – this the key requirement for easy spotting to occur.

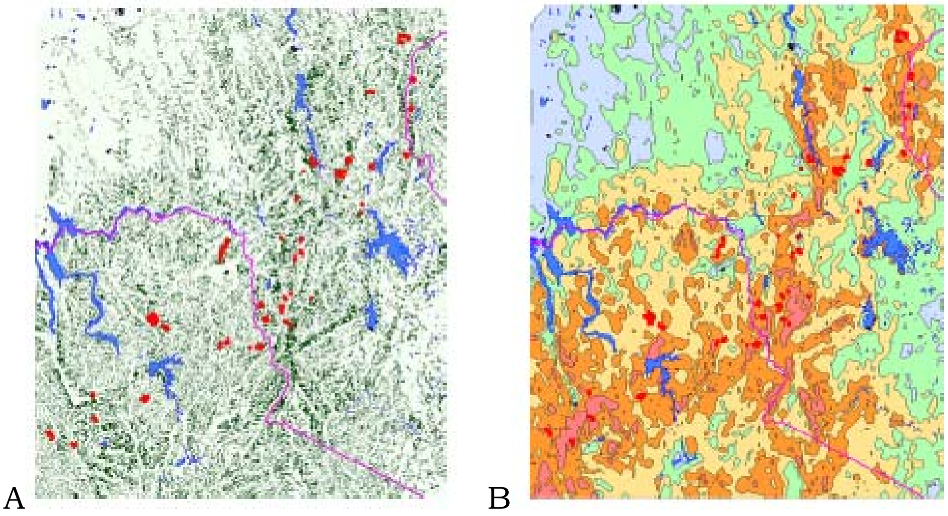


Figure 11. Comparison of lightning ignition data from 8 January 2003 with (A) lightning-prone landscape elements and (B) rugged lands (orange). Together these analyses explain a lot about this lightning ignition swarm.

Figure 12. A typical location for a lightning ignition – down off the main ridge, near a saddle on a spur line.

Figure 13. Care must be taken when backburning at night. Photograph courtesy of Dave Tunbridge, ACT RFS.

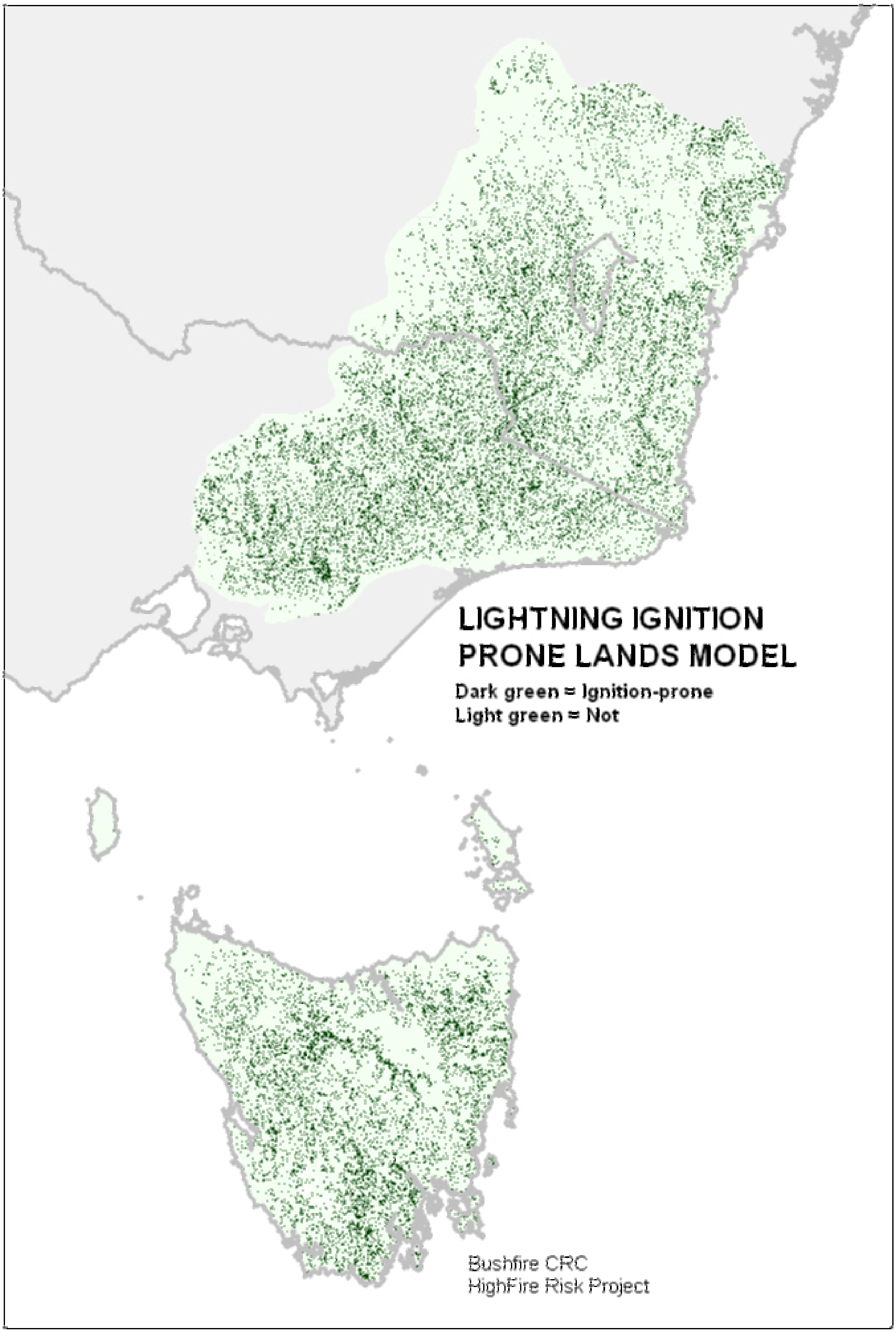


Figure 14. Regional mpa of lightning-ignition prone lands.

RESEARCH SUMMARY

- The work is based on McRae, 1992.
- That work was extended to the whole high country region using the SRTM DEM.
- For the more recent fires we tested the hypothesis that the ignitions was clustered around the most rugged elements of the landscape. Statistical results confirmed this.
- Thus a specific model variant was developed to include both locality information, the MSER, and the context (the macro-scale elevation part). This was implemented in MapInfo using Vertical Mapper for the analysis.
- Model validation now includes the original ACT (1990 to 2008) and collated MODIS hotspot data for the recent Alpine Fires (2003 and 2006).
- A paper is under preparation.

REFERENCES

McRae, R. (1992). Prediction of areas prone to lightning ignition. *Int. J. Wildland Fire* **2(3)**: 123-130.

NIGHTTIME DEW POINT DEPRESSION EVENTS

Alpine sites experience frequent nighttime events that lead to peaks of fire danger between midnight and sunrise. These events have serious effects on incident strategies.

Almost every fire behaviour model ever run in Australia has based weather on observations at a single point, usually a BoM AWS. Weather at each of the set of sites for which the model is implemented is extrapolated from those observations using the dry adiabatic lapse rate to adjust temperature and relative humidity. Wind has always been problematic, with models using rules-of-thumb, look-up tables or, recently, extremely simplified fluid models.

Temperature drops by 10°C for every kilometre of height gained, while RH doubles for every 1200m height gained (but not passing 100%).

Missing from this list is proper consideration of dew point, which is assumed constant.

Thus working from a site on a valley floor it is an inevitable conclusion that elevated sites are cooler and moister, and thus that fire behaviour will be considerably less severe, unless there is an expectation that those elevated sites have stronger winds. This then leads to adoption of strategies such as burning out a containment edge in the high country at 10pm.

However many crews given such tasking in recent years have seen their burns immediately crown and run away uphill. What is happening?

The clue has been there all along in the AWS data.

At alpine sites, on one night in seven, on average, the dew point will plummet between midnight and sunrise, giving a nocturnal peak in fire danger.

It must be noted that many of the more observant fire controllers have suspected just that.

In considering why, we have found a number of possible processes may occur:

- **Subsidence inversions**, formed as large high-pressure systems pass overhead.
- **Nocturnal low-level jets**, a complex process, discussed in detail later in this report.
- **Foehn winds**, especially of the blocking type, discussed elsewhere in this report.

OPERATIONAL WATCH-OUTS

Field observations are essential before lighting up backburns at night, to ensure that the dew point is as expected. Remember that most events do not intensify until after midnight. An early start to a burn that may take hours to complete must be carefully planned, and should be discussed with the weather forecasters.

In the longer term, if operations are being planned in the high country, a similar discussion with the local fire weather forecaster should address the likelihood of any of the events listed.

While it is recognized that many agencies use standardized protocols for requesting special fire weather forecasts for emergency or planned fire situations, these do not generally provide space for discussion of these events. The absence of mention of these processes should not be seen as a green light, especially if there is a large local relief. A proper dialog is required.

RISK MODELLING

Events such as these must force models to use multiple weather regimes: 1 day in 7 with an event and 6 days in 7 without. These events cannot be ignored – they offer an ability for a fire to escalate overnight, while the alternative suggests possibly reaching moisture of extinction levels.

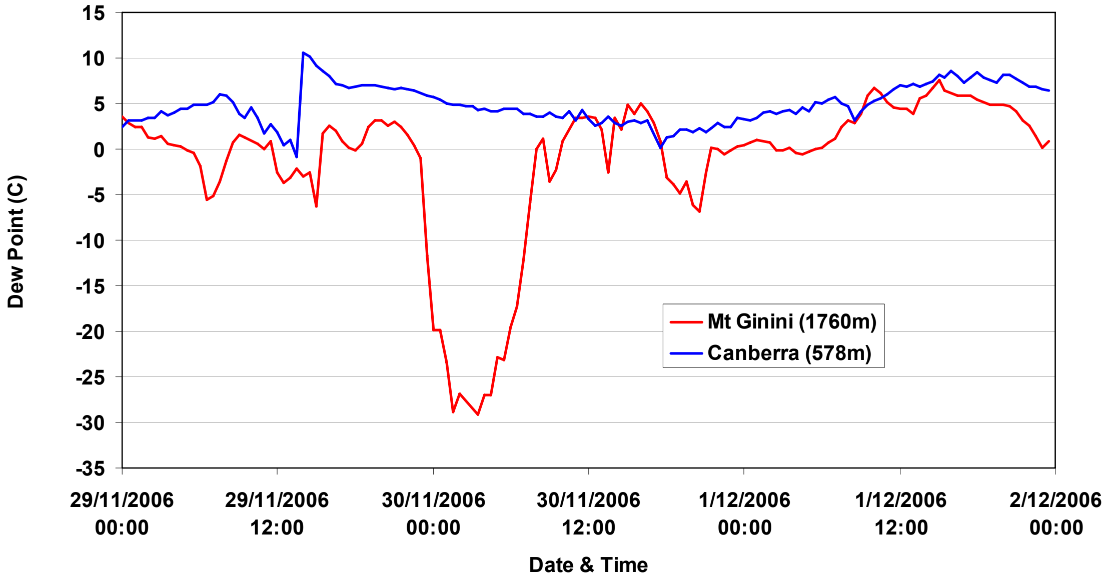


Figure 15. Dew Point traces from Curtin Automatic Weather Station (ACT ESA, at 580 m ASL), upper line, and Mt Ginini AWS (Bureau of Meteorology and ACT ESA, at 1760 m ASL), lower line.

RESEARCH SUMMARY

- The work resulted from operational experience with the problem and discussion with BoM forecasters and researchers.

- Conducted literature review and prepared review paper (Sharples, submitted).
- Portable Automatic Weather Station (PAWS) transect data were used to verify the events were occuring.
- MesoLAPS modfelling at BMRC was used to validate hypothesised causal processes for those events.
- Spoken and poster presentation have been made at conferences (Bushfire Research Conference, Brisbane 2006, AFAC/Bushfire CRC Conferences at Auckland 2006 and Hobart 2007) and forums (GeoScience Australia seminars and BushfireCRC HighFire community forums) to generate feedback.
- Two papers are being prepared.

REFERENCES

Sharples, JJ. (submitted). Review of mountain meteorological effects relevant to fire behaviour and bushfire risk.

DAYTIME DEW POINT DEPRESSION EVENTS

Key events have been identified that are associated with blow-up fire events. The passage of dry upper air over areas of enhanced thermal mixing is especially dangerous.

During daytime shifts fire fighters are experienced at monitoring the movement of hot dry continental air masses from the inland towards their region. This advection of dry air is not the only transport mechanism that can be important. Any enhanced vertical motion of air can brind down upper air that is dry.

Duringa forced descent such air would warm with the dry adiabatic lapse rate, but would retain its lowered dew point. Very low relative humidites can appear on the surface as a result.

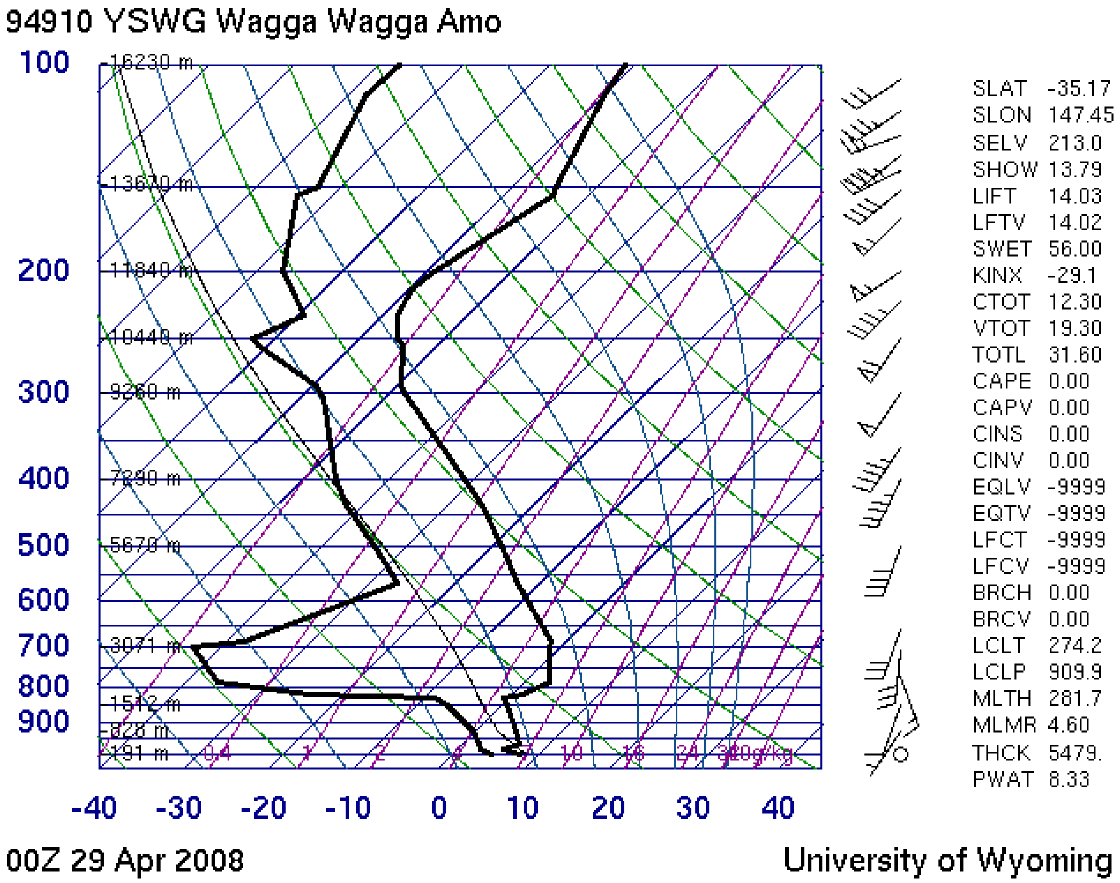


Figure 16. Skew-T Log-P Aerological Diagram for Wagga airport. This shows a drop-off in dew point temperature above c.1600m ASL or 830hPa. The DP falls from 4°C near sea level to –43°C

