Proceedings of Bushfire CRC & AFAC 2013 Conference Research Forum

Monday September 2, 2013

Melbourne Convention & Exhibition Centre

Edited by L.J. Wright

Published by:

Bushfire Cooperative Research Centre

Level 5 340 Albert Street

East Melbourne 3002 Australia

Citation: L.J. Wright (Ed) 2013, 'Proceedings of Bushfire CRC & AFAC 2013 Conference Research Forum' 2 September 2013, Melbourne Australia, Bushfire CRC

Welcome from Editor

It is my pleasure to bring to you the compiled papers from the Research Day of the AFAC and Bushfire CRC Annual Conference, held in the Melbourne Convention & Exhibition Centre on the 2nd September 2013.

A key part of the conference, the Research Forum highlights the diversity of research being conducted across the sector. The extent of this diversity is demonstrated in the many different disciplines and topics provided in this volume. Topics covered include fire weather, community safety, smoke toxins, prescribed burning and a special discussion on the impacts of heatwaves. The papers also highlight the user driven nature of the Bushfire CRC research program and demonstrate the Research Forum is not just for scientists, but for all emergency management personnel and the wider researcher community.

Not all papers presented are included in these proceedings as some authors opted to not supply full papers, however collectively the work presented in the Research Forum reflects the breadth of the work being undertaken across the Bushfire CRC.

These papers were anonymously referred. I would like to express my gratitude to all the referees who agreed to take on this task diligently; this is an important and valued part of the scientific process but isn't without its challenges. I would also like to sincerely thank all those involved in the organising and conducting of the Research Forum which is truly a wonderful event and cannot go ahead without your contribution.

The full presentations from the Research Forum and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Lyndsey Wright

December 2013

Table of Contents

Table of Authors

ABSTRACT

'How do Residents in Bushfire Prone Areas View the Bushfire Risk of their Local Area and their Homes?'

This paper is part of a larger research project investigating people's perception of the bushfire risk of their own property. It analyses the 46 survey responses from residents living in Mount Wilson and Pretty Beach, NSW, Australia. It looks at two issues: resident's perception of the bushfire risk of their local area and their own property, and in response to this perception of the local bushfire risk, which parts of their home would they seek shelter in during a bushfire and which parts would they avoid. The paper concludes that: the residents' perception of risk did not match the NSW RFS determinations; the residents' perception of risk did not seem to correlate closely with the construction of their house but seemed to correlate more with the characteristics of their immediate environs; there were commonalities in the spaces residents suggested they would take shelter in their own house during a bushfire.

Brown, Douglas
Faculty of Architecture, Design & Planning
University of Sydney
Bushfire CRC PhD scholarship recipient
Email: douglas.brown@sydney.edu.au

INTRODUCTION

Australian bushfire case studies (Blanchi and Leonard, Bushnell, Woolcott, McLennan) have looked at resident's bushfire preparation activities, their behaviour immediately prior, during and post a bushfire event plus assessed damage to homes. This paper seeks to add new knowledge by considering the two issues that have not previously been addressed by these case studies. The first examines residents' perception of the bushfire risk of their local area and their own (individual) property. The second seeks to find out which parts of their homes residents would seek shelter during a bushfire and which parts would they avoid.

The paper investigated residents' perceptions by conducting a survey of residents of Mount Wilson and Pretty Beach, NSW, Australia. Of the 78 households in Mount Wilson, 28 completed the survey Of the 218 households in Pretty Beach, 18 completed the survey. These 46 responses from 296 households are part of a larger study undertaking between 2011 and 2012, where 175 responses were collected from eight villages with a sample pool of approximately 1,430 occupied dwellings (households) in either the Blue Mountains or the Central Coast of NSW, Australia.

The Study Sites

Figure 1: Map of Mount Wilson, Blue Mountains, New South Wales, Australia, showing streets.(NSW Government 2013)

Mount Wilson is surrounded by the Blue Mountains National Park. It does not have mains water or electricity. Access is limited and the population is approximately 300 with about 78 occupied dwellings.

Figure 2: Map of Pretty Beach, Central Coast, New South Wales, Australia, showing the streets.(NSW Government 2013)

Pretty Beach is a coastal village with a population of 533 people and 218 occupied dwellings. These figures include the neighbouring village of Hardy's Bay as the Australian Bureau of Statistics merge the two together as a single population (Australian Bureau of Statistics 2013). Pretty Beach experienced a bushfire one month before the survey was distributed. No property was damaged. Residents have access to a nearby Bay.

METHODS

The method used for data collection in both Mount Wilson and Pretty Beach was a survey made available electronically to residents on community email trees. There were 28 responses for Mount Wilson representing the 78 households. Pretty Beach returned 18 responses out of a potential sample of 217 households. The survey responses were collected electronically using the Survey Monkey software program. Data was analysed using Microsoft Excel 2010. This paper looks at the responses to seven of the 37 questions covered in the questionnaire. The individual questions and the responses are described in detail in the following two sections of the paper.

SECTION 1 Method

Resident's Perception of the Bushfire Risk of their Local Area and their own Property

This section addresses three questions related to residents' perception of their local bushfire risk: What is the resident's perception of the bushfire risk of their local area? How well do these perceptions match the bushfire risk as assessed by their state fire authority? What is the resident's perception of the bushfire risk of their own property? The following survey questions were used to test these issues:

- Question 6: How do you rate the risk of bushfire in this locality?
- Question 13: How do you rate the risk of bushfire to your current house?
- Question 14: Why do you give (your current house) that risk rating?

For both questions 6 and 13, the residents were required to select a response from the following options: Extreme; Very High; High; Medium; Low and Very Low. Question 14 asked why the residents gave that particular bushfire risk rating. Their responses were compared with the bushfire risk rating given for their area by the NSW Rural Fire Service, which is the state fire authority for all of New South Wales.

Supporting questions

To test the effect of previous bushfire experience and investigate whether residents in newer homes, which are more likely to be compliant with standards (Standards Australia 1999) / (Standards Australia 2009) and the Building Code of Australia (Australian Building Codes Board 2013) had the same or a different risk perception for their homes, the following questions were asked:

- Question 10: Have you ever experienced a bushfire that threatened the house you were living in? A Yes and No response box was given.
- Question 25: If known, in what year or decade was the house built? (e.g. '1962' or 1960s'). No response options were given.

SECTION 1 Results

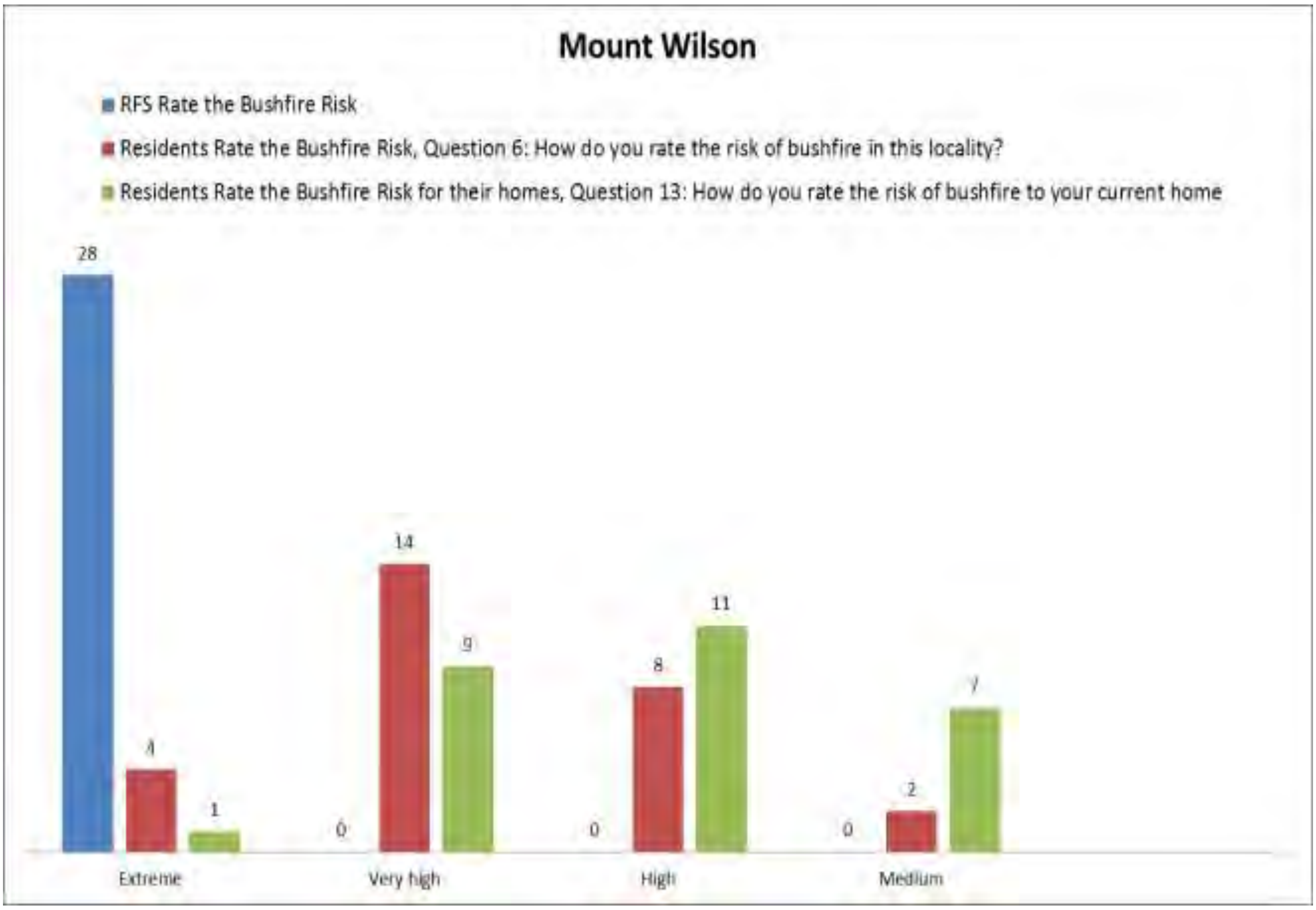


Figure 3: Comparison between the RFS Risk Assessment and survey respondents in Mount Wilson

NSW RFS Risk Rating for Mount Wilson

The NSW Rural Fire Service assesses the village of Mount Wilson as being of *Extreme* bushfire risk. It does this using the *Blue Mountains Bush Fire Risk Management Plan(NSW Rural Fire Service 2010),* map reference number 32, under the heading of Human Settlement/Residential for Mount Wilson/ Mount Irvine – Dispersed.

Mount Wilson Residents Responses

The majority of respondents rate the Mount Wilson area as having a *Very High* (14 out of 28) or *High* risk rating (8 out of 28) with only four agreeing with the RFS's risk assessment. When residents view the risk that their own homes present they perceive the risk as *High* (11 out of 28), *Very High* (9 out of 28) or *Medium* risk (7 out of 28). To understand why residents gave their answers to Question 13 (How do you rate the risk of bushfire to your current house?) which is represented by the green bar in Figure 3, we need to look at their responses to Question 14 (Why do you give the risk that rating?). The *High* category of risk received 11 out of 28 responses, nine focussed on the lack of a hazard reduction for years, proximity to the National Park, bushland, steep slopes and the closeness of trees to their homes, while only two of them made reference to their house ('Brick house on slab' & 'Old house with lots of gaps'). The *Very High* category was the next most popular with 9 out of 28 respondents. Eight respondents focussed on the surrounding areas and its proximity to the National Park, steep slopes and the anticipated fire threat direction, while only one respondent gave the construction materials of their house as the reason ('Double brick and brick veneer house with a tile roof on pine trusses'). The 7 out of 28 respondents who attributed the risk as *Medium* noted that they had engaged in bushfire preparation activities which included regularly mown grass, cleared areas around house, no overhanging trees and for two respondents, sprinklers with access to water tanks and generators. Finally the single *Extreme* risk respondent gave their reason as there being 'no hazard reduction for years'.

In response to having previously experienced a bushfire that threatened their home (Question 10), 8 out of 28 respondents from Mount Wilson answered yes. Six gave their current home a lower risk rating than the local area and two gave their home the same risk rating as the area. In response to what year or decade the house was built (Question 25), 6 out of 28 Mount Wilson homes were built after the year 2000, four of these attributed their risk rating to the surrounding area: slope; vegetation and proximity to the National park and only two to the new construction of their homes.

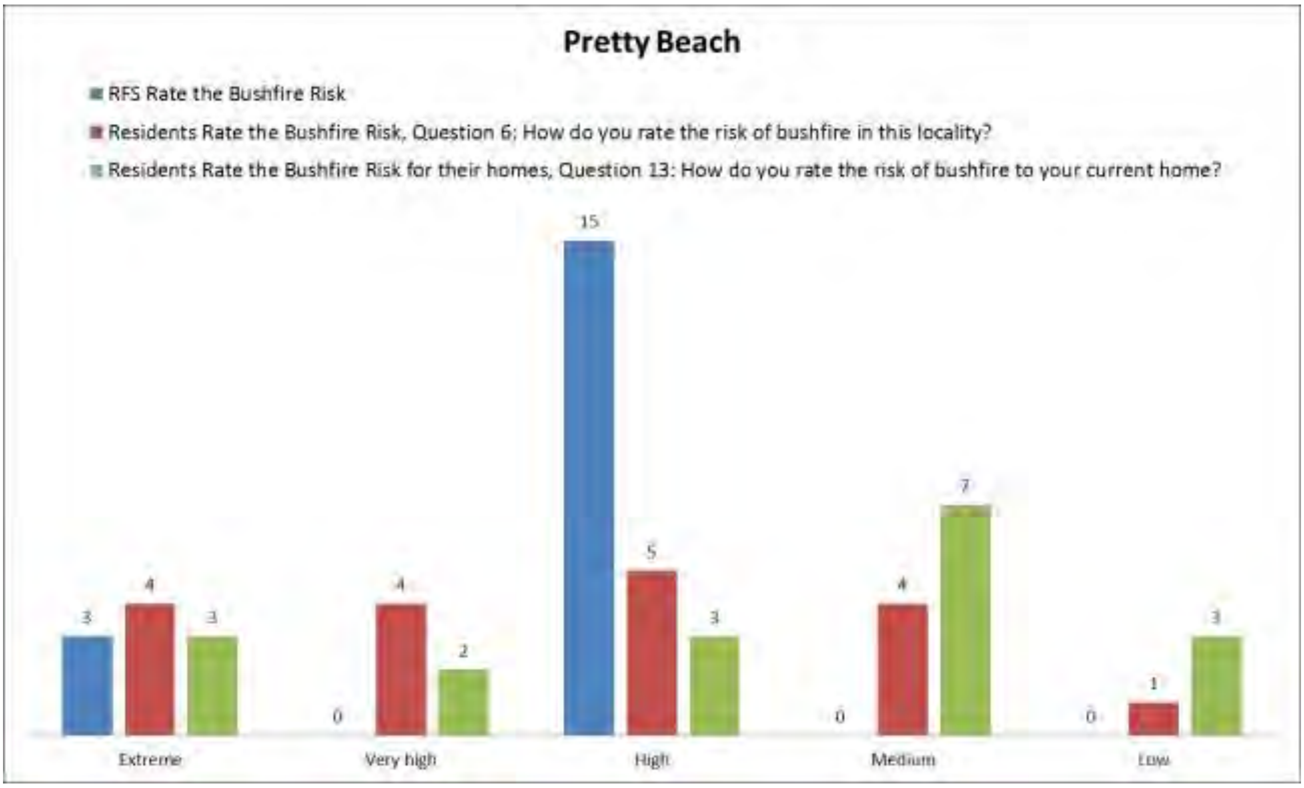


Figure 4: Comparison between the RFS Risk Assessment and survey respondents in Pretty Beach

NSW RFS Risk rating for Pretty Beach

The NSW Rural Fire Service assesses the village of Pretty Beach as primarily being of *High* bushfire risk, although it includes a few properties of being of *Extreme* risk. It does this using the *Gosford Bush Fire Risk Management Plan (NSW Rural Fire Service 2011)* map reference number 219, where it has been categorised as one residential asset along with its neighbouring villages of Hardys Bay and Wagstaffe (map reference number 85).

Pretty Beach Residents Responses

The way that residents rate the risk of bushfire in their area and to their home is generally spread across all five risk categories. For *Extreme*, *Very High* and *High*, residents view the risk to their homes as lower than the surrounding area but for the *Medium* and *Low* risk categories they view the bushfire risk to their homes as higher than the area in which they are located. For just the risk rating they attribute to their homes, the *Medium* risk rating had the highest number of responses (7 out of 18), with *Extreme*, *High* and *Low* each registering three responses. *Very High* had the lowest number of responses (2 out of 18).

As with our Mount Wilson example, to understand why residents gave their answers to Question 13 (How do you rate the risk of bushfire to your current house?) represented by the green bar in Figure 4, we need to look at their responses to Question 14 (Why do you give the risk that rating?). Four of the seven *Medium* responses cited not being damaged by the recent bushfire as their reason for giving this risk rating. Others gave their location as being a bit removed from bushland, with good vehicle access, largely surrounded by residential blocks and roads, or with an open space in the surrounding area. Neighbours with well watered and mown lawns were also mentioned. Only one respondent gave the construction of their home as the reason for attributing this risk rating. Two of the three *Extreme* responses gave reasons that directly reflected the recent bushfire; such as 'Because the fire came to within 5 metres of our house', while the third gave proximity to the National Park. Answers from the three *High* respondents were mixed: ranging from the risk they had received from the RFS, to the 2012 construction of their home and a range of reasons that highlighted the neglect of maintenance by neighbours and public ignorance potentially resulting in bushfires by visitors to the area. The three *Low* responses all gave factors relating to the immediate environs of the building but not the building construction elements, as the reasons for allocating this risk rating. Both *Very High* responses were in relation to the threat posed by bushland and the proximity to the National Park.

In response to having previously experienced a bushfire that threatened their home (Question 10), 9 out of 18 Pretty Beach respondents answered yes. Five of these gave the risk to their home as lower than the surrounding area and four gave it the same bushfire risk rating. In response to what year or decade the house was built (Question 25), 5 out of 18 Pretty Beach homes were constructed after 1999. Four made reference to the bushfire risk of the surrounding area with only one respondent attributing their risk rating as resulting from the material construction and new design of their home.

Discussion

When comparing the bushfire risk level residents gave their local area, for both Mount Wilson and Pretty Beach, it was either the same or one level lower than the bushfire risk they gave to their homes. This pattern is the same irrespective of what year the house was constructed or if residents had previously experienced a bushfire. There were two exceptions to this, one in Mount Wilson and one in Pretty Beach, where the risk was perceived as either two and three levels lower for their homes. Both lived in brick houses and both were renting. The Mount Wilson resident was on a 252 hectare property and presumably didn't have the issue of neighbours' overhanging trees. It appears that landscape and vegetation rather than the materials used in construction of the house determine residents' perception of the bushfire risk of their homes.

For residents in Mount Wilson the bushfire risk they allocated for their local area did not match the risk allocated for that area by the local state fire authority (NSW RFS). Half the respondents gave the next rating level down and a quarter the level below this. Pretty Beach respondents allocated the bushfire risk to their local areas almost evenly across five risk rating scales (from *Low* to *Extreme*) while the NSW RFS allocated it as either *Extreme* or *High.*

SECTION 2 Method

In Response to their Perception of the Local Bushfire Risk, which Parts of Their Homes Would Residents Seek Shelter in During a Bushfire and which Parts would they Avoid.

This section addresses the following issue: What parts of their homes and immediate environs impact on residents' perception of safety and vulnerability during a bushfire? The following survey questions were used to test this issue:

- Question 29: If you had to stay in your home during a bushfire, which part of the house will you take shelter in while the bushfire passes? Why there?
- Question 32: If you had to stay in your home during a bushfire, which part of your house would you avoid as the bushfire passes? Why there?

Both these questions were open ended; no options were provided.

SECTION 2 Results

Mount Wilson Responses

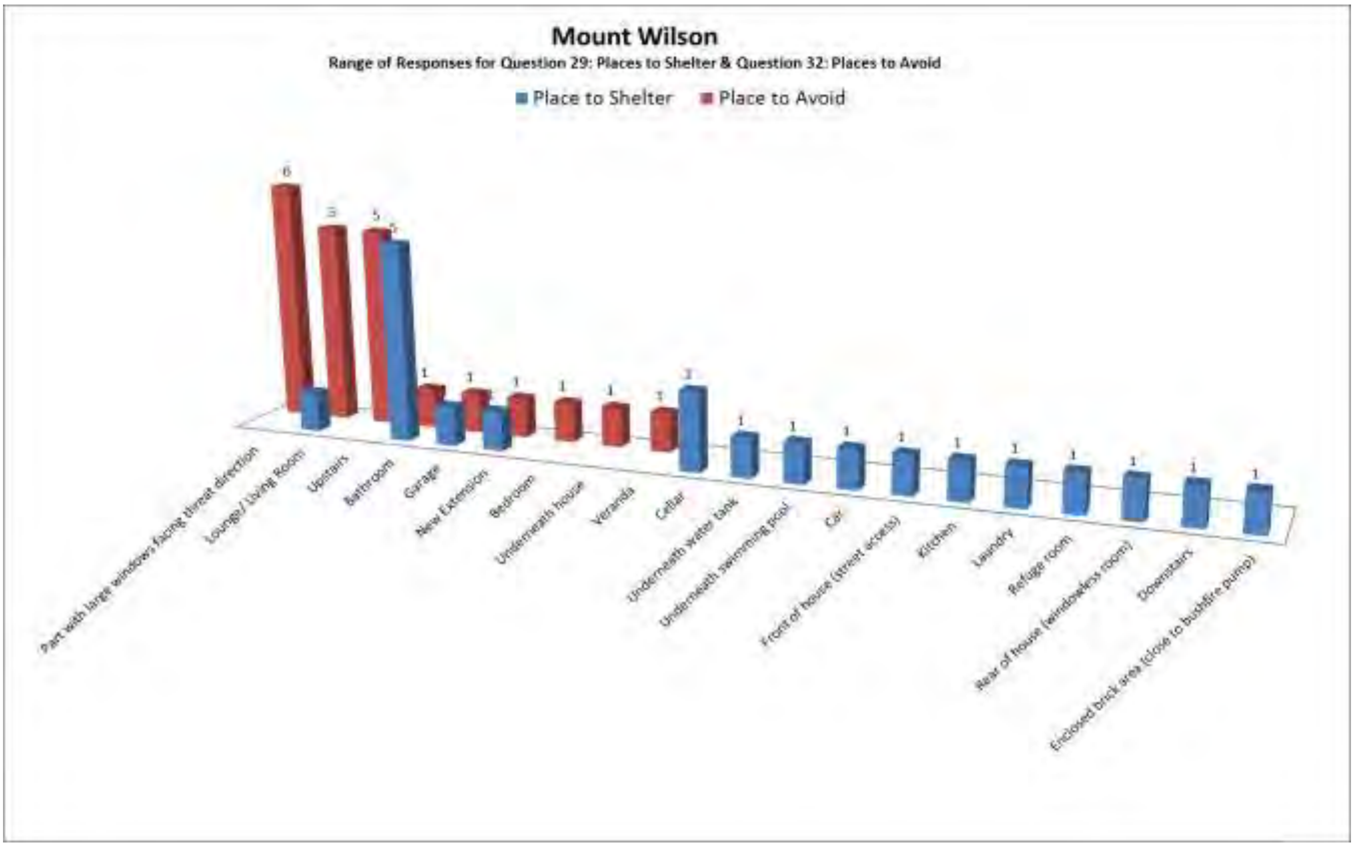


Figure 5: Mount Wilson - Range of Responses for Question 29: Places to Shelter & Question 32 Places to Avoid.

Within the Mount Wilson sample there are fifteen different types of response to Question 29 (If you had to stay in your home during a bushfire, which part of the house will you take shelter in while the bushfire passes? Why there?). The bathroom had the greatest number of responses (5 out of 28), although one respondent viewed the bathroom as a place to avoid. While with the garage and the new extention there was an equal distribution of those who viewed these places as either safe or vulnerable (1 out of 28 for both). For Question 32 (If you had to stay in your home during a bushfire, which part of your house would you avoid as the bushfire passes? Why there?), there were nine different types of response. The most popular was the category of avoiding any part with large windows facing the anticipated bushfire direction (6 out of 28). This was followed by the lounge/living room and upstairs (both have 5 out of 28 responses). The lounge/living room was also for one other respondent a place to shelter.

Pretty Beach Responses

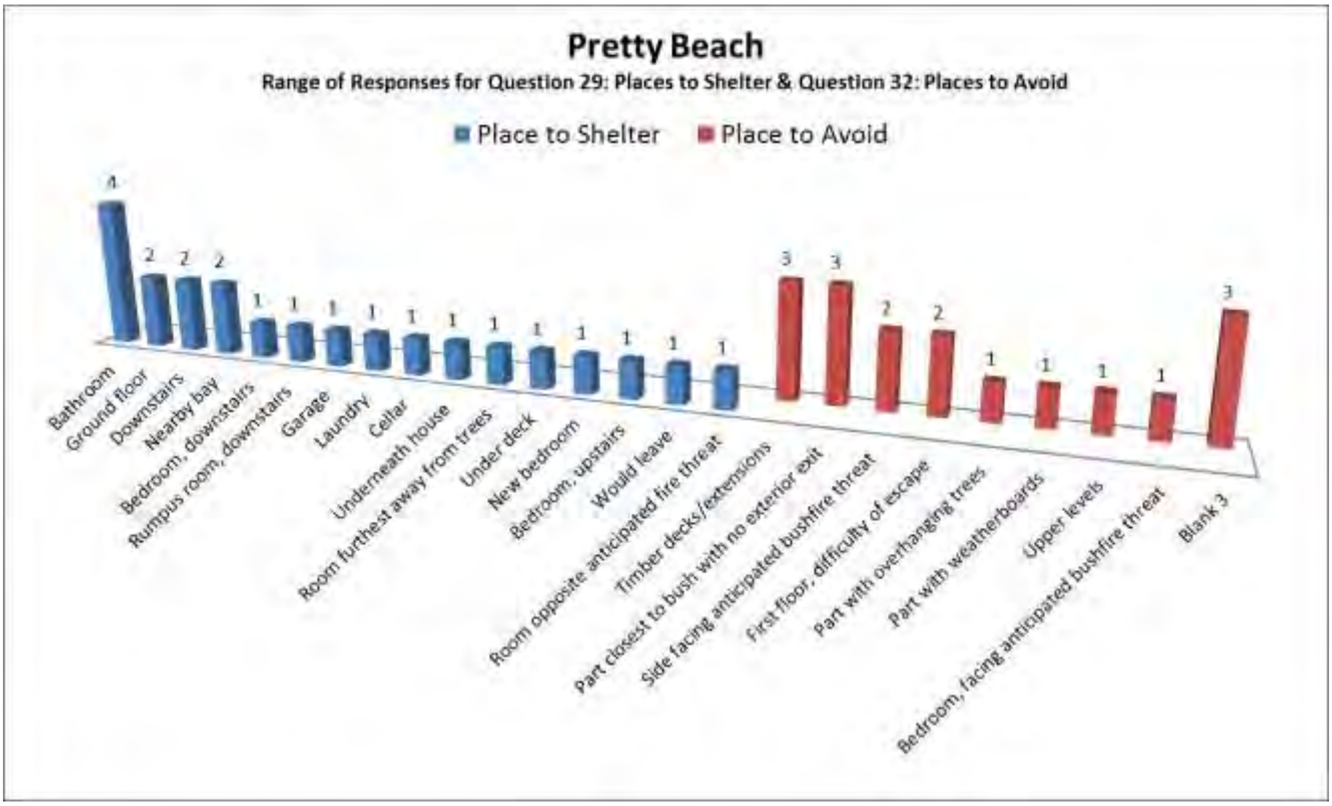


Figure 6: Pretty Beach - Range of Responses for Question 29: Places to Shelter & Question 32 Places to Avoid.

In the Pretty Beach responses to Question 29 (If you had to stay in your home during a bushfire, which part of the house will you take shelter in while the bushfire passes? Why there?) The section of the house that residents intended taking shelter in was given rather than specific rooms. Where rooms were identified it was in relation to the floor they were on and its proximity to the direction of the anticipated bushfire threat. The four bathroom examples illustrate this: bathroom (lower level); bathroom (middle of house); bathroom (level not given) and bathroom with external door. Similarly this occurs with the four 'downstairs' examples: downstairs (easy escape); downstairs bedroom (easy escape); downstairs rumpus room (adjacent to paved area) and downstairs. For Question 32 (If you had to stay in your home during a bushfire, which part of your house would you avoid as the bushfire passes? Why there?) The places residents intended to avoid during a bushfire were mainly the parts of their house exposed to the anticipated direction and threat from bushfires. Upper levels were perceived as places to avoid as they were considered more difficult to escape from.

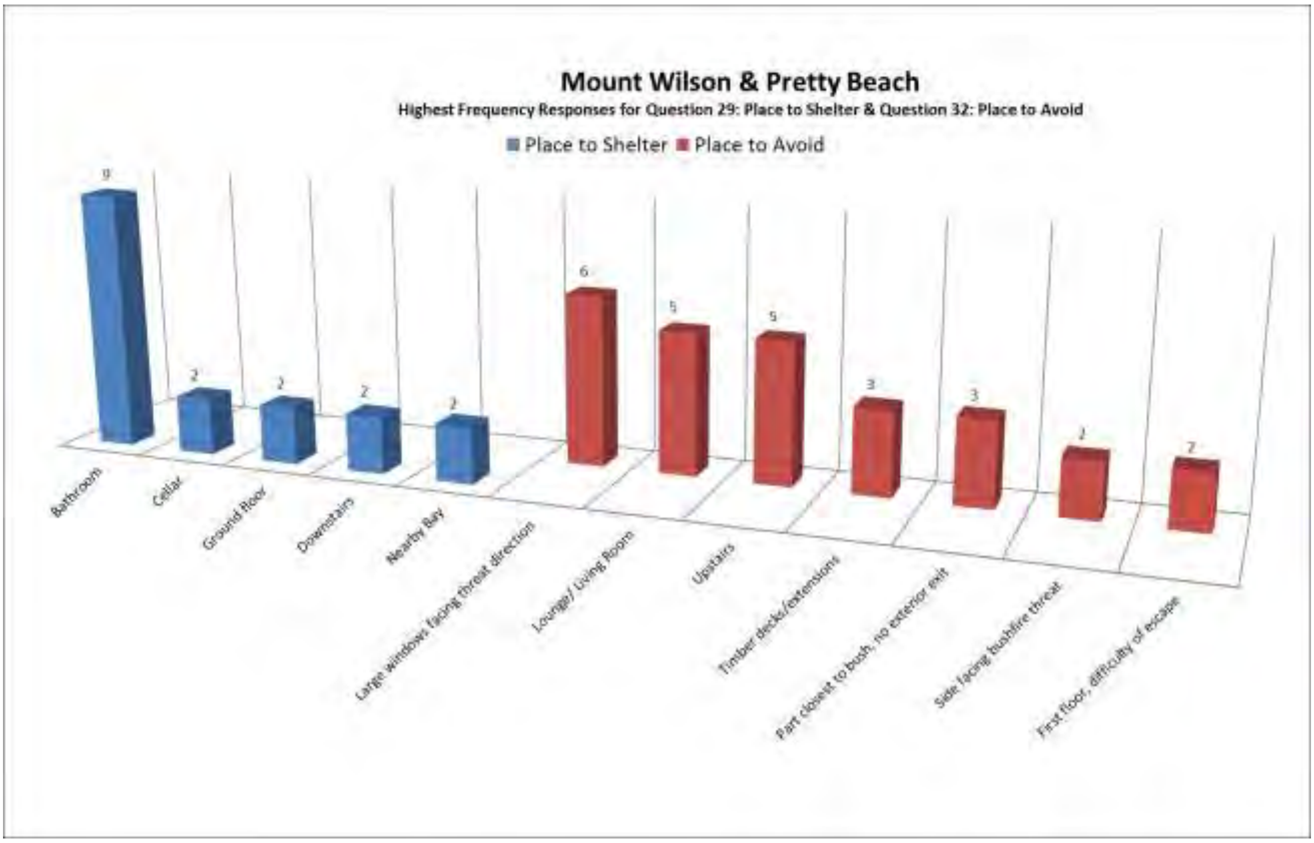


Figure 7: Summary of Highest Frequency responses for both Mount Wilson and Pretty Beach

Discussion

When individual responses with frequencies of two or more, for both ‘Place to Shelter & Place to Avoid’, for both Mount Wilson and Pretty Beach are represented (see Figure 7), the following findings appear. The most popular place to shelter was the bathroom (9 out of 46). The cellar, ground floor, downstairs and nearby ocean all had the same response rate (2 out of 46). The range of responses for ‘place to avoid’ was greater with seven different responses. The most popular response was the part of the house with ‘large windows facing the anticipated bushfire threat direction’ (6 out of 46). The lounge/living room and upstairs each had 5 out of 46 responses. Timber decks/extensions and the part closest to the bush each had 3 out of 46 responses and the side of the house facing the bushfire threat and the first floor each had 2 out of 46 responses. Lower or ground levels were favoured as places to shelter during a bushfire while upper levels were perceived as places to avoid as they were considered more difficult to escape from.

CONCLUSION

Residents living in Mount Wilson and Pretty Beach give their area a lower bushfire risk rating than their state fire authority. When allocating the risk rating to their own homes they either matched the risk rating they had allocated to their area or gave it the next lowest ranking. There were two exceptions to this, one in each location. The residents in each case were renting and lived in brick homes. There was no difference between the way that residents living in recently constructed homes (presumably AS 3959 compliant) versus those living in older homes attributed the risk to their homes. It was not the materials used in the construction of their homes that residents used to ascertain the bushfire risk of their home; rather it appeared to be factors in the surrounding area. These factors included slope, proximity to bushland and the direction of the anticipated bushfire. While there was a large variety of answers for the parts of their house respondents would seek shelter in during a bushfire, the bathroom was the most popular with a number of others focussed on the ground floor to facilitate escape. Places to avoid could be categorised as falling into three groups: spaces with large amounts of glass; upstairs spaces (limited escape) and parts/sections closest to the direction of the anticipated bushfire threat. For many residents of Pretty Beach surviving the recent bushfire was a strong factor and appears to have masked the potential protection the nearby ocean could provide as an escape option during a bushfire event.

REFERENCES

Australian Building Codes Board (2013). National Construction Code series : guide to volume one : Building Code of Australia. Class 2 to Class 9 Buildings. Canberra, A.C.T, Australian Building Codes Board.

Australian Bureau of Statistics (2013). "2011 Census data." from http://www.abs.gov.au/websitedbs/censushome.nsf/home/Census?opendocument#from-banner=GT.

Blanchi, R. and J. Leonard (2005). Investigations of bushfire attack mechanisms resulting in house loss in the ACT bushfire 2003. Melbourne, Australia, Bushfire CRC: 3–6.

Bushnell, S., A. Cottrell, et al. (2006). Thuringowa Bushfire case study - technical report, School of Tropical Environment Studies and Geography, James Cook University: 127.

McLennan, J. D., P. Kelly, L. Elliott, G. (2011). Lake Clifton Fire 10 January 2011: Field Interview Task Force Report - Community Bushfire Safety. Melbourne, Victoria: 38.

NSW Government (2013). SIX (Spatial Information Exchange) Maps, Land & Property Information, NSW Government

NSW Rural Fire Service (2010). Blue Mountains Bush Fire Risk Management Plan (Approved 17/09/2010). Blue Mountains Bush Fire Management Committee (Policy No.1/2008), NSW Rural Fire Service 97.

NSW Rural Fire Service (2011). Gosford Bush Fire Risk Management Plan (Approved 18 July 2011). Gosford District Bush Fire Management Committee (Policy No.1/2008), NSW Rural Fire Service: 70.

NSW Rural Fire Service and Woolcott (2010) NSW Rural Fire Service: bush fire readiness study report 2010. 67 slides

Standards Australia (1999). AS 3959-1999 (Incorporating Amendments Nos.1). Construction of buildings in bushfire-prone areas. Sydney, Australia, Standards Australia International: c35.

Standards Australia (2009). AS 3958-2009 (Incorporating Amendment No.1-3) Construction of buildings in bushfire-prone areas. Sydney, Australia, Standards Australia: c190.

Fire authorities and planners: reducing risk across diverse landscapes

Jessica K. Weir

University of Canberra; University of Western Sydney

Abstract

Bushfire risk mitigation measures have become increasingly integrated into the responsibilities held by planning professionals, and this is indicative of a broader trend of emergency management responsibilities being formally adopted by other sectors. This paper considers how the integration of bushfire risk into urban and regional planning is being grappled with across four landscapes and jurisdictions in Australia. The paper draws on four focus groups held between fire authorities and planners in the Australian Capital Territory, Victoria, New South Wales and the Northern Territory. The research reveals the common challenges of this work, and instances where innovation is occurring between fire authorities and planners. However, it remains that there is no straightforward 'planning solution' for reducing bushfire risk.

Introduction

Fire authorities, planners, forestry officials and formal bushfire inquiries all identify land use planning as both cause of, and solution to, bushfire risk (Bosomworth 2011, p.144; Ellis et al. 2004, p.79; Bihari et al. 2012, p.4). However, properties continue to be built in high bushfire risk locations (Hughes and Mercer 2009, p.126; Buxton et al. 2011, p.7; Stephens and Collins 2007, p.34). The risk mitigation priorities of fire authorities are frustrated by planning decisions that increase bushfire risk, and thus also increase the likelihood of an emergency event requiring their response. Whilst 'shared responsibility' for bushfire risk across sectors and between citizens and governments is the new policy rhetoric (McLennan and Handmer 2013), the emergency management authorities are the ones who are interrogated by the public, the media, the judiciary and others in the cycles of blame and inquiry that follow large bushfires (Ellis et al. 2004).

On the other hand, planners must consider bushfire risk in relation to prioritising and regulating a diversity of economic, social and environmental priorities, including transport, housing availability and affordability, infrastructure, amenity, sustainability, community services and cohesion. Planners receive pressure from politicians, developers, landowners and others to make inclusions or exclusions to plans and planning regulations (Bihari et al. 2012, p.4). Local councils are influenced by the income they receive from development to maximise the number of homes sited in a subdivision, thereby leaving less room for bushfire risk reduction measures. When enforcing bushfire risk regulations, planners must consider how they might be challenged in court by property owners, with consideration given to the common law tradition of protecting individual property rights and freedoms (Hughes and Mercer 2009, pp.125-6; Kelly 2010, p.49).

Many planning decisions do place fire authorities and planners at odds, however it is also true that they are strategizing on innovative solutions. Indeed, fire authorities are employing planners in house, and planning authorities are employing staff with fire expertise. This was reflected in the career paths of some of the research participants in this study, who had transferred from local government positions to the fire authorities, and vice versa. This integration of bushfire risk reflects the heightened priority it is receiving in policy, as well as the emergency management trend to broaden its activities out from just the risk event (Handmer and Dovers 2013, p.12).

Methodology

This paper draws on focus group research that was conducted between August and December 2012 by the University of Canberra, as part of a larger project on “Mainstreaming Fire and Emergency Management across Legal and Policy Sectors”, for the Bushfire Cooperative Research Centre. Four focus groups were convened with public officials to talk about different aspects of the integration of bushfire risk into planning. The aim was to explore the challenges and opportunities of their work across four different jurisdictional and landscape contexts.

Focus groups are a qualitative research methodology that brings together a group of people to discuss a topic for one or two hours, usually in a semi-structured facilitated format with set questions as a starting point. Focus groups enable:

- In-depth group discussion between participants who have either a shared concern, or a shared experience;
- Facilitated discussion on a topic with one or more moderators; and,
- Interaction between participants to explore and clarify points of view between each other (Liamputtong 2011, p.5).

This group discussion takes the focus away from the researcher. In the intra-group interaction, ‘accounts are articulated, censured, opposed, and changed through [the] social interaction’, reflecting ‘peer communication and group norms’ (Kitzinger 2005, p.58). However, the group setting can also mean that some participants may dominate, that others may conform, and that personal information is not revealed (Liamputtong 2011, p.8).

For this project, the main focus group participants were the fire authorities and planners from local and regional organisations, however also represented were foresters, a weeds manager, parks, and occasionally officials involved in climate change, sustainability and economic development at the state/territory level. Public officials were selected for both their expertise and their professional role, and individuals were identified through advice given by industry partners at each location (listed below), as well as consultation with the local municipal authorities. The focus groups were limited to fourteen participants. To manage the research scope, elected officials, the community and the private sector were excluded.

Each focus group was situated in a different jurisdictional and landscape context:

- The first focus group was held in the Australian Capital Territory (ACT) in partnership with the ACT Rural Fire Service, and considered the new residential subdivision of Molonglo. Molonglo is on the bushfire prone western edge of Canberra, adjacent to national parks and mountains.
- The second focus group was held in the Northern Territory (NT) in partnership with Bushfires NT and considered the issues facing the Litchfield Shire Council area which includes the growing complexity of peri-urban Darwin. Marked wet and dry seasons facilitate annual fuel growth on the monsoonal savannah woodlands, as well as water logged lands.
- The third focus group was held in New South Wales (NSW) in partnership with the NSW Rural Fire Service, and considered the two neighbouring shires of Shoalhaven and Eurobodalla. This is a mountainous coastal area in southern NSW, with steep forested slopes leading to flat coastal floodplains.
- The fourth focus group was held on the Mornington Peninsula, Victoria, in partnership with the Victorian Country Fire Authority. This narrow coastal peninsula on the edge of Melbourne has a complex urban-bush landscape with coastal towns and rural land use.

The four focus group locations provided a diversity of bushfire risk experiences and regulatory schemes, and the opportunity to compare experiences between northern and south eastern Australia. South eastern Australia has the higher bushfire risk with more intense bushfires and a more complex urban-bush interface, whereas in the Northern Territory bushfire risk is increasing in part from African fire weeds and growing land use complexity. The ACT, NSW and Victoria all have detailed regulatory schemes for bushfire risk and planning, with accompanying guides for community and government use (NSWRSF 2006; ACT Government 2009a; ACT Government 2009b; ACT Government 2009c; CFA 2012). The Northern Territory has a less prescriptive bushfire and planning risk scheme, with legislative provisions and a short guide on landholder responsibilities (CFA 2013), but no comprehensive law, policy or other direction on the integration of bushfire risk and planning.

In each of these four locations the focus group participants were asked the same six questions about integrating bushfire risk into urban and regional planning, and these were: what are we doing well; what are we not doing well; why – what are the barriers to doing better; is integrating bushfire risk into urban and regional planning important; what is the influence of climate change on this work; and, what are your priorities for this research project? Participants made their contributions anonymously, albeit in front of their colleagues.

Planning was described to the focus group participants as ‘urban and regional planning’ and as including ‘land use planning’ in relation to bushfire risk. This encompasses diverse planning methods, from strategic planning which sets the planning agenda; statutory planning which creates the structures for practice; and management practice which interprets and implements the planning regulations. Discussion in the focus groups usually kept to these planning topics, however the discussion would flow into other related issues, and planning was interpreted more broadly by some public officials who were not planning professionals.

Focus Group Results

The results from the focus groups were summarised under each question and then compared and analysed across the four jurisdictions to draw out the key issues and themes. The results are grouped under three interrelated themes: biosocial risk context; governance; and, management. For the purposes of this paper the most salient results from each of these themes will be summarised.

It is worth noting that each focus group had its own distinct dynamic. For example, in Litchfield Shire Council, the discussion was very energetic and participants expressed the value of taking time out to meet with each other. Whereas in the ACT, the participants had already met over 100 times to discuss planning for Molonglo, although afterwards many participants commented that it was cathartic to talk more broadly and without having an agenda to push. In all focus groups bushfire risk was acknowledged as a very serious matter. It was the question of how to manage this risk in urban and regional planning, particularly the effectiveness of the methods employed and the pressure of other objectives, that revealed the complexity of the issues faced across different participant experiences.

Biosocial risk context

A dominant theme across the focus groups was the prevalence of different perceptions of risk held, and how this fundamentally affected the work of the agencies. For example:

> *Our first challenge that we've had is just simply saying, "Bushfire is a constraint on land use planning." If you don't buy into that, you're not going to buy into any of the responses. … [It's been] a massive step change in the last two or three years.*
> Focus Group Participant, Mornington Peninsula, 14 December 2012

> *Planning for a long time has said 'you don't build on flood affected land'…. Whereas [with] bushfires, we haven't got that same mentality or view in the community. With bushfires, we are expected to prevent the risk or manage the risk.*
> Focus Group Participant, Shoalhaven-Eurobodalla, 8 November 2012

> *There are risks not just in terms of the physical fire exposure, it's the ecological values that are present.*
> Focus Group Participant, Molonglo, 16 August 2012

> *Our level of concern about the risk isn't keeping pace with the changes in that population and the way that area is being developed.*
> Focus Group Participant, Litchfield Shire Council, 19 October 2012

In each risk and regulatory context, participants grappled with this fundamental issue of how to live with and value bushfire risk, and regularly brought the wider societal and environmental context into the discussion. Planners often played a pro-active role in this, bringing in other risks or priorities that they are required to consider. For example, in the Litchfield Shire Council focus group, the fire authorities discussed the bushfire risk consequences of new urban growth settlements being placed in previously semi-rural areas. This urban growth challenge to emergency service practice is occurring at the same time as bushfire intensity is increasing from weeds such as gamba grass. However, towards the end of this discussion one of the planners explained how the urban design was intended to reduce fresh water consumption so as to protect the underground aquifer which is at risk of saltwater intrusion, even more so with sea level rise. The planner was establishing the importance and validity of their decision making process, even though one of the consequences has been a more complex bushfire risk mitigation landscape.

Governance

Governance concerns, including law, policy and regulation, formed the bulk of the participant responses. Participants in the Litchfield Shire Council focus group appreciated the flexibility of their less prescribed regulatory scheme, whilst focus group participants from south eastern Australia appreciated the guidance of their policy and other documents. In describing their governance roles, the planners and fire authorities revealed how they were strategizing to find solutions for integrating planning objectives with bushfire risk, including: the strategic location of settlement and subdivisions, access roads, space for additional asset protection, formal zoning for asset protection activities, site specific requirements for houses, and community engagement.

In the Shoalhaven-Eurobodalla focus group, both the planners and the fire authorities noted that developers who had allowed for land for riparian zones and threatened species legislation, but did not also consider bushfire risk, were caught out when asset protection zones required fuel reduction on these ecologically sensitive lands, thereby undermining the development application as a whole. One planner blamed the bushfire legislation for this problem, but was corrected by others who identified the problem as the failure to include bushfire risk at an earlier stage of development.

Including bushfire risk at an earlier stage of development is happening on the Mornington Peninsula, where addressing bushfire risk in bushfire prone areas is now a mandatory part of planning:

> *In the past, fire was too hard, conservation was too hard in terms of trying to balance the two out. But, now, because it's become quite pointed, there's a much better understanding of each department within council's role of how they plan that space between balancing bushfire and conservation and trying to come to practical solutions.*
> Mornington Peninsula, Focus Group participant, 14 December 2012

For example, synergies are being found with respect to the siting of buildings on large properties:

> *More often than not, there's actually an alignment between bushfire and conservation. … The most appropriate location [of the house] for bushfire [risk] is the most appropriate location from an ecological point of view as well because it's usually the most disturbed part of the site.*
> Mornington Peninsula, Focus Group participant, 14 December 2012

The focus group participants also identified slashing weed growth as an important activity with win-win outcomes for both ecological and bushfire risk objectives.

In Shoalhaven-Eurobodalla, the participants discussed the role of strategic planning in better addressing bushfire risk and environmental objectives. Instead of incrementally spreading into areas of high environmental value and increased bushfire risk, and thereby compromising both, some planners argued for "sacrificing" one area for development and then "offsetting" this with another area for conservation, as is possible under New South Wales planning instruments. However, participants then raised the difficulty of choosing whose land gains the development windfall, and whether it is okay to offset development on private land with conservation on public lands? The planners did report on an example where they researched and worked through these issues so as to take such a strategic approach, but it was rejected by the council reluctant to reserve any land from development.

In Molonglo, the ACT government is the sole land holder and focus group participants reported that this has made it easier to integrate and coordinate across issues. Focus group participants presented on how they had comprehensively mapped and formalised bushfire risk and ecological values, and consulted with stakeholders, to make careful planning decisions. Even so, one participant noted that the amendments had reduced Molonglo to two-thirds of its original size and with a lengthier perimeter. Amendments to the original design were necessary because it had a poor understanding of the approach of Federal and Territory environmental protection laws (pers. comm. Andrew Mackenzie). Further, the focus group discussed how detailed environmental research about the site, conducted after the strategic planning process, reduced the design options. In this instance, the planners' responsibility to balance multiple values and regulatory schemes led to a decrease in housing availability and an increase in exposure to bushfire risk. Other planning contributions, such as the provision of water storage ponds along the river corridor, were mentioned as design elements that addressed some of the bushfire risk as well as matching with environmental priorities.

Management

Specific management treatments were usually brought up by focus group participants in the context of governance issues, with discussion held on logistical difficulties, the effectiveness of certain methods, funding issues, and the role of new information and technologies. The fire authorities from the Litchfield Shire Council focus group suggested planning could assist with the inclusion of better access for bushfire risk mitigation activities in subdivision design. They also discussed how access to water logged areas could be improved by building rock roads, or purchasing mulchers on skid steers, although both are expensive measures. A planner from the Shoalhaven-Eurobodalla focus group identified financial constraints as challenging the application of bushfire regulations not originally considered as part of a subdivision. They discussed a subdivision approved in the 1990s which made allowances to protect riparian vegetation, but the land for housing is now mapped as an asset protection zone. The blocks of land are currently for sale for $120,000, and the planners have been advised that an extra $80,000 in building costs is required for bushfire risk treatments to comply with the guidelines (NSWRFS 2006).

There was a lot of discussion in all the focus groups about the use of new technologies and information, such as mapping methods, aerial photographs, research, and more in-house agency expertise. There was also a strong demand for much more information. A Molonglo focus group participant requested that a GIS scenario plan was needed as a decision support tool that balanced the trade-offs and objectives of land management with socio-economic priorities. This was countered by another focus group participant who noted that there are important value judgements in such decisions that cannot be modelled.

Planning as 'solution' for bushfire risk

The experiences raised by the Mornington Peninsula focus group participants provide a unique insight to the potential of planning as 'solution' for bushfire risk. Land use planning was a central focus of the Victorian Bushfire Royal Commission (Teague et al. 2010), and the principal of the 'primacy of life' in strategic measures as well as mandatory provisions now ensure planners address bushfire risk. The focus group participants discussed how their systematic engagement with planning has been very productive, but, the participants also very clearly reported that planning regulations can only do so much:

> *We're using planning to fix the problem, rather than saying, 'Let's address the hazard.' And then when we want to develop, planning will make sure development is appropriate. We're not addressing the hazard until a planning application has come in.*
> Mornington Peninsula, Focus Group participant, 14 December 2012

There are reforms across the planning spectrum, but it many of the focus group participants were responsible for addressing the mandatory provisions for development applications and subdivisions. As stated above, this has produced results, however for these participants it has also concentrated bushfire risk mitigation to just one point in time and on one place on the map. The focus group participants reported there were key constraints with this standard – it is largely blind to ongoing compliance, to the activities of neighbouring landholders, and to the legacy of previous planning decisions. In addition, the participants reported that the importance of these mandatory provisions has led to some expectations in the community that bushfire risk was being adequately addressed. However, they emphasised that there were still many other matters that needed addressing across society as part of shared responsibility for bushfire risk, as well as the continuing uncertainty and dynamism of bushfire risk.

The focus group results revealed that expecting planning to be a straightforward technical managerial solution to 'self-evident' problems, such as bushfire risk, is unrealistic (Gleeson 2012). Planning is a professional expertise, but it is one that is steeped in the influence of socio-cultural values and norms, power structures, and their interplay with the landscape. The potential of bushfire aware planning fundamentally rests on how risk is perceived and prioritised in society, including the influence of dynamic factors such as climate change, seasonal change, and destructive bushfire events. The focus groups revealed that rather than planners and the fire authorities being at odds over bushfire risk, they are both grappling with responsibly addressing a risk whose sway and effects extends far beyond their job description.

Acknowledgements

I thank the focus group partners for their invaluable assistance with organising the focus groups, as well as for their contributions as focus group participants: the ACT Rural Fire Service, Bushfires NT, the NSW Rural Fire Service and the Victorian Country Fire Authority. I thank all the focus group participants for the time they gave to this research project, in many cases travelling substantial distances to attend. I also thank Barbara Norman for chairing the focus groups, and Lyndsey Wright for her support with documenting the focus group responses. All errors or omissions remain my responsibility. This research was funded by the Bushfire Cooperative Research Centre.

References

ACT Government 2009a, Strategic Bushfire Management Plan for the Act: Version 2, Canberra.

ACT Government 2009b, Strategic Bushfire Management Plan for the Act: Factors Contributing to Bushfire Risk, Supporting Information Part 1, Canberra.

ACT Government 2009c, Strategic Bushfire Management Plan for the Act: Bushfire Policy and Management Framework, Supporting Information Part 2, Canberra.

Bihari et al 2012 Understanding the Role of Planners in Wildfire Preparedness and Mitigation, *ISRN Forestry*, (2012):1-12.

Bosomworth, K. Adaptive governance in fire management: Exploring the role of bureaucrats in reflexive learning, PhD Thesis, RMIT University.

Buxton, M, Haynes, R, Mercer, D and A Butt. 2011, Vulnerability to Bushfire Risk at Melbourne's Urban Fringe: The Failure of Regulatory Land Use Planning, *Geographical Research*, 49(1): 1-12.

CFA (Country Fire Authority) 2013 Planning for Bushfire Victoria: Guidelines for Meeting Victoria's Bushfire Planning Requirements, CFA, Melbourne.

Ellis, S, Kanowski, P and Whelan, R, 2004, National Inquiry into Bushfire Mitigation and Management, Council of Australian Governments, 31 March 2004, Commonwealth of Australia.

Gleeson, B. 2012 'Make No Little Plans': Anatomy of Planning Ambition and Prospect, *Geographical Research*, 50(3): 242-255.

Handmer, J and S Dovers, 2013. *Handbook of Disaster Policies and Institutions: Improving emergency management and climate change adaptation*, Earthscan from Routledge, New York.

Hughes, R and D Mercer 2009. Planning to Reduce Risk: The Wildfire Management Overlay in Victoria, Australia, *Geographical Research*¸47(2): 124-141.

Kelly, K. 2010, PIA Policy Response to the Victorian Bushfires of February 2009, *Australian Planner,* 47(1): 48-51.

Kitzinger, J, 2005, 'Focus Group Research: using group dynamics to explore perceptions, experiences and understandings', in Holloway I. (ed.) *Qualitative Research in Health Care*, Maidenhead, Open University Press, pp.56-61.

Liamputtong, P. 2011 *Focus group methodology: Principles and practice.* Sage Publications, London.

McLennan, B.J., and Handmer, J.H., 2013, Sharing responsibility in Australian disaster management, RMIT University & Bushfire CRC, Melbourne.

NSWRFS (NSW Rural Fire Service) 2006, Planning for Bush Fire Protection, New South Wales Rural Fire Service.

Paterson, R.G. 2007, 'Wildfire Hazard Mitigation as 'safe' Smart Growth', in Troy, A and R.G. Kennedy (eds) *Living on the Edge*, Advances in the Economics of Environmental Resources, Volume , Emerald Group Publishing, pp.43-71.

Stephens, S.L and B.M. Collins 2007. 'Fire Policy in the Urban-wildland Interface in the United States: What are the Issues and Possible Solutions?', chapter in Troy, A and R.G. Kennedy (eds) *Living on the Edge*, Advances in the Economics of Environmental Resources, Volume , Emerald Group Publishing, pp.33-42.

Teague, B., McLeod, R., Pascoe, S., 2010, '2009 Victorian Bushfires Royal Commission: final report.', State of Victoria, Melbourne.

Acknowledging structural variances of communities to aid in communicating risk information

Sondra Dickinson

The University of Melbourne, Bushfire CRC

Given the serious risk that bushfire poses to Australian communities, an understanding of how people mobilise social networks as resources for dealing with the threat of bushfire is crucial. Social networks as an object of study constitute the pathways through which people offer and obtain information, forge relationships and engage in pursuits or interactions. These networks indicate ways people are able to process and share significant information, thus highlighting avenues for safety agencies to best reach target audiences and effectively provide emergency services.