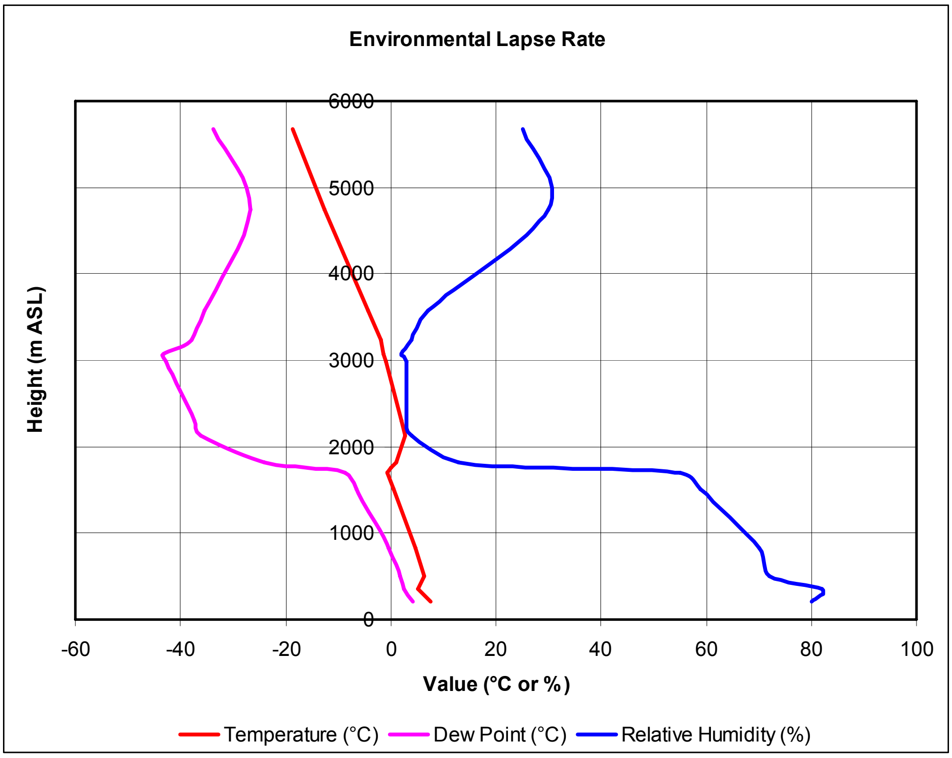


Figure 17. The same data plotted as a non-skewed graph with height. Note the major drop-off in humidity at about the level of the alpine peaks. Note also the height is based on a standard atmosphere.

A number of transport mechanisms are feasable:

- The passage of a slot of dry air into the zone of enhanced vertical mxing due to a fire.
- Vertical mixing ahead of a sea breeze front.
- Pre-frontal troughs.
- Subsidence inversions under a high pressure cell.
- Foehn winds
- Low level jets

Many of these are discussed elsewhere in this report. It is possible that mountain wind waves should also be on this list.

DRY SLOTS

Work by Mills at BMRC (2005) examine slots of dry upper air seen in water vapor imagery – see Figure 18 for an example. If one passes over an on-going very large fire, then the thermally enhanced mixing can bring down the dry upper air onto the fire.

SEA BREEZES

Further work by Mills (2007) has shown that dry slots can, under some conditions, be seen in water vapor imagery ahead of a sea breeze front. He has shown that the ACT Fires in 2003 were influenced by a combination of a dry upper air slot and a sea breeze front.

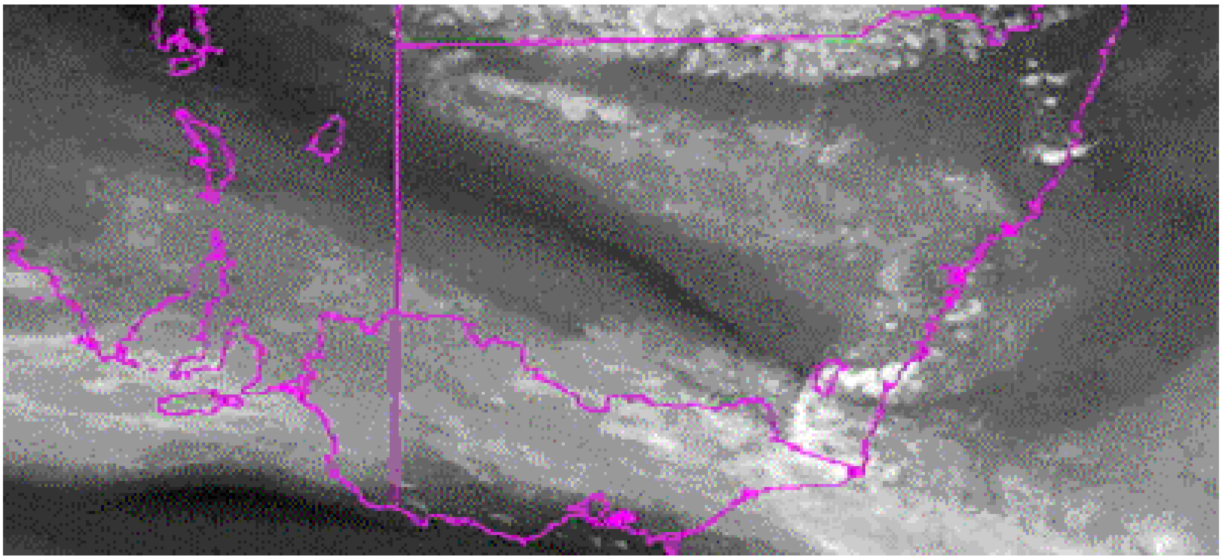


Figure 18. Water vapour imagery from the time of peak intensity of the ACT Fires. The dry upper air is seen in black. The intense convection, seen in white, matches the passage of the dry air over established fires.

OPERATIONAL WATCH-OUTS

There is an expectation that fire weather forecasters will be monitoring water vapour imagery for dry slots of various forms. There is, however, an obligation on Incident Controllers to seek such information, or at least notify BoM of on-going fire activity, even if they are not of sufficient intensity to require special fire weather forecasts.

The BoM web sites gives registered users access to hourly water vapor imagery, while other sites provide animations of recent images. The approach of a dry slot can be seen with perhaps a few hours notice, given time for incident strategies to be reviewed. Earlier images may show a slot, but that slot may evolve as it approaches and not pose a threat.

Skill and care are needed is interpreting water vapor images – only qualified staff should be using them.

In more general terms there should always be discussions with fire weather forecasters when a fire is in or adjacent to the alpine area. Special fire weather forms do not allow mention of the risk of daytime dew point presssion events in some parts of the fire ground.

RISK MODELLING

Currently there is insufficient climatology data to allow inclusion othese events in likelihood studies. We know that they dramaticall increase the probability of a fire escalating.

RESEARCH SUMMARY

- The work resulted from operational experience with the problem and discussion with BoM forecasters and researchers.
- Conducted literature review and prepared review paper (Sharples, submitted).
- Collaborated with Graham Mills, BMRS, on the key processes and accessing his findings on dry slots and sea breeze fronts, and on MesoLAPS modfelling at BMRC to validate hypothesised causal processes for these events and Foehn wind events.
- Spoken and poster presentation have been made at conferences (AFAC/Bushfire CRC Conferences at Auckland 2006 and Hobart 2007) and forums (GeoScience Australia seminars and BushfireCRC HighFire community forums) to generate feedback.
- Two papers are being prepared.

REFERENCES

Mills, GA. (2005). Lower atmospheric drying, stability, and increased wildfire activity. Proceedings, *Sixth Symposium of Fire and Forest Meteorology*, Canmore, Canada, American Meteorological Society.

Mills, GA (2007). On easterly changes over elevated terrain in Australia’s southeast. *Aust. Met. Mag.* **56**: 177-190.

Sharples, JJ. (submitted). Review of mountain meteorological effects relevant to fire behaviour and bushfire risk.

LOW LEVEL JETS

Some parts of the high country are prone to the development of nocturnal low-level jets. These result from bulk winds being isolated from the ground as an inversion develops, and gives wind elevated fire danger and dry air on higher ground.

Low-level jets are a poorly known feature of the interaction of mountains and wind.

As air flows over terrain, there is considerable interaction between the two, with the result of frictional slowing of the air close to the surface. If a low-level inversions forms, the denser air below the inversion can isolate higher-level air from the surface. Freed of friction the air above the inversion can increase its speed.

If we consider where inversions form in and around the high country, we will realise that valleys and other low parts of the landscape will tend to be below the inversion, while ridgetops and mountains will tend to be above it.

So under the right conditions the high ground can experience stronger winds than the rest of the landscape. This is true on both sides of the ranges – unlike some features that are limited to, say, the lee side.

Across the inversion we will have large changes in air speed and in other air properties, including RH. Whenever there are changes in ari speed across a boundary, turbulent mixing will occur. This process blurs the air speed gradient, but can also mix drier upper air down to the surface.

Detailed modelling indicates that low-level jets can be of quite limited extent, and may in fact fail to register of BoM observation sites.

They are most likley to form at night, as this is when the inversions cause the “decoupling” effect.

OPERATIONAL WATCH-OUTS

LLJs can be difficult to detect. As with so many other processes, good field observations are the best way to anticipate potential problems.

Always discuss the potential for LLJs with fire weather forecasters when planning the next shift at a campaign fire on high ground.

Apart from the direct effect of wind pseeds on FDIs, the effects of turbulence should be considered.

RISK MODELLING

As an initial rule, all areas on or adjacent to the high country should be considered prone to LLJs. Future work must take event reconstruction modelling and build a climatology.

RESEARCH SUMMARY

- BoM advised that a LLJ had impacted on the situation in the ACT on 18 January 2003.
- As a result of this LLJs were discussed with meoteorologists, who advised that LJS were a candidate for risk drivers and they were not well known in southeast Australia.
- They were covered in the literature review (Sharples, submitted).
- Some candidate events were detected in BoM data, on the basis of dew point depression with associated wind anomalies.
- Some events were reconstructed at BMRC in collaboration with Mills.
- As an example event, MesoLAPS modelling showed the event of 28 November 2006 (Figure 20) was a jet ahead of a subsidence inversion. The dewpoint depression was weaker than that from the latter event.
- Follow-up research is needed, especially with regard to the event climatology.

REFERENCES

Commonwealth Bureau of Meteorology (2003). Submission to the ACT Coroner’s Bushfire Inquiry.

Sharples, JJ. (submitted). Review of mountain meteorological effects relevant to fire behaviour and bushfire risk.

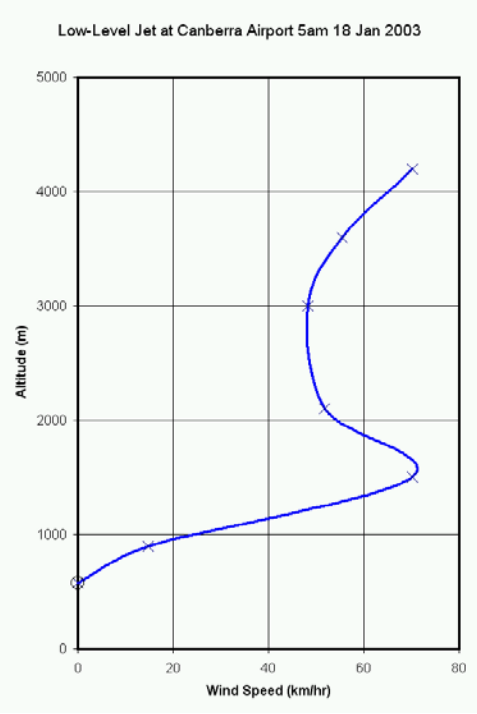


Figure 19. Observations of a critical event.

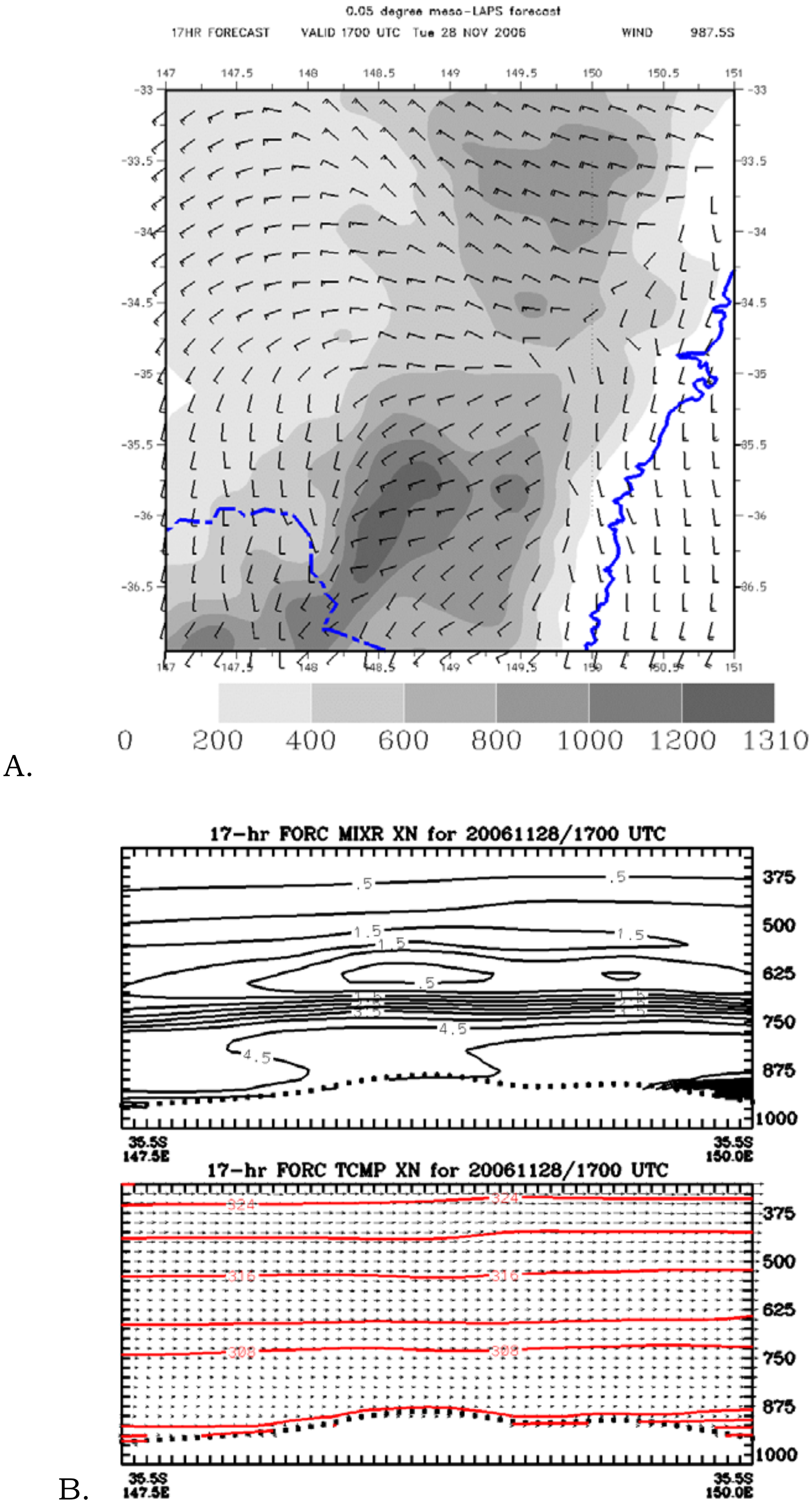


Figure 20. MesoLAPS model of a LLJ event. In (A) we can see a localised area of elevated wind speed over the high country. In the matching cross-section we can see in the upper panel the movement of a band of dry air (the zig-zigs in the mixing ratio contours) in from the west at low level. The lower panel shows the inversion (close-spaced potential temperature contours at low elevations) that may have produced the decoupling that allowed the enhanced wind speeds.