The primary focus of this paper centres on methods to communicate future risks, by discussing two outcomes of combining applied anthropological methods with the discipline of Emergency Management. Using field data obtained from a comparative ethnography conducted in two different Victorian (AU) regions, these outcomes include:

1) evidence of network constructions in bushfire-risk areas that are highly influenced by elements of physical and social landscapes, and

2) presentation of insights on selection processes that influence how people (in these particular landscapes) are able to share, receive, and importantly, accept, different types of information.

These outcomes indicate the significance of assessing at-risk areas independently, as social landscapes will differ in construction despite similarities or differences in physical environments.

Introduction

Ah, “risk”. A term that can be applied to a variety of settings, contexts and magnitudes, yet suggests one overarching certainty – there exists a looming problem, which may, one day, need to be addressed in order to mitigate a negative impact (Blaikie et al., 1994; Douglas and Wildavsky, 1983).

With all the potential for “risk” that exist in our lived environments, how do Emergency Managers communicate the gravity of potential risks, and discuss the most appropriate mitigation methods available (Beer et al., 2004; Clarke and Short, 1993; Caplan, 2000)? This paper addresses the very issue by discussing two outcomes of combining qualitative, applied anthropological methods with the discipline of Emergency Management. These methods include a comparative ethnography, where qualitative data was collected through the use of semi-structured interviews and participant observation. Utilising comparative, qualitative research assists technical and applied disciplines with understanding social behaviour in different settings, providing insights into how people experience and interact with the environments around them (Ely et al., 1997; Goetz, 1981; Ritchie and Spencer, 1994; Silverman, 2004). The following discussion presents the significance of acknowledging structural variances of community networks, which suggests that social landscapes will differ in construction despite similarities or differences in physical environments. Using this approach demystifies the issue of how to communicate risks by eliminating the idea that Emergency Management occurs in a vacuum, set apart from ongoing social processes (Buckle, 2001; Head, 2007; Houghton et al., 2006). Communication is an animated practice that evolves with the surrounds, and as such, is an empirical process that should be addressed with a flexible approach. It is as fluid and unique as the people we meet, and most effective when social variables are taken into account. Though the fundamental complexities involved in such an adaptive approach are likely to be many, I recognise the need for Emergency Managers to create standards for quality control. However, it is imperative that aspirations for standardised approaches should not overshadow the latitude necessary for a range of fluid approaches (Betts, 2007; Walia, 2008).

The methods for analysis included using field data obtained from a comparative ethnography conducted in two different bushfire-risk regions in Victoria, Australia. The dual outcomes of this component of the research study focus on: 1) evidence of network constructions in bushfire-risk regions that are highly influenced by elements of physical and social landscapes; and 2) presentation of insights on selection processes that influence how people, in these particular landscapes, are able to share, receive, and importantly, accept, a myriad of information from others. These outcomes address what I consider to be structural variances of communities, which are differences in the ways social networks are structured, and how these structures are influenced or utilised (Huber, 2012; Vayda, 1983). Significantly, researching structural variances discerns the multitude of vital and influential impacts that social networks can have on the way people position themselves relative to environments.

Commencing with the first outcome involving network constructions, I present two key social landscape characterisations that arose from the field, where comparative, regional-level analyses provided examples of relationships observed in these areas. These characterisations establish a foundation for discussing what it means to be “connected” within and across such varied social landscapes. Unique differences have assisted with the comparison of the two areas, allowing for the examination of each to develop as a region of "fractures" or a region of "enclaves", respectively. As this paper focuses on the types of network connections established in these social landscapes, detail on how to analyse character landscapes is not as essential to this discussion as is emphasising the more critical import of defining *selection* (Site One fieldnotes: 10 August, 2010 - 30 January, 2011; Site Two fieldnotes: 16 March, 2011 - 20 August, 2011).

The process of selection is how people become a recognised part of a particular social landscape (Bogenhold, 2013; Dijkstra et al., 2013; Lennon et al., 2012; Morrill et al., 2007; Steglich et al., 2010). Stated plainly, selection defines how people become engaged with one another, and to what level those engagements occur, which, in turn, can improve our knowledge of how to interact and engage more proactively in different types of community structures we encounter. In this particular analysis, the processes of inclusionary and exclusionary selection were identified as the primary modes of selection. These modes indicated how people from the two fieldsites engaged with others and subsequently defined their social networks. The awareness of these approaches, in a broader sense, can indicate prevailing modes of selection in other areas that share similar patterns of network construction and character qualities (Morrill et al., 2007; Site One fieldnotes: 10 August, 2010 - 30 January, 2011; Site Two fieldnotes: 16 March, 2011 - 20 August, 2011).

Through the exploration of these two outcomes, the data reveals how people make associations within and across different types of social and physical landscapes. By acknowledging and employing these outcomes, Emergency Managers can potentially adjust their approaches to communicate risk, by improving their knowledge of how to interact and engage with people when manufacturing and communicating vital risk information (Melhuus et al., 2009).

Comparative context and key terminology

It is likely not surprising that once compared, the data collected from the two different bushfire-risk fieldsites were noticeably distinct in regional character (ABC News, 2009). It may, however, be less immediately obvious to suggest that data collected from *within* these regions was just as disparate. Often it may be presumed that a uniform character applies across a particular regional area. Yet this generalisation can only apply on the surface until inconsistencies become visible. Generalising for a single geographic region is no more plausible than generalising between two obviously different regions. Thus, the issue of how to "communicate" risk in any particular region should avoid conventional labels attributed to the geography of that area, looking instead at the holistic character landscape of any particular region. For though technical risks may be consistent within and across physical environments, the way people understand and respond to the presence of those risks are experienced differently among accompanied, yet ultimately varied, social structures (Beggs, 1996; Clarke and Short, 1993; Rogers, 1992; Van den Eeckhaut et al., 2010).

From the data collected throughout the comparative analysis, the first fieldsite was classified as having a "fractured" character, whilst the second embodied a character of "enclaves" (Site One fieldnotes: 10 August, 2010 - 30 January, 2011; Site Two fieldnotes: 16 March, 2011 - 20 August, 2011). Bear in mind that that whilst I discuss qualities and characteristics of social and physical landscapes that may have implications for similarly defined areas, no two spaces will ever be exact replicas. Nevertheless, they can replicate and display uncanny similarities that *guide* our awareness and the resultant communicative approaches when engaging people in other areas. Furthermore, there are likely to be additional classifications of character structures observed in other regions besides that of "fractured" and "enclave", which is why any approach to communicating risk must be flexible in development and application. That aside, certain network influences that establish and maintain the character developments taking place in any two areas may become visible through identification of analogous qualities. And those common threads can inform appropriate understandings of how relationships manifest within related regions and/or communities (Barnes, 1972; Epstein, 1969; Paton et al., 2008).

Furthermore, when referring to "community", this term is reflective of an abstract social structure that develops through the connection of individuals, and these networks are not constrained by a particular location or space. Though communities can often overlay or be associated with physical boundaries (i.e. towns, geographical regions, etc.), they are not limited to these margins (Dickinson, 2012; Lewicka, 2010). As I explore the structural variances of communities as identified from the data analysis, each landscape is discussed from observations recorded in a physical place, but is expected to overlay and extend across multiple physical boundaries.

Outcome One: Variances in network structures

Having established a baseline context for understanding terminology, I move on now to discuss critical elements of the findings, where Site One outwardly presents the appearance of a united front. This means that collectively, the area maintains the appearance of a uniform lifestyle quality and ideology. Upon closer inspection, however, there exist rifts in the communicative structures of the region, lending this region to be considered "fractured". This is observed through the existence of what can be considered a "local divide" – a discernable gap in the perceived "community", between those who are considered vested in the area (i.e. resident and home-owners) versus those who traditionally are presumed to have minimal vested interest (i.e. tourists, holiday-seekers) (Site One fieldnotes: 10 August, 2010 - 30 January, 2011). Further polarisation occurs among the "vested" side of the local divide, with exclusive cliques or clusters forming within the broader social landscape, supporting the "fractured" identifier on an even deeper level (Gross and Brown, 2006; Mitchell, 1969; Scannell and Gifford, 2010, Site One fieldnotes: 10 August, 2010 - 30 January, 2011).

In fractured communities, connections within social networks are limited, and in some cases entirely closed between people who are aware and have often acknowledged the existence of others. There are groups, or associations, of people that congregate or associate with this specific area, but have further narrowed, or fractured, their associations within their own networks. This description portrays how abstract fractured regions display limited movements between social network structures despite witnessing and initially acknowledging those pervading amongst them (Barth, 1969; Laumann, 1976; White, 2011).

In Site Two, a constant stream of "unknown" inhabitants and visitors silhouette movements of social networks in this area, allowing membership to remain relatively anonymous. This idea of anonymity suggests that people are overlooked from the outset. In contrast to Site One, people in this region are relatively unaware of the movements of others, establishing connections through purposeful involvement via similar ideas and/or activities. This type of structural engagement defines this particular area as a region of “enclaves” (Site Two fieldnotes: 16 March, 2011 - 20 August, 2011).

Enclave communities are areas where the platforms for establishing and maintaining connections are not predicated on the mere presence of people, who would otherwise remain relatively autonomous. Instead, enclave communities are defined through membership of select factions that share and engage in specific interests and pursuits. These areas are defined by a dependence on developing enclaves, for the anonymous character of the area inhibits awareness of others’ movements. Thus, associations are created on the basis of shared interests, and connections must be *accepted* in order to broaden the span of any community structures (Brown et al., 2003; Coombs, 1973; Holloway and Jefferson, 2004).

In review, fractured communities are areas where people generate network divisions that require a certain level of navigation to engage. In contrast, enclave communities are spotted with specialist areas of membership, which require access before any sort of navigation ensues. Importantly, the existence of variations in how people engage with different types of network structures indicates that - a) by acknowledging that variations in structures exist; and b) by observing how people make associations within and across different types of regions - Emergency Managers can improve their knowledge of how to interact and engage more proactively with people in different types of community structures.

Outcome Two: Variances in modes of selection

Having identified the importance of the structural variations for understanding how people engage with others and their environment, the next issue to address is how acknowledging the existence of various regional structures matters, especially in regards to communicating risk. This outcome is of critical significance because identifying how relationships are established and maintained in different regions indicates the prevailing methods of social *selection* employed in those regions (Passy and Giugni, 2001; Silberbauer, 2003).

Selection, in this context, can be understood as the process through which people define or become a part of the social landscape (Bogenhold, 2013; Dijkstra et al., 2013; Lennon et al., 2012; Morrill et al., 2007; Steglich et al., 2010). Stated plainly, selection defines how people become engaged with one another, and to what level those engagements occur. There will of course be many layers and levels of selection occurring simultaneously, for the operation itself is perpetual and occurs at any stage where networks and environments converge, regardless whether the persons in question are new to the social landscape or have been part of the social landscape for a significant period of time. Yet for the purpose of explaining the process in its purest form, I will only elaborate on selection in a singular state.

Focusing on modes of selection employed within the frameworks of “fractured” and “enclave” communities, I now present the relevance of exclusive and inclusive selection. Of note, there should not be any negative connotations associated with the nomenclature of the terms, for though the words “exclusionary” and “inclusionary” can suggest certain levels of social acceptance in different contexts, this is not the case for this discussion. The application of these terms is indicative only of how the process of selection is employed, as opposed to how members are viewed by others in any network.

In the case of a "fractured" community (as observed in Site One), selection processes are marked by a tendency towards *exclusionary selection*, where a particular social landscape defines membership through the closure or limitation of networks (Site One fieldnotes: 10 August, 2010 - 30 January, 2011; Site Two fieldnotes: 16 March, 2011 - 20 August, 2011). Exclusionary selection is defined by an initial acknowledgement of one's presence in the social landscape, followed by the passive assessment that a member's presence is/is not distinguished among the social landscape. In this sense, the selection process is exclusionary because members are included in the social landscape until they are not. This suggests that selection is based on the identification of those who can or cannot remain a part of the social landscape in the same way as initially defined (Dijkstra et al., 2013; Lewicka, 2005; Stratford, 2009).

This form of selection is best understood through the following example, from the vantage of an existing resident living in a particular region. Participant A – hereafter referred to as Sally - became a resident of a town five years previously, and immediately felt right at home, becoming an active member of many social groups, one in particular being a member of the "community" group charged with local social event planning. Things began to shift however once Sally's spouse took on a new job that required a significant amount of travel, impacting how often Sally could take part in her usual planning activities, as her attention was dedicated more towards managing responsibilities at home. As a result, the planning team no longer called upon Sally. This omission from subsequent planning activities and social contact with members of that perceived "community" highlights the process of exclusionary selection, as Sally was no longer considered a vital member of that group. Significantly, this exclusion occurred only in *one* aspect of her regular social interactions, and her involvement with the other social groups mentioned previously remained consistent.

This illustration demonstrates how Sally became "excluded" from one particular faction once there was a reduced need or desire to have *as* direct a role in the social landscape. She was part of the structure until it was deemed she could no longer be recognised by the network in the same way as before.

In the case of enclave communities (as observed in Site Two), where members are essentially autonomous and rely on areas of compatibility to become part of the social landscape, the process of selection is quite different. In these instances, membership is not presumed at the outset. Instead, all people are initially treated as equally detached from the landscape. Becoming part of the social landscape requires an active engagement. This form of selection is considered an inclusionary process, where people need to solicit or be drawn in/encouraged to become embedded in the social landscape. Those who actively seek or respond to opportunities for connections are, subsequently, *included* (Dijkstra et al., 2013; Lewicka, 2005; Site One fieldnotes: 10 August, 2010 - 30 January, 2011; Site Two fieldnotes: 16 March, 2011 - 20 August, 2011; Stratford, 2009).

To illustrate this form of selection, I present an example from the view of an initial engagement within a generic social landscape. Participant B - hereafter known as Harry - frequents the same café every morning over a three-month period. Harry exchanges pleasantries with staff and patrons, but does not become directly engaged with anyone in that particular network. One day Harry asks a staff member if they know where he could go to hear live music. The staff member tells Harry where to go, and invites him to come to the next live music showcase scheduled the following Wednesday, for which Harry happily complies.

In this scenario, it was not enough for Harry to simply be present on a repeated basis for him to become part of the social landscape. It was only when there was an *active* attempt made to engage within the social landscape that an invitation was extended, and Harry was included. Thus, inclusionary selection is observed through his deliberate appeal for membership and the staff member's reciprocation through inclusion.

Identifying selection processes enables outsiders to understand ways target audiences engage with one another. This is a vital outcome for the issue of sharing risk information, as methods of dissemination and sharing can potentially be adjusted to suit the prevailing forms of selection in any particular area. For this research study, the prevailing modes of selection were exclusionary and exclusionary. Thus, when these modes are understood relative to the prevailing social landscape, others can better identify and navigate through limited networks (in exclusionary contexts) or actively source direct engagements with organised networks (in inclusionary contexts), thus establishing effective, meaningful connections among specific target audiences.

Conclusion: Acknowledging structural variances to aid in communicating risk information

Given the serious risk that bushfire poses to Australian communities, an understanding of how people mobilise social networks as resources for dealing with the threat of bushfire is crucial (Hughes and Mercer, 2009). Social networks as an object of study constitute the pathways through which people offer and obtain information, forge relationships and actively engage in pursuits or interactions (Heimer, 1998). These networks indicate ways people are able to process and share significant information, thus highlighting avenues for safety agencies to best reach target audiences and effectively provide emergency services.

In summary of the outcomes discussed today, key differences in the abstract structures of regions are useful to identify how networks are constructed in different regions. Additionally, the selection of networks, defined as either exclusionary or inclusionary in this comparative study, can indicate the best methods for reaching target audiences.

This research is thoroughly significant in an applied sense because it recognises the complexities that face many Emergency Managers and contributors as they try to construct a single, generalised way of communicating interactively with the public (Bravo et al., 2012; Kamuya et al., 2013). Specifically dealing with the communication of bushfire risk and mitigation measures, this research calls attention to where problems often arise in the transmission and absorption of risk information, signalling prospective ways to address communication of these issues.

Principally, this paper has sought to broaden our understanding of how communicative processes are established and utilised within particular settings, and has revealed that by understanding how people make associations within and across different types of regions, Emergency Managers can improve their knowledge of ways to interact and engage with people in those areas when manufacturing and communicating vital risk information.

References

ABC News. (2009). Bushfire hit list: 52 towns at risk. Retrieved from http://www.abc.net.au/news/2009-08-18/bushfire-hit-list-52-towns-at-risk/1395318

Barnes, J. A. (1972). Social Networks. Modular Publications Anthropology, 26.

Barth, F. (1969). Ethnic groups and boundaries : the social organization of culture difference. Boston: Little, Brown.

Beer, T., Bobrowsky, P., Canuti, P., Cutter, S., & Marsh, S. (2004). Hazards—Minimising Risk, Maximizing Awareness, Prospectus for a Key Theme for the International Year of the Planet Earth 2005-2007 Paper presented at the Earth Sciences for Society Foundation, Leiden, The Netherlands. http://webra.cas.sc.edu/hvri/pubs/2004_Hazards_Minimizing RiskMaximizingAwareness.pdf

Beggs, J. J., Haines, V. A., & Hurlbert, J. S. (1996). Situational Contingencies Surrounding the Receipt of Informal Support. Social Forces, 75(1), 201-222.

Betts, R. (2007). Community Engagement in Emergency Management – Uncertainty, Risky, and Challenging. Paper presented at the 5th Flood Management Conference, Warrnambool.

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). At Risk: Natural Hazards, People's Vulnerability, and Disasters. London; New York: Routledge.

Boegenhold, D. (2013). Social Network Analysis and the Sociology of Economics: Filling a Blind Spot with the Idea of Social Embeddedness. American Journal of Economics and Sociology, 72(2), 293-318. doi: http://www.blackwellpublishing.com/journal.asp?ref=0002-9246&site=1

Bravo, G., Squazzoni, F., & Boero, R. (2012). Trust and partner selection in social networks: An experimentally grounded model. Social Networks, 34(4), 481-492. doi: http://dx.doi.org/10.1016/j.socnet.2012.03.001

Brown, B., Perkins, D. D., & Brown, G. (2003). Place attachment in a revitalizing neighborhood: Individual and block levels of analysis. Journal of Environmental Psychology, 23(3), 259-271. doi: 10.1016/s0272-4944(02)00117-2

Buckle, P. (2001). Community Based Management: A New Approach to Managing Disasters. Department of Management; Department of Human Services Victoria Australia. RMIT Univerity.

Caplan, P. (Ed.). (2000). Risk Revisited. London: Pluto Press.

Clarke, L., & Short, J. F., Jr. (1993). Social Organization and Risk: Some Current Controversies. Annual Review of Sociology, 19, 375-399.

Coombs, G. (1973). Networks and Exchange: The Role of Social Relationships in a Small Voluntary Association. Journal of Anthropological Research, 29(2), 96-112.

Dickinson, S. (2012, 17-19 April, 2012). Discussing Ancillary Ways to Consider Community Awareness Contexts. Paper presented at the 3rd Human Dimensions of Wildland Fire, Seattle, WA (USA).

Dijkstra, J. K., Cillessen, A. H. N., & Borch, C. (2013). Popularity and adolescent friendship networks: Selection and influence dynamics. Developmental Psychology, 49(7), 1242-1252. doi: 10.1037/a003009810.1037/a0030098.supp (Supplemental)

Douglas, M., & Wildavsky, A. (1983). Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers. Berkeley and Los Angeles: University of California Press.

Ely, M., Vinz, R., Downing, M., & Anzul, M. (1997). On writing qualitative research : living by words. London; Washington, D.C.: Falmer Press.

Epstein, A. (1969). The Network and Urban Social Organization. In J. C. Mitchell (Ed.), Social Networks in Urban Situations: analyses of personal relationships in Central African towns. Manchester: Manchester University Press.

Goetz, J. P., & LeCompte, M. D. (1981). Ethnographic Research and the Problem of Data Reduction. Anthropology & Education Quarterly, 12(1), 51-70. doi: 10.1525/aeq.1981.12.1.05x1283i

Gross, M. J., & Brown, G. (2006). Tourism experiences in a lifestyle destination setting: The roles of involvement and place attachment. Journal of Business Research, 59(6), 696-700. doi: 10.1016/j.jbusres.2005.12.002

Head, B. W. (2007). Community Engagement: Participation on Whose Terms? Australian Journal of Political Science, 42(3), 441-454.

Heimer, C. A. (1988). Social Structure, Psychology, and the Estimation of Risk. Annual Review of Sociology, 14, 491-519.

Hollway, W., & Jefferson, T. (2004). Doing qualitative research differently: free association, narrative and the interview method (2nd ed.). London: SAGE.

Houghton, R. J., Baber, C., McMaster, R., Stanton, N. A., Salmon, P., Stewart, R., & Walker, G. (2006). Command and control in emergency services operations: a social network analysis. [Article]. Ergonomics, 49(12/13), 1204-1225. doi: 10.1080/00140130600619528

Huber, F. (2012). On the sociospatial dynamics of personal knowledge networks: formation, maintenance, and knowledge interactions. Environment and Planning A, 44(2), 356-376.

Hughes, R., & Mercer, D. (2009). Planning to Reduce Risk: The Wildfire Management Overlay in Victoria, Australia. Geographical Research, 47(2), 124-141.

Kamuya, D. M., Marsh, V., Kombe, F. K., Geissler, P. W., & Molyneux, S. C. (2013). Engaging communities to strengthen research ethics in low-income settings: selection and perceptions of members of a network of representatives in coastal Kenya. Developing World Bioethics, 13(1), 10-20. doi: 10.1111/dewb.12014

Laumann, E. O. (1976). Networks of collective action: a perspective on community influence systems. New York: Academic Press.

Lennon, R., Rentfro, R. W., & Curran, J. M. (2012). Exploring relationships between demographic variables and social networking use. [Article]. Journal of Management & Marketing Research, 11, 1-16.

Lewicka, M. (2005). Ways to make people active: The role of place attachment, cultural capital, and neighborhood ties. Journal of Environmental Psychology, 25(4), 381-395. doi: 10.1016/j.jenvp.2005.10.004

Lewicka, M. (2010). What makes neighborhood different from home and city? Effects of place scale on place attachment. Journal of Environmental Psychology, 30(1), 35-51. doi: 10.1016/j.jenvp.2009.05.004

Melhuus, M., Mitchell, J., & Wulff, H. (2009). Ethnographic practice in the present.

Mitchell, J. C. (Ed.). (1969). Social networks in urban situations: analyses of personal relationships in Central African towns. Manchester: The Institute for Social Research, University of Zambia, by Manchester U.P.

Morrill, C., Snyderman, E., & Dawson, E. J. (1997). It's Not What You Do, but Who You Are: Informal Social Control, Social Status, and Normative Seriousness in Organizations. Sociological Forum, 12(4), 519-543.

Passy, F., & Giugni, M. (2001). Social Networks and Individual Perceptions: Explaining Differential Participation in Social Movements. Sociological Forum, 16(1), 123-153.

Paton, D., Burgelt, P. T., & Prior, T. (2008). Living with Bushfire Risk: Social and Environmental Influences on Preparedness. Australian Journal of Emergency Management, The, 23(3), 41-48.

Ritchie, J., & Spencer, L. (1994). Qualitative data analysis for applied policy research. In A. Bryman & R. G. Burgess (Eds.), Analyzing qualitative data (pp. 173-194). London; New York: Routledge.

Rogers, G. O. (1992). Aspects of Risk Communication in Two Cultures. International Journal of Mass Emergencies and Disasters, 10(3), 437-464.

Scannell, L., & Gifford, R. (2010). Defining place attachment: A tripartite organizing framework. Journal of Environmental Psychology, 30(1), 1-10. doi: 10.1016/j.jenvp.2009.09.006

Silberbauer, G. (2003). Structural and personal social processes in disaster. The Australian Journal of Emergency Management, 18(3), 8.

Silverman, D. (Ed.). (2004). Qualitative research: theory, method and practice (2nd ed. ed.). London: SAGE.

Steglich, C., Snijders, T. A. B., & Pearson, M. (2010). Dynamic networks and behavior: Separating selection from influence. [Article]. Sociological Methodology, 40(1), 329-393. doi: 10.1111/j.1467-9531.2010.01225.x

Stratford, E. (2009). Belonging as a Resource: The Case of Ralphs Bay, Tasmania, and the Local Politics of Place. Environment and Planning A, 41(4), 796-810. doi: http://www.envplan.com/epa/epa_current.html

Van Den Eeckhaut, M., Poesen, J., Vandekerckhove, L., Van Gils, M., & Van Rompaey, A. (2010). Human–environment interactions in residential areas susceptible to landsliding: the Flemish Ardennes case study. Area, 42(3), 339-358.

Vayda, A. (1983). Progressive contextualization: Methods for research in human ecology. Human Ecology, 11(3), 265-281. doi: 10.1007/bf00891376

Walia, A. (2008). Community based disaster preparedness: Need for a standardized training module. The Australian Journal of Emergency Management, 23(2), 68-73.

White, D. R. (2011). Kinship, Class, and Community. [Article]. World Cultures, 18(2), 1-31.

"Should I Stay or Should I Go?" Defining the Preparatory Conditions in Support of Active Defence for Different Fire Danger Ratings

Yinghui Cao[1,], Bryan J. Boruff[1], Ilona M. McNeill[2]*
1. School of Earth and Environment, the University of Western Australia
2. School of Psychology, the University of Western Australia
** Corresponding Author. Email: caoy02@student.uwa.edu.au*

Abstract

In Australia, householders can stay and defend their properties during a bushfire if the household is adequately prepared. State (and territory) fire agencies have provided householders with checklists of desirable preparatory actions, including property preparation, judging ability of individuals, and acquiring equipment and resources for active defence. However, the lack of consistency in the existing checklists implies not all the listed preparatory actions are *critical* for making the decision of actively defending; in addition, agencies agree that the levels of desired preparedness should be associated with Fire Danger Ratings (FDR), the indicator of fire weather intensity. Still, no clarification exists concerning the exact levels to which a household should prepare to actively defend during different FDRs. This study therefore attempts to explore the *critical* nature of preparatory actions in relation to FDRs based on expert knowledge. To this aim, a survey was conducted with bushfire experts who were requested to rate whether each preparatory action is critical under different FDR conditions. Results from 36 experts confirmed our hypothesis that some preparatory items are not critical or only critical at certain FDRs. However, a more in-depth study with a range of experts is required to provide further consensus concerning the critical preparatory actions and to clarify discrepancies of opinions for items highlighted as controversial through the survey process.

Additional Keywords.
Bushfire, preparedness, stay and defend

Background

The AFAC policy (2010, p.11) on Bushfires and Community Safety states that 'people usually have two safe options when threatened by bushfire: leaving early or actively defending adequately prepared properties'. Therefore, it is important for householders to understand what is meant by 'being adequately prepared' when deciding on whether or not to defend their property. However, post-fire studies have indicated that many people who plan to stay and defend often overestimate their preparedness levels and capability to actively defend a property (Handme *et al.* 2010; McLennan *et al.* 2011; Whittaker *et al.* 2013). One major issue that may have contributed to the misjudgement is the lack of explicit explanation or guidelines for sufficient household preparedness for staying and defending.
The AFAC position paper (2010) has outlined two major aspects concerning household preparedness to enhance the chance of successfully staying and defending:

a) The defendability of a property. House defendability should be ensured by creating and maintaining a defendable space, within which bushfire fuels must be reduced to eliminate or significantly attenuate the ability of a fire to burn and spread to buildings, as well as ember-proofing the building structure to minimise the chance of its ignition (AFAC 2010).
b) Householders' competence in defending their home. The AFAC position paper (2010, p. 10) identified that 'for those planning to defend their homes, they must ensure that they are fit, and have personal protective equipment, adequate water supplies and firefighting equipment for the expected fire conditions'. In addition to physical fitness, defenders must also be psychologically ready to cope with trauma and injury and strategically plan for different circumstances and possible predicaments during the active defence (AFAC 2010).

Corresponding to these aspects of household preparedness, fire agencies across Australia have provided householders with checklists of desirable preparatory actions. However, the existing checklists are only suggestive, and do not provide definitive insight into the required preparatory actions for staying and defending or whether completing a subset is sufficient. In addition, there is little consistency among the various agency-distributed preparation checklists across Australia. Although several studies have attempted to identify subsets of the more important preparatory activities (Paton *et al.* 2006; McLennan and Elliott 2011), these checklists were only developed as research instruments, and thus cannot serve as an indicator of sufficient preparedness in an operational setting. Further research is needed to investigate the operational significance of agency-listed preparatory actions in relation to households' safety for staying and defending.