DYNAMIC CHANNELLING

Winds blowing over deep valleys may flow down into and along those valleys. Should fire enter a channeled flow a catastrophic escalation may quickly follow. Complete ignition of the landscape downwind for up to 6 km and a lateral spread along the valley of up to 5 km/hr are key features.

Many fire fighters in the high country have experienced "valley winds", however these had never been fully explored from a fire point-of-view. New Zealand research in 2002 suggested that they may influence fire behaviour (Kossmann *et al* 2002). Before this could be followed up the 2003 ACT fires and NSW alpine fires occurred. In both cases dynamic channeling was well recorded as playing the major role in fire escalation (McRae 2008). Detailed analysis of linescans, thermal imagery and photography has yielded stunning insight into this extremely dangerous fire driver (McRae 2004, Sharples *et al* 2007, Sharples *et al* in prepn).

Meteorologists knew that when winds blow over an incised valley, they may be diverted into the valley (Whiteman 2000, Sharples submitted). Pressure-driven channeling draws down into large valleys and in the direction of a pressure gradient. More significantly for fire managers is dynamic or forced channeling where air is drawn down into the valley in the direction of least resistance. This means that the wind chooses the valley direction closest to the wind direction, and the difference can be nearly 90°.

Fire officers must recognize that when winds are nearly perpendicular to the valley orientation, a slight change in wind direction aloft can mean a total reversal of winds in the valley. Studies at Albury - Wodonga (Moriarty @@@@) linked the likelihood of wind shifts to the Pasquil atmospheric stability index, a routine component of fire weather forecasts. This makes it feasible to assess the risk of catastrophic wind changes in valleys.

Our research has identified a previously unreported phenomenon – *lee-slope channeling*. Here the sudden drop of slope as the wind hits a steep lee-slope can influence air flow as though it was a valley.

In either valleys or lee-slopes the switch to a downslope often causes the air flow to separate from the ground, as it's upwards momentum from the windward ascent prevents it swinging downwards fast enough. The gap between the slope and the main airflow is filled by an eddy, or horizontal vortex.

Data from the 2003 ACT fires has shown us what happened when fire gets into such an eddy. It *may* be the most critical event that can happen on a fire ground, but it *is* certainly capable of the same severity as a cold front hitting the fireground, as happened in Ash Wednesday in 1983.

The eddy flow produces in various places upwards, downwards and sideways flows, as shown in the diagram below. If fire enters the flow, any embers produces are rapidly circulated within the eddy, and most importantly sideways within the eddy. The eddy “fills with fire”. This causes the air to expand, forcing ember-ladden air up into the overhead (non-eddy) flow. These embers then very efficiently ignite the landscape downwind. As the lateral flow within the eddy proceeds, this downwind component follows in lockstep. Linescans from 2003 show the downwind ignitions occurring for over 6km, and the lateral spread at just under 5km/hr. This resulted in a phenomenal, nearly square flaming zone of around 20 square kilometres. This has been shown to be the trigger for the violent pyro-convection that had global impacts on the atmosphere (discussed elsewhere in this report).

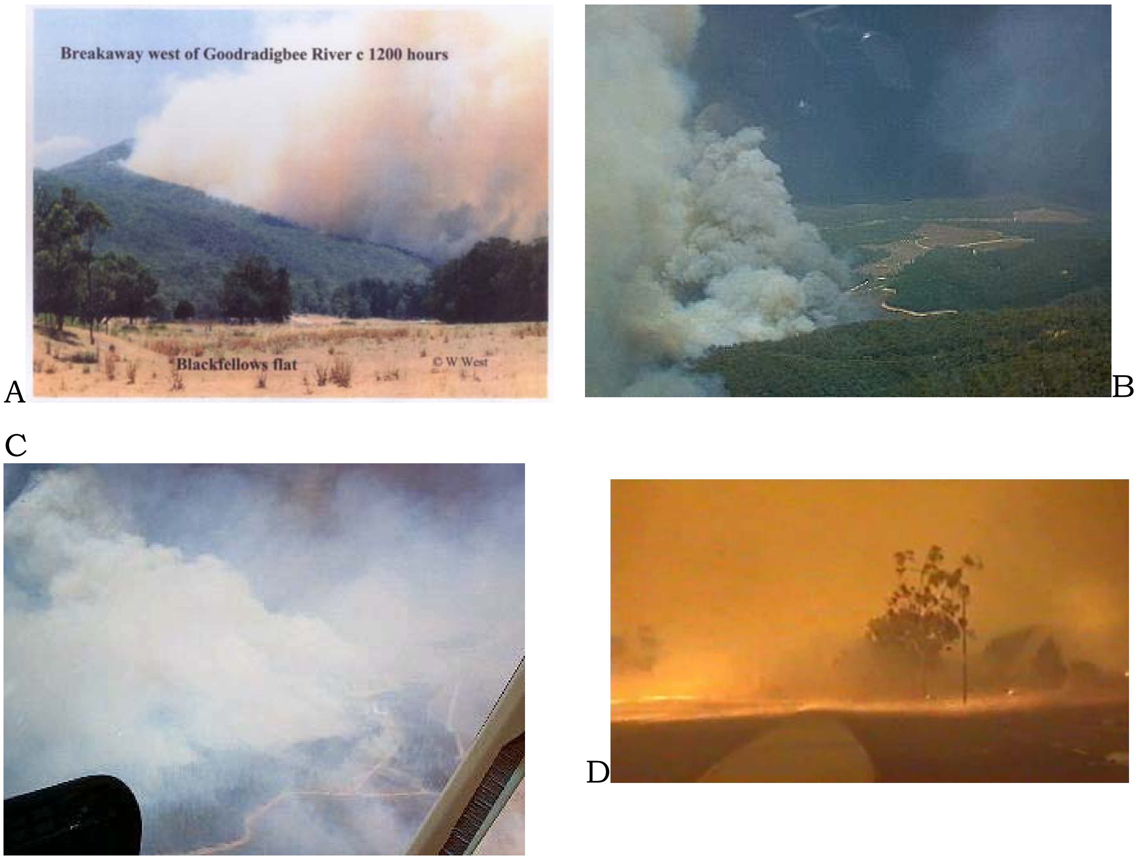


Figure 21. Photographs of intense fire channeling and its effects. A: Channeling near Limestone Creek on the very upwind edge of the McIntryes Hut Fire. Winds were from the left and the fire broke away on the right. B: Channeling upway in the lee of Blue Range, Uriarra area. The fire is moving to the right in the eddy. C: Channeling under way in the gorge of the Murrumbidgee River south of Uriarra Crossing. The fire is moving laterally to the right. D: An intense ember storm on the urban edge at Duffy in the outflow of the event in C. Photographs courtesy of (a) Wayne West, (B) & (C) Stephen Wilkes and (D) WIN TV News.

Aerial video footage of fires near Thredbo in late January 2003 shows fire crews operating adjacent to a major channeling event. A wind change to the north would have rapidly put them at risk. The smoke there was very thick, and the landscape downwind was fully involved in fire. The total engagement of the lee slope of the valley was the clue that we now know indicated what was happening.

Early in the afternoon of the 18 January 2003, a tree fell over the 3 day old containment line of the Bendora Fire, on Flat Rock Spur just above Bendora Dam. There was no active fire in that part of the Cotter Valley. Within an estimated 2 hours channeling had turned the resulting fire into one of the most intense ever recorded. Had fire crews been operating there, they would not have expected such severe escalation, nor would they have been able to seek refuge in time.

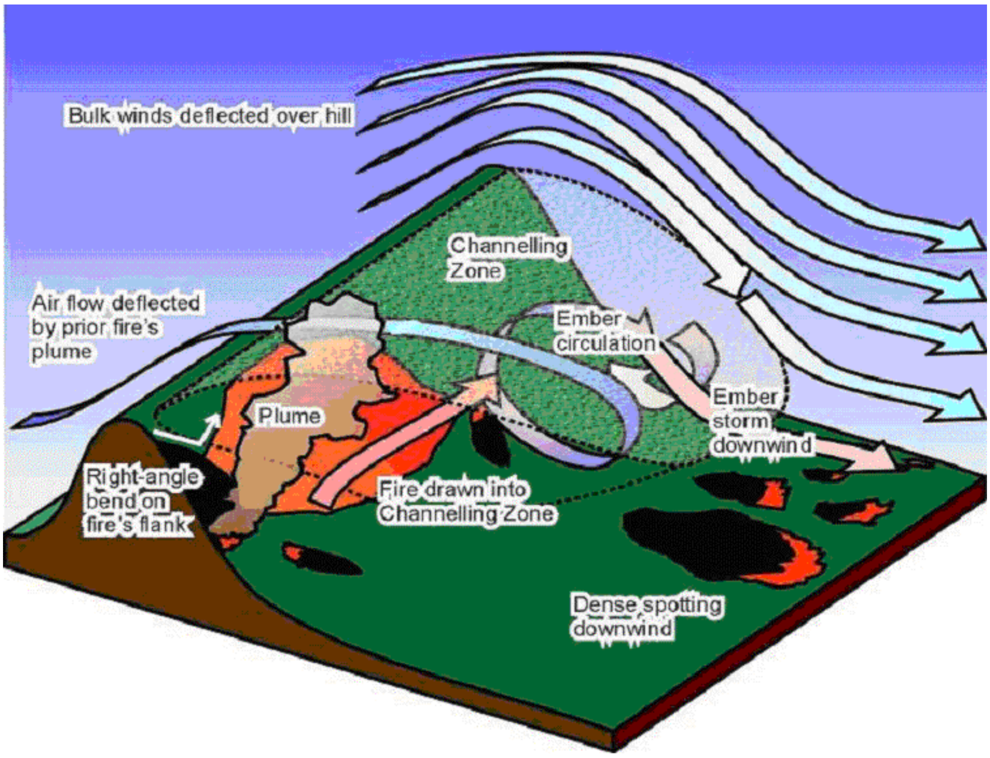


Figure 22. Schematic diagram of a channeling event.

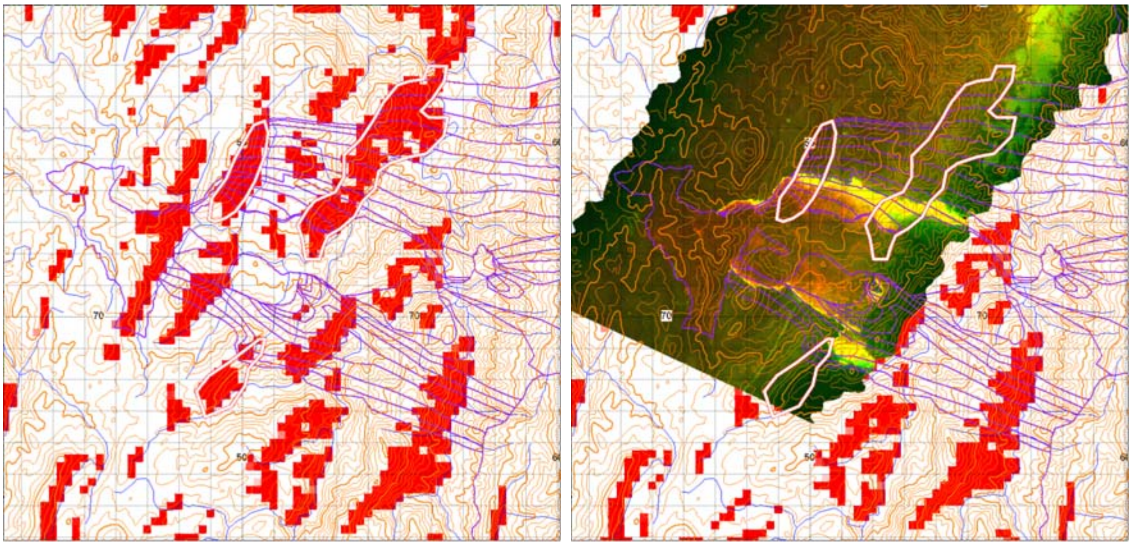


Figure 23. Example of output from a model of channeling prone parts of the landscape (red). Purple lines are 10-minute isochrones of the Broken Cart Fire, showing the influence of three events (outlined) on its lateral spread.

OPERATIONAL WATCH-OUTS

The speed and intensity of a channeling-driven fire event is such that it would be difficult to react in time to achieve crew safety or protect life and property. This requires (a) prior identification of channelling-prone landforms, and (b) clear instructions to crews operating in remote rugged areas on safety actions.

It is expected that precursor events may include low level jets, mountain wind waves and dry upper air slots. Occurrence or prediction of any of these should also be treated as a trigger for fire channelling.

Of greatest concern, the largest channelling-driven fire events have all arisen off contained if not cool fire edges.

RISK MODELLING

Currently no risk models are able to fully ultilise channelling. The ACT risk transition model includes consideration of channelling-prone lands (see Figure 4).

To model channelling prone lands, we are currently evaluating a model based on the SRTM DEM detuned to 1500m resolution, but still on a 90m grid, using steep slopes and aspects broadly normal to the regional wind. For the detuned DEM the slope cut-off was set to 4°, but is should be noted that this is an artefact for the DEM's sepcifications. The raw SRTM DEM could not be used, as, being basically a LIDAR product, it resolved features that are not part of the terrain (such as raodside trees), giving irrelvant values for slope and aspect.

This model output changes with wind direction. For the ACT most problems arise with W to NW winds, bust this needs to be reviewed across the high country.

RESEARCH SUMMARY

- The work started with detailed analyses of operational linescans, photographs and other material from the 2003 fires. This is ongoing.
- A literature review was conducted (Sharples, submitted). This included significant historical US fires, such as the 1949 Mann Gulch Fire (Rothermel 1993) and the 1994 Storm King Mountain Fire (Butler *et al* 1998, Butler *et al* 2006)
- Analysis of identified high country events was undertaken in MapInfo using the SRTM DEM. Key common features were identified.
- Presentations were made to conferences (Bushfire Research Conference Adelaide 2004, AFAC/BushfireCRC Conference Hobart 2007) and forums (BushfireCRC HighFire public fourms) to generate feedback.

REFERENCES

Butler, B.W., Bartlette, R.A., Bradshaw, L.S., Cohen, J.D., Andrews, P.L., Putnam, T., Mangan, R.J. (1998) Fire behaviour associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado. *Research Paper RMRS-RP-9*. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Butler, B.W., Bartlette, R.A., Bradshaw, L.S., Cohen, J.D., Andrews, P.L., Putnam, T., Mangan, R.J., Brown, H. (2003) The South Canyon fire revisited: lessons in fire behaviour. *Fire Management Today*, **61(1)**, 14-26.

Kossmann, R, Sturman, A & Zawar-Rezar, P (2001). Atmospheric Influences on bush fire propagation and smoke dispersion over complex terrain. *Proceedings, 2001 Australasian Bushfire Conference,* Christchurch, NZ.

McRae, RHD. (2004). The Breath of the Dragon – Observations of the January 2003 ACT Bushfires. *Proceedings, 2004 Australasian Bushfire Conference,* Adelaide.

McRae, RHD, Weber, RO & Sharples, JJ (2006). Lessons from the January 2003 fires – advancing bushfire risk management in the high country. *Proceedings, Bushfire Conference 2006*, Brisbane.

Moriarty ref @@@@@@

Rothermel, R.C. (1993) Mann Gulch Fire: A race that couldn't be won. United States Department of Agriculture. Forest Service. *General Technical Report* **INT-299**. Intermountain Research Station.

Sharples, JJ. (submitted). Review of mountain meteorological effects relevant to fire behaviour and bushfire risk.

Whiteman, CD. (2000). *Mountain Meteorology: Fundamentals and Applications*. Oxford University Press, New York.

Figure 24. Fire, driven by dynamic channelling, crossing the Alpine Way near Thredbo, January 26 2003. Image: Australian Government.