Furthermore, the current risk communication materials distributed by Australian fire agencies (e.g. CFA 2010; DFES 2012) propose different required levels of preparedness depending on the Fire Danger Rating (FDR) levels. The current FDR system (as summarised in Table 1) is derived from the Fire Danger Index and intends to provide a scale to indicate potential fire behaviour (if started), and the difficulty of suppression given the forecasted weather conditions (Dowdy *et al.* 2009). Table 1 shows a sample of messages distributed by the Country Fire Authority (2010) concerning the meaning of FDRs and their relationships with the action of staying and defending. It illustrates that higher levels of preparedness are desired for actively defending a property at higher FDR levels. The terminology in the messages is abstract, however, in that it does not specify what being sufficiently prepared entails under different FDRs.

Table 1. Fire Danger Ratings and associated advices regarding household preparedness for staying and defending (adapted from Country Fire Authority 2010, *Prepare. Act. Survive. Fire Ready Kit*.)

FDR Categories	Fire Danger Index	What does it mean?	Staying and defending can only be considered if one's home is…
Catastrophic (Code Red)	100+	These are the worst conditions for a bush or grassfire. Homes are not designed or constructed to withstand fires in these conditions.	Never
Extreme	75 – 99	If a fire starts and takes hold, it will be uncontrollable and unpredictable. Spot fires will start, move quickly and come from many directions.	Situated and constructed or modified to withstand a bushfire, prepared to the *highest* level and can be actively defended.
Severe	50 – 74	If a fire starts and takes hold, it may be uncontrollable.	*Well prepared* and can be actively defended.
Very High	25 – 49	If a fire starts, it can most likely be controlled in these conditions.	Not stated
High	12 – 24		
Low to Moderate	0 – 11		

This study attempted to explore the *critical* nature of preparatory actions in relation to FDRs based on expert knowledge. A survey was conducted with relevant experts across Australia. In this paper, the following research questions are to be investigated via the analysis of experts' responses:

i. Are some preparatory actions critical for staying and defending whilst some are not so?
ii. Does the critical nature of a preparatory action for staying and defending vary at different FDR levels?

Throughout this paper, a '**critical**' preparatory action is referred to as an item that is essential for staying and defending in a bushfire; failing to complete a 'critical' item will dramatically decrease the chance of house survival or the possibility of properly defending the property, and thus actively defending is probably not a safe option under such circumstances. On contrary, some items may be helpful but not necessary, and thus should be regarded as non-critical. Failing to complete such items will have only a slight impact on the chance of successful defence if all the critical items have been assured. Theoretically, the clarification of the critical nature of the preparatory actions will provide better reference for residents to assess their preparedness level and make relatively sound and confident decisions regarding active defence; however, it should be recognised that the safety of a household in a bushfire can never be guaranteed, especially during intensive fires.

An exploratory study of preparatory actions

Collection of preparatory items

A comprehensive checklist of preparatory actions was derived from a range of agency-distributed materials concerning household preparedness, including the ‘Prepare. Act. Survive’ pamphlets released by seven Australian state (and territory) agencies[1] and two materials from U.S. organisations [2] .To integrate all materials, similar items were amalgamated, while omnibus items with multiple detailed actions were split to form an accurate and inclusive list of 100 items. Furthermore, the items were classified into sixteen categories (as shown in Table 2) that were created based on the important preparation aspects identified by the AFAC position paper (e.g. preparation for property defendability, judging ability of individuals, and acquiring equipment and resources for active defence) for the purpose of delineating the entire collection of preparatory actions.

When examining overlap of items across the different materials, around 32% of items were mentioned by four or more of the nine reviewed materials. These items may be more important than others as they were more consistently mentioned. For instance, the item ‘cut long grass within the inner zone’ is probably critical to mitigate fire impact as it is mentioned by all nine agencies.

[1] North Territory was the only state excluded in this review because no specific Prepare. Act. Survive brochure was released online by the time of research.

[2] The two U.S. materials are ‘Wildfire Preparedness’ released by American Red Cross, and ‘Checklist for Homeowners’ developed by the Federal Emergency Management Agency.

Table 2. Categories of household preparatory actions included in the collective checklist

Categories			Code	Number of preparatory actions
PROPERTY DEFENDABILITY	To create defendable space, …	Create an *Outer Zone* by managing vegetation and reducing fine fuels.	D1	7
		Maintain vegetation and clear fine fuel within the *Inner Zone.*	D2	12
		Clear flammable materials within the *Inner Zone*.	D3	5
		Create fire breaks within the defendable space.	D4	5
	To Ember-proof the house, …	Clear fine fuels and combustible materials on the building.	D5	4
		Block all gaps in a structure and place metal fly wire mesh on all vents.	D6	13
		Use non-combustible building materials.	D7	9
PEOPLE, RESOURCE AND EQUIPMENT TO ACTIVELY DEFEND	Prepare equipment for actively defending.		D8	10
	Prepare water resource for actively defending.		D9	5
	Prepare food and water supply for people who are actively defending the home.		D10	4
	Prepare survival kit.		D11	7
	Ensure accessibility for firefighters.		D12	3
	Ensure coping capacity of those who are staying and defending the home.		D13	6
	Prepare psychologically for staying and defending.		D14	6
	Plan for staying and defending.		D15	3
	Prepare a fire shelter or bunker to shelter in home as a last resort.		D16	1

Questionnaire

In May 2012, a questionnaire based on the collective list of preparatory actions was deployed online. In the beginning of the survey, a self-assessment question was used to ensure only experts who are familiar with the pertinent subjects complete the survey. A snowball sampling strategy was employed to recruit preparedness experts from state (and territory) bushfire agencies as well as research institutions across Australia. A list of 48 contacts consisting of relevant experts from each organisation was initially constructed based on recommendations by our personal network and identification through a web search. Emails were sent to each identified expert to request their participation in the survey if they held the necessary level of expertise; moreover, they were asked to help circulate the survey to or provide recommendations of the appropriate personnel within their organisations. Two reminders were sent in two-week intervals. A total of six additional experts were suggested during this process and were thus emailed following the same contact protocol. Besides this, some experts helped propagate the survey link within their personnel's email network. Eventually thirty-six valid responses were garnered. A majority of the participants (33/36) were agency-based emergency management officers and/or experienced fire fighters, and the other three responses came from bushfire community safety related researchers.

Within the questionnaire, fire experts were asked to identify 'at which FDR level(s) does each preparatory action become critical and therefore needs to be completed by the household in order to stay and defend', followed by the definition of '**critical'** preparatory actions. Logically, a preparatory action that is critical at low FDRs should also be critical at high FDRs; however, an action that is not necessary at low FDRs may turn out to be critical at high FDRs to fortify the protection against severe fire conditions. Therefore six options, as listed in Table 3, were given for the raters to choose from. This particular method was adopted to provide an understanding of whether an item is critical for staying and defending, and if yes, whether it is critical at all FDRs. The ratings associated with FDRs should be interpreted as a scale of how critical it is to complete a preparatory item for staying and defending. The items rated as critical at all FDRs are considered to be the most critical and should be completed under any bushfire condition to provide primary protection for active defence.

The items **Table 3.** Rating scale adopted in the Household Preparedness Survey and the coding values for analysis

Answers from the survey	Code
The preparatory item is critical at the FDR Levels of …	
Low-Moderate, High and all levels above	4
Very High and all levels above	3
Severe and all levels above	2
Extreme level only	1
Not critical at any levels	0
Not sure	Missing Value

rated as critical at Extreme FDR only serve as vital protection for a property only under severe fire circumstances when the fire can easily become out of control. Furthermore, items rated as not critical at any FDR levels are not considered as necessarily critical, and failing to complete them should not influence the choice of staying and defending in any fire condition. The five viable answers were thus translated to an indicator representing how critical an item is based on a five-point ordinal scale from 0-4, where a larger value signifies a preparatory item is more critical to complete for staying and defending.

Analysis of Survey Results

Criticality ratings

Most preparatory actions obtained at least 32 valid rating values from the survey. All of the experts differentiated their ratings for the 100 items using the 0 to 4 spectrum identified in Table 3. Some experts adopted a more conservative approach than others by rating a large portion of the items as 4, but small clusters of 0 ratings were also observed for some items. This suggests that the experts acknowledged the different degrees of importance inherent in the preparatory actions, and there was relative agreement that some preparatory actions are not critical in making the decision of staying and defending.

A calculation of the mean rating values for each preparatory item manifested that on average, 70/100 of the items were rated greater than 3 (M_{max} = 3.8), while 29/100 of them were between 2 and 3 and only one item was rated below 2 (M_{min} = 1.2). The average rating for each item was compared with the overall mean rating value ($M_{overall}$ = 3.11) through one sample t-tests. As shown in Table 4, 29 items obtained average ratings significantly higher than 3.11 and 15 items obtained average ratings significantly lower than that. The differences in ratings among the items are thus not due to chance, supporting the idea that the critical nature of the preparatory actions should vary at different FDRs. We then examined the relationship between the average rating values and the number of references. For the items referenced in less than four sources, 16 items were rated significantly higher than average (3.11) while 13 were rated significantly lower than 3.11; in contrast, the ratio is substantially larger for the items referenced by four or more sources (12 items significantly larger than 3.11 and one item significantly lower than that). This confirms our prediction that less referenced items may be less critical (i.e. lower rating scores) for staying and defending; however, 'number of sources' is not an explicit indicator of how critical a preparatory action is.

Table 4. Comparison of item mean rating values with the overall mean value (3.11)

Item mean rating value	Number of preparatory Items			
	From 1 -3 sources	From 4 - 9 sources	Other[a]	Total
> = 3.11	33	24	1	58
(significantly* >=3.11)	(16)	(12)	(1)	(29)
< 3.11	34	7	1	42
(significantly < 3.11)	(13)	(1)	(1)	(15)
Total	67	31	2	100 (44)

* $p < 0.05$, based on one sample t-tests to compare the mean rating value of each item against overall mean value.

a. Two items were not sourced from the reviewed materials, and their average rating values are both significantly different from 3.11. The first one is 'have a fire shelter or bunker built in the home which can provide shelter for people', rated as 1.2 on average. The safety of this item has been a controversial, but its construction has been specifically regulated (ABCB 2010), and a well-designed bushfire shelter is recognised as a useful backup option (VBRC 2009). The second item, 'be fully committed to defending the home', was rated as 3.36 on average. Although not explicitly listed in the current materials, this item is proven to be an important facilitator for successfully staying and defending (Brennan 1998).

Interrater Agreement

The interrater agreement (IRA) was investigated to explore whether it is possible to build a national consensus on the identification of critical vs. non-critical preparatory actions at various FDR levels. Analysis of IRA is usually employed to test the absolute agreement among human judges for rating a subject (Richardson 2010). In the present case, two common indices, the r_{wg} (James *et al.* 1984) and Average Deviation (AD) index (Burke and Dunlap 2002), were calculated for each preparatory item. The r_{wg} derives from a comparison of the actual variance obtained from multiple raters and the variance expected in the case of no agreement (usually reflected by assuming a uniform response distribution). Values for r_{wg} should range between 0 and 1 with larger values indicating better agreement. However, negative values of r_{wg} can be observed when the actual variance exceeds the expected variance for a random response, suggesting a complete disputation (LeBreton and Senter 2008). According to the interpretation of r_{wg} statistics proposed by LeBreton and Senter (2008), 46/100 preparatory actions suggested moderate to high level of agreement with r_{wg} values larger than .50, and 27/100 were between .30 and .50, denoting a week agreement. The remaining 27/100 of the items showed discrepancy among experts' answers with r_{wg} values less than .30.

We further calculated AD, which estimates agreement in the metric of the original scale by averaging the absolute deviation of each rating from the overall mean rating. Accordingly, smaller values of AD indicate better agreement. The AD values calculated for the 100 items ranged from 0.28 to 1.30; 79/100 of the estimates were less than 1.01, the cut-off point for a five-point scale with 36 judges (Burke and Dunlap 2002), suggesting a high level of agreement.

By cross-referencing the IRA indices with the number of sources and mean rating values for the 27 controversial preparatory items (identified as lack of agreement by r_{wg}) in Table 5, we discovered that 23/27 (85%) items were collected from 1 to 3 source materials, and 18/27 (67%) items were with average rating values less than 3. This coincides with our initial conjecture that the controversial items are those less referenced in the sourced materials; however, not all the less recommended items were controversial. In addition, given that only 30/100 items in the overall checklist were rated below 3 on average, it is apparent that the items with low mean rating values occupy a larger proportion (67%) in the list of controversial items. It implies that discrepancy mostly happened when a group of experts provide an item with low rating scores, referring to a rating as critical only in severe fire scenarios or not critical at all.

One major reason for the disagreement is that some experts tended to adopt a conservative approach by rating most items to be critical at all FDR levels, whereas some experts employed a distinct strategy by distinguishing the preparatory items as related to the corresponding FDRs. For instance, item D6_13 'install wire mesh screens 1.5mm (not aluminium) over all external doors' obtained nine ratings of 4, ten ratings of 3, seven ratings of 2, three ratings of 1 and another three of 0. One expert supplemented his rating of 0 by commenting that this item is 'unnecessary if other listed actions undertaken'. Some raters may have held a similar position by rating it as 1 or 2, while the others probably took a more conservative approach. In fact, all the nine ratings of 4 in this case were served by conservative raters who rated more than 70% of the preparatory items as 4. A different type of discrepant distribution of ratings can be observed of item D10_9, 'ensure that smoke alarms are fitted on every level of the house'. Twenty-nine experts rated this item as 4 with a comment that 'this is part of a general requirement and not linked to a FDR', whilst three experts gave scores of 3, 2 and 1 respectively, and another three rated it as 0, coupled with a comment that it 'will not provide reliable warning of fire in the home due to presence of bushfire smoke'. It is evident in this case that most experts considered this item as highly critical, whereas several experts held extremely different opinions, which could not be fully explored through the survey process.

Thereby, an in-depth study with a taskforce of experts in an interactive environment is needed with the aim to obtain concrete consensus for rating the preparatory items, or explore the complex reasons for disputation. Given that nearly half of the items received moderate agreement indicated by both r_{wg} and AD, it is promising that acquiring expert consensus is possible, at least for a subset of the checklist. The results would therefore be valuable to serve as a unanimous national starting point for bushfire agencies to start clarifying the checklist and identifying the critical items for different FDRs in local contexts so as to define the necessary preparatory conditions for staying and defending.

Table 5. Controversial preparatory items identified by r_{wg}

Preparatory Items	Mean ± SD	AD	r_{wg}	Sources[a]
D2_11: Within the Inner Zone, replace all highly-flammable plants with low-flammability plants.	3.1 ± 1.26	0.97	0.20	FEMA. NSWRFS. TFS
D2_12: Within the Inner Zone, chemically treat the area around outbuildings and sheds to prevent the regrowth of vegetation.	3.0 ± 1.26	0.95	0.20	CFS
D3_4: Within the Inner zone, keep the gas grill and propane tank at least 5 meters from house, and clear an area of 5 meters around the grill.	3.0 ± 1.45	1.13	-0.05	ARC. FEMA
D4_2: Establish a landscaped garden, vegetable garden, cultivated soil or gravelled areas.	2.5 ± 1.52	1.27	-0.16	DFES. CFS. TFS
D4_3: Build wide paths, paving, driveways, or tennis court that can provide fuel breaks.	2.6 ± 1.52	1.27	-0.15	CFA. CFS. TFS
D4_4: Locate any dams, pools and any effluent disposal areas on the side of buildings facing the most likely direction of fire.	2.6 ± 1.48	1.22	-0.09	CFA. DFES. CFS. TFS
D4_5: Create radiation shields and windbreaks such as stone or metal fences and hedges using low-flammability plants.	2.3 ± 1.45	1.24	-0.05	DFES. NSWRFS. TFS
D5_2: Install metal gutter protection.	3.0 ± 1.42	1.12	-0.02	ARC. NSWRFS. CFS
D6_4: Maintain the paint on windows sills so there is no flaking or exposed wood.	2.6 ± 1.38	1.18	0.05	CFA
D6_6: Ensure that garage doors are tight fitting to door frame if garage is attached to the house.	2.7 ± 1.24	1.06	0.23	CFA
D6_8: Ensure that external house timbers have a sound coat of paint.	2.7 ± 1.39	1.17	0.03	FEMA
D6_10: Block all vents and weepholes (e.g. chimneys, stovepipes) with wire mesh screens 1.5mm (not aluminium).	2.7 ± 1.19	1.06	0.30	DFES. ARC. FEMA. ACTF&R. CFS
D6_13: Install wire mesh screens 1.5mm (not aluminium) over all external doors.	2.6 ± 1.27	1.04	0.20	CFA. ACTF&R. NSWRFS. QFRS. CFS

Preparatory Items	Mean ± SD	AD	r_{wg}	Sources[a]
D7_2: Fit the roller shutters with an ember guard at the top of the garage door if the garage is attached to the house.	2.8 ± 1.21	0.97	0.27	CFA

Continued

Table 5. Controversial preparatory items identified by r_{wg} *(Continued)*

Preparatory Items	Mean ± SD	AD	r_{wg}	Sources[a]
D7_8: For pipes that are essential to water delivery, ensure that they are metal, or non-metal pipes are buried to a depth of at least 300mm below the finished ground level.	2.7 ± 1.27	1.02	0.20	CFA. TFS
D7_9: Have a non-combustible doormat, or remove the doormat when there is a fire danger.	3.0 ± 1.35	1.03	0.09	ACTF&R. NSWRFS
D10_5: Know the maximum operating temperature as specified for the pump by the manufacturer.	3.1 ± 1.34	1.06	0.11	CFA
D10_9: Ensure that smoke alarms are fitted on every level of the house.	3.5 ± 1.25	0.85	0.22	ARC
D10_10: Prepare knapsack spray or garden backpack spray to help you put out spot fires. If using a garden backpack, make sure it has been cleaned out before using it in a bushfire.	3.3 ± 1.25	0.94	0.22	CFA. DFES
D11_4: Install a sprinkler system around the property.	2.3 ± 1.27	1.07	0.19	CFS
D11_5: Install a roof-mounted sprinkler system.	2.4 ± 1.31	1.11	0.14	CFA

Preparatory Items	Mean ± SD	AD	r_{wg}	Sources[a]
D12_1: Obtain an emergency supply of drinking water (3L per person per day for four days).	2.4 ± 1.25	1.09	0.22	DFES. ACTF&R. TFS
D12_2: Obtain canned or dried food to last four days.	2.3 ± 1.28	1.12	0.18	DFES
D12_3: Obtain a water container suitable for washing or cooking.	2.0 ± 1.50	1.31	-0.13	DFES
D12_4: Obtain a can opener, cooking gear and eating utensils.	2.1 ± 1.48	1.29	-0.09	DFES
D14_3: No elderly who is not fit to defend.	3.0 ± 1.29	1.03	0.17	CFA. NSWRFS
D14_4: No children under 16 is staying and defending.	2.7 ± 1.42	1.22	-0.02	CFA. NSWRFS
N = 27				

a. CFA = Country Fire Authority (VIC), QFRS = Queensland Fire and Rescue Service (QLD), DFES = Department of Fire and Emergency Services (WA), ACTF&R = ACT Fire & Rescue (ACT), NSWRFS = NSW Rural Fire Service (NSW), CFS = Country Fire Service (SA), TFS = Tasmania Fire Service (TAS), ARC = American Red Cross, FEMA = Federal Emergency Management Agency.

Checklist adjustment

In addition to the ratings, results suggested an adjustment of several existing items as well as enrichment of the list with several additional preparatory actions, resulting in a refined checklist of 104 items. Moreover, the qualitative comments coupling with missing values (i.e. 'not sure') or controversial ratings explained the obstacles in providing a confident rating and helped identify several types of potential adjustment needed for some items:

Type 1. The criteria of some preparatory items need to allow for adjustment according to jurisdiction policies. For instance, the item 'isolate clumps of shrubs and small trees from one another by at least 10 metres to avoid a continuous wall of trees within the Outer Zone' was claimed to be critical at all fires by one expert, but the criteria of isolation distance was regulated to be 'at least 1 (1.5) times the mature height of any in the clump' by his/her local government.

Type 2. Some preparatory items may be critical only under some circumstances. For example, the item 'clear vegetation along the boundary of the property to create a firebreak' was suggested to only be critical for certain types of properties, depending on 'the size of the property and distance from the boundary to the dwelling'. A lack of specification of such circumstances in the current survey caused a difficulty in rating.

Type 3. Some preparatory items may be compensatory for each other, and therefore only one of the actions has to be completed to allow active defence. One example is the item 'install metal gutter protection', which was suggested as not critical if the other item 'ensure that roof gutters and valleys are clear of leaves and bark' was completed. Therefore, the two actions may be combined as one critical action to allow householders' choice of at least one of them.

These three types of issues shed light on the potential difficulties that may be encountered whilst trying to further clarify if a preparatory item is critical when there is disagreement between experts from different organisations. However, adjustment can be made to adapt the items relevant to these three issues to various local environments, jurisdictional regulations, or other specific conditions. Therefore the three types of potential adjustment suggested from the survey responses can be used as a guideline during future engagements with experts to help identify the issues for relevant preparatory items, solicit opinions to address these issues, and attain relative consensus upon the viable solutions for defining or explicating the critical nature of these complicated items for specific situations in different states.

Conclusion

Through an initial overview of the current communication materials within Australia, we identified a need to clarify the relationship between the necessity of different preparatory actions and FDR levels. This pilot study provides evidence that some but not all preparatory items are critical for making the decision of staying and defending, and in addition, their critical nature should be examined in relation to FDRs. Moderate to high interrater agreement was observed for approximately half of the items, with both high and low average rating values. However, statistics for the controversial items suggest that experts do employ diverse approaches during the individual rating process, and thus a more explicit study should be undertaken to understand the rationale of consensual ratings, to reconcile the different opinions as well as to investigate the specific reasons for disputation. Although the disparate physical and political context across Australia is likely to make it difficult to obtain a national consensus over many preparatory items, we believe this study is a breakthrough in clarifying the operational significance of the preparatory items. It provides a starting point from which a new instrument of household preparedness measure can be developed by bushfire agencies at different scales to assist residents' estimation of their preparedness levels and decision making with respect to active defence. Nevertheless, it should be acknowledged that in a bushfire, although the completion of all the critical preparatory actions will substantially enhance the chance of successful defence, the safety of a household can never be guaranteed due to the complex nature of these types of events.

Acknowledgement

We thank all the experts who generously contributed to the survey. Thanks also go to Bushfire Cooperative Research Centre, the University of Western Australia, Austraining and Department of Education, Employment and Workplace Relations, Australia for funding the PhD project.

References

Australasian Fire and Emergency Service Authorities Council (AFAC) (2010) Position Paper on Bushfires and Community Safety, Version 4.1. (Melbourne)

Australian Building Codes Board (ABCB) (2010) Performance Standard for Private Bush Fire Shelters. (Canberra)

Brennan P (1998) 'Bushfire Threat: Response in a Small Community.' (Australian Emergency Management Institute: Macedon, Vic)

Burke MJ, Dunlap WP (2002) Estimating Interrater Agreement with the Average Deviation Index: A User's Guide. *Organizational research methods* **5**, 159-172.

Country Fire Authority (CFA) (2010) Prepare.Act.Survive. Fire Ready Kit. (http://www.cfa.vic.gov.au/fm_files/attachments/plan_and_prepare/frk/fire-ready-kit-complete.pdf)

Department of Fire and Emergency Services (DFES) (2012) Prepare. Act. Survive. Version 4. (http://www.dfes.wa.gov.au/safetyinformation/fire/bushfire/BushfireManualsandGuides/FESA_Bushfire-Prepare_Act_Survive_Booklet.pdf)

Dowdy AJ, Mills GA, Finkele K, Groot WD (2009) Australian fire weather as represented by the McArthur Forest Fire Danger Index and the Canadian Forest Fire Weather Index. CAWCR Technical Report No 10. (Centre for Australian Weather and Climate Research: Victoria, Australia)

Handmer J, O'Neil S, Killalea D (2010) Review of fatalities in the February 7, 2009, bushfires. Prepared for the Victorian Bushfires Royal Commission April 2010. (Centre for Risk and Community Safety RMIT University & Bushfire CRC: Melbourne)

James LR, Demaree RG, Wolf G (1984) Estimating within-group interrater reliability with and without response bias. *Journal of applied psychology* **69**, 85-98.

LeBreton JM, Senter JL (2008) Answers to 20 Questions About Interrater Reliability and Interrater Agreement. *Organizational Research Methods* **11**, 815-852.

McLennan J, Elliott G (2011) Checklist Items For Researchers: Householder Preparations For Bushfires. (Bushfire Cooperative Research Centre and School of Psychological Science La Trobe University: Melbourne)

McLennan J, Elliott G, Omodei M (2011) Issues in Community Bushfire Safety: Analyses of Interviews Conducted by the 2009 Victorian Bushfires Research Task Force. (School of Psychological Science, La Trobe University: Melbourne)

Paton D, Kelly G, Burgelt PT, Doherty M (2006) Preparing for bushfires: understanding intentions. *Disaster Prevention and Management* **15**, 566-575.

Richardson JTE (2010) Perceived Academic Quality and Approaches to Studying in Higher Education: Evidence from Danish Students of Occupational Therapy. *Scandinavian Journal of Educational Research* **54**, 189-203.

Victorian Bush Fires Royal Commission (VBRC) (2009) Interim Report 2 – Priorities for Building In Bush Fire Prone Areas. (Parliament of Victoria: Melbourne)

Whittaker J, Haynes K, Handmer J, McLennan J (2013) Community safety during the 2009 Australian 'Black Saturday' bushfires: an analysis of household preparedness and response. *International Journal of Wildland Fire* **(in press)**.

Are you ready? Ready for what? – Examining intended fire responses and preparedness by residents of fire prone areas

Ilona M. McNeill[1A], Patrick D. Dunlop[1], Timothy C. Skinner[2], & David L. Morrison[3]

[1] School of Psychology, University of Western Australia

[2] School of Psychological and Clinical Sciences, Charles Darwin University

[3] Chancellery, Murdoch University

[A] Corresponding author. Email ilona.mcneill@uwa.edu.au

Abstract

When it comes to preparing for bushfires, not all residents prepare to the same extent. In addition, they differ in the way they intend to respond to a fire threat. Results from a pilot study (Dunlop et al. 2012a, 2012b) suggest that differences in such intended fire responses may be related to differences in levels of preparedness for different types of preparedness. In order to further explore this we conducted a 2-wave field-study amongst residents of fire prone areas in Western Australia during the 2011-2012 fire season. Results from 229 respondents showed that those who intended to defend completed more defence preparatory actions than those who had more ambiguous response intentions (e.g. defend until fire directly threatens property), even though this latter group also holds defending as a viable option. Those who intended to evacuate completed the fewest defence preparations and the fewest property preparations, and had the fewest survival kit items. This study thus supports the idea that those with more ambiguous response intentions are more likely to end up being under-prepared.

Introduction

When threatened by bushfire, residents of fire prone areas in Australia can choose between defending their property or evacuating, preferably well ahead of the fire (Llewellyn 2012; Tibbits et al. 2008; Tibbits and Whittaker 2007). Australian fire agencies urge residents to decide how they will respond to the threat of bushfires ahead of time, and be well prepared for this response. Many residents, however, lack a specific (i.e., defend *vs.* evacuate) response intention; They intend to defend their property until it is too dangerous, wait for more information before deciding what to do, or wait for authorities to tell them what to do.

A pilot study run in 2011 suggested that different response intentions might be tied to different levels of preparedness (Dunlop et al. 2012a, 2012b). However, this could be caused by the fact that not all preparatory actions are relevant for all response intentions. For example, completing actions that are only relevant in case of defending will not be relevant if defending the house is not considered an option. It is therefore important to specify both residents' intended response to a bushfire and specify different types of preparedness.

The present study explored how residents' intended fire response is related to differences in their levels of preparedness for the specific actions of defending versus evacuating. Furthermore, it explored how their different response intentions relate to psychological preparedness and preparing properties to reduce the risk of the house burning down. In addition, the authors examined whether different response intentions and different levels of preparedness were tied to differences in residents' perceived preparedness to respond to bushfires. To do so, we collected data on the above variables in a longitudinal field study amongst residents of fire prone areas in multiple communities across Western Australia (WA) during the 2011-2012 fire season.

Method

We collected data in several wildfire prone communities in Western Australia over two time-points. The main study areas were all within 180 km of the State's capital city and represented a mix of high-density urban, medium-density peri-urban and low-density rural communities. Specifically, study areas included Gelorup, Stratham, College Grove (all to the south-west of Perth), Gidgegannup, Brigadoon, Red Hill (north-east of Perth), Roleystone and Kelmscott (south-east of Perth). The first time point (T1) was just prior to the fire season (October 2011), and the second (T2) was towards the end of the fire season (March 2012). The following variables were measured at T1: Intended Fire Response and Perceived Preparedness for Bushfires. At T2 we measured five different types of preparedness, namely Defence Preparation, Evacuation Preparation, Property Preparation, Preparation of a Survival Kit, and Psychological Planning.

Intended Fire Response

To record intended fire response we used a measure by Whittaker et al., 2010), which asks people 'Which of the following do you think you will most likely do if a bushfire occurs in your town or suburb?' with the following response options: R1 = Stay and try to protect your property throughout the fire; R2 = Do as much as possible to protect your property but leave if the fire directly threatens it/reaches your property; R3 = Wait to see what the fire is like before deciding whether to stay and defend or leave; R4 = Wait for police, fire or other emergency services to tell you what to do on the day; R5 = Leave as soon as you know there is a fire threatening your town or suburb; R6 = Would not be at home on days of extreme or catastrophic fire danger; R7 = Have not thought about it; and R8 = Other.

Perceived Preparedness

We measured perceived preparedness at T1 by asking people 'Overall, how prepared do you feel you are for bushfires?' (1=extremely unprepared, 6=extremely prepared).

Actual Preparedness

We measured five different types of preparedness, namely Defence Preparation, Evacuation Preparation, Property Preparation, Preparation of a Survival Kit, and Psychological Planning (based on a measure used by McNeill, Dunlop, Heath, Skinner, & Morrison, in press). These were all measured at T2 by asking participants 'Which of the following are currently true (i.e. true when you started filling out this survey) for you/your household?' (currently true/currently not true/not applicable). The preparedness scores were calculated as the percentage of applicable items that were marked as 'currently true'.

Defence Preparation. Defence preparation was measured with nine items, such as 'You possess and have prepared equipment to put out spot fires and sparks, such as metal buckets, rakes, shovels, and mops' and 'You possess fire fighting equipment that is operational' (Cronbach's α = .73; see Cronbach, 1951).

Evacuation Preparation. Evacuation preparation was measured with eight items, such as 'You have selected a suitable planned destination for evacuation' and 'You have mapped out an evacuation route' (Cronbach's α = .76).

Property Preparation. Property preparation was measured with 22 items, such as 'Fuels (e.g., leaves, twigs and long grass) are cleared for a distance of at least 20m around the house' and 'All of your roof coverings fit tightly so that there are no openings for sparks' (Cronbach's α = .81).

Survival Kit. Preparation of a Survival Kit was measured with nine items, such as 'You have obtained a portable battery-operated AM/FM radio' and 'You have obtained a waterproof torch' (Cronbach's α = .64).

Psychological Planning. Preparedness through Planning was measured with eight items, such as 'You have formed a household bushfire emergency plan' and 'You have thought carefully about what each person in your household would need to do in the event of a bushfire' (Cronbach's α = .80).

Results

Participants and Design

We sent 1700 surveys out at T1, and received 350 completed responses (a response rate of 20.6%, which is comparable to other bushfire survey studies in the area; e.g. McNeill et al., 2013; McNeill et al. in press). Of these 350 participants asked to participate at T2, we received a total of 233 completed responses (a response rate of 66.6%). Three out of the eight fire response categories contained less than 1% of participants ($N < 5$) (these were R6 – Would not be at home on days of extreme or catastrophic fire danger, R7 – Have not thought about it, and R8 – Other; see Table 2a for the percentage of people selecting each intended response). These three categories were disregarded in subsequent analyses as conclusions are difficult to draw based on such low numbers. The remaining 229 participants consisted of 118 males and 111 females, with an average age of 54.63 years (*SD* = 12.39, *Median* = 55). The majority of respondents owned the property or were in the process of buying it (96.1% at T1), 38.0% lived in a house or unit on a residential block, 56.3% lived on a hobby farm or small acreage, and 2.6% lived on a large farm or property.

Main Analyses

Upon examining the correlations between the different types of preparedness (Table 1) we found that all types were significantly correlated. Two correlations stood out as particularly strong, namely Defence Preparation with Survival Kit (r = .60) and Evacuation Preparation with Psychological Planning (r = .70). We will return to these results in the discussion.

Table 1. *Means of and Correlations between Different Preparedness Types*

	Mean (SD)	1.	2.	3.	4.	5.
1. Perceived Preparedness	4.47 (.97)	-				
2. Defence Preparation	66.56 (.24)	.44**	-			
3. Evacuation Preparation	64.85 (.27)	.36**	.20*	-		
4. Property Preparation	59.29 (.19)	.48**	.40**	.21*	-	
5. Survival Kit	78.17 (.21)	.37**	.60**	.34**	.37**	
6. Psychological Planning	70.78 (.29)	.44**	.25**	.70**	.29**	.33**

* $p < .01$; ** $p < .001$

In order to test the influence of Intended Fire Response on the different dependent variables we ran multiple ANOVA's and performed Bonferroni post-hoc tests for the analyses that showed significant effects for Intended Fire Response (see Table 2 for means and standard deviations for preparedness types across the different intended fire responses.

Table 2. *Mean Perceived Preparedness (P1) and Mean Percentage of Preparedness Items Completed (P2-P5) across Different Intended Fire Responses (R1-R5).*

	N (%)	P1 *M* *(SD)*	P2 *M* *(SD)*	P3 *M* *(SD)*	P4 *M* *(SD)*	P5 *M* *(SD)*	P6 *M* *(SD)*
R1	52 (22.3%)	4.88 (.90)	86% (.15)	65% (.28)	64% (.17)	87% (.14)	75% (.25)
R2	101 (43.3%)	4.37 (1.07)	62% (.24)	63% (.28)	60% (.19)	75% (.22)	67% (.30)
R3	43 (18.5%)	4.24 (.85)	65% (.24)	65% (.24)	55% (.19)	81% (.18)	69% (.29)
R4	18 (7.7%)	4.50 (.86)	63% (.17)	70% (.32)	60% (.22)	77% (.18)	74% (.29)
R5	15 (6.4%)	4.27 (.59)	38% (.20)	67% (.21)	47% (.18)	61% (.26)	80% (.26)

R1 = Stay and try to protect your property throughout the fire; R2 = Do as much as possible to protect your property but leave if the fire directly threatens it/reaches your property; R3 = Wait to see what the fire is like before deciding whether to stay and defend or leave; R4 = Wait for police, fire or other emergency services to tell you what to do on the day; R5 = Leave as soon as you know there is a fire threatening your town or suburb. P1 = Perceived preparedness; P2 = Defence Preparation; P3 = Evacuation Preparation; P4 = Property Preparation; P5 = Survival Kit; P6 = Psychological Planning.

Intended Fire Response and Perceived Preparedness

There was a significant effect of Intended Response on Perceived Preparedness, $F(4, 220) = 3.55$, $p < .01$, PES = .06. Post-hoc analyses (Bonferroni at $p < .05$) showed that those who intended to defend ($M = 4.88$, $SD = .90$; R1) perceived themselves as more prepared for bushfires than those who intended to do as much as possible ($M = 4.37$, $SD = 1.07$; R2), and those who intended to wait and see ($M = 4.24$, $SD = .85$; R3).

Intended Fire Response and Actual Preparedness

Defence Preparation. There was a significant effect of Intended Response on Defence Preparation, $F(4, 221) = 18.08$, $p < .001$, PES = .25. Post-hoc analyses (Bonferroni at $p < .05$) showed that those who intended to defend ($M = .86$, $SD = .15$; R1) completed a higher proportion of preparatory actions for defence than those who intended to do as much as possible ($M = .62$, $SD = .24$; R2), those who intended to wait and see ($M = .65$, $SD = .24$; R3), those who intended to wait for police or other emergency services to tell them what to do ($M = .63$, $SD = .17$; R4), and those who intended to evacuate ($M = .38$, $SD = .24$; R5). The last completed a significantly lower proportion of defence preparatory actions than any of the other groups.

Evacuation Preparation. There was no significant effect of Intended Response on the proportion of evacuation related preparatory actions completed, $F(4, 221) = .30$, *ns.*

Property Preparation. There was a significant effect of Intended Response on Property Preparation, $F(4, 221) = 2.88$, $p < .05$, PES = .05. Post-hoc analyses (Bonferroni at $p < .05$) showed that those who intended to evacuate ($M = .47$ $SD = .18$; R5) completed a lower proportion of property preparations than those who intended to defend ($M = .63$, $SD = .17$; R1).

Survival Kit. There was a significant effect of Intended Response on preparing a Survival Kit, $F(4, 221) = 5.94$, $p < .001$, PES = .10. Post-hoc analyses (Bonferroni at $p < .05$) showed that those who intended to defend ($M = .87$ $SD = .14$; R1) completed a higher proportion of survival kit actions than those who intended to do as much as possible ($M = .75$, $SD = .22$; R2), and those who intended to evacuate ($M = .61$, $SD = .26$; R5). Those who intended to wait and see also completed a higher proportion of survival kit actions ($M = .81$, $SD = .18$; R3), than those who intended to evacuate.

Psychological Planning. There was no significant effect of Intended Response on the proportion of Psychological Planning actions completed, $F(4, 221) = 1.18$, *ns.*

Discussion

This study showed that people who have different intended fire responses tend to differ in the extent to which they prepare, but only for some types of preparations. Firstly, those who intend to defend their property prepare more for defence than any of the other groups. This may not be a problem for those who intend to evacuate, as defence preparations are not part of their plan of action. However, for those with more ambiguous intentions (e.g. defend until the fire directly threatens/reaches property) it means that they will tend to be less prepared for defence than those who have a more specific defence intention.

Secondly, there were no differences in levels of evacuation preparation or psychological planning. This indicates that those who intend to defend prepare to the same level for evacuation as those with a more ambiguous intention and those who specifically intend to evacuate. This would seem to indicate that those who intend to defend may well hold evacuation as a possibility, something which fire agencies encourage since evacuation should always be considered in case of a catastrophic fire danger rating day (CFA, 2010; DFES, 2012).

Evacuation preparation and psychological planning were highly correlated. A likely explanation for this correlation is that both types of preparations are mostly psychological in nature, and therefore not restrained by physical ability or expenditures. Also, even though intended fire response was not related to differences in these two types of preparedness, both evacuation preparation and psychological planning reached an average completion of around two-thirds to three-quarters of the preparatory actions, leaving room for improvement. Future research could focus on examining other factors that may predict differences in evacuation preparation or psychological planning, and use them to motivate higher levels of these types of preparedness in the future.

Thirdly, those who intended to evacuate performed fewer preparations that would reduce the risk of the house burning down than those who intend to defend. This could indicate that those who intend to defend generally care more about the survival of their house than those who intend to evacuate. However, it could also mean that evacuators are not aware of the fact that these preparations will increase the chance of their house surviving even in their absence. Further research is needed to reveal the reasons for their relative lack of property preparation.

Finally, both those who intended to defend and those intending to wait and see had a larger number of survival kit items than those intending to evacuate. Those intending to defend until the fire would threaten their property had significantly fewer survival kit items than those who intended to defend throughout the fire.

Preparation of a survival kit was highly correlated to defence preparations. One of the reasons could be that people do not see a survival kit as being as necessary when evacuating. Still, agencies stress that everyone should prepare a survival kit, regardless of whether they are defending or evacuating (e.g. DFES, 2012). It therefore appears that communications about survival kits is not effectively understood or appreciated by the community. Future research could examine what factors could motivate residents to prepare a survival kit, regardless of their intentions or preparations for defence. In addition, future research should test whether the same relationships are present in other Australian States and different countries.

Practical Implications

These findings indicate a need for agencies to target those with a less specific response intention (e.g. defend until fire reaches property). This group may be significantly less prepared for defence than those who specifically intend to defend, even though many of the former will still consider defending as an option. People who hold such ambiguous intentions should be fully prepared for both defence and evacuation.

Interestingly, this study showed that those who intended to defend were most prepared for defence, but also well prepared for evacuation. Overall, the intend-to-defend group thus appeared to be the best-prepared. This is partially in line with their own perceptions, as those who intended to defend did see themselves as better prepared than those who intended to defend until threatened and those who intended to wait and see. Future research could focus on what makes this defence group more motivated to prepare than the other groups, so that agencies can use this in their communications to motivate the other groups within the community.

Another aspect agencies could focus on is the fact that those who intend to evacuate seem to perform significantly fewer property preparations. Increasing property preparations is useful, as it would decrease the chance of the house burning down even when people evacuate. As mentioned, one possible reason may be that evacuators are not aware of the fact that these preparations reduce the risk of their house burning down in their absence. Educating people about such risk reduction could potentially serve as a motivator.

In sum, this study has shown the need to distinguish between different types of preparedness, and has highlighted how response intentions relate to these preparedness types. Although future research is needed to determine the exact motives behind these differences, we believe the current study serves as a good starting point.

References

Country Fire Authority (CFA) 2010, *Prepare.Act.Survive. Fire Ready Kit*, http://www.cfa.vic.gov.au/fm_files/attachments/plan_and_prepare/frk/fire-ready-kit-complete.pdf, [August 09, 2013].

Cronbach LJ (1951) 'Coefficient alpha and the internal structure of tests.' Psychometrika **16** (3), 297–334. doi: 10.1007/BF02310555

Department of Fire and Emergency Services (DFES) 2012, *Prepare. Act. Survive. Version 4*, http://www.dfes.wa.gov.au/safetyinformation/fire/bushfire/BushfireManualsandGuides/FESA_Bushfire-Prepare_Act_Survive_Booklet.pdf, [August 09, 2013].

Dunlop PD, McNeill IM, Skinner TC, Morrison DL (2012a) 'Brief report on the University of Western Australia and Bushfire CRC pilot study**.**' (University of Western Australia, Bushfire Cooperative Research Centre: Crawley, Western Australia)

Dunlop PD, McNeill IM, Stacy J, Morrison DL, Skinner, TC (2012b) 'Preparing… for what? Exploring the dimensionality of community wildfire preparedness.' Paper presented at the 3rd Human Dimensions of Wildland Fire Conference, Seattle, WA.

McNeill IM, Dunlop PD, Heath J, Skinner TC, Morrison DL (2013) 'Expecting the Unexpected: Predicting Physiological and Psychological Wildfire Preparedness from Perceived Risk, Responsibility, and Obstacles.' Risk Analysis **33**, 1829-1843. doi: 10.1111/risa.12037

McNeill IM, Dunlop PD, Skinner TC, Morrison DL (in press) 'Predicting delay in residents' decision on defending versus evacuating through antecedents of decision avoidance.' International Journal of Wildland Fire.

Tibbits A, Handmer J, Haynes K, Lowe T, Whittaker J (2008) Prepare, stay and defend or leave early. In 'Community Bushfire Safety' (Eds J Handmer, K Haynes) pp. 59-71 (CSIRO Publishing: Melbourne).

Tibbits A, Whittaker J (2007) Stay and defend or leave early: Policy, problems and experiences during the 2003 Victorian bushfires. Environmental Hazards **7**, 283-290. doi: 10.1016/j.envhaz.2007.08.001

Whittaker J, Haynes K, McLennan J, Handmer J, Towers B (2010) 'Victorian 2009 Bushfire Research Response: Household Mail Survey.' (Bushfire Cooperative Research Centre: Melbourne) Available from http://www.bushfirecrc.com/managed/resource/bushfire-crc-housholder-mail-survey-executive-summary-10-1-10.pdf [Verified April 24, 2013]

Title: Firefighting the ‘paradox of place’ – the risks and dilemmas associated with knowing the place of fire

Authors *Tarnya M. Kruger* [A, B] *and Ruth Beilin* [A, C]

[A] Department of Resource Management and Geography, Melbourne School of Land and Environment, The University of Melbourne, Victoria 3010 Australia

[B] Bushfire Co-operative Research Centre Victoria 3002 Australia

[C] Corresponding author Email: rbeilin@unimelb.edu.au

Additional keywords: Australia, bushfire/wildfire, hazards, local knowledge

Abstract

This research investigates the relationship between firefighters and landscape, and considers how ideas about the location of a fire can affect firework. In 2012, interviews were conducted with 68 Australian bushfire firefighters from selected agencies and volunteer brigades in contrasting localities: the north-east coast of Tasmania, the urban-rural interface of Canberra, and the grazing farmlands of western Victoria. Stories of fire events and the various roles undertaken were analysed. What emerged is how the ‘place’ of fire can be a paradox for firefighting and this can play out in several ways. Firefighters attending a fire in their local area would seem a safer proposal, then when deployed to a distant fire, surrounded by many unknowns. However, local fire crews will arrive first on scene and despite knowing the landscape must resist taking more risks in defence of their place. Instead, they must work toward a structured order of firefighting. The fire further afield has many potential hazards for deployed firefighters because they do not have local knowledge, yet, the fire will be burning for hours or days and the command structure will be set up by the time the non-local firefighters arrive. The ‘paradox of place’ is where the local fire can at times be more hazardous for local firefighters because of their ‘local knowing’ of place. In contrast, proceeding cautiously at a distant fire, can make for safer firework. The involvement of both local and deployed firefighters at any fire, must strive to find the ‘right balance’ of local knowledge, adaptive decision-making and risk, whilst operating safely within the structure and rules of firework. This is one of our findings associated with aspects of firefighting and place, which indicates the complexity inherent in the concept of local knowledge.

Introduction

Historically there appears a progression from the days of local brigades and local firefighting, to contemporary deployment of firefighters across regions, borders and even oceans. During the nineteenth century in Australia, brigades of volunteer firefighters established at the local level, as farmers banded to protect their patch and gold mining communities sought to defend their newly created towns (Murray and White 1995). Since the late 1990s firefighters from, for example, New Zealand and North America, and fire trucks from interstate and volunteers from everywhere attend large-scale fires in Australia. This is part of the 'surge capacity' (Kelen and McCarthy 2006) where all available resources are deployed in response to an emergency or disaster. Most obviously, there will be people deployed in the field who do not come from the landscapes in which they are fighting the fire (Gill 2005).

We initially speculated that this migratory response challenged the value of local knowledge (Pyne 2006) and the meaning of knowing the physical and social 'lie of the land' for firefighters. We wondered about the implications for firefighters' adaptive response (Gibson and Tarrant 2010) in firework. We envisaged the deployment of firefighters to distant areas surrounded by many unknowns as the 'stone in the firefighter's boot', striving to adjust to a new set of fire conditions and hazards in unfamiliar terrain. In this paper, we present a range of the dilemmas experienced by firefighters, which suggests knowing the place of fire is complicated and can affect firework in many ways.

Background

The difficulty of adapting to a unique set of circumstances – every fire is different – makes it complex and challenging to not only carry out firework but to understand the landscape in which firefighters encounter the fire (Weick 2002). The initial training undertaken by all personnel involved in Australian bushfire response provides a foundation for understanding operations, equipment, safety protocols and fire behaviour. However, firefighters can encounter vastly different landscapes and may lack local knowledge of particular landscape types. For example, they may be from a place where the dominant landscape is grassland plains, and deployed to an area where there is forest and hilly terrain. This diversity emphasises the importance of (the now institutionalised) reliance on paramilitary type training that is intended to provide cues (Whiteman and Cooper 2011) for fire response behaviour across multiple landscapes and terrains.

Firefighters responding at the nexus of the bushfire and landscape must quickly take on board information about the site, its bush, fire, and people; as well as about their peers involved in the fire response at the place of fire. However, information without meaning is not knowledge, and firefighters must integrate information (Wenger 1998) and give it meaning in order to act adaptively. Furthermore, this adaptive firework can only operate in a command structure that at times provides the flexibility for firefighters who have the experience to step outside a tightly ordered system (Perrow1999) and make appropriate decisions for the fire attack. Here lies a major dilemma; the required experience on the part of the firefighter, to know when to act adaptively or to stay within the hierarchal response to the fire. The structure may not account for variations associated with being on the spot and needing to make relevant decisions, some of which may be due to the individual's knowledge of place.

Desmond (2011) argues that what occurs during a fire event demands a unified response and adherence to the rules. When things go wrong such as a serious accident or fatal injury, it is likely the fire authority/agency will find the individual or team has worked outside the standard operating orders. Desmond finds it is almost impossible for firefighters to stay within the rules at all times during a fire, in this way, responsibility lies with the firefighter and not the organisation.

We first assumed local knowledge would be important for fighting fire and wondered about its role and any tensions between the structured attack versus the intuitive or 'local knowing' of place. Every firefighter brings their own experience, opinions and values but these must sit within the rules (Kaufman 1960) and strategies of firefighting. We set out to ask firefighters about their experience in relation to local knowledge of place and their interaction with fire.

Methods

For this study, we asked how firefighters understand and relate to place, and how the locality of a fire affects their firework. We sort to include a representative sample of firefighters (Holstein and Gubrium 1995, p.74), from locations with different fire management agencies operating in contrasting landscapes and a history of large and small fires. This allowed for comparative analysis. Guided by the fire agencies, we contacted brigades and staff and met with firefighters to outline the study and invite participation. The areas were:

- the coastal area and forested hinterland with small and regional townships of north-east Tasmania (18 firefighters);
- the urban rural fringe of Australia's capital city, Canberra, in the Australian Capital Territory (ACT) surrounded by grasslands, and mountainous bushland, forest, (18 firefighters) and;
- the undulating grasslands and farmlands with small towns and regional centres of the Wimmera and southern Mallee region of western Victoria (32 firefighters)

We incorporated mixed methods (Creswell 2009, p.25) using a semi-structured question guide and a mapping task, with individuals and groups of firefighters. The use of open questions encourages the interviewee/s to tell their stories (their narrative). We investigated themes associated with landscape, local knowledge, hazards and decision-making. We also outlined a scenario of a local fire with deployed firefighters coming to assist. Interviewees considered the important features to relay about their landscape and using this information, constructed their' mud map'

Pilot interviews were conducted between September and December 2011 with five firefighters, and the major study involved a further 63 firefighters and ran between March and August 2012. The 32 interviews comprised 21 individual and 11 group interviews. We intentionally kept the size of each group small (~4) to allow for shared discussion (Krueger and Casey 2000). A group interview is an appropriate method, as firefighters operate in groups in their firework (Haski-Leventhal and McLeigh 2010). However, we provided the option for individual or group interviews, noting the challenges of particular fire events that might make it difficult for some firefighters to discuss. This study largely focussed on volunteer firefighters (48); although we did include eight career firefighters and 12 seasonal firefighters (staff within a government department, who participate in fire duties). The whole study included 13 females (19%) and this reflects the national ratio for the estimated female participation in brigades at 17 percent (Birch 2001, p. 31).The lead author transcribed all interviews verbatim. The interview times averaged 70 minutes for individuals and group interviews were approximately 100 minutes. The interview data was organised using spreadsheets and QSR NVivo10 software. Transcripts were coded by topic and then analytically coded (Richards 2009 p. 96). Key ideas and underlying meanings were identified in this process.

Findings

All firefighters named in this paper are ascribed a pseudonym. The following excerpts from the interviews, unless otherwise stated, reflect the majority of what firefighters described, and what we have termed, 'paradox of place'.

Fighting at the local fire place

The hazards associated with attending a fire can be a matter of timing. When a fire breaks out, the local volunteer brigade will likely be first on scene. The pressure upon the first responders to control the fire is high.

> "Because you are first responder, your adrenalin is up, you are a bit more pumped up ... So, your thought processes are different for the first response. When you go away, the fire may not be any different, but you don't have that adrenalin rush, right, you are going there in an orderly fashion, and you get a briefing and told you are going to go and do this" [Barry, volunteer Victoria].

The local brigade attending a fire in their patch, experiences a level of trepidation entering the fire ground, to bring the fire under control. In 'ideal conditions'—dry, hot, windy— a fire can quickly become disastrous and create a period of chaos before order, as Charles described:

> "I think it seems the bigger the fire the more chaos actually, not saying it is bad but because what happens is the normal brigade responds and they say they need assistance. And, so they might bring in the neighbouring brigade and it sort of, just keeps building from there as the fire changes and it gets bigger, gets away, or the wind changes. I was probably critical first up that it was so *ad hoc* but since then I have been on a couple more and I don't think there is really any other way to staff it first up." [Charles, volunteer Tasmania]

This period of 'initial chaos', Charles suggested has to happen. This *ad hoc* approach can be understood as adapting to new conditions until the command structure resolves the 'unknowns' to establish a 'known' ordered practice. Garry corroborated the danger in the early stages of a fire, he described as the "s*** fight stage". However, if the structure is not set up within reasonable time, this makes following orders very difficult. "...if you arrive two hours into it, and there are guys and no one in control and no clear lines, and if they start saying 'you are going down there', I think 'no way'!" [Garry, seasonal ACT]. Gary has considered 'order begets safety', however; this conflict situation could further compound problems at the fireground.

Another firefighter described that even small local fires can go ‘pear-shaped’, unless someone takes command at the fireline: “...someone has got to take charge of that incident, like straight away or it just gets higgledy piggledy” [Ryan, volunteer Victoria]. The organised attack and structure is what the local or deployed firefighter relies upon to assist their firework. Their sense of security, to operate in a ‘known place’ incorporates local knowledge and the structured attack which reflects a marrying of place and ordered firework, at least in the early stages of a fire. The initial order at the fireground is reliant upon one of the local firefighters quickly taking charge because they know the area. However, if the fire grows beyond his or her capability then hand-over to a more experienced leader (not necessarily local) should occur.

In the rush to contain an outbreak, first responding crews wrestle with attacking the fire or waiting for an ordered command, as one firefighter described his experience at a rapidly escalating fire. “...there were a few mistakes, like I was on the [brigade] tanker and you got in there and it was fairly chaotic at the time, but you got left to your own devices and we sort of freelanced around the fire instead of being called into a Strike Team and all stuck together” [Cameron, volunteer Victoria]. During this high fire danger day, the brigades rushed to the scene and with little time to establish order, commenced attack, ‘freelancing’ in protection of their township. Fortunately, the fire attack fell into order and the fire was contained. The concept of ‘freelancing’ was raised by another firefighter, deployed to a major fire. Firefighter Rowan [career Tasmania] described the challenge of assigning crews to stay and protect a bridge, when local brigades wanted to continue direct attack. This points to a tension between the ‘local knowing’ associated with the urge to defend a particular place and the broader strategic requirements of fighting fire.

Negotiating the faraway fire place

Deployed firefighters usually reach a fire some hours or days into the fire, when the firework is routine and ordered. “... like you are travelling a reasonable distance before you get there, you have got time to think about it and hopefully when you do get there that they have got a local or someone with a bit of knowledge to be able to show you”[Wayne, volunteer Victoria]. The likely duties for the deployed firefighter include, ‘mopping up’, back burning and logistical support. “We knew we only had to protect and blacken out, so the unknown fear isn’t there” [Darren, volunteer Tasmania]. The fire agencies recognise the limitations of firefighters not knowing the place, and assign deployed firefighters to ‘safer areas’, and generally not in direct fire attack.

The deployed firefighter relies on fire updates, opportunities for reconnaissance of the area, and local firefighters and their knowledge of place. However, Adam discovered when deployed to the USA, it is not always firefighters who provide essential information.

> “... there were a couple of bear researchers that I got as my guides first time around. They knew their way around. They didn’t know much about fire behaviour, but they knew who was who” [Adam, career Victoria].

A number of firefighters described how with experience you become perceptive about who can assist and who holds critical information about an area. “The two dozer drivers out working with us, they were local blokes and they were able to provide us with a lot of information and it was handy” [Barry, CFA Victoria]. At the fireground with hundreds, sometimes thousands of people, all going about their business, it is not always apparent who the knowledge bearers are.

> "So you very quickly work out who, who the people are that are experienced, and sometimes they are not the staff that work for the wildfire management branch, sometimes they are the contractors. ... generally it is conversations, you start to talk to people and you watch how others interact" [Shane, seasonal ACT].