Figure 25. Overhead visual image from linescan aircraft of intense channelling event, Bendora Dam, 18th January 2003.

VIOLENT PYRO-CONVECTION

Rugged landforms are able to cause deep flaming zones to occur. The convection column then may generate a pyro-cumulonimbus. The resulting plume-driven fire reacts to completely different drivers and is extremely dangerous.

Under normal conditions there is a balance between the rate of spread of a fire and its vertical motion – its convection. In other words the faster a fire moves, the faster it consumes fuel and generates heat, and thus the faster its plume rises keeping the two forces in balance.

Experienced fire controllers know that short-term events like wind gusts can make flames lean over unburnt fuel, causing a dangerous intensification - but for only a short while. Things then return to normal, and assigned suppression tactics are safely resumed.

In violent pyro-convection there is no balance, and things are very different.


18 Jan 2003 15:46

Figure 26. Photograph of intense pyro cumulonimbus development over the Uriarra forest area. The cloud top has passed the tropopause into the upper atmosphere. Photograph courtesy of Stephen Wilkes.

Before discussing these events, we need to explore the relationship between a fire and its convection.

In mild fires or on flanking fires, the smoke almost immediately mixes with surrounding air. The differences in heat and buoyancy are quickly removed, and the plume plays a minor role in events. At a headfire we can consider – as a rule-of-thumb – that the plume resists mixing to a height that is based on the width of the flaming zone. The unmixed zone can influence the behaviour of the fire that generates it, through a number of processes. These include ember movement, alteration of wind flow and heat transfer.

We discuss elsewhere in this series the way that dynamic channelling can cause vast areas of terrain to ignite at once. Thermal linescans of the ACT fires showed flaming zones of over 6 km depth. This implies that the plume can easily resist mixing for a number of kilometres of height – shown in numerous photos taken of the event. Some recent fires such as the Pilliga Fire and the Billo Road fire near Tumut have achieved deep flaming with a wind change.

Now, [based on the ACT fires] if the temperature at the surface is 38°C, and the dew point temperature is -15°C, and we apply a dry adiabatic lapse rate to the atmospheric profile, we can expect air to reach saturation at a height of about 4.5 km – still before effective mixing kicks in. At this point water vapour is converted to liquid water, releasing the latent heat of condensation. Research into the Chisholm Fire in Canada has shown that this can add to the plume triple the heat that the fire did (Trentmann *et al* 2006).

When this occurs two main consequences follow: firstly, a cloud forms; and secondly, the drivers of the fire change.

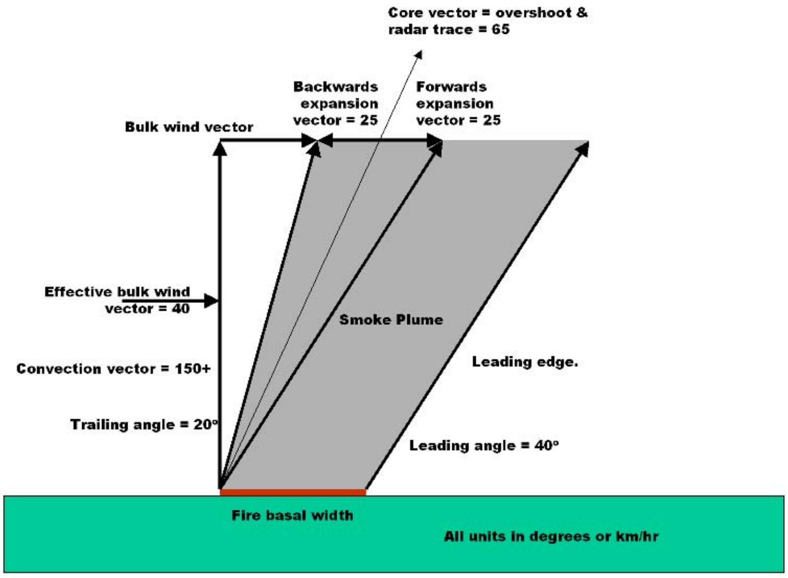


Figure 27. Interpretation of limited observations of convective flow seen in Figure 26.

It has been known for some years now that fire officers should be careful when clouds form in the convection column. The work of John Bally and the post-fire studies of the Berringa fire in Victoria (Chatto 1999, Leggett 1999 & Treloar 1999) have shown how big an impact this can be – the collapse of a pyro-cumulus (or pyro-cu) can create a downburst which fans the fire below in unexpected directions.

Bally's work on the Haines Index (Bally 1995) showed how atmospheric stability can be as good a predictor of intense fire activity as an extreme fire danger rating. Intense convection does depend on an unstable atmosphere – a Haines Index of 5 or 6 is one measure of this.

International researchers studying the upper atmosphere and processes that can affect it from below (volcanoes and nuclear detonations in particular) suspected that fires may have an impact. The Chisholm fire showed that this could happen (Trentmann *et al*, 2006) and the ACT fires proved it – they were in fact proof of the nuclear winter hypothesis (Fromm *et al*, 2006). The ACT fires formed what is variously called a fire thunderstorm, a pyro-cumulonimbus or a pyro-cb. This is violent pyro-convection and is able to take smoke into the upper atmosphere.

Such thunderstorms can produce lightning which can start new fires. Rain is unlikely as the droplets sizes are abnormally small. The ACT fires produced a major tornado, which was nearly a natural disaster in its own right.

Figure 28. Photograph from linescanning aircraft of convection resisting mixing with surrounding air up to around 7000m height. Photograph courtesy Target Air Service Pty Ltd.

With an intense surface fire, and a convection column that is resisting mixing and being drawn upwards from above (due to the latent heat release) the drivers of the fire change. The fire undergoes a phase change to become a plume-driven fire. Here the convection column is pushed along by middle and upper winds, and is not influenced by fuel or terrain. Plume-driven fire runs have been recorded as traveling for over 20km. The plume of those in the ACT fires moved at 65 km/hr, but no observations were made of conditions within the runs for safety reasons, although John Dold and others (Dold *et al*, 2005) have examined what might have happened. It is likely that fire spread within the system is primarily by means of spotting, and that spotting becomes a very efficient process.

Not all violent pyro-convection occurs over the fire – in Victoria it has occurred when the plume hits a sea-breeze front some way from the fire. International research is underway into the range of violent pyro-convection types.

OPERATIONAL WATCH-OUTS

IMTs need to arrange monitoring of fire behaviour either in terrain conducive to channeling or when wind changes are forecast. The formation of deep flaming must be treated as a dangerous event that may be the harbinger of the transition to a plume-driven fire. Monitoring a fuel moisture content is also needed

Figure 29. Photograph from Wanniassa of large tornado approaching Chapman. Its basal diameter was 450m. Photograph courtesy Jim Venn.

Additonally observers placed some kilometers away from the fire at right angles to the wind direction should watch for pyro-cu or pyro-cb formation. These need to be reported in as soon as possible, in the same way that approaching thunderstorms are reported on.

RISK MODELLING

It is difficult to include all of the possible triggers for deep flaming into a risk model. Inclusion of this must wait for future research results.

It is perhaps useful to estimates that rugged terrain and up to 5km adjacent and “downwind” be assessed as at risk from a violent pyroconvection event.

The probabilities of such an event is also difficult to estimate. In risk modelling, use the starting point of a very-lrage fire on the landscape. Some subset of these will experience violent pyro-convection, but it is a small unknown fraction.

Given the consequences, the resultant risk is definitely elevated.

RESEARCH SUMMARY

- The Fromm *et al* (2006) paper was the first link for Australian fire events into an international research effort. This is continuing and expanding, and strongly overlaps this the HighFire Risk project.

- Climatology studies are underway in a number of countries, including Australia. These use satellite data streams and field observation reports.
- The significance of the events in the ACT in Janaury 2003 indicated that they added a significant component to the bushfire risk spectrum. This was incorporated into the HighFire Risk project's risk model.

REFERENCES

Bally, J. 1995. The Haines Index as a predictor of fire activity in Tasmania. *Proceedings of Bushfire '95, Australian Bushfire Conference, 1995*, Hobart, Tasmania.

Chatto, K. (ed) (1999). *Development, Behaviour, Threat and Meteorological Aspects of a Plume-Driven Bushfire in West Central Victoria: Berringa Fire February 25-26 1995.* Victorian Department of Natural Resources and Environment Fire Management Branch Research Report No. **48**.

Dold, J, Weber, R, Gill, M, Ellis, P, McRae, R & Cooper, N. (2005). Unusual Phenomena in an Extreme Bushfire. *5th Asia-Pacific Conference on Combustion*, The University of Adelaide.

Fromm. M, Tupper, A, Rosenfeld, D, Servrancx, R & McRae, R, (2006). Voilent pyro-convective storm devastates Australia's capital and pollutes the stratosphere. *Geophys. Res. Lett.* 33, **L05815**.

Leggett, T. (1999). *Meteorological Aspects of the Berringa Fire of 25-26 February 1995.* Bureau of Meteorology special report.

Treloar, A. (1999). *Meteorology of the Berringa Bushfire Smoke Plume.* Bureau of Meteorology special report;

Trentmann, J., Luderer, G., Winterrath, T., Fromm, M.D., Servranckx, R., Textor. C., Herzog, M., Graf, H.-F., and Andreae, M.O. (2006). Modelling of biomass smoke injection into the lower stratosphere by a large forest fire (Part I): reference simulation. Atmos. Chem. Phys. Discuss., 6, 6041-6080

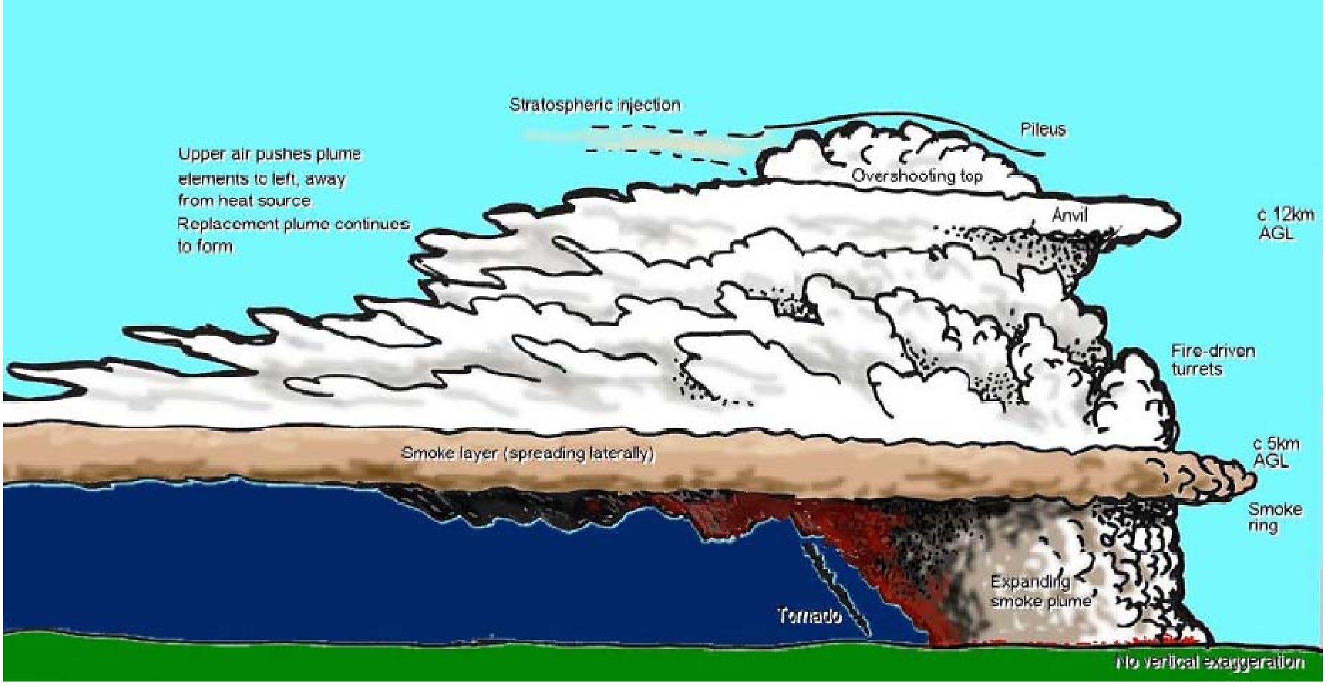


Figure 30. Diagrammatic cross-section of a pyro-cumulonimbus from the ACT fires.

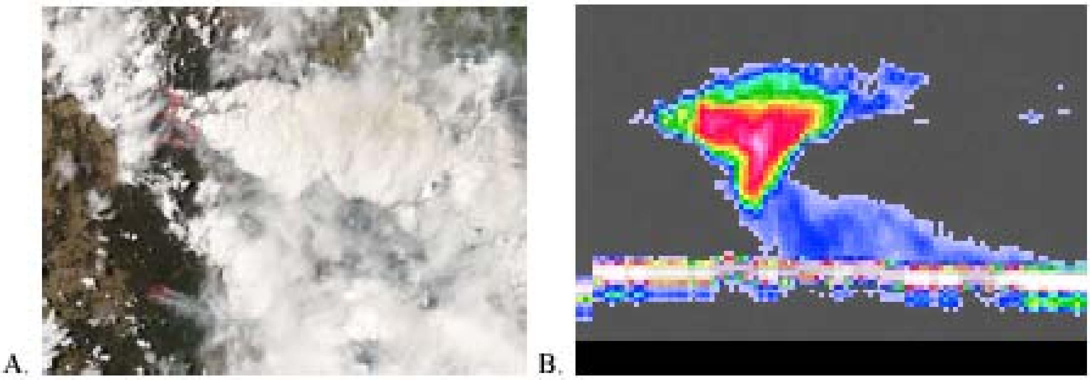


Figure 31. Satellite data from the Wollemi Fire, 22 November 2006. (A) MODIS image of a pyro-Cb, (B) CloudSat radar cross-section of the pyro-Cb (red indicates the most moisture).

FOEHN WINDS

The effects of barrier ranges on the movement of moist air can create a downflow of warm dry air on the lee side. The resulting Foehn wind can elevate fire danger.

Around the world there are regions where fire fighters and their communities know the dangers of Foehn winds. Many of us are familiar with the names given to these events: Foehn in Switzerland, Chinook in Alaska, Mistral in France, Santa Ana in California to name a few.

What they have in common is that they are a hot dry wind blowing downslope from mountains.

Our studies have shown that Foehn wind events do occur in southeast Australia. The combination of north-west air flows, the orientation of the Great Dividing Range and the extensive coastal forests and development areas towards the coast make this a real concern.

Many events occur during the passage of pre-frontal troughs ahead of shallow cold fronts, but they can also occur in zonal westerly flows associated with the passage of broad areas of low pressure from the Bight.

Satellite images clearly show all of the classical features of a Foehn event, and these events often cause unexpectedly intense fire behaviour over a band over 100km wide in the lee of the ranges.

Satellite images also show that the key features also form over parts of Tasmania, but not necessarily of the same days.

BoM high-resolution computer modeling can recreate these events and give useful insight into them – and valuable guidance for fire managers.

PROCESS – PRECIPITATION-DRIVEN

You are near the Murray River on a damp day with winds blowing towards the Divide. We can extrapolate the temperature up to the top of the ranges using a saturated adiabatic lapse rate – cooling by 5°C per kilometer. So we might start with 20°C and a dew point temperature of 14°C at 400m ASL and at 2000m ASL estimate 12°C. Now at the tops the air is cooler than its original dew point. As it has been rising it has therefore lost a lot of its moisture content through precipitation.

If this was a Foehn event the air would have lost so much of its moisture that its dew point would have fallen to 12°C and as soon as it begins its downhill flow on the lee of the ranges it warms with a dry adiabatic lapse rate of 10°C per kilometre. So when we get back down to 400m ASL the temperature is 28°C.

On the windward side the relative humidity would have been over 90%, rising to 100% on the ascent. At the end of the process the RH may be below 30%. Corresponding Fuel Moisture Contents would be 60% at the start, over 90% on the tops, and 10% finally (assuming drought factors of, say, 3, 2 and10 respectively).

Detailed modeling has shown that the vertical motion of the air is significant. Near the ground just past the Divide there is a significant downwards air flow and acceleration of surface wind speed.

PROCESS – BLOCKING

With the development of a high pressure cell over the region, subsidence inversions may form. This process brings drier air close to the surface, often down to the level of the mountain tops. This is discussed in detail under dewpoint depression events.

To consider this by example, you are again near the Murray River and it is a damp, foggy day, but there is only a light wind. At the tops, the ranges have blocked or dammed this air mass. Above that air mass we have the drier upper air, with a northwest wind.

This upper air is what flows downslope, with a low dew point, warming at the dry adiabatic lapse rate and significant downslope speeds. Think of a dam spillway for what may happen.

Figure 32. Moist air being partially blocked by the Liverpool Ranges near Muswellbrook. Note the downslope flow where clouds are overtopping the range. This is a Foehn wall.

OPERATIONAL WATCH-OUTS

There is no substitute for good field observations. Weather can vary greatly over short distances and short periods of time.

As these events can occur at nighttime satellite images may be of little value. The alpine Lone Pine Fire in the southern ACT (see Figure 34) was crowning at midnight in May with rain reported 10km to the west. Discussions with fire weather forecasters in BoM should address Foehn events.

The longer a fire takes to black-out, the greater the chance of encountering an event.

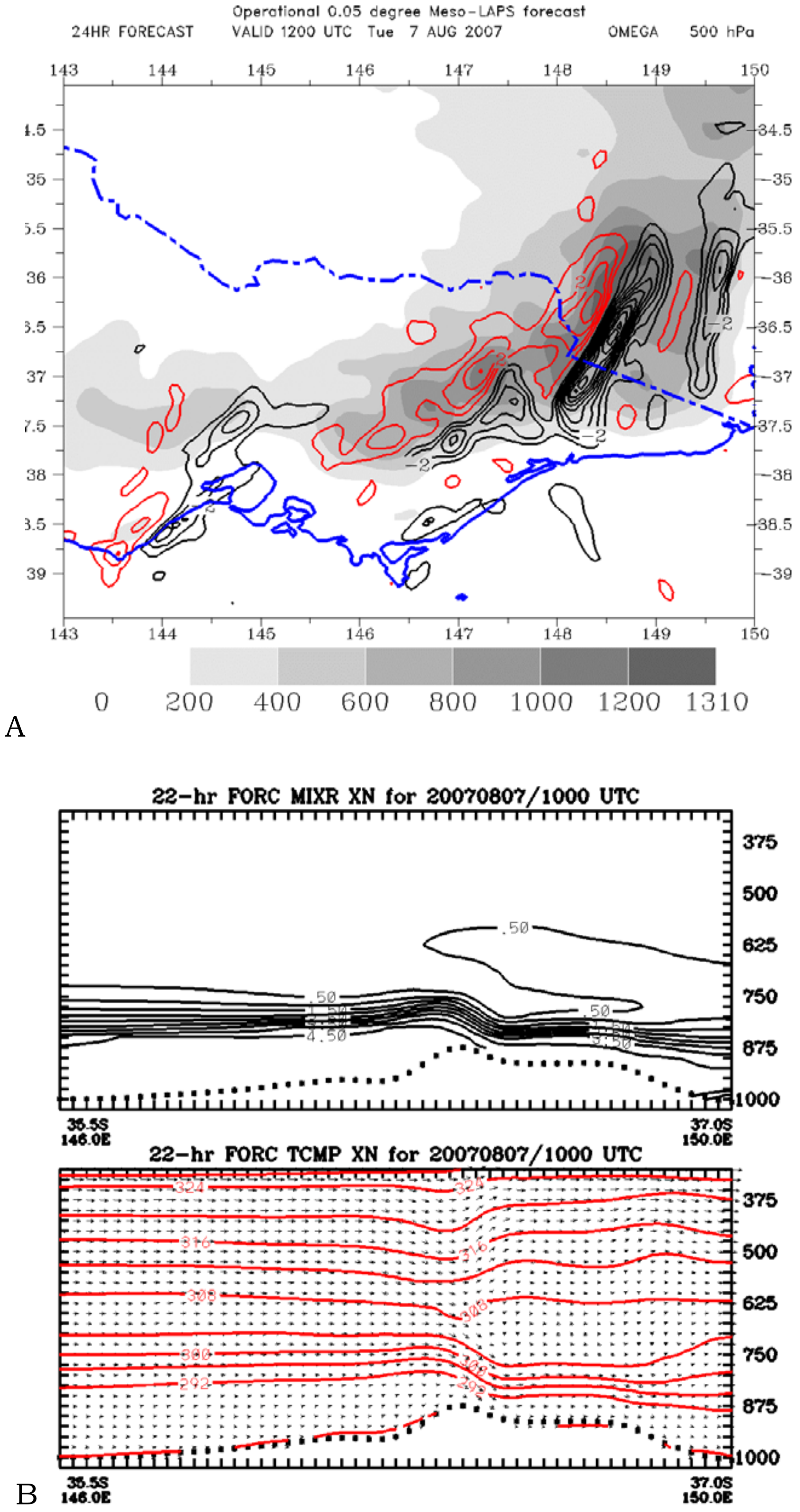


Figure 33. Examples of BoM numerical weather models of a Foehn Wind event. (A) shows upwards movement of the WNW winds in red, downwards in black, clearly showing the flow over the Divide. (B) shows a cross-section which indicates the impact of the barrier on air flow. The cross-section is over the Victorian Alp and is for 7th August 2007.

RISK MODELLING

These events will be difficult to include in risk models as they are at times localised and difficult to pick up from real-time weather observations or satellite imagery.

It is required to include their frequency, their magnitude (effect on FDI) and the vertical element of air flow. Further research is needed to achieve these.

RESEARCH SUMMARY

- Direct operational experience with these events put them onto the project agenda.
- A literature review was carried out (Sharples, submitted).
- Stronger events were detected from real-time weather data from BoM. Detailed modelling was done at BMRC using MesoLAPS to confirm these events, and the processes behind them. MODIS satellite data were to document the manifestations of the events (clouds and fire).
- Presentations were made to conferences (AFAC/Bushfire CRC Conference Hobart 2007) and forums (Bushfire CRC HighFire public forums) to generate feedback.
- A paper is being prepared.

REFERENCES

Sharples, JJ. (submitted). Review of mountain meteorological effects relevant to fire behaviour and bushfire risk.

Sharples, JJ, McRae, RHD, Mills, GA & Weber, RO (in prepn). *Elevated fire danger conditions associated with foehn-like winds in southeastern Australia.*

Sharples, JJ, Weber, RO, McRae, RHD & Mills, GA. *Elevated Fire Danger Conditions Associated with Foehn-Like Winds in Eastern Victoria*. Poster presented at AFAC/Bushfire CRC Conference Hobart, 2007.

Yeo & Bannister

Figure 34. An alpine fire driven by Foehn winds. This is the Lone Pine Fire, southern ACT, May 2005. Note the downhill flow of the convection.

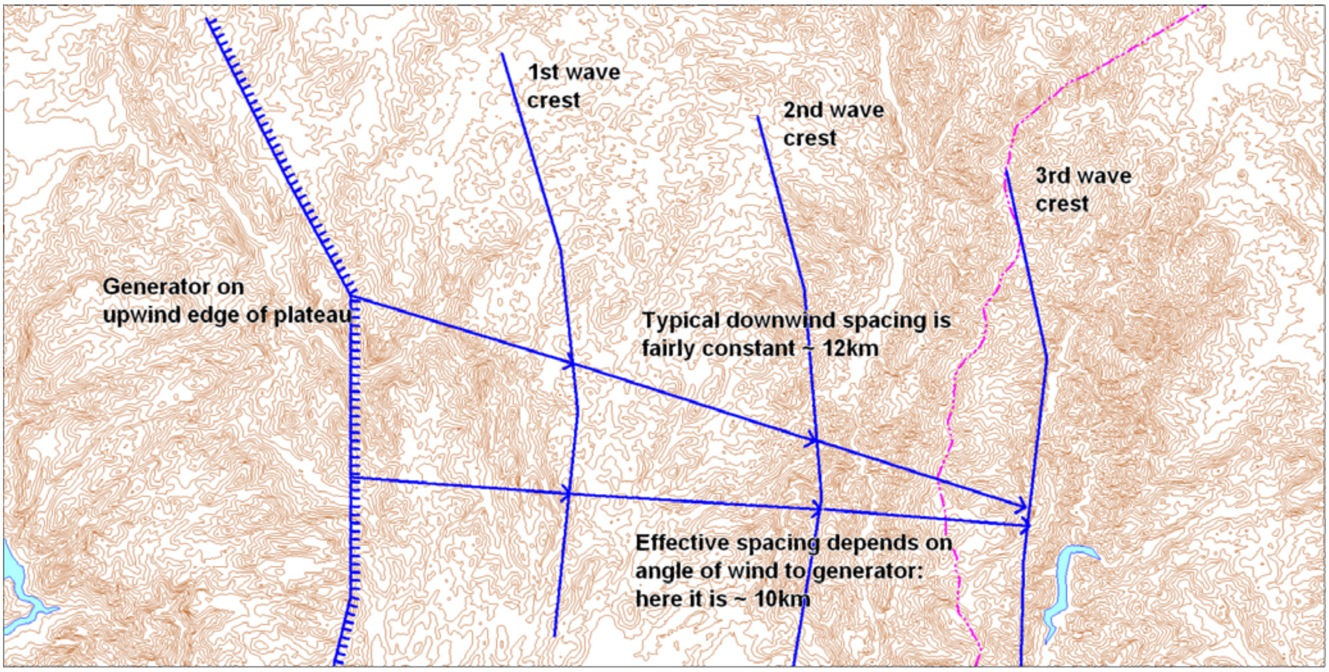


Figure 35. Diagram of wind wave generation.

MOUNTAIN WIND WAVES

When winds are forced to rise upwards to pass over barrier ranges, a series of wind waves can result, for up to 100km downwind. These can have significant effects of fire behaviour.

Imagine a westerly wind. It has blown across the Southern Ocean, the Bight, Bass Straight or even the flatlands of the Murray valley. Then it hits a mountain range. If the range is oriented across the flow (a barrier) and is long and uniform, the air has little choice other than to go up and over the range. Under some circumstances the upwards momentum is such that the vertical motion continues past the barrier, then there is a downwards flow under the effect of gravity, forming a wave. There may be rebound waves, and these may continue for some distance downwind – for over 100km.

These are mountain wind waves.

Before describing them we must ask why they are important for fire managers.

In extreme events the winds at a fire ground are strongly influenced by where they are in the wind wave cycle. Under a wave crest there has been an upwards air flow, effectively creating localized instability with its well known effects on fires – intense convection and ember transport. Under (or in) a wave trough there is a downburst wind effect- giving amplified wind speeds and more variation in wind direction. Clearly these produce the sort of problems that often beset fire controllers. Predicting these waves may allow better anticipation of containment loss.

Wind waves frequently betray their presence through the roll clouds that form in their crests. Satellite images show up to a dozen parallel bands of cloud. These bands are stationary with respect to the ground.

We can see which escarpments are most prone to generating wind waves – from Tumut to the Flinders Ranges and southern Tasmania. These have been mapped.

They will generate waves as long as the wind is strong, steady and oriented within about 40° either way to the face of the barrier.

The orientation is critical. Along any flowline in the wind, the waves will be spaced, typically, at 12 km intervals (but depending on wind speeds). The waves will be parallel to the escarpment and its twists and turns. Therefore the spacing on the ground, as seen by fire controllers, will change as the wind direction changes. This is shown in Figure 35.

OPERATIONAL WATCH-OUTS

Field observers must look out for parallel lines of cumulus that are stationary over the ground. At higher level the appearance of “lennies” or altocumus standing lenticularis clouds indicates strong waves reaching high levels. Pressure charts should always be checked to see if the fresh or stronger bulk winds are aligned with local escarpments.

RISK MODELLING

RESEARCH SUMMARY

REFERENCES

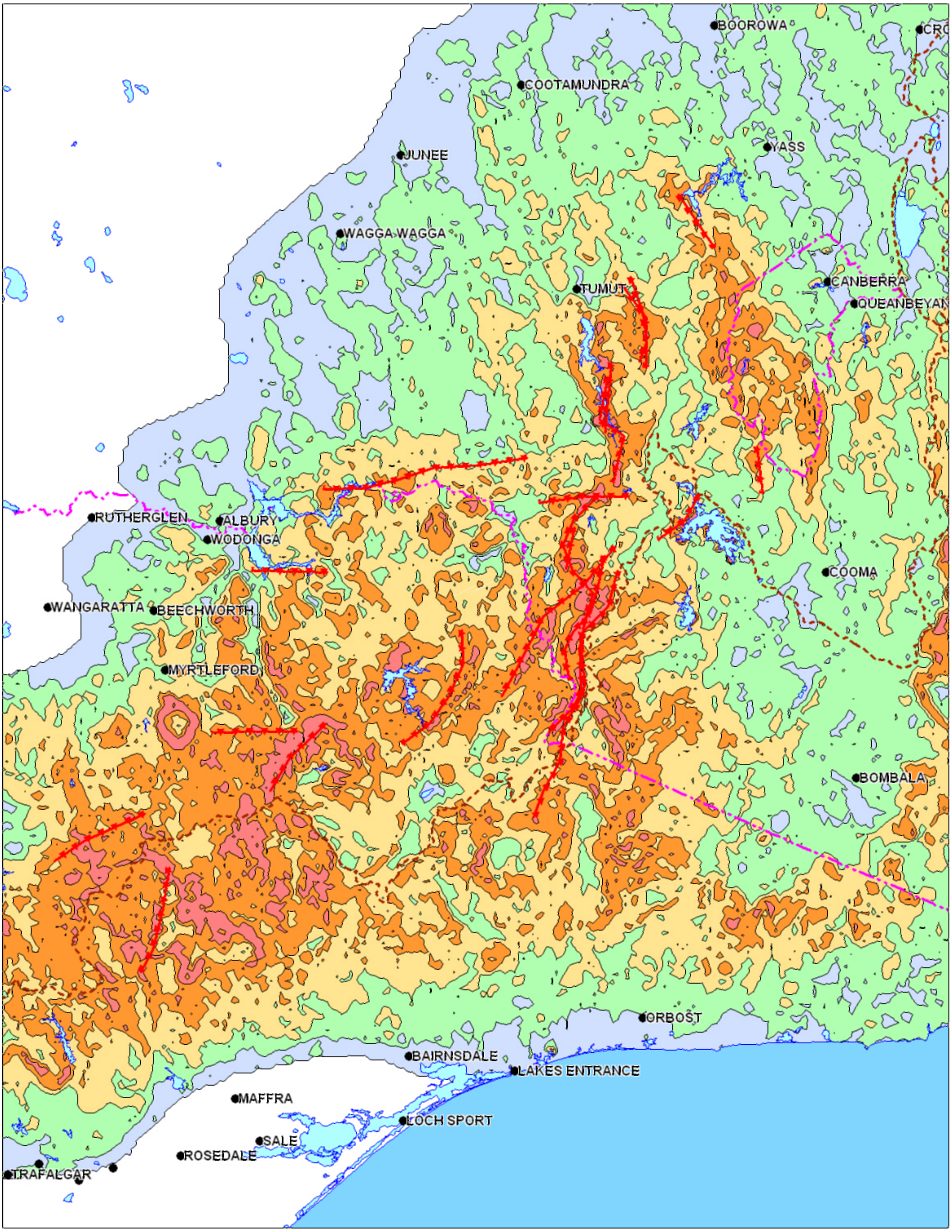


Figure 36. Map of the core mainland alpine area showing inferred mountain wind wave generators. These cause a series of parallel waves downwind for up to 100km.