On the flipside, a firefighter must learn how to discern who is not so useful. "I have seen that where old Joe has been around for 30 years he knows what he is on about, well maybe old Joe doesn't quite know, he just happens to be around for a while" [Liam, seasonal ACT]. Deployed firefighters look to build their understanding of place, and local people can be one way of developing this knowledge. Furthermore, judgement is required, and experience helps firefighters (Lewis et al. 2011) to consider or find reliable sources of information.

Other techniques described by deployed firefighters are about 'making time', slowing the process of the urgency of response, wherever practical.

> "You have to take a step back and put the fire on hold, until you can put a handle on your resources and what you've got, where the hell are they all [crews]. But if you let it get at you, well you can go into panic mode..." [Evan, volunteer Tasmania].

Harry reiterates Evan's experience: "Take a step back, take a look at it and get things under control, which is not easy at times" [Harry, Volunteer Tasmania]. The pressure to respond quickly, straddles the need to operate safely and find the time required to assess all conditions at the fireground. This can mean the firefighter in-charge must push back against the expectation of crews of firefighters ready for action, as Jake explained:

> "Once you hold that rank, you think these people's lives and safety is really in my hands. I do what I tell them to do and if make a bad decision I could really hurt them, so sometimes I am very cautious ... I can see why people in the past were reluctant to let me go off [freelance] and do what I wanted, because they were being cautious to protect me. At the time, I did not appreciate it. When you have that responsibility for others then it really dawns on you, how big it is and now I understand why. I am far more cautious then I use to be" [Jake, volunteer ACT].

Firefighters attending fires over-time, build their technical skills and adroitness to consider both the physical and the human factors of firefighting. A firefighter's adaptiveness at the fireground, adjusting to working with new personnel, finding reliable sources of local knowledge and 'making time' are all part of the skills and aptitude of fighting fires in any location.

Conclusion

In conclusion, we move from fighting fires in unfamiliar surrounds as the 'stone in the firefighter's boot', where firework is hampered to some degree by operating in a new area; to finding other stumbling stones at play, when firefighters defend their own patch. Local firefighters as first responders, tasked with direct fire attack, enter a most hazardous period, not the least because the command structure may not be set. In catastrophic conditions the dangers amplify, as local firefighters negotiate the fire, 'freelance' in defence of their place with a heightened awareness and 'local knowing' of likely impacts. Whereas, firefighters sent to a distant fire, arrive hours or days later and while the fire may still be unruly, fighting strategies will be in order. Deployed firefighters focused on foreign surrounds, learn to adjust to new circumstances, to seek out the 'right locals', resist urgency and 'make time' to assist their firework. Furthermore, most deployed firefighters are assigned safer tasks away from the fire front. We find the 'paradox of place' can affect all types of firefighters (volunteer, seasonal or career), where at times the nearer the fire the riskier the fire fight, in contrast, a fire further afield can make for safer firework.

The 'local knowing' of the social and cultural aspects of place is not separate to the physical business of firefighting. This response to the place of fire, such as freelancing and *ad hoc* firework, particularly in the early stages of a fire, whilst appearing to operate outside the structured order of firefighting, can allow the firefighter to be much more adaptive. However, it requires the command structure to have confidence in a firefighter's local knowledge and judgement to operate adaptively and spontaneously. This adaptive response suits the ever-changing nature of fire, but this approach must still abide the rule of self-preservation and the safety of other firefighters. Firefighting at local or distant fires depends on local knowledge and this underpins the firefighter's firework – to use their own local knowledge or sought from others – in an objective way about each site of fire.

The complexity of the 'fire place' in training and deployment could consider the challenges identified in this study, to find the poise between local knowledge, adaptive response and risk, which can operate safely within the structure of firefighting. In addition, fire management could check issues of local firefighters arriving ahead of 'order' and the pressure to 'freelance' and take risks; and to reaffirm with deployed firefighters to pace firework and to seek and ascertain reliable local knowledge. These are all steps towards fighting the 'paradox of place'.

Limitations of the study

This qualitative research has identified an issue in firefighting. These finding provide insight into practical responses that may be applicable to other localities, countries and other natural hazards where the emotional connection to place for responders exists. Further research to explore and quantify this is a management consideration in hazard response would be required.

Acknowledgements

This research is supported through a scholarship provided by the Bushfire Co-operative Research Centre, Australia. We especially thank the firefighters interviewed for this study.

References

Birch A (2011) 'Recruiting and Retaining Volunteer Fire fighters in Australasia – An Integrative Summary of Research.' (La Trobe University, Bushfire CRC, Melbourne)

Creswell JW (2009) 'Research design: qualitative, quantitative, and mixed methods approaches.' 3rd edn. (Sage Publications, Thousand Oaks, Calif.)

Desmond M (2011) Making Firefighters Deployable. *Qualitative Sociology* **34** (1), 59-77.

Gibson CA, Tarrant M (2010) A 'Conceptual Models' Approach to Organisational Resilience. *The Australian Journal of Emergency Management* **25** (2), 6-12.

Gill AM (2005) Landscape fires as social disasters: An overview of 'the bushfire problem'. *Global Environmental Change Part B: Environmental Hazards* **6** (2), 65-80.

Haski-Leventhal D, McLeigh J (2010) Firefighters Volunteering Beyond Their Duty: An Essential Asset in Rural Communities. *Journal of Rural and Community Development* **4** (2), 80-92.

Holstein JA, Gubrium JF (1995) 'The active interview.' Qualitative research methods (SAGE Publications, Thousand Oaks)

Kaufman H (1960) 'The forest ranger: a study in administrative behavior.' (Published for Resources for the Future by Johns Hopkins Press, Baltimore)

Kelen GD, McCarthy ML (2006) The Science of Surge. *Academic Emergency Medicine* **13** (11), 1089-94.

Krueger RA, Casey, MA (2000) 'Focus groups: a practical guide for applied research.' 3rd edn. (Sage Publications, Thousand Oaks, Calif.)

Lewis A, Hall TE, Black, A (2011) Career stages in wildland firefighting: implications for voice in risky situations. *International Journal of Wildland Fire* **20** (1), 115-24.

Murray R, White K (1995) 'State of fire : a history of volunteer fire fighting and the Country Fire Authority in Victoria.' (Hargreen Publishing, Melbourne)

Perrow C (1999) 'Normal accidents: living with high-risk technologies' (Princeton University Press, Princeton, NJ)

Pyne SJ (2006) 'The still-burning bush.' (Scribe, Carlton North, Vic.)

Richards L (2009) 'Handling qualitative data : a practical guide.' 2nd edn. (SAGE, London)

Weick KE (2002) Human factors in fire behavior analysis: Reconstructing the dude fire. *Fire Management Today* **62** (4), 8-15.

Wenger E (1998) 'Communities of practice : learning, meaning, and identity.' (Cambridge University Press, Cambridge, U.K. ; New York, N.Y.)

Whiteman G, Cooper WH (2011) Ecological Sensemaking. *Academy of Management Journal*, **54** (5), 889-911.

Heatwave defined as a heat impact event for all community and emergency sectors in Australia.

John Nairn
Bureau of Meteorology, South Australia, Australia

Abstract

Lack of agreement over a heatwave definition has impeded spatial and temporal analysis of events within Australia and with comparable locations internationally. Given that heatwaves impact all natural and human engineered systems in a similar manner it seems logical to derive a measure that permits this form of analysis so that heatwave mitigation best practices may be shared.

As Australia is yet to develop a national heatwave warning system, features that have shaped heatwave warning systems in Europe and the USA are examined to inform how a domestic system may evolve.

A heatwave definition that can serve an Australian heatwave warning system has been created through considering how systems respond under heat load. Systems susceptible to failure under thermal stress have natural or engineered design limitations. These limits are an adaptive response to commonly experienced rates of heat accumulation found over both the long (climate scale) and short (acclimatisation) term. When these limits are exceeded, systems begin to fail. The larger the thermal load, the greater is the impact and scale of failure. Short and long term heat anomalies are factored together to derive a measure of heatwave intensity. This heatwave intensity measure has been shown to be useful for charting Australia's heatwave climate history, forecasts, warnings and assessment of risk arising from climate change.

A statistical interpretation of the climatology of heatwave intensity has then been developed to provide guidance on heatwave severity in chart form providing guidance on the level of impact anticipated due to the intensity of the heatwave (Nairn and Fawcett, 2013).

Introduction

Historically, heatwaves have been responsible for more deaths in Australia than any other natural hazard, including bushfires, storms, tropical cyclones and floods (Coates, 1996). McMichael et al. (2003) has estimated that extreme temperatures contributed to the deaths of over 1000 people aged over 65 each year across Australia.

Health authorities across Australia have recently recognised heatwaves as a serious and increasingly hazardous threat to our communities. This threat was realised in 2009 when over 400 people died across southeast Australia during the

January/February extreme heatwave (Mason et al., 2010; Victorian Department of Health, 2009), immediately preceding the 173 deaths arising from the Victorian Black Saturday fires (Teague et al., 2010). In subsequent seasons Australian communities have continued to experience impacts from intense heatwaves. This is consistent with expected increases in heatwave duration, frequency and intensity under projected climate change (Alexander et al., 2007).

State authorities have engaged the Australian Bureau of Meteorology (the Bureau) to explore effective mitigation and response strategies. The Bureau has responded by developing a national heatwave intensity measure that enables tracking and alerting for severe and extreme impacts (Nairn and Fawcett, 2013).

Creation of a heatwave intensity measure is only one of many ingredients required to implement and operate an effective Heat Health Warning System (HHWS). Analysis of existing HHWSs deployed across Europe and North America has recently been undertaken by the author with the support of the Bureau and a Churchill Fellowship (Nairn, 2013) to understand how the differing heatwave services have evolved, and what lessons may apply to the creation of a national heatwave warning system in Australia.

This investigation also considered the scientific methodologies employed to identify and alert for heatwave severity. International comment was invited on Australia's new heatwave intensity measure. UK and USA contacts expressed great interest in the Australian heatwave methodology leading to offers for collaborative studies to investigate impact sensitivity.

International Heatwave Lessons

There is significant heatwave service diversity around the world. The unitary states of the UK, France and Macedonia operate high profile services supported by very effective partnerships across government and non-government organisations. By comparison other nations with federated jurisdictions had lower profile services that were less effective unless central government explicitly deployed compensation measures (Nairn, 2013).

The central government in Italy provides payment incentives to clinic doctors to register patients at risk of heat stress thereby improving access to medical help during heatwaves. Another example of effective central government intervention occurs in the USA where leadership across a partnership of federal agencies guides a program of research, training and development designed to establish best practices for health and environment practitioners at state and regional levels. This whole-of-government partnership has led to a large number of federal agencies building internal business targets for the delivery of health and environment outcomes, strengthening community resilience through a range of programs delivered by different arms of the federal government. Apart from national health agencies, other federal government agencies have come to recognise and prioritise how they can contribute to public health and environment outcomes.

Despite Australia's investment in climate adaptation research (NCCARF, 2008-2013) there are comparatively weak heatwave mitigation partnerships across federal government agencies. Building effective heatwave knowledge and response systems centred on research, training and development in Australia requires multi-agency partnerships, heatwave mitigation role acquisition and community resilience policies that extend responsibility for improved health and environmental outcomes to the wider community and across federal government agencies.

Stakeholder management has been quite straightforward in France and some neighbouring countries following the 2003 extreme heatwave in which 15,000 people died in Paris alone (Robine, et al 2008). Political demand has maintained a steady stream of research and policy initiatives in countries strongly impacted by this event. Australia's extreme heatwave impacts are yet to gain political attention, particularly as these very high impact events frequently occur in close proximity to catastrophic bushfires. The fundamental difference between these hazardous events is the rate at which impact intelligence is acquired and shared.
Rapid sharing of health impact data has become standard practice in the UK and USA, where situational awareness from shared Syndromic Surveillance Systems[1] data has empowered partner agencies to commit to mitigation strategies and respond more effectively.

Well communicated peer reviewed science has also been instrumental in governing the pattern of heatwave services supplied to the community. The UK has enshrined this approach within the Cabinet Office by assigning a Civil Contingencies Secretariat to oversee agency collaborations to ensure that hazards listed on the National Risk Register (NRR) (Gov.UK, 2013) have appropriate treatment options. Executive government ownership of NRR treatments for reduction of risk creates an environment where empowered government agencies plan and act with authority and communicate readily with the Cabinet.

International Heat Health Warning Systems are triggered by thresholds set against a range of temperature indices. The diversity of temperature thresholds employed is accompanied by difficulty in verifying their suitability for accurately identifying impact thresholds. Despite the strength of UK and USA health and weather service partnerships their use of threshold methodologies limits their ability to resolve heatwave events at resolutions requested by stakeholders (Health Protection Agency, 2007). Threshold methodologies also limit their ability to build heatwave climatologies suited to mitigation and education purposes. By comparison Australia's candidate heatwave service compares heatwave intensity against the record of past heatwaves to assign a level of severity for each locality. The identification of heatwave intensity and its relative severity can be resolved at a local resolution which relates well to impact and permits statistically driven mitigation plans.

The unitary and federated state structures of countries in Europe and North America have required service development strategies that are sensitive to sovereign

[1] Where data is systematically collated and reported from health sector records. ie. clinic, hospital and ambulance records

divisions of power. Effective health and environment agency partnership structures are sensitive to these divisions of power. Rapid impact data gathering and sharing mechanisms support partner agencies and executive government in the delivery of effective heatwave services. An underlying principle for service development is the presence of well communicated peer reviewed science. The science of heatwave measurement and attribution of impact is still under development across Europe and the USA. Australia's heatwave methodology was considered to be a strong candidate for future heatwave services.

Heatwave Intensity

Heatwave terminology constructed by Nairn and Fawcett (2013) permits the understanding and calculation of heatwave intensity. Heatwave intensity is derived from factoring together long-term temperature (Excess Heat) and short-term temperature anomaly (Heat Stress) indices.

Excess Heat: *This is unusually high heat arising from a high daytime temperature that is not sufficiently discharged overnight due to unusually high overnight temperature. Maximum and subsequent minimum temperatures averaged over a three-day period are compared against a climate reference value to characterise this unusually high heat in an excess heat index. This is expressed as a long-term (climate-scale) temperature anomaly.*

Heat Stress: *This arises from a period where temperature is warmer, on average, than the recent past. Maximum and subsequent minimum temperatures averaged over a three-day period and the previous 30 days are compared to characterise this heat stress in a second index. This is expressed as a short-term (acclimatisation) temperature anomaly.*

Heatwave Intensity (Excess Heat Factor): *The combined effect of Excess Heat and Heat Stress calculated as an index provides a comparative measure of intensity, load (accumulated excess heat), duration and spatial distribution of a heatwave event. Heatwave conditions exist when the EHF is positive.*

EHF = Excess Heat x (1, Heat Stress)

Heatwave severity

Heatwave severity thresholds are derived from the 85th percentile of the Cumulative Distribution Function (CDF) of daily heatwave intensity (figure 1). This threshold intensity value marks the transition from frequently observed low intensity heatwaves to rarer, high intensity heatwaves.

Heatwave severity is a function of each location's climatology of heatwave intensity. Statistical evaluation of the frequency distribution of heatwave intensity provides an objective severity threshold that is unique for each location.

Severe Heatwave: *An event where EHF values exceed a threshold for severity that is specific to the climatology of each location.*

Extreme Heatwave: *An event where EHF values are well in excess of the severity threshold, resulting in widespread adverse outcomes. This has been empirically determined to be where EHF values are greater than two times the severity threshold.*

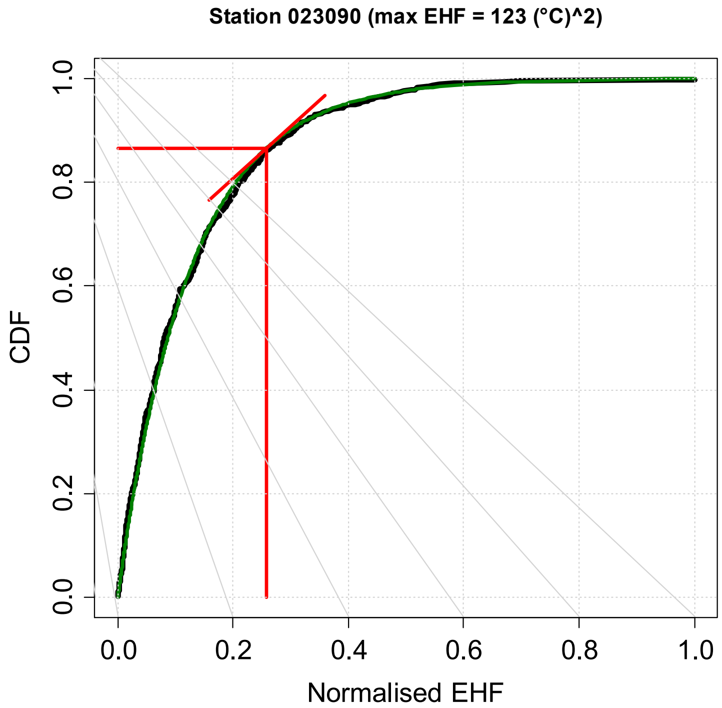


Figure 1 : Adelaide cumulative distribution function (CDF) of positive EHF (black line under the green line) normalised with respect to the maximum observed EHF, modelled generalised Pareto distribution (green line), and showing the turning-point method for determining the severe EHF threshold (red lines).

When each location's climatology has been processed as shown in figure 1 the map of Australia's heatwave intensity threshold for severity can be mapped, figure 2.

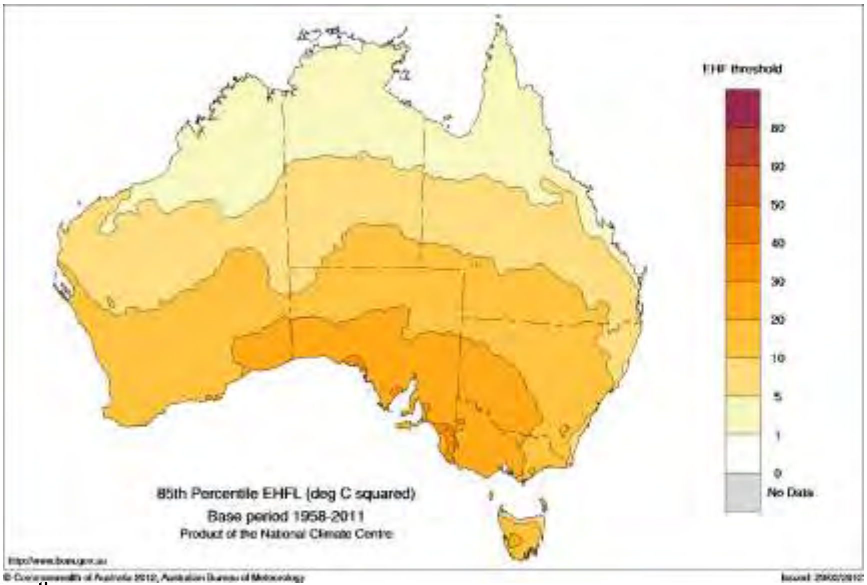


Figure 2: 85th percentile for positive EHF values (that is, EHF_{85}), calculated over the period 1958-2011, using gridded Daily Mean Temperature (DMT) analyses.

Climatologically-derived severe heatwave intensity thresholds are then mapped to charts of heatwave intensity illustrating areas of low, severe and extreme intensity, (Heatwave and Severe L1 to Severe L4 in figure 3).

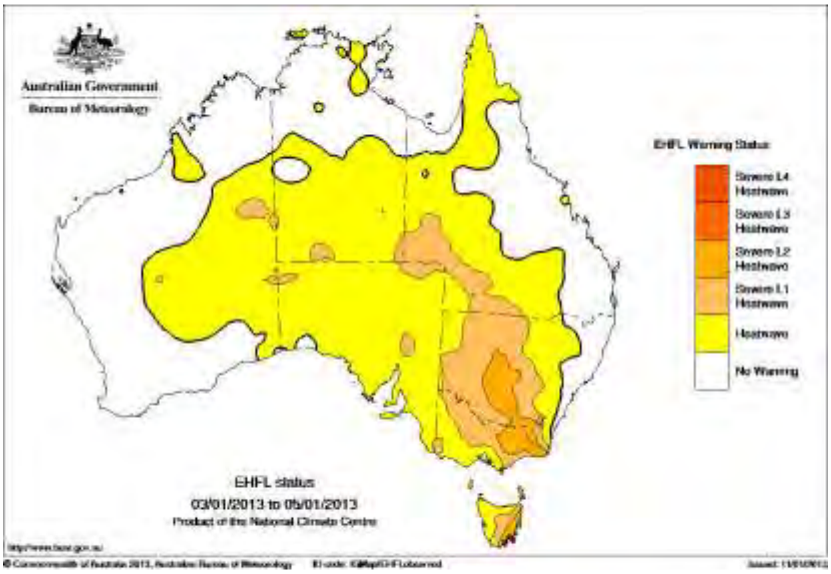


Figure 3: Areas with positive EHF for the period 03-05 January 2013, mapped for incidence of heatwave and level of severity. The contour band "Severe L1 Heatwave" indicates EHF values between one and two times the EHF severity threshold, while the contour band "Severe L2 Heatwave" indicates EHF values between two and three times the EHF severity threshold, and so on.

On 4th January 2013 several large bushfires became established across Tasmania. It is notable that figure 3 shows the eastern half of Tasmania was experiencing Severe L1 and L2 Heatwaves in a period which spans these fires. These levels denote rare and very intense heatwave conditions which were conducive to unusual bushfires as well as health challenges for vulnerable people.

2009 Extreme Heatwave and Catastrophic Fires

In January and February 2009 southeast Australia experienced an extreme heatwave sequence culminating in Black Saturday on 7th February (National Climate Centre, 2009). Figure 4 shows the accumulated heat load calculated from gridded climate data (Jones et al., 2009) across southern Australia encompassing this period.

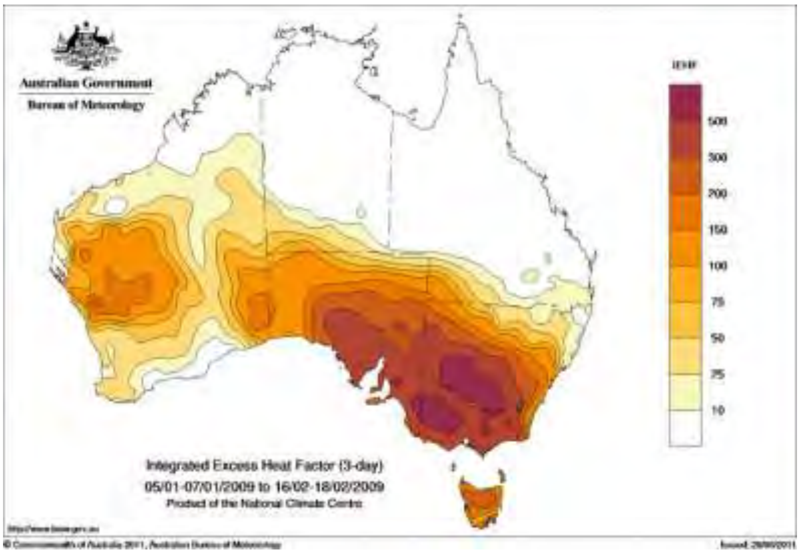


Figure 4. Accumulated Excess Heat Factor (EHF) from 5 January to 16 February 2009.

Catastrophic bushfires in the state of Victoria at the end of the heatwave resulted in the death of 173 people (Teague et al., 2010). Prior to this bushfire over 400 excess deaths occurred in the states of South Australia and Victoria (Mason et al., 2010; Victorian Department of Health, 2009, Langlois et al., 2013). Accumulated EHF over 400°C^2 in these two states is broadly indicative of the area impacted (figure 4).

Adelaide's time sequence for EHF and day of heat attributed mortality shown in Figure 5 shows the peak heatwave intensity leading the mortality peak by two days. It is also notable that the first day of severe heatwave intensity led the first record of heat mortality by one day. Each EHF value on the chart is an expression of the average heat load over a three day period, inclusive of the current and following two days. Calculated in this manner EHF shows a predictive capacity for the heat mortality response.

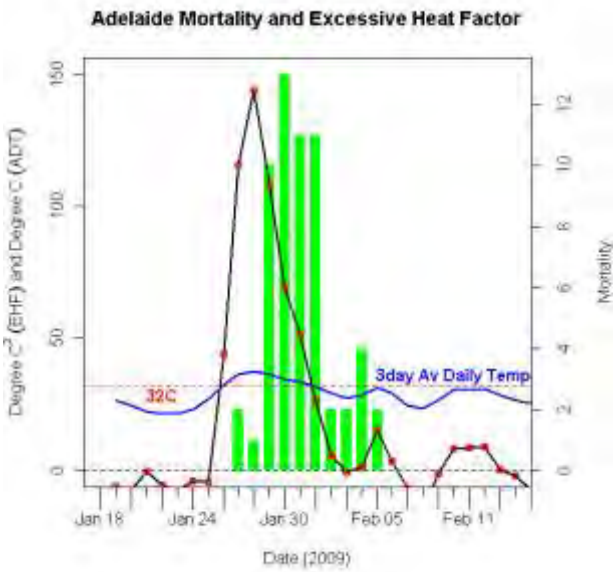


Figure 5. Mortality and EHF for 2009 extreme heatwave in Adelaide, South Australia. Heat related mortality (green bars), Excess Heat Factor (black lines with red dots) and three day average daily temperature (blue line). Severe EHF threshold of 32°C^2 (---)

In Adelaide's 120 year climate record the 2009 EHF peak amplitude of 144°C^2 shown in figure 5 is the top ranked event which is over four times the severe threshold value of 32°C^2. Values of EHF greater than twice the severe threshold value have been found to align with extreme heatwave impacts in Australia, USA and Europe (Nairn and Fawcett, 2013).

The corresponding chart of heatwave severity shown in figure 6 conveys the spatial spread of this extreme heatwave at the time of peak EHF in Adelaide, providing a ready assessment of the stress systems were enduring across the south and southeast of Australia at this stage of the heatwave.

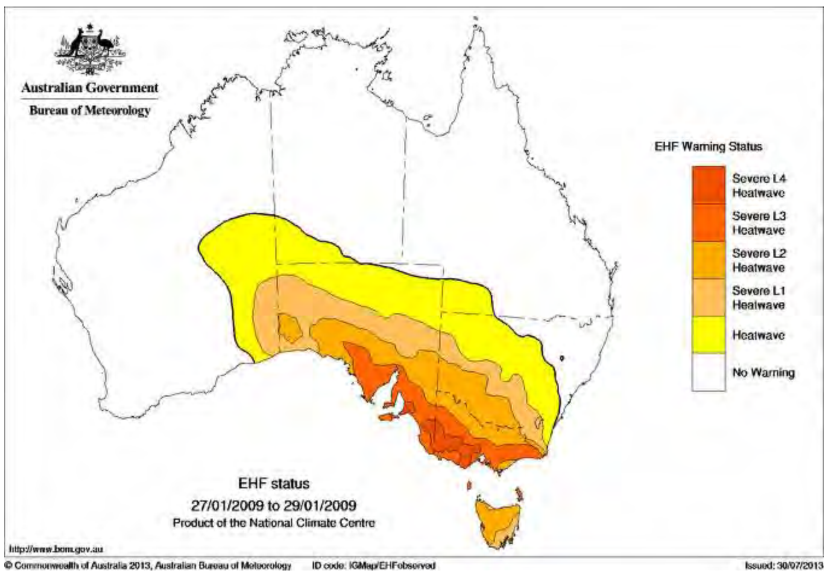


Figure 6. Heatwave severity for 27 January 2009 (three day period).

The accumulated EHF for this event was 586°C^2 which is also the top ranked event in Adelaide's 120 year climatology. Adelaide's second ranked heatwave occurred in January 1939. The 1939 extreme heatwave also coincided with devastating bushfires, with 438 heatwave deaths reported in South Australia, Victoria and New South Wales (EMA, 2007).

Potential Heatwave Services

The Bureau's capacity to develop and provide a heatwave service is predicated on capacity building;

(i) in developing a well-understood and scientifically defensible heatwave definition;

(ii) in acquiring stable systems for the examination of the climate record; and

(iii) the provision of reliable and robust forecast and warning services.

The Bureau of Meteorology's roll out of the Next Generation Forecast and Warning System (NexGenFWS, Hart and Jacobs) by the end of 2014 will provide a gridded data set on which a potential heatwave service could be based. Gridded climate data already permits studies into past heatwaves allowing examination of the sensitivity of EHF to impact on other business sectors such as agriculture losses, bushfire severity or power distribution system efficiency and reliability.