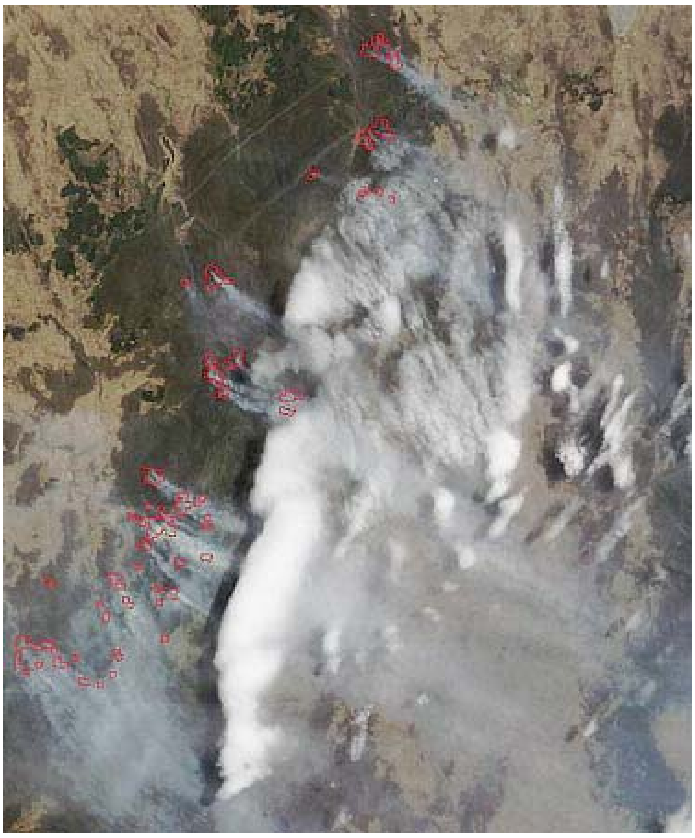


Figure 37. MODIS image of lenticularis clouds indicating intense mountain wind waves, ACT, 17 January 2003. Rectified imagery courtesy of NASA Goddard Space Flight Centre.

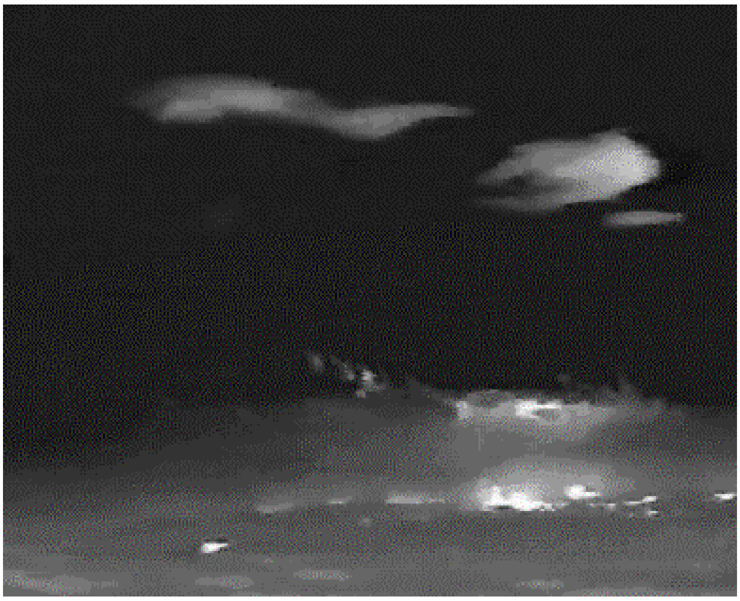


Figure 38. A screenshot from an airborne thermal video of fire at Thredbo in January 2003. In this image dark is cold, white is hot. The lowest white areas are the fires on the ground. Above them, but below image centre, is the thermal reflections off the bases of pyro-cu clouds forming above and slightly downwind of the fires. Near the image top is thermal reflection off a band of lenticularis clouds indicating a mountain wind wave. It is likely that these waves influenced fire activity. Note that lenticularis are very cold and are composed of ice crystals, which reflect thermal radiation from below. Imagery courtesy of Australian Government.

FIRE IN RUGGED LANDSCAPES

Very large fires in rugged landscapes tend to be constrained to the rugged lands, and are very difficult to control within those landscapes.

When very large fires in the high country are overlaid on maps of ruggedness, it is clearly seen that the big fires tend not to leave the rugged lands. They start there, spread there and go out there.

This is counter-intuitive: fires are seen to be more intense on a net downslope run then they are on adjacent flat country. Slope thus not the driver. The most likely explanation is the set of interactions that occur between rugged landscapes and the weather.

Many fire officers will suggest that it is when fires enter the flat lands that we have lower fuels, better access and good water supplies. That is why the fire go out where they do. However, satellite data showed that the 2006 Victorian alpine fires were producing violent pyro-convection at that stage and would have been uncontrollable.

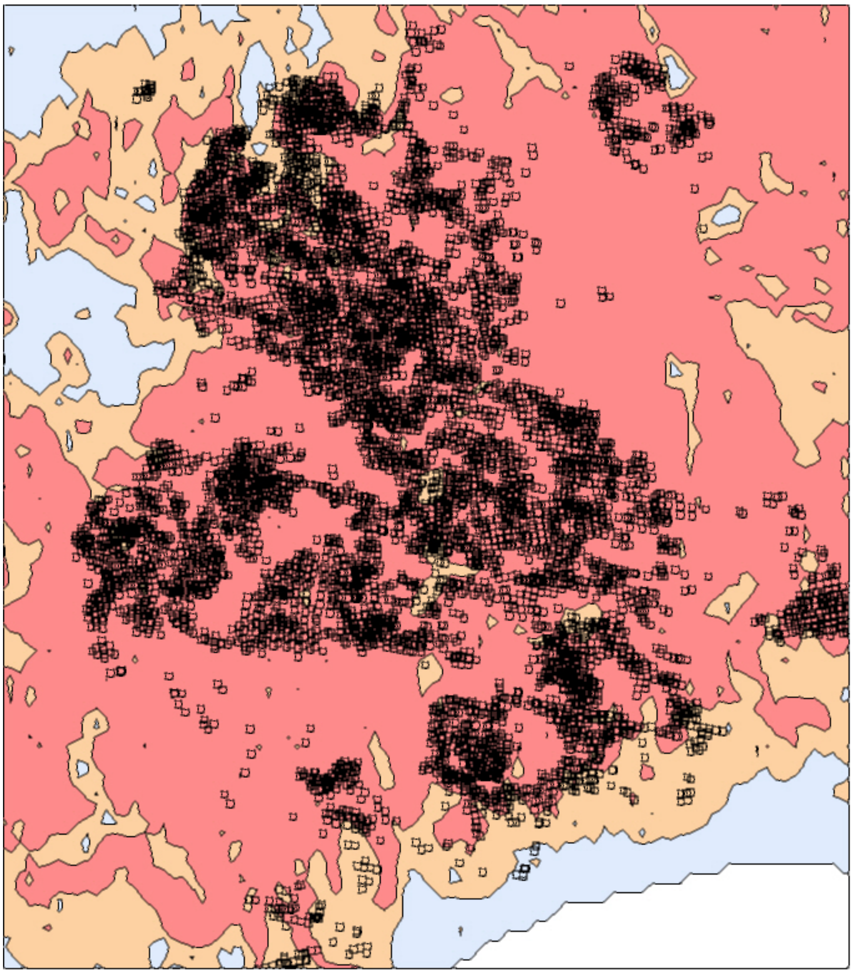


Figure 39. MODIS hotspot data from Victorian alpine fires of December 2006 overlaid on a map of ruggedness. Fires in the lower right displayed intense pyro-convection and yet remained confined to rugged lands. Thermal data courtesy of University of Maryland.

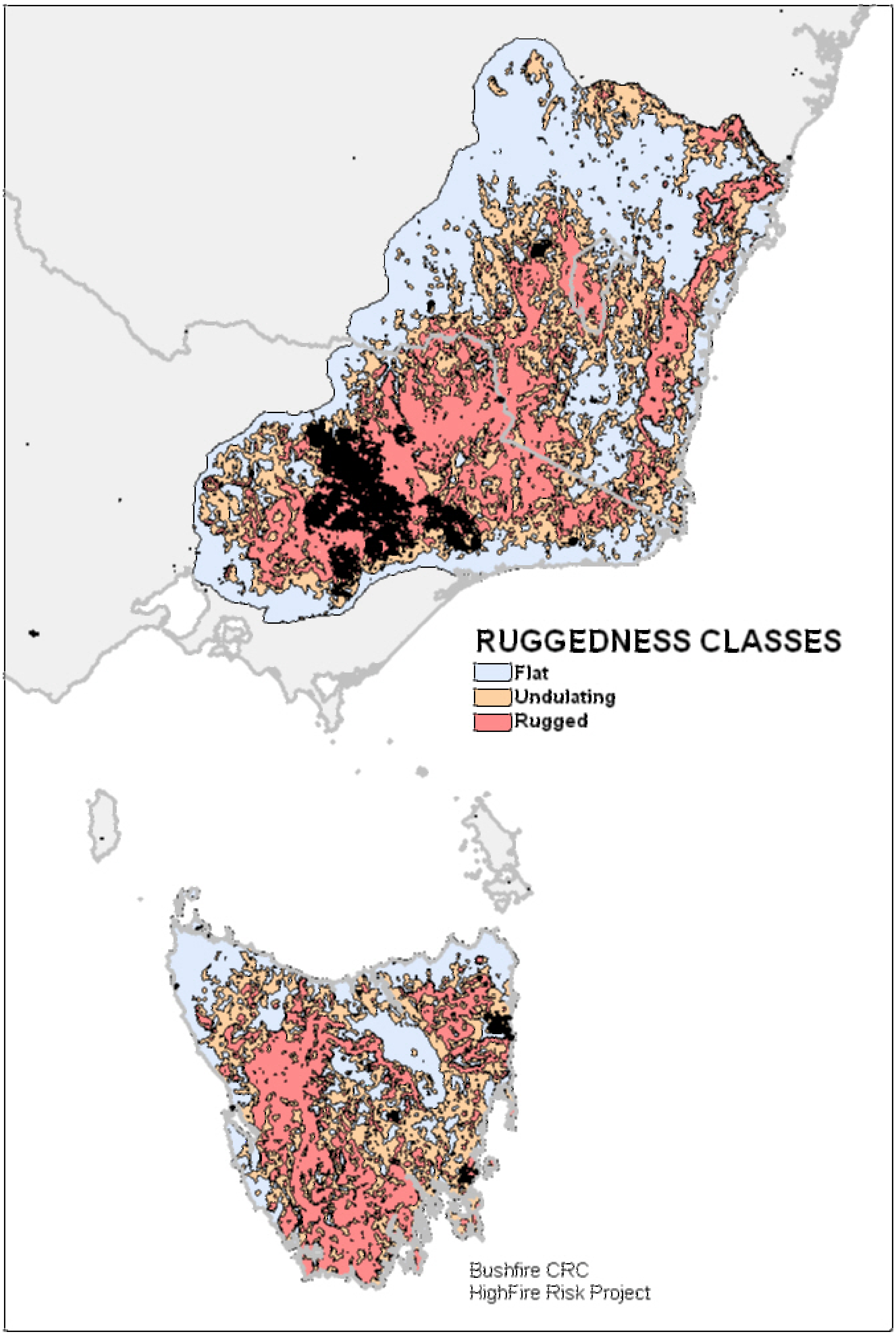


Figure 40. Regional map showing association of large fires across south east Australa and rugged landforms.

Terrain limiting of the December 2006 Victorian Alpine Fires. Rugged terrain is shown in yellow, orange or red. The southern margin made significant runs that produced some of the largest convection columns seen and yet failed to leave the rugged area.

Data from the ACT 2003 fires suggests that fires can travel for up to 5km on flat lands before abating.

On the basis of these observations, we suggest that there are three types of fire in the high country:

- Fires on flat lands are essentially wind-driven ellipses, which are extinguished by pinching the head from the flank and by cleared breaks ahead of the fire.
- Fires on undulating lands are a mosaic of rapid, intense uphill runs with associated spot fire potential and slow, mild downhill runs which offer suppression options.
- Fires in rugged lands which may under some conditions present few containment options until they reach the limit of the rugged lands.

OPERATIONAL WATCHOUTS

Planning Officers should note when fires are in rugged lands. If containment proves unexpectedly difficult then a review of incident objectives or of current objectives' achievability is strongly recommended.

RISK MODELLING

There is a clear indication that risk models should incorporate the following input:

If a large fire escalates within a zone of rugged terrain, and fire weather is forecast to remain elevated, then the fire unlikely to be suppressed within the forecast period with that zone.

In climatology terms, if those precursors are met then the consequences are extreme or catastrophic. Areas more than 5km from that zone are possibly unaffected by the event, assuming fire crews are able to mop-up the resultant fire edge when the fire decays.

RESEARCH SUMMARY

- It was noted that the ACT 2003 fires were “reluctant” to leave the rugged lands.
- This was followed up by examination of historical fires, which supported the concept that there was terrain limiting for very-large fires.
- Recent very-large fires were treated as natural experiments, with ultimate extents predicted, and largely confirmed from observations.
- DEM based modelling, using SRTM data, have been done to identify the limiting terrain zones.

REFERENCES

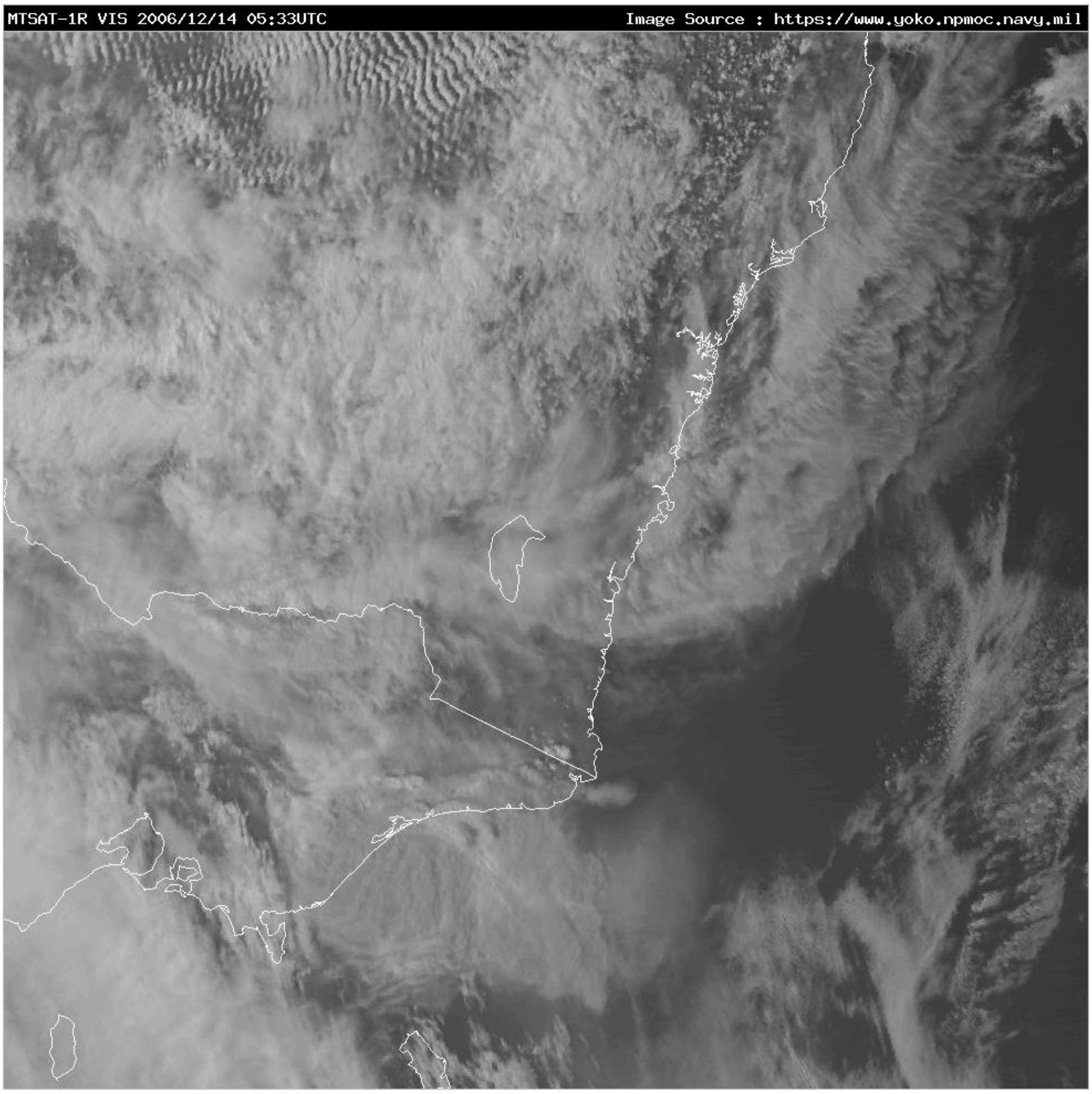


Figure 41. Intense pyro-convection, forming over Sale, as the 2006 fires reached the edge of the rugged terrain. Despite this the fires did not enter the flat country downwind.