Conclusions

Bureau of Meteorology research has established a heatwave intensity methodology which is suitable for identifying and tracking severe and extreme impact heatwaves.

Established Heat Health Warning Systems in the UK and USA rely upon strong partnerships between health and environment agencies which are supported by impact data sharing systems underpinned by peer reviewed research. Best international practices are marked by policy initiatives that are sensitive to jurisdictional divisions of power. Establishment of a national heatwave warning system in Australia would benefit a whole-of-government strategy that treats heatwaves as a national public health threat. A Bureau of Meteorology heatwave warning system needs to be one of many federal government initiatives aimed at improving the effectiveness of state and local government and non-government agencies mitigation strategies.

There is a clear link between extreme heatwaves and catastrophic bushfires resulting in high loss of life. Differentiating between heatwave and bushfire impacts can be achieved through the rapid acquisition and sharing of impact data across the government. New partnerships across the federal government are required to achieve this outcome, particularly with health agencies.

References

Alexander, L., Hope, P., Collins, D., Trewin, B., Lynch, A. and Nicholls, N. 2007. Trends in Australia's climate means and extremes: a global context. Australian Meteorological Magazine, 56, 1-18.

Coates, L. 1996. An overview of fatalities from some natural hazards in Australia. In Proceedings of NDR96 Conference on Natural Disaster Reduction. Gold Coast, Australia.

EMA, 2007: Heatwaves – In My Backyard? www.ema.gov.au/www.ema/schools.nsf/Page/LearnAbout_HeatwavesIn_My_Backyard

Gov.UK, 2013. National Risk Register for Civil Emergencies - 2013 edition.

https://www.gov.uk/government/publications/national-risk-register-for-civil-emergencies-2013-edition

Hart T. and Jacobs H. A Digital Weather Forecast Database. http://www.hpe.com.au/emc/documents/TerryHart.pdf

Health Protection Agency, 2007. Evaluation of the Department of Health National Heatwave Plan. http://www.hpa.org.uk/Publications/EmergencyPreparationAndResponse/0707EvaluationoftheDeptofHealthNationalHeatwaveplan/.

Jones D.A., Wang W. and Fawcett R., 2009: High-quality spatial climate data sets for Australia. Australian Meteorological and Oceanographic Journal. Aust. Met. & Oc. J 58(2009) 233-248.

Langlois N., Herbst J., Mason K., Nairn J. and Byard R.. Use of excess heat factor (EHF) to predict the risk of heat related deaths. J Forensic Leg Med. 2013 Jul:20(5):408-11..

Mason K., Nairn J., Herbst J. and Felgate P., 2010: Heatwave – The Adelaide Experience. 20th International Symposium on the Forensic Sciences, Sydney Australia.

McMichael, A.J., Woodruff, R., Whetton, P., Hennessy, K., Nicholls, N., Hales, S., Woodward, A. and Kjellstrom, T. 2003. Human Health and Climate Change in Oceania: A Risk Assessment 2002. Canberra: Commonwealth of Australia.

Nairn J. To assess strategies for reducing health and business impacts of severe and extreme heatwaves. Churchill Trust Report, 2013. http://churchilltrust.com.au/fellows/reports/

Nairn J. and Fawcett R., 2013: Defining Heatwaves, heatwave defined as a heat impact event servicing all community and business sectors in Australia, CAWCR Technical Report. http://cawcr.gov.au/publications/technicalreports/CTR_060.pdf

National Climate Centre, 2009: The exceptional January-February 2009 heatwave in southeastern Australia. Bureau of Meteorology, Special Climate Statement 17 (http://www.bom.gov.au/climate/current/statements/scs17d.pdf).

National Climate Change Adaptation Research Facility (NCCARF). 2008-2013. http://www.nccarf.edu.au/ website last visited November 2013.

Robine, Jean-Marie; Siu Lan K. Cheung, Sophie Le Roy, Herman Van Oyen, Clare Griffiths, Jean-Pierre Michel, François Richard Herrmann (2008). Death toll exceeded 70,000 in Europe during the summer of 2003. Comptes Rendus Biologies 331 (2): 171–178. doi:10.1016/j.crvi.2007.12.001

Victorian Department of Health, 2009: January 2009 Heatwave in Victoria: an Assessment of Health Impacts. www.health.vic.gov.au/chiefhealthofficer/downloads/heat_impact_rpt.pdf

Teague B. (The Hon. AO), McLeod R. (AM), Pascoe S. (AM) 2010: The 2009 Victorian Bushfires Royal Commission final report. www.royalcommission.vic.gov.au/Commission-Reports/Final-Report.

The Eyre Peninsula Fire of 11 January 2005: an ACCESS case study

Authors: R J B Fawcett[1,2], W Thurston[1,2], J D Kepert[1,2] and K J Tory[1,2]

[1] High Impact Weather, CAWCR, Docklands, VIC, Australia
[2] Bushfire CRC, Melbourne, VIC, Australia

Abstract:

As part of The Centre for Australian Weather and Climate Research's contribution to the Bushfire Cooperative Research Centre's Fire Impact and Risk Evaluation – Decision Support Tool project, high-resolution and very-high-resolution simulations of the meteorology across the Lower Eyre Peninsula (LEP) in South Australia on 11 January 2005 have been performed. These simulations are described and validated against available observational data.

A significant bushfire, commonly known as the Wangary fire, broke out on the LEP in the afternoon of 10 January 2005 and continued to burn under severe weather conditions on the 11th. The most significant feature of the meteorology in relation to the fire on the 11th is the passage across the LEP of a cold front and associated wind change in the late morning to early afternoon. This feature is well modelled in the simulations, with timing errors of only 15 to 30 minutes. The simulations show the wind change transforming from an undular bore in the stable maritime boundary layer to a density current over land, accompanied by a weakening of the updraft as it passes over the location of the fire. Boundary-layer rolls are simulated further up the peninsula.

1. Introduction

A significant bushfire broke out on the Lower Eyre Peninsula (LEP) in South Australia on 10 January 2005, not long after 1500 CDT (Central Daylight Time = UTC + 10.5 hours). Under favourable conditions for bushfire spread, it burnt some 1800 hectares of swamp, scrubland and pasture paddocks that day. The following morning strong northwesterly winds caused the fire to break out of containment lines established overnight. By 1300 CDT on the 11th, the fire had changed direction under the influence of southwesterly winds behind the wind change and reached North Shields, 35 km from the original fireground (Schapel 2007).

The fire caused 9 deaths and 115 injuries. 77964 hectares of land were burnt, with 47000 in stock losses and around $100 million in total property damages (Schapel 2007). Figure 1 shows the fire-scar boundary across the LEP as of 13 January 2005. The meteorology of this fire was studied in detail by Mills (2008) using the Bureau of Meteorology's (hereafter, "the Bureau") operational LAPS analyses and forecasts of the time. A significant meteorological factor was an observed extreme reduction in the near-surface humidity, in association with a band of dry mid-tropospheric air (Mills 2008).

The present study aims to reconstruct the meteorology across the LEP on 11 January at very high resolution (0.012° and 0.004° latitude/longitude grid spacings), using a state-of-the-art numerical weather prediction (NWP) system, the Australian Community Climate and Earth-System Simulator (ACCESS). ACCESS includes the UK Met Office Unified Model as its atmospheric component. The model is run in research mode, at grid spacings much higher than those currently available (0.036°) for operational activity within the Bureau, and in consequence much more fine-scale detail is evident in the results.

2. Synoptic meteorology

The meteorological situation on 11 January 2005 consisted of a high-pressure system in the Tasman Sea, an- other high-pressure system to the west of the continent and a low-pressure system with an embedded cold front between them crossing the Southern Ocean (Figure 2). The cold front crossed the Eyre Peninsula in the late morning to early afternoon. The change in the wind direction associated with the passage of the cold front had the expected consequence of broadening the fire front and sending the fire in a north-easterly direction, as can be inferred from the fire-scar map (Figure 1).

Figure 1: Fire-scar map for the January 2005 fires on the Lower Eyre Peninsula (obtained from Schapel 2007).

3. Model details

To reconstruct the weather conditions across the LEP on 11 January 2005, a sequence of nested model runs was employed. There were five stages and the nesting was one-way, which means that meteorological information only passed from the coarser resolutions to the higher resolutions. The first stage was a global model run, with a longi- tude spacing of 0.5625° and a latitude spacing of 0.375°. The second stage had a latitude-longitude grid spacing of 0.11° for a wide region covering Australia and surrounding waters, while maintaining a 20° buffer to the south, 35° to the east and 35° to the north. The third stage (hereafter G36) had a grid spacing of 0.036° (approxi- mately 4.00 km in the north-south direction and 3.29 km in the east-west direction at the latitude of Port Lincoln, 34.722°S). The fourth stage (hereafter G12) had a grid spacing of 0.012° (approximately 1.33 × 1.10 km), with the last stage (hereafter G04) having a grid spacing of 0.004° (approx. 0.44 x 0.37km). The third-stage, fourth stage and fifth-stage domain boundaries are shown in Figure 3.

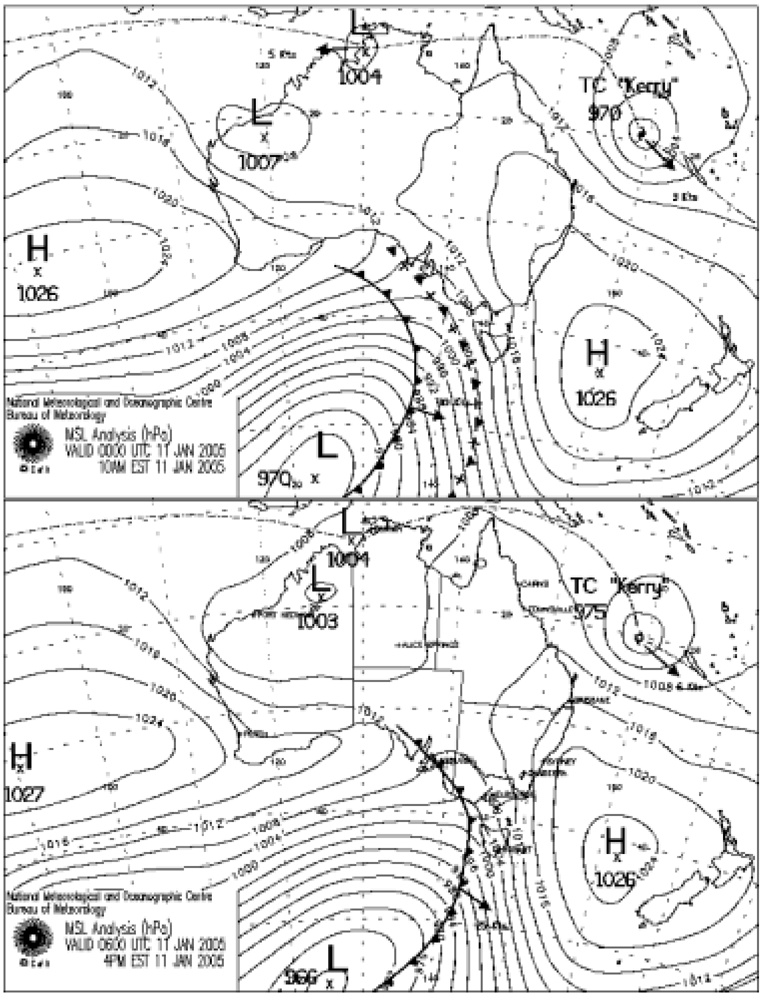


Figure 2: Synoptic pressure analyses for (upper) 0000 UTC (1030 CDT) and (lower) 0600 UTC (1630 CDT) on 11 January 2005.

The atmospheric model within ACCESS is non-hydrostatic, with an Arakawa-C grid in the horizontal and a Charney-Phillips grid in the vertical (BoM 2010). Consequently, regridding was required for the calculation of some fire-relevant meteorological quantities, such as wind speed and direction. All five stages of the modelling used 50 vertical levels, with the lowest model level being approximately 10 metres above the surface for some variables (e.g., the u and v components of the horizontal wind) and approximately 20 metres above the surface for other variables (e.g., potential temperature θ). The top level was around 60 km above sea level. The vertical aspects of the gridding were the same across all five stages; a stretched grid with 10 levels in the lowest 2000 m.

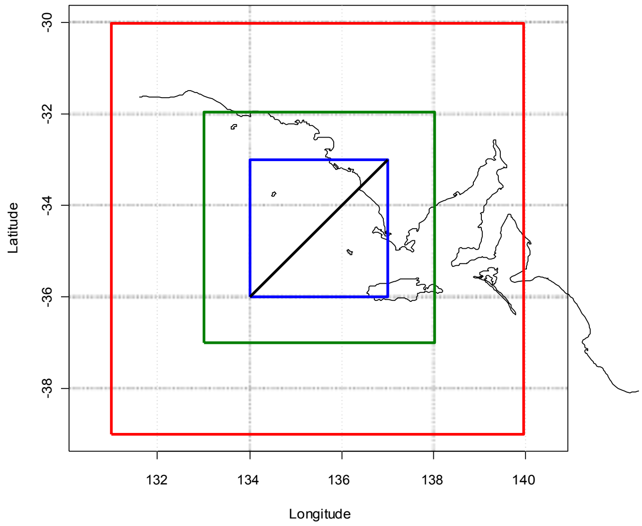


Figure 3: Boundaries of the third (0.036°, red), fourth (0.012°, green) and fifth (0.004°, blue) nesting levels for the LEP model runs. The diagonal black line represents denotes the location of the vertical cross-sections shown in Figure 6.

For the coarser resolutions (0.036° and above), the model used a parameterised convection scheme. The lowest 13 model levels, approximately the lowest 3000 metres of the atmosphere, were treated as being potentially boundary-layer levels. Boundary-layer mixing was parameterised using the one-dimensional scheme of Lock et al. (2000). For the finer resolutions (G12 and G04), the parameterised convection scheme was turned off. Also turned on at these finer resolutions was a sub-grid turbulence scheme applied in three dimensions for model levels 2 to 49. The whole vertical extent of the model domain was in effect treated as being potentially available for the boundary layer to grow into, and in fact boundary- layer depths of up to 5000 metres were seen in the simulations.

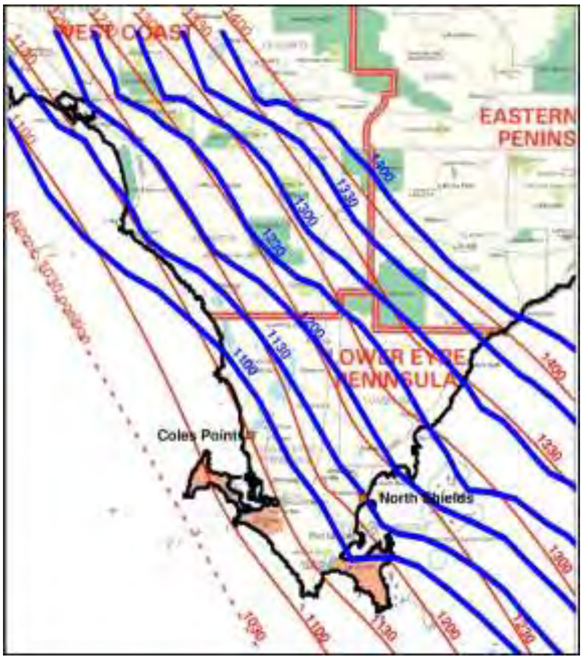


Figure 4: Comparison of modelled (blue lines; G12 model run) and analysed (red lines) wind-change isochrones across the LEP from 1100 to 1400 CDT on 11 January 2005. The locations of the two AWSs on the LEP are also shown (orange squares).

All model runs were initialised at 0000 UTC (1030 CDT) on 10 January 2005, using an ERA-Interim initial condition for the global model run, and re-configured versions thereof for the nested regional models. Because all five nesting levels were initialised from the same time, little attention was paid to the first twelve hours of the simulations.

Surface outputs (e.g., screen-level air and dewpoint temperature, 10 metre wind velocity) where archived at five-minute intervals in these simulations, with upper air outputs on the model levels being archived at fifteen-minute intervals. Derived surface fields calculated included wind speed and direction, relative humidity, divergence and voracity of the horizontal wind, and grass/forest fire danger indices.

4. Model validation

The simulations may be compared directly against independent observational data from automatic weather stations (AWSs) and radiosondes. Observational data were obtained from the Bureau's Australian Data Archive for Meteorology (ADAM) data-base, apart from those for North Shields. The AWS data come from a network of one-minute reporting and thirty-minute reporting sites across South Australia. Eight AWSs (Ceduna, Minnipa, Wudinna, Port Augusta, Whyalla, Cleve, Coles Point and North Shields (Port Lincoln Airport)), are available across the Eyre Peninsula to validate the G12 simulation but only one of those (Ceduna) is a one-minute reporting site and only two of them (Coles Point and North Shields) are on the LEP itself. Additional sites are available for the Yorke and Fleurieu Peninsulas. Ten-minute reporting data for North Shields was provided by the Bureau's South Australian Regional Office.

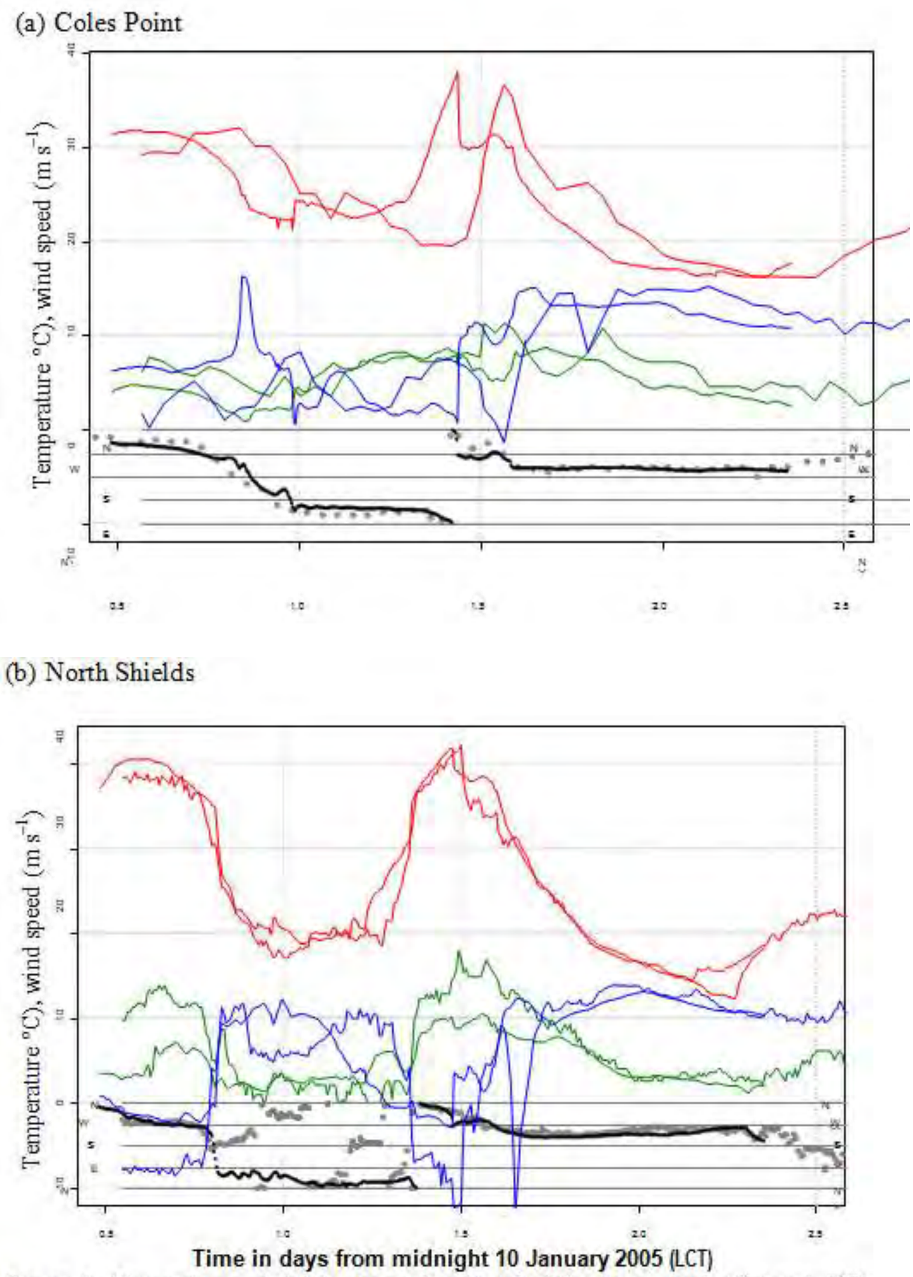


Figure 5: Comparison of AWS observational data (thin lines, grey dots) and G12 simulation data (thick lines, black dots) for (a) Coles Point and (b) North Shields. Air temperature is shown in red, dewpoint temperature in blue (both in °C), 10-metre wind speed in green (in m s^{-1}) and wind direction (dots).

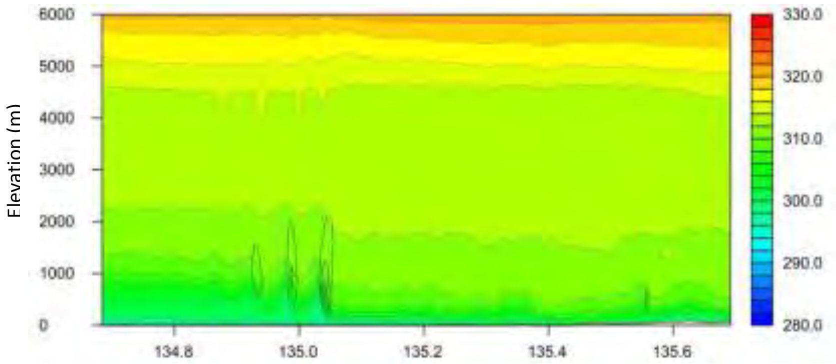
Figure 4 shows isochrones of the position of the cold front on the 11th. Positions analysed from observations (Nairn et al. 2005) are shown in red, while those from the G12 simulation are shown in blue. Timing errors in the simulated location of the primary wind change are around 15 to 30 minutes across the LEP, with the modelled wind change mostly being ahead of the observed wind change. A slight difference in the angle of approach is implied in Figure 4.

Figure 5 shows a comparison of the observational data from the two AWSs on the LEP with model data from the G12 simulation extracted from the nearest model grid point to the AWS. Both sites are coastal, and neither is likely to be representative of conditions at the fire ground (M Peace, pers. Comm.). At Coles Point on the west coast of the LEP (Figure 5a), the early morning minimum temperature on the 11th is over-forecast, as is the afternoon maximum temperature (although to a lesser extent), but the timing of the latter is well forecast. Unlike the previous day, the overnight cooling on the 11th and the early morning minimum on the 12th are well forecast. Wind direction is generally well forecast (including the timing of the main wind change), as are wind speeds on the afternoon of the 11th, although peak 10-metre wind speeds are under-estimated, something often seen in NWP.

At North Shields on the east coast of the LEP (Figure 5b), the timings of the maximum temperature and the primary wind change are seen to be well forecast, as is the wind direction immediately after the change. Temperatures for the preceding evening are also well forecast, but although the overnight light wind speeds are well forecast, the associated variable wind direction is not well captured. Again, there is a tendency for peak wind speeds to be underestimated in the afternoon. There were two periods of extremely low dewpoint temperatures on the 11th at North Shields (Mills 2008). The first (and longer) period was reproduced by the model, although with reduced amplitude. In the simulations, it appears to arise from widespread northerly flow. The second (and shorter) period was not seen in the modelling. The reasons for this are not clear. Northwest-southeast oriented dry slots are seen in the satellite imagery passing over the LEP after the main change. Similar features are seen in the simulations (e.g., at 720 to 980 metres of elevation in the G04 simulation), but without the observed impact at the surface.

Radar data are unfortunately not of much use in validating these simulations. The southern part of the Eyre Peninsula, including the LEP fire ground, is effectively beyond the range of the radars located at Adelaide, Sellicks Hill, Ceduna and Woomera, although the smoke plume from the fire on the 11th is seen on the Sellicks Hill radar once it drifts east of Port Lincoln over Spencer Gulf.

(a) 2100 UTC



(b) 0130 UTC

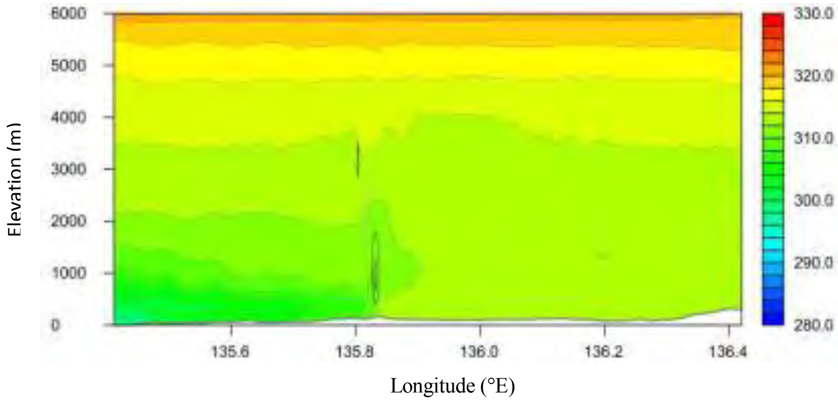


Figure 6: Vertical cross-sections of potential temperature (in K) for portions of the line shown in Figure 3, at (a) 0730 CDT and (b) 1200 CDT. Black (grey) contours denote positive (negative) vertical velocity in 1.5 m s intervals. The vertical coordinate represents elevation above 1.5 m s mean sea level (in metres). The thick grey line denotes the land surface. Data from the G04 simulation.

5. Discussion

Compared with the modelling technology available to reconstruct the weather in studies of earlier significant Australian fires, for example those of Ash Wednesday 1983 (Mills 2005a) and Canberra 2003 (Mills 2005b), the new modelling technology contained with ACCESS includes improved numerics, improved physical parameterisations, developments in analysis formulations, and assimilation of new sources of data, particularly from new satellite sounders (Puri et al. 2010). Added to this are the significantly higher grid spacings now possible.

Figure 6 shows vertical cross-sections of potential temperature along the line of cross-section indicated in Figure 3, taken from the G04 simulation. Potential temperature can be thought of as air temperature adjusted for the variation in pressure which typically decreases with increasing height above the surface, and is a useful indicator of atmospheric stability. Contours of vertical velocity are also shown, where appropriate.

As the cold front approaches the LEP, vertical cross-sections of the simulations suggest that it has the characteristics of an undular bore (Figure 6a). The atmospheric conditions ahead of the cold front, a stable near-surface layer (caused by the cool ocean) sitting underneath a deep well-mixed layer of near-constant potential temperature, are suitable for the formation of a bore

(Knupp 2006, Hartung et al. 2010). Updrafts of around 6 m s^{-1} are modelled at the leading edge of the change. In the G12 simulation, and even more so in the G04 simulation in which multiple updrafts can be seen, the cold front has a rippled appearance as it approaches the coast. Interaction with the coastline sees the undular bore transition into a density current (cooler denser air sliding in under warmer lighter air) and the temporary collapse of the updraft (Figure 6b; updrafts up to 3 m s^{-1} are shown), although the updraft does subsequently reform further up the peninsula. While large amounts of spot- ting were observed on the 11th (Schapel 2007), the simulations do not indicate strong updrafts while the primary wind change was actually over the fire ground. [This obviously does not preclude the potential for a strong updraft from the fire itself, which is not represented in the present modelling.]

Figure 7 shows notional instantaneous Grass Fire Danger Index (Mark 5; Noble et al. 1980) values for two time-steps on the 11th. As the primary wind change approaches the fire ground in the simulation, GFDI values in the 40-60 range are modelled, rising to the 60-70 range in a few more elevated locations (Figure 7a). As the wind change passes through the fire ground, GFDI values on those more elevated locations rise into the 70-90 range. Immediately behind the wind change, the GFDI values typically fall, consistent with the cooler conditions, but strengthening winds behind the change cause values to rise again into the 60-70 range across a broad area. Cheney and Sullivan (2008), citing McArthur (1966), say the following in respect of grass fires when the Mark 4 GFDI exceeds 50: direct attack will generally fail, back- burns from a good secure line will be difficult to hold because of blown embers, flanks must be held at all costs. Blanchi et al. (2010) report a Forest Fire Danger Index value of 120 for this fire.