UNUSUAL COMBUSTION

Many old hands have stories of fire balls. They go along the lines of "the fire went along the ridge top and then exploded and this big ball of black and orange went up in the air and came down again on the plains". These have always been treated with a grain of salt because there has never been much hard evidence.

Figure 42. A video screen capture of a landscape scale flashover on Mt Awawang, Canberra, 18 January 2003. Image courtesy @@@ Bates.

A member of the public was filming Mt Arawang in suburban Canberra on 18th January 2003. In the footage is an incredible event, seen in the screen shot above. In the time between two video frames – 0.05 seconds – 112 hectares of Canberra Nature Park ignite.

The calculations of the power of that event gives ridiculously large numbers of Watts (we need to use ExaWatts).

The tornado was on the far side of the hill, drawing the air away from this slope. Winds speeds exceeded 200 km/hr. When the tornado rounded the corner and restored the air flow there was a landscape-scale flashover.

Immediately prior to the flashover there were spotfires traveling at 30km/hr, on the basis of photogrammetry.

John Dold from Manchester University has studied this and other spectacular events (Dold *et al* 2006) and found a pattern in the eyewitness accounts.

The evidence suggests a form of pre-mixed combustion was occurring. When combustion has insufficient oxygen, vapourised fuel may be released and may travel downwind. On reaching supplies of oxygen and flame a second combustion event may occur. This can also involve vertical gradients, producing horizontal sheets of flame. There are reports of fire burning across paddocks with no vegetation or fuel present. We suspect that aerial, vapourised fuel was involved.

It may prove that pre-mixed combustion is the basis of fireball reports.

OPERATIONAL WATCH-OUTS

All reported cases that have been assessed in this project have involved:

- Proximity to a channeling event
- Underneath violent pyro-convection

These are described in detail elsewhere. Should either be reported then unusual combustion should be added to the list of current threats to crew safety.

RISK MODELLING

There is currently no ability to factor these events into a risk model.

RESEARCH SUMMARY

- This work began with a collaboration between ADFA and Manchester University (Weber and Dold).
- As Dold collected testimony from fire fighters it became obvious that there were some significant processes occuring, which needed explaining.
- There is an on-going need to collate first-hand observations from the fire ground.
- Detailed analysis of multi-spectral linescan data (in collaboration with Robert Cook and Stephen Wilkes) confirms the presence of significant but unexplained processes.
- Further research is essential.

REFERENCES

Dold, J, Weber, R, Gill, M, Ellis, P, McRae, R & Cooper, N. (2005). Unusual Phenomena in an Extreme Bushfire. *5th Asia-Pacific Conference on Combustion*, The University of Adelaide.

SUMMARY OF OPERATIONAL WATCHOUTS

Risk Transition Model	
High Country Rugged landscapes	
Thermal Belt	**When planning overnight operations in mountainous valleys always consider a thermal zone**. When assessing the timing for implementing assigned tactics never rely solely on observations on ridgetops or in valleys. Observations from convex mid-slopes are essential. This may be difficult to achieve safely. Observers should always to able to leave safely and rapidly. Always estimate fuel moisture content and fire behaviour at both extremes. Remember to assess **spotting potential**. Remember also that if the cold air pool becomes saturated you will **lose air ops** (noting of course that this would be instrument rated aircraft only – linescanners, aeromedical helicopters and some observer machines).
Lightning Ignition-Prone Lands	Crew safety can be threatened if they are between a lightning ignition and the ridgetop, or if a spotfire occurs below them. Spotting risk eases once the headfire's uphill run ends. Knowledge of when fuel moisture contents fall below 5% is vital – this the key requirement for easy spotting.
NighttimeDew point depression events	Field observations are essential before lighting up backburns at night, to ensure that the dew point is as expected. Remember that most events do not intensify until after midnight. An early start to a burn that may take hours to complete must be carefully planned, and should be discussed with the weather forecasters. In the longer term, if operations are being planned in the high country, a similar discussion with the local fire weather forecaster should address the likelihood of any of the events listed. While it is recognized that many agencies use standardized protocols for requesting special fire weather forecasts for emergency or planned fire

	situations, these do not generally provide space for discussion of these events. The absence of mention of these processes should not be seen as a green light, especially if there is a large local relief. A proper dialog is required.
Daytime Dew point depression events	There is an expectation that fire weather forecasters will be monitoring water vapour imagery for dry slots of various forms. There is, however, an obligation on Incident Controllers to seek such information, or at least notify BoM of on-going fire activity, even if they are not of sufficient intensity to require special fire weather forecasts. The BoM web sites gives registered users access to hourly water vapor imagery, while other sites provide animations of recent images. The approach of a dry slot can be seen with perhaps a few hours notice, given time for incident strategies to be reviewed. Earlier images may show a slot, but that slot may evolve as it approaches and not pose a threat. Skill and care are needed is interpreting water vapor images – only qualified staff should be using them. In more general terms there should always be discussions with fire weather forecasters when a fire is in or adjacent to the alpine area. Special fire weather forms do not allow mention of the risk of daytime dew point presssion events in some parts of the fire ground.
Low Level Jets	LLJs can be difficult to detect. As with so many other processes, good field observations are the best way to anticipate potential problems. Always discuss the potential for LLJs with fire weather forecasters when planning the next shift at a campaign fire on high ground. Apart from the direct effect of wind pseeds on FDIs, the effects of turbulence should be considered.
Dynamic Channelling	The speed and intensity of a channeling-driven fire event is such that it would be difficult to react in time to achieve crew safety or protect life and property. This requires (a) prior identification of channelling-prone landforms, and (b) clear instructions to crews operating in remote rugged

	areas on safety actions. Of greatest concern, the largest channelling-driven fire events have all arisen off contained if not cool fire edges.
Violent Pyro-convection	IMTs need to arrange monitoring of fire behaviour either in terrain conducive to channeling or when wind changes are forecast. The formation of deep flaming must be treated as a dangerous event that may be the harbinger of the transition to a plume-driven fire. Monitoring a fuel moisture content is also needed Additonally observers placed some kilometers away from the fire at right angles to the wind direction should watch for pyro-cu or pyro-cb formation. These need to be reported in as soon as possible, in the same way that approaching thunderstorms are reported on.
Foehn Winds	There is no substitute for good field observations. Weather can vary greatly over short distances and short periods of time. As these events can occur at nighttime satellite images may be of little value. The alpine Lone Pine Fire in the southern ACT was crowning at midnight in May with rain reported 10km to the west. Discussions with fire weather forecasters in BoM should address Foehn events. The longer a fire takes to black-out, the greater the chance of encountering an event.
Mountain Wind Waves	Field observers must look outs parallel lines of cumulus that are stationery over the ground. At higher level the appearance of "lennies" – altocumus standing lenticularis – clouds indicates strong waves reaching high levels. Pressure charts should always be checked to see if the bulk winds are aligned with local escarpments.
Fire in Rugged Landscapes	Planning Officers should note when fires are in rugged lands. If containment proves unexpectedly difficult then a review of incident objectives or of current objectives' achievability is strongly recommended.
Unusual combustion	All reported cases that have been assessed in this project have involved: • Proximity to a channeling event • Underneath violent pyro-convection

	These are described in detail elsewhere. Should either be reported then unusual combustion should be added to the list of current threats to crew safety.

RISK MANAGEMENT IMPLICATIONS

MODELLING

A significant impact of this research on bushfire risk modeling arises from the identification of the three types of fire: flat, undulating and rugged. The drivers of these are different and need to be factored into a risk model.

Another impact arises from the nature of many of the weather processes described. Consider two points. The first, called W, is where weather observations are made. The second, called F, is on the fire perimeter. The Planning Section is tasked with estimating the weather at F, to permit assessments of strategies.

There are five types of predictability of the weather at F from the weather observed at W.

Weather at F can be predicted from weather at W:

$$wx(F) = f(wx(W))$$

1. Based on direct interpolations involving only the (x,y,z) coordinates of P and Q, such as applying a dry adiabatic lapse rate based correction: drop temperature by 1°C for every additional 100m of height & double RH for every additional 1200m height (capped to 100%).
2. But requiring knowledge of the setting of P, to permit effects such as wind-terrain interactions to be calculated. Requires a sub-model: full fluid flow model; partial fluid flow model; phenomenological model.

Weather at F can not be predicted from weather at W

$$wx(F) \neq f(wx(W))$$

3. Due to the setting of P, producing effects such as dynamic channelling.
4. Due to local weather events, such as a thunderstorm, mountain wind waves or Foehn winds.
5. Due to regional discontinuities in weather, such as inversions, cold fronts or sea breeze fronts.

These five predictability classes apply differently across the three landform types:

Local weather predictability class: "How well can we predict the weather at a fireground point F given the weather at a nearby point Q?"	**Landform type**		
	Flat	**Undul-ating**	**Rugged**
wx(F) = f(wx(W)) based on direct interpolations involving only the (x,y,z) coordinates of F and W	+	+	-
wx(F) = f(wx(W)) but requiring knowledge of the setting of F	-	+	+
wx(F) ≠ f(wx(W)) due to the setting of F	-	-	+
wx(F) ≠ f(wx(W)) due to local weather events	+	+	+
wx(F) ≠ f(wx(W)) due to regional discontinuities in weather	+	+	+

Where: "-" = not relevant; "+" = relevant. Grey-shaded cells are currently well implemented.

In order to appropriately implement a risk model for rugged lands (the right-most column), there are clearly some major gaps in the current capability. The research findings discussed in this paper offer some guidance towards fixing this problem.

We can also examine how the predictability classes fit into the fire size classes:

Local weather predictability class: **“How well can we predict the weather at a fireground point P given the weather at a nearby point Q?”**	**Fire Size Class**				
	Small	**Medium**	**Large**	**Very Large**	**Plume-Driven**
wx(F) = f(wx(W)) based on direct interpolations involving only the (x,y,z) coordinates of F and W	++	++	+	?	-
wx(F) = f(wx(W)) but requiring knowledge of the setting of F	+	+	++	+	-
wx(F) ≠ f(wx(W)) due to the setting of F	-	-	+	++	++
wx(F) ≠ f(wx(W)) due to local weather events	-	+	+	++	-
wx(F) ≠ f(wx(W)) due to regional discontinuities in weather	?	?	+	++	+

Where: “-” = not relevant; “+” = relevant; “++” = very relevant; “?” = may be relevant. Grey-shaded cells are currently well implemented.

Again there are clear gaps in the current capability. It should be noted in particular that:

- Plume-driven fires are currently not modellable.
- The drivers of very large fires are mostly the most difficult to predict.

A final consideration for the predictability classes is the radius of relevance. For model runs operating over domains spanning a distance of less than this radius, the weather at F is easily estimated from that at W by the standard techniques of class 1. Above that radius then additional techniques must be applied. Indicative values for the radii are:

Predictability class	**Typical radius of relevance (km)**
wx(F) = f(wx(W)) based on direct interpolations involving only the (x,y,z) coordinates of F and W	n/a
wx(F) = f(wx(W)) but requiring knowledge of the setting of F	1
wx(F) ≠ f(wx(W)) due to the setting of F	2
wx(F) ≠ f(wx(W)) due to local weather events	5
wx(F) ≠ f(wx(W)) due to regional discontinuities in weather	20

There is an important message in the tables above. All fire shave the potential to become unpredictable, given current best practices, if there size approaches or exceeds the radii of relevance for the last two predictability classes – 5km or 20km. Additionally fires in rugged landscapes can become unpredictable at a size of 2km, reflecting the third predictability class. This smaller critical size is of concern and reflects much experience in recent years.

MITIGATION

Given the scope of the previously poorly known drivers of bushfire risk in the high country, it is premature to go too deeply into the ramifications for risk mitigation.

As an example of this, imagine a fire behaviour model running in a rugged landscape. Assuming the use of a McAthur “engine” there is a need to predict the drought factor (DF). FFDI, and rate-of-spread are both directly proportional to the DF.

It is well known that in rugged country at our latitudes in spring the sun will not reach sheltered slopes and dry out surface fuels until months after exposed slopes. In order to assess the DF we need a drought index (the KBDI or the SDI), and in order to assess these we need rainfall data. We can use BoM weather station data, but then need to extrapolate into the modelling domain. It is at this point that we fall foul of the predictability classes discussed above.

The extent of storm rainfall will not necessarilyu be known, nor will the drying effects of Foehn winds or dew point depression events. If a typical inversion level is passed, we may not have any reliable data on wind speed or directrion (and thus air masses).

So a ridgetop site could be assessed as being very dry or very wet based on how the predictability classes are applied and what assumtpions are made.

A major outcome from the fire size transition model is that we must focus on prescribed burning. These burns are done under conditions when the probabilities of the last two escalations are low. If, on the other hand, we do not undertake prescription burning, then fuels will be consumed at some future time in wildfires, which may be able to escalate into very large or even plume-driven fires.

Over the next three years there must be a concerted effort to take field measurements within rugged landscapes and to compare these against concerted efforts to predict the conditions. We need data on standard weather variables and on drought levels and fuel moisture content. We desperately need observations on occurrence, if not extent of lee-slope eddies. We need feedback from IMT Situation Units if ANY of the processes discussed in this report impact on fire operations.

One thing is clear. There are some millions of hectares of forest fuels of roughly the same fire age. Eventually, and probably by 2023, they will become hazardous as a single cohort. It is the clear ogligation of the stakeholders involved to prevent this being the recursor to another set of catastrophic mega-fires.

If we are to achieve that goal, then we must recognise the fire management problems peculiar to the high country.

USING THE TRANSITION MODEL

Considerable research remains to be done on the technical side of the transition model. Despite this we can given some indication of where it is taking us.

Image you are in an IMT, with a fire in a rugged area. In planning for the next shift, you need some guidance as to what the fire could do. We can reword the question, using the concepts discussed above, to be:

" Given a fire of a specifc size class and a forecast range of FDI, will the fire escalate, decay or persist?"

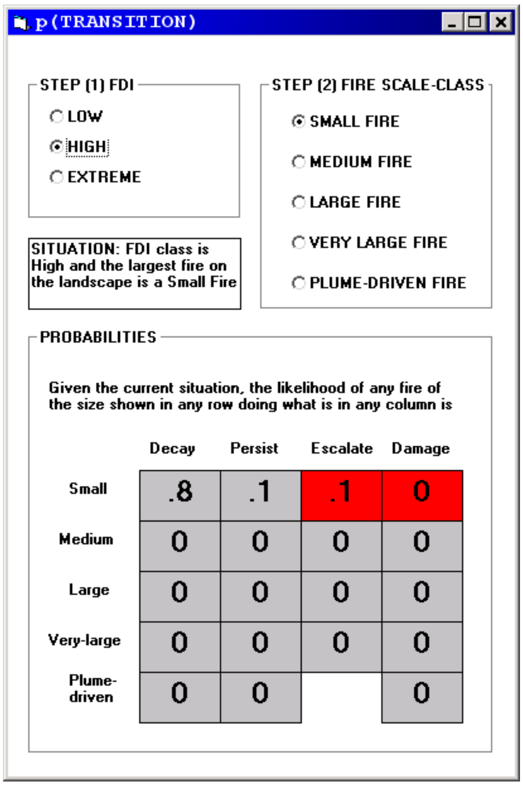
We have developed some initial estimates of the probabilities of the transitions. They are best described by way of example.

EXAMPLE

We start with a small fire and high fire danger. We have an 80% chance of the fire decaying (going out) and 10% chances of persistance or escalation.

This does not assume the occurrence of any particular processes – it is simply an attempt to incorporate a lot of historical information.

Note also that the model indicates a low likelihood of damage.



p(TRANSITION)

STEP (1) FDI
○ LOW
● HIGH
○ EXTREME

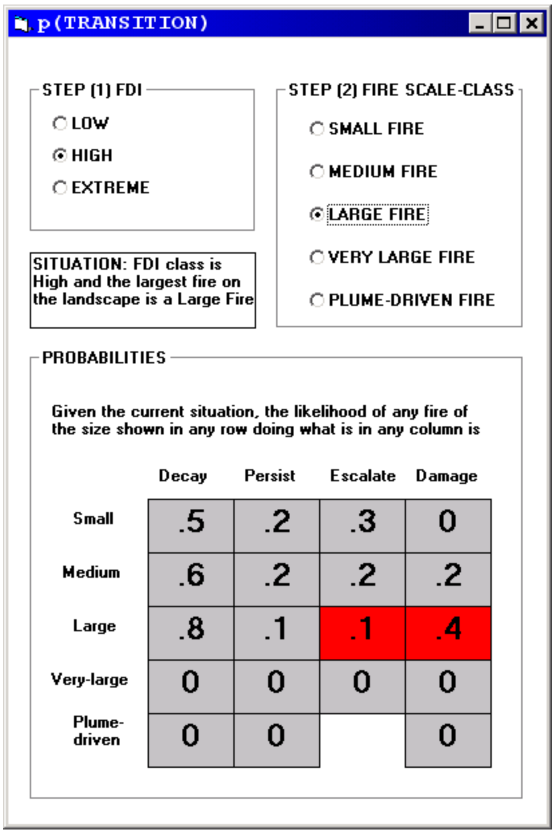
STEP (2) FIRE SCALE-CLASS
● SMALL FIRE
○ MEDIUM FIRE
○ LARGE FIRE
○ VERY LARGE FIRE
○ PLUME-DRIVEN FIRE

SITUATION: FDI class is High and the largest fire on the landscape is a Small Fire

PROBABILITIES

Given the current situation, the likelihood of any fire of the size shown in any row doing what is in any column is

	Decay	Persist	Escalate	Damage
Small	.8	.1	.1	0
Medium	0	0	0	0
Large	0	0	0	0
Very-large	0	0	0	0
Plume-driven	0	0		0



p(TRANSITION)

STEP (1) FDI
○ LOW
● HIGH
○ EXTREME

STEP (2) FIRE SCALE-CLASS
○ SMALL FIRE
○ MEDIUM FIRE
● LARGE FIRE
○ VERY LARGE FIRE
○ PLUME-DRIVEN FIRE

SITUATION: FDI class is High and the largest fire on the landscape is a Large Fire

PROBABILITIES

Given the current situation, the likelihood of any fire of the size shown in any row doing what is in any column is

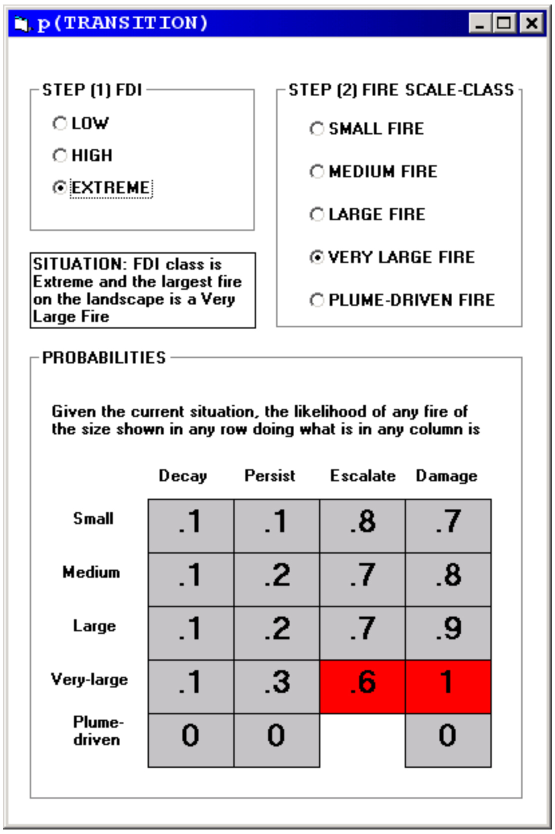
	Decay	Persist	Escalate	Damage
Small	.5	.2	.3	0
Medium	.6	.2	.2	.2
Large	.8	.1	.1	.4
Very-large	0	0	0	0
Plume-driven	0	0		0

Now, lets assume that the fire did escalate, and on a future day we have a large fire and, again, forecast high fire danger. The forecasts for the fire now cover a range of fire size classes. The model works off the largest fire on the landscape. The chances of decay or escalation have not changed. The chance of damage has gone up, as expected from a larger fire.

Next we again assume escalation of the fire. We now have a very large fire on the landscape and forecast extreme fire danger. There is a 10% chance of decay, a 30% chance of persistance and a 60% chance of escalation to a plume-driven fire. Damage is essentially guaranteed.

While these values are still somewhat stylised, they give a feel for where the model will take us with future development.

This is the sort of guidance that is essential for IMTs working in rugged landscapes, as there is a critical need to estimate the likelihood of achieving assigned objectives for the incident.



STEP (1) FDI
○ LOW
○ HIGH
● EXTREME

STEP (2) FIRE SCALE-CLASS
○ SMALL FIRE
○ MEDIUM FIRE
○ LARGE FIRE
● VERY LARGE FIRE
○ PLUME-DRIVEN FIRE

SITUATION: FDI class is Extreme and the largest fire on the landscape is a Very Large Fire

PROBABILITIES

Given the current situation, the likelihood of any fire of the size shown in any row doing what is in any column is

	Decay	Persist	Escalate	Damage
Small	.1	.1	.8	.7
Medium	.1	.2	.7	.8
Large	.1	.2	.7	.9
Very-large	.1	.3	.6	1
Plume-driven	0	0		0

BRINGING IT TOGETHER

The following are the “take home messages” from this project:

1. We knew far less than we thought we did about fire behaviour drivers in the high country. While there are many times when fires behave “as expected” we now know that there are MANY times when they will not. We also know that, while we may be able to explain away anomalies within the scope of the usual methods, doing so is pointless. Unless we understand the processes we cannot ensure safety for fire crews or the public.
2. There are (at least) three fire “habitats” to be found in and around the high country: flat, undulating and rugged. Each produces different fire behaviour in response to different drivers. Each offers different options for fire controllers and for fuel managers.
3. Fires are best thought of in a formal framework that recognises that they all start small and may escalate, or in fact decay (two forms of “transition”). Each fire size class responds to different drivers and to different types of prior mitigation works. Each requires different approaches to incident objectives by IMTs.
4. Knowledge of the processes that have been identified if not analysed permits a set of “watch-outs” that need to be heeded by IMTs to ensure safe and effective fire ground operations. Some of these watch-outs are for events that could easily prove fatal.
5. All fire spread models in Australia, if not elsewhere, have serious deficiencies in their inability to predict many if not all of the key processes studied in this project. However models run on small domains with local weather observations remain valid. This limitation must be clearly recognised.
6. Many of the findings of this study have been previously known to some extent, by meteorologists doing non-fire work, by experienced local hands or by researchers, especially overseas. Some had found their ways into fire trainnig material, generally in a cursory manner.
7. In order to work safely and effectively in the high country, we need:
    - Knowledge and awareness in IMTs, espcially through the new Fire Behaviour Analyst and Fire Behaviour Specialist roles.
    - Knowledge and awareness across fire weather forecasting desks.
    - Good field observations that are shared with forecasters.
8. There are many stakeholders in risk management, and all of these need to be given an understanding of the implications of our deeper understanding of the risk drivers in and around the

high country. It is essential that there is a commitment to act where new knowledge indicates enhanced risk or even non-sustainability.

9. There must be commitment to undertake further studies of these processes. This may include:
    - Further numerical studies of observed events to build up a climatology.
    - Development of higher-resolution modelling that can resolve the key landform elements.
    - Reporting of critical first-hand observations to a central repository, to contribute to the climatology work.
    - Immediate reporting of intense pyro-convection, so that overseas researchers can be alerted – ther emay opportunites to train unexpected remote sensing platforms onto events if enough forewarning is given.
10. We must understand that past legal enquiries have assumed that only the normal drivers operate, and have assessed contribution to impacts from very large fires on that basis. It must be accepted that processes may occur that will radically alter the ability to predict a fire, the ability to suppress a fire and the ability fulfil incident objectives.

REFERENCES

PUBLICATIONS

ACT Emergency Services Authority 2005. *Strategic Bushfire Management Plan for the ACT. Version 1.* ACT Government, Canberra.

Bally, J. 1995. The Haines Index as a predictor of fire activity in Tasmania. *Proceedings of Bushfire '95, Australian Bushfire Conference, 1995*, Hobart, Tasmania.

Butler, B.W., Bartlette, R.A., Bradshaw, L.S., Cohen, J.D., Andrews, P.L., Putnam, T., Mangan, R.J. (1998) Fire behaviour associated with the 1994 South Canyon Fire on Storm King Mountain, Colorado. *Research Paper RMRS-RP-9*. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Butler, B.W., Bartlette, R.A., Bradshaw, L.S., Cohen, J.D., Andrews, P.L., Putnam, T., Mangan, R.J., Brown, H. (2003) The South Canyon fire revisited: lessons in fire behaviour. *Fire Management Today*, **61(1)**, 14-26.

Chatto, K. (ed) (1999). *Development, Behaviour, Threat and Meteorological Aspects of a Plume-Driven Bushfire in West Central Victoria: Berringa Fire February 25-26 1995.* Victorian Department of Natural Resources and Environment Fire Management Branch Research Report No. **48**.

Commonwealth Bureau of Meteorology (2003). Submission to the ACT Coroner's Bushfire Inquiry.

Dold, J, Weber, R, Gill, M, Ellis, P, McRae, R & Cooper, N. (2005). Unusual Phenomena in an Extreme Bushfire. *5th Asia-Pacific Conference on Combustion*, The University of Adelaide.

Esplin, B., M. Gill and N. Enright (2003). *Report of the Inquiry into the 2002-2003 Victorian Bushfires*. State Government of Victoria.

Fromm. M, Tupper, A, Rosenfeld, D, Servrancx, R & McRae, R, (2006). Voilent pyro-convective storm devastates Australia's capital and pollutes the stratosphere. *Geophys. Res. Lett.* **33**, L05815.

House of Representatives Select Committee on the Recent Australian Bushfires 2003. *A Nation Charred: Inquiry into the Recent Australian Bushfires*. The Parliament of the Commonwealth of Australia, Canberra.

Kossmann, R, Sturman, A & Zawar-Rezar, P (2001). Atmospheric Influences on bush fire propagation and smoke dispersion over complex terrain. *Proceedings, 2001 Australasian Bushfire Conference,* Christchurch, NZ.

Leggett, T. (1999). *Meteorological Aspects of the Berringa Fire of 25-26 February 1995*. Bureau of Meteorology special report.

McRae, R. (1991a). ACT Fire Hazard Assessment. *Proceedings of Eighth AARFA National Conference.* Australian Association of Rural fire Authorities, Victoria.

McRae, R. (1992). Prediction of areas prone to lightning ignition. *Int. J. Wildland Fire* **2(3)**: 123-130.

McRae, RHD. (2004). The Breath of the Dragon – Observations of the January 2003 ACT Bushfires. *Proceedings, 2004 Australasian Bushfire Conference,* Adelaide.

McRae, RHD, Sharples, JJ & Weber, RO. (2007). Are Big Fires Inevitable? Proceedings, 2007 AFAC Conference, Hobart.

McRae, RHD, Sharples, JJ, ??Wilkes, SR & Weber, RO. (in prepn). The Thermal Belt in an Australian Bushfire Context.

McRae, RHD, Weber, RO & Sharples, JJ (2006). Lessons from the January 2003 fires – advancing bushfire risk management in the high country. *Proceedings, Bushfire Conference 2006*, Brisbane.

Mills, GA. (2005). Lower atmospheric drying, stability, and increased wildfire activity. Proceedings, *Sixth Symposium of Fire and Forest Meteorology*, Canmore, Canada, American Meteorological Society.

Mills, GA (2007). On easterly changes over elevated terrain in Australia's southeast. *Aust. Met. Mag.* **56**: 177-190.

National Rural Fire Authority (2002). *Wildfire Threat Analysis – Technical Documentation.* New Zealand.

Rothermel, R.C. (1993) Mann Gulch Fire: A race that couldn't be won. United States Department of Agriculture. Forest Service. *General Technical Report* **INT-299**. Intermountain Research Station.

Sharples, JJ. (submitted). Review of mountain meteorological effects relevant to fire behaviour and bushfire risk.

Sharples, JJ, McRae, RHD, Mills, GA & Weber, RO (in prepn). Dewpoint anomalies in the Australian high country and their implication for bushfire management.

Sharples, JJ, McRae, RHD, Mills, GA & Weber, RO (in prepn). Elevated fire danger conditions associated with foehn-like winds in southeastern Australia.

Sharples, JJ, McRae, RHD, Weber, RO & Wilkes SR (in prepn). Wind-terrain effects on rugged landscape fire propagation: fire channeling.

Standards Australia (2004). *AS 4360 Risk Management.*

Treloar, A. (1999). *Meteorology of the Berringa Bushfire Smoke Plume.* Bureau of Meteorology special report;

Werth, P., Ochoa, R. (1993) The evaluation of Idaho wildfire growth using the Haines Index. Weather and Forecasting, 8, 223-234.

Whiteman, CD. (2000). *Mountain Meteorology: Fundamentals and Applications*. Oxford University Press, New York.

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CRC PROGRAM 3 POSTERS:

2006

Sharples, JJ, Weber, RO & McRae, RHD. *HighFire Risk: Bushfire Risk Management in High Country Landscapes*

McRae, RHD, Weber, RO & Sharples, JJ. *HighFire Risk: Fire Size-Class Transition Model*

2007

Sharples, JJ, Weber, RO & McRae, RHD. *Wind-Terrain Effects on Rugged Landscape Fire Propagation: Lee-Slope Channelling.*

Sharples, JJ, Weber, RO, & McRae, RHD. *A Simple Fuel Moisture Index for Eucalypt Litter.*

Sharples, JJ, Weber, RO, McRae, RHD & Mills, GA. *Elevated Fire Danger Conditions Associated with Foehn-Like Winds in Eastern Victoria.*

WEB SITES

Two web sites are recommended:

Firstly the BushfireCRC web site holds information about the HighFire project:

http://www.bushfirecrc.com/research/highfire/highfire.html

Secondly there is web site dedicated to dissemination of the material arising from this research:

http://www.highfirerisk.com.au/