Further up the Eyre Peninsula and beyond the fire ground, the emergence in the simulation of boundary layer rolls (Figure 7b) with their attendant downdrafts causes the modelled GFDI to temporarily spike above 100. Embedded small-scale vortices along the primary wind change are also simulated; these too lead to spikes in the modelled GFDI (Figure 7b). The elevated wind speed is the principal contributor to the elevated GFDI here. Boundary-layer rolls (Engel et al. 2012) and embedded small-scale vortices along the primary wind change (Fawcett et al. 2013) were also seen in analogous simulations of the Black Saturday (7 February 2009) meteorology. Such features can be the cause of marked variability in wind direction in the near-surface winds, which can lead to broadening of the fire front in grass fires (Cheney and Sullivan 2008).

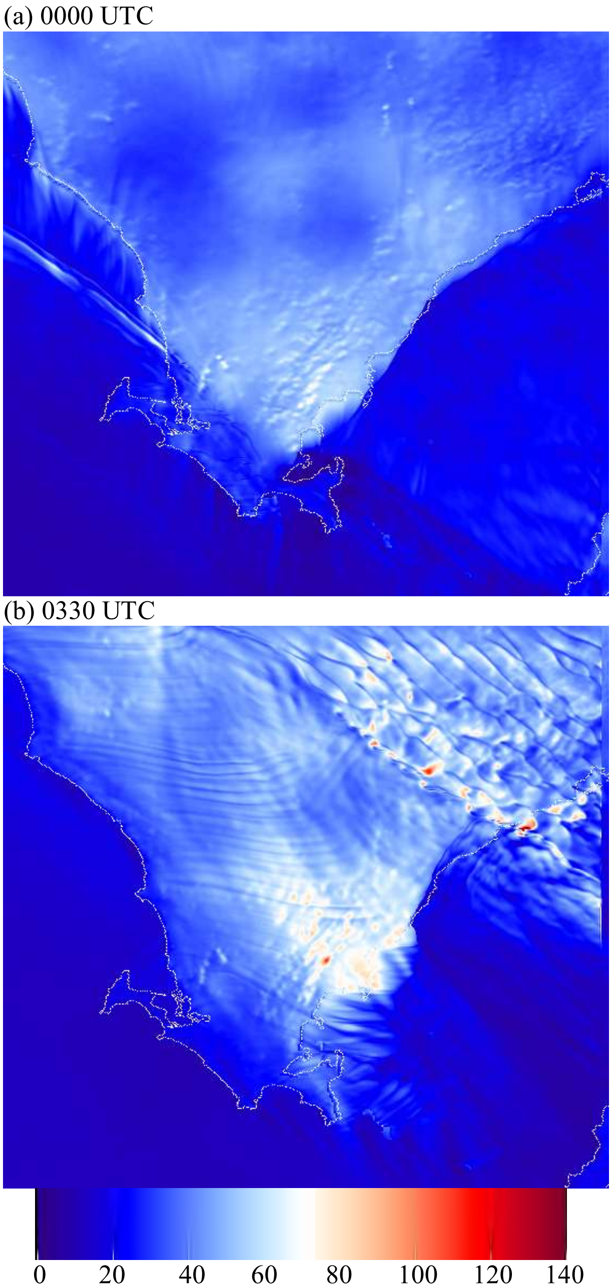


Figure 7: Notional instantaneous Grass Fire Danger Index (Mark 5) across the Eyre Peninsula at (a) 1030 CDT and (b) 1400 CDT on 11 January 2005. A notional 5 tonnes per hectare fuel load, 100% cured, is assumed in the calculation, which is based on the G04 simulation.

6. Concluding remarks

High-resolution hindcasts have been performed of the meteorology across the Lower Eyre Peninsula (LEP) on 10 and 11 January 2005, around the time of the Wangary fire, using a state-of-the-art numerical weather prediction system, ACCESS. The principal feature of the meteorology is the passage of a cold front and associated wind change across the LEP in the middle of the day on the 11th, this wind change having a significant impact on the fire behaviour. The hindcasts capture the timing of the wind change well. Although they occurred at some distance from the fire location, the simu- lations show small-scale meteorological features (vortices, boundary layer rolls) generating elevated grass fire danger index values exceeding 80 units. Such features have been seen in other simulations of fire weather in southeast Australia, and may be more common than current operational weather forecasts suggest.

7. Acknowledgements

This work is partially funded by the Bushfire Cooperative Research Centre, through its Fire Impact and Risk Evaluation – Decision Support Tool (FIRE-DST) project. The assistance of colleagues within The Centre for Australian Weather and Climate Research for their assistance in setting up the ACCESS simulations is also gratefully acknowledged. The authors wish to thank Chris Lucas and Mika Peace for their helpful comments on an early version of the paper, and Kylie Egan (Bureau of Meteorology, Adelaide) for providing the North Shields AWS data.

8. References

Blanchi R, Lucas C, Leonard J and Finkele K 2010. Meteorological conditions and wildfire-related house loss in Australia. International Journal of Wildland Fire, 19, 914-926.

Cheney P and Sullivan A 2008. Grassfires: fuel, weather and fire behaviour (2nd ed.). CSIRO Publishing, Collingwood, Victoria, Australia. 150pp.

Engel C B, Lane T P, Reeder M J and Rezny M 2012. The meteorology of Black Saturday. Quarterly Journal of the Royal Meteorological Society, DOI:10.1002/qj.1986.

Fawcett R J B, Thurston W, Kepert J D and Tory K J 2013. The meteorology of Black Saturday: a high-resolution ACCESS modelling study. CAWCR Technical Report (in review).

Hartung D C, Otkin J A, Martin J E and Turner D D 2010. The life cycle of an undular bore and its interaction with a shallow, intense cold front. Monthly Weather Review, 138, 886-908.

Knupp K R 2006. Observational analysis of a gust front to bore to solitary wave transition within an evolving nocturnal boundary layer. Journal of the Atmospheric Sciences, 63, 2016-2035.

Lock A P, Brown A R, Bush M R, Martin G M and Smith R N B 2000. A new boundary layer mix- ing scheme. Part I. Scheme description and single-column model tests. Quarterly Journal of the Royal Meteorological Society, 128, 3189-3199.

McArthur A G 1966. Weather and grassland fire behaviour. Forestry and Timber Bureau Leaflet No. 100, Canberra, Australia. 23pp.

Mills G A 2005a. A re-examination of the synoptic and mesoscale meteorology of Ash Wednesday 1983. Australian Meteorological Magazine, 54, 35-55.

Mills G A 2005b. On the subsynoptic-scale meteorology of two extreme fire weather days during the Eastern Australian fires of January 2003. Australian Meteorological Magazine, 54, 265-290.

Mills G A 2008. Abrupt surface drying and fire weather Part 1: overview and case study of the South Australian fires of 11 January 2005. Australian Meteorological Magazine 57 299-309.

Nairn J, Prideaux J, Ray D, Tippins D and Watson A 2005. Meteorological report on the Wangary and Black Tuesday Fires: Lower Eyre Peninsula, 10-11 January 2005. Bureau of Meteorology, South Australian Regional Office, Kent Town, South Australia. 72pp.

Noble I R, Bary G A V and Gill A M 1980. McArthur's fire-danger meters expressed as equations. Australian Journal of Ecology, 5, 201-203.

Puri K and coauthors 2010. Preliminary results from Numerical Weather Prediction implementation of ACCESS. CAWCR Research Letters, 5, 15-22. Obtained from http://cawcr.gov.au/publications/researchletters.php .

Schapel A E 2007. Inquest into the deaths of Star Ellen Borlase, Jack Morley Borlase, Helen Kald Castle, Judith Maud Griffith, Jody Maria Kay, Graham Joseph Russell, Zoe Russell-Kay, Trent Alan Murnane and Neil George Richardson. Coroners Court, Government of South Australia, Adelaide. 689pp.

Applications of very high resolution atmospheric modelling for bushfires

Jeffrey D. Kepert, Robert J.B. Fawcett, Kevin J. Tory and William Thurston
Centre for Australian Weather and Climate Research, Melbourne, Australia
J.Kepert@bom.gov.au

Introduction

Bushfire behaviour is well known to be sensitive to the weather. What is less well appreciated is that the behaviour is affected by all scales of atmospheric behaviour, from the large-scale and long-term (drought), through the medium-scale (weather systems such as fronts and wind changes) to the small-scale (short-term fluctuations in humidity and wind strength and direction). Ongoing improvements in numerical weather prediction (NWP) have given us the ability to resolve features as small as a few hundred metres, and provide an unprecedented window into atmospheric structures that may affect a bushfire.

Here, we summarise the past two years of research by our group into fine-scale modelling of severe fire weather. In that time, we have modelled and verified the meteorology of events including Black Saturday of 2009, the Eyre Peninsula fire of 2005, the Margaret River fires of 2011, the Blue Mountains fires of 2001, and the Dunalley fire of 2013. We have identified several medium to small-scale meteorological phenomena that have the potential to significantly escalate a fire, and in the case of the Margaret River fire have good evidence that the small-scale meteorology was *the* major contributor to the fire intensity and spread at a critical point in its history. We will summarise some of these phenomena, and indicate the prospects for predicting them in the future, thereby improving fire-fighter effectiveness and safety. However, while our focus is on meteorology, we note that other factors, including fuels and topography, also strongly influence fire behaviour.

This paper is an interim review and summary of our research, and aims for breadth at the expense of depth. Readers interested in more detail should refer to the more detailed reports cited herein.

This research forms one section of the Fire Impact and Risk Evaluation Decision Support Tool (FireDST) project, and has been funded by the Bushfire CRC and the Australian Bureau of Meteorology. The results of our meteorological modelling have also been a key input into fire modelling, smoke dispersion and risk-assessment research under that project.

Modelling approach

A numerical weather prediction (NWP) model is an application of relevant laws of physics to the problem of modelling atmospheric flow. Those laws include the equations of fluid flow, the laws of thermodynamics, the interaction between electromagnetic radiation and gasses, the physics of moisture including phase changes, and an equation of state describing the relationship between atmospheric density, temperature, pressure and humidity. The atmosphere is approximately represented by a three-dimensional grid, and these laws are applied at each grid point to predict the state of the atmosphere a short time into the future. Longer forecasts can be prepared by taking many such time steps.

This process has been developed to a high level of sophistication over the past few decades, and such forecasts now exhibit useful skill out to a week or more. Running such a forecast requires two types of information: an initial condition, and boundary conditions. The initial condition, or analysis, is an estimate of the three-dimensional atmospheric state at the forecast start time, and is usually prepared by blending a short-term forecast from the previous analysis with all available satellite and *in situ* meteorological observations. The boundary conditions include data on topography, sea-surface temperatures, vegetation type, and soil moisture, as well as lateral boundary conditions from the nesting process described in the next paragraph.

Models may be run at a variety of resolutions, depending upon the spacing between grid cells[1]. Global models predict the weather for the entire atmosphere, but the large horizontal extent necessitates relatively coarse resolution. Finer resolution requires that the forecast be restricted to a limited area, and that the forecast be "nested" within a larger-scale forecast to provide an estimate of how conditions vary along the boundaries of the finer domain – this allows weather systems to migrate into the limited-area domain. Very fine resolution can be achieved by successive nesting steps. In this project, grid spacings of down to 400 m were used, which required four levels of nesting from the global-domain model (and consequently five separate model runs in total). As an example, the domains for the three finest resolutions in our Black Saturday simulations are shown in Fig. 1.

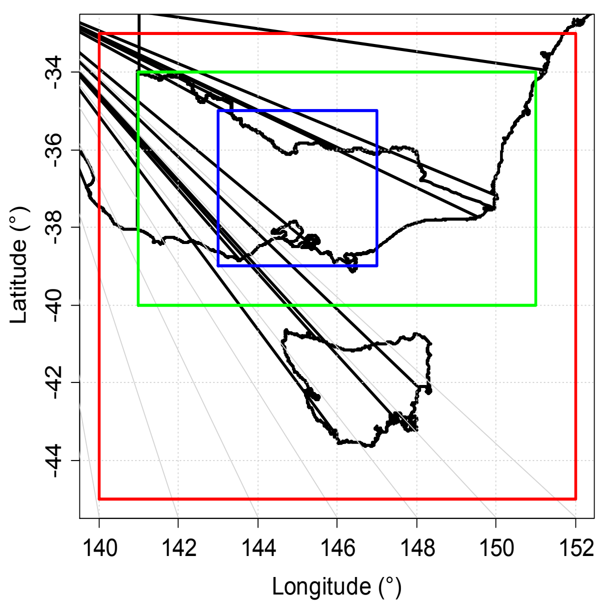


Fig. 1: Boundaries of the third (0.036°, red), fourth (0.012°, green) and fifth (0.004°, blue) nesting levels for the Black Saturday model runs. Model boundaries are chosen, as far as is possible, to avoid areas of elevated topography. The 0.036°-resolution model run is nested in a large regional model comprising all of Australia and surrounding areas of the oceans.

High-resolution modelling of this nature provides additional information for two main reasons. Firstly, the successively higher resolution nests can use more detailed topography and other boundary conditions, to which the simulated atmosphere can then respond. Secondly, the atmosphere can itself generate fine-scale structures such as the very strong temperature gradients across cold fronts. The higher-resolution simulations can more accurately depict the natural processes that cause these structures, and thereby better resolve them.

The NWP system used in this study is the Australian Bureau of Meteorology's ACCESS (Australian Community Climate and Earth Simulation System). It is a substantial improvement over the former LAPS system in the model dynamical core, the representation

[1] The smallest feature that can be represented in a model is twice the grid spacing, but the evolution of such small features is not accurately modelled. The smallest feature for which the flow dynamics are well represented is somewhat larger – for example, Skamarock (2004) suggests that this length scale is about seven times the grid spacing in the WRF model.

of physical processes, and the data assimilation system. Full details may be found in Puri et al. (2013).

Verification

Weather forecasts continue to improve, but are not perfect. One source of error arises because the model itself is not exact: a finite grid resolution used and some physical processes, such as turbulence or convection, have to be approximated. Another source is that the initial condition and boundary conditions (both lateral and surface) are not exact. A third is that the atmosphere is chaotic, which means that small initial errors grow exponentially and eventually swamp useful information in the forecast. Therefore, it is necessary to verify forecasts.

For this project, we used two main verification techniques. Where suitable meteorological features were present, we verified the location and/or timing of those features. An example of this object-oriented verification is our verification of the timing of the wind change on Black Saturday, in which Fig. 2 shows the difference in timing of the wind change between the model and AWS sites with a measurement frequency of 1 minute, and Fig. 3 compares the location of the wind change at four-hour intervals from two of the available resolutions, to that analysed by the Bureau of Meteorology. The other technique was direct verification against observations. The simulated data were compared to all available AWS observations within the model domain, enabling a qualitative assessment to be made of the model accuracy. An example of this type of verification can be seen in Fig. 4, which shows the observed 1-minute data at Eildon Fire Tower, together with the modelled 5-minute data at the nearest gridpoint.

Full verification of the simulations, together with detailed discussion, can be found in our various project reports and other publications, including Fawcett et al. (2012a,b, 2013a,b,c,d,e,f,g), Kepert and Fawcett (2013a,b), and Kepert et al. (2012a,b, 2013).

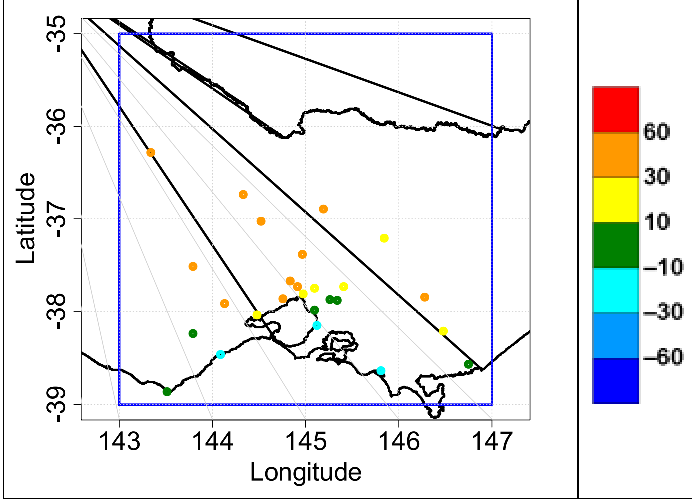


Fig. 2: Approximate timing errors in minutes for the location of the primary wind change on Black Saturday. Positive (*negative*) values imply that the primary wind change in the 0.004°-resolution simulation is late (*early*) relative to the change at the indicated AWS locations. The blue box denotes the model domain.

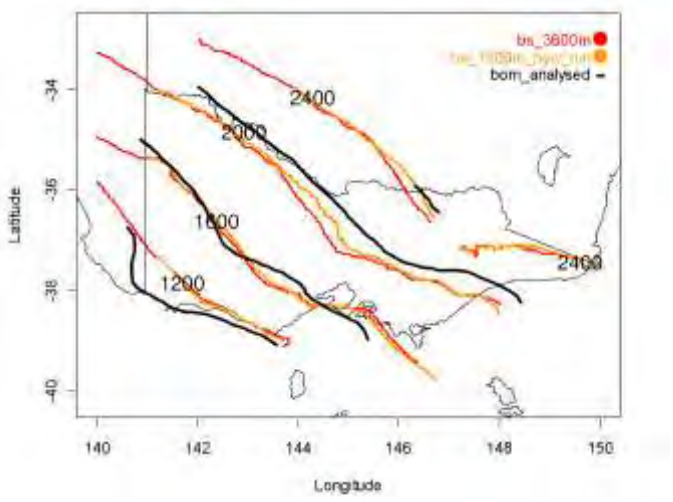


Fig. 3: Comparison of analysed primary wind-change positions (black lines) with model wind-change positions from the 0.036°-resolution (red lines) and 0.012°-resolution (orange lines) simulations, for 1200, 1600, 2000 and 2400 EDT (0100, 0500, 0900 and 1300 UTC) on Black Saturday. Analysed wind-change positions are from VBRC (2010). Modelled wind-change positions are determined semi-objectively from the 10-metre wind-direction field.

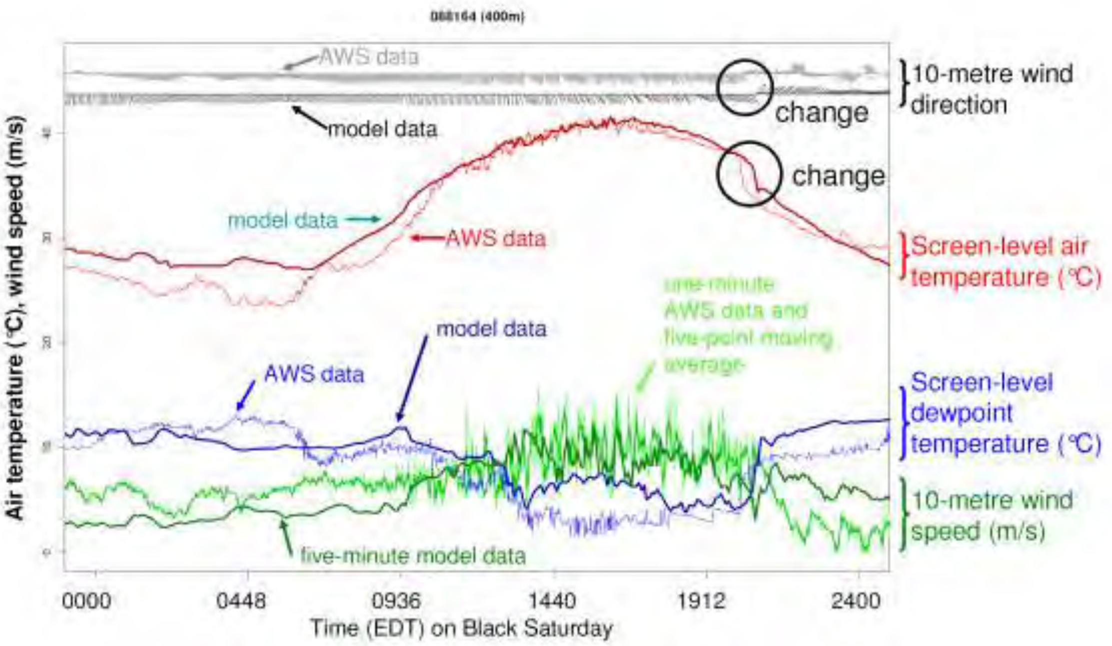


Fig. 4: Verification of the 400-m resolution simulation of Black Saturday against 1-minute observations from the Eildon Fire Tower. Model data is shown by thick curves and observations by thin. Meteorological variables are as annotated on the diagram. The timing of the change is indicated in the wind direction and temperature data.

The meteorology of the Black Saturday fires, February 7 2009.

Black Saturday, February 7 2009, was the worst fire disaster in Australia's recorded history, with 173 deaths over 2100 houses and many other buildings destroyed, and major environmental damage (VBRC 2010). The fires followed a decade-long drought, and an extreme heatwave the preceding week, which combined to cause extremely dry fuels. The fires spread exceptionally quickly, exceeding the upper limit of the expectations of experienced professionals. The spread mechanism was both direct, and due to spotting over distances exceeding 30 km, and the fires were extremely intense. The weather on the day itself was broadly similar to earlier major disasters such as Black Friday of 1939 and Ash

Wednesday of 1983, with hot dry gusty northerly winds preceding a strong south-westerly change. As in the earlier events, the majority of the deaths occurred close to the change.

The quality of our weather simulations was high. Maximum temperatures were very accurately predicted, humidity somewhat less so, while the wind speeds showed a consistent negative bias of 10 to 20 %. The timing of the change was within an hour of that observed or analysed. The ACCESS NWP system is therefore substantially more accurate in this regard than the LAPS system, which was the operational limited-area model within the Bureau at the time. A small ensemble of ACCESS runs was made by running the model from initial conditions from two NWP centres and different times. The spread of timing of the wind-change from this ensemble is consistent with the actual timing error.

The simulations showed a wealth of fine-scale detail, including the complex time-varying structure of the wind changes, the development of boundary-layer rolls and their transition to cellular convection, and the development of fine-scale vortices on the wind changes. These features are briefly discussed below. Several of these features possessed significant updrafts, which we suggest may have interacted with the fire plume to facilitate long-range spotting. Research is continuing to confirm this hypothesis, and to eventually provide a means to forecast the processes.

The main wind change originated from a synoptic-scale trough reinforced by an overnight land-sea temperature contrast along the coast to the west of Cape Otway, which began to propagate to the north-east around dawn. There was a weaker, east-west oriented change over western Victoria, and several less extensive lines that originated at other coastal boundaries. This structure is apparent in the plot of surface wind and temperature at 06 UTC (1700 EDT) shown in Fig. 5. The simulated main change moved a little slower than observed during the day, but sped up during the evening such that the timing error in northern Victoria was only 15 minutes. During the day, the change had the character of a density current, transitioning to a bore propagating on the nocturnal inversion as this formed (Fig. 6). Radar data from Yarrawonga clearly showed the bore as it passed through, and also strongly suggested that it caused a significant intensification of the plume from the Beechworth-Mudgegonga fire at around midnight. The modelled change had an updraft in excess of 5 m s^{-1} at 500 m above the surface for much of the time, whether as a density current or as a bore, which is similar to the fall speed of embers and would have helped suspend and transport embers lofted to that level by the plume. We suggest that it thus contributed to the major outbreak of spotting at the Beechworth-Mudgegonga fire discussed in the Bushfire Royal Commission report (VBRC 2010).

The simulated change also featured a string of small-scale vortices along its length, associated with small patches of stronger winds and perturbations to the quasi-linear nature of the change (Fig. 7). These features were small enough that they are not resolved by the observational network, so we do not have independent evidence of their existence, but would clearly warrant further investigation. However, they would likely cause locally more intense fire behaviour, so confirmation of their occurrence would provide extra knowledge of the dangers of wind changes.

From late morning, the flow ahead of the change developed an extensive area of boundary-layer rolls. This sequence of counter-rotating horizontal vortices aligned approximately with the mean wind direction had meandering quasi-linear updrafts in excess of 5 m s^{-1}. As with the updraft on the wind change, we suggest that these may have contributed to ember transport. They also led to significant fluctuations in near-surface wind speed and direction, temperature and humidity, on a time-scale of the order of 10 minutes, which would have likely influenced fire behaviour. The variation in wind direction is perhaps especially significant, since it would have helped the fire front to broaden, leading to a more intense and faster-moving fire. Figure 8 shows a plan view and cross-section of these rolls. The presence of the rolls is confirmed by radar and satellite data. As time progressed, daytime heating caused the boundary layer to deepen, and hence the rolls to deepen and broaden. The character of the rolls also changed, with them becoming less linear and eventually breaking up into cellular convection.

Full details of the above research may be found in the major publications by Fawcett et al. (2013a) and Thurston et al. (2013a). Briefer accounts are contained in Fawcett et al. (2012a, 2013d).

.

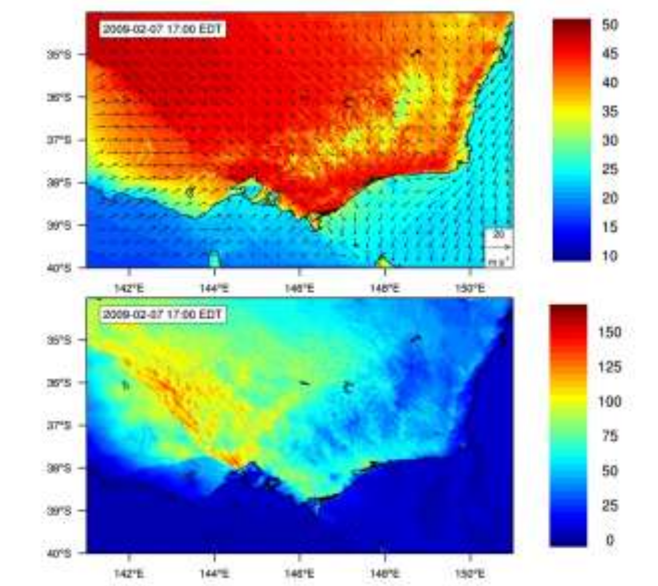


Fig. 5: Simulation of the surface meteorology over Victoria at 1700 EDT (0800 UTC) on Feb 7 2009. Top: 2-m air temperature (colour) and wind (vectors). Bottom: Notional instantaneous forest-fire danger index (FFDI). The dual structure of the wind change to the west is clearly apparent. The variations in wind direction ahead of the change, and the fine-scale structure in the FFDI field, are due to mesoscale convective features in the boundary layer following the breakdown of the rolls.

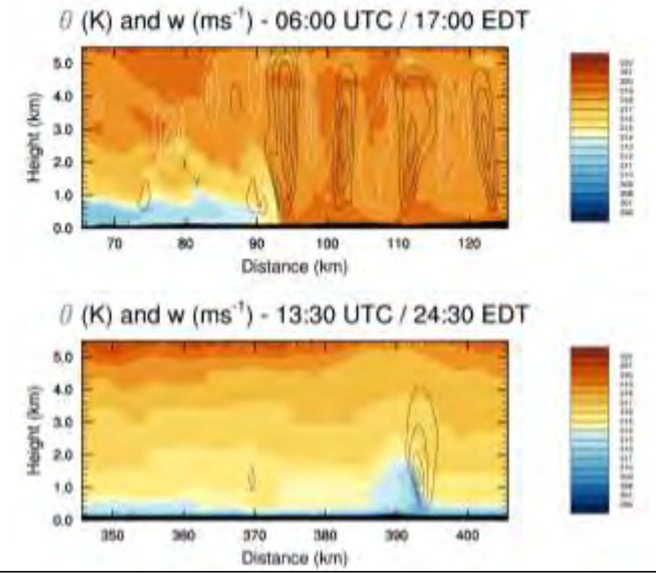


Fig. 6: Cross-sections of potential temperature (colour) and vertical velocity (contours, interval 1.5 m s^{-1}, black is upwards and white downwards motion) oriented approximately perpendicularly to the wind change at 1700 Feb 7 EDT (top) and 0030 Feb 8 EDT (bottom) on Black Saturday. During the afternoon, the wind change has the structure of a density current propagating into the unstable boundary layer. By midnight, the change has transformed into a bore, propagating on the near-surface nocturnal stable layer.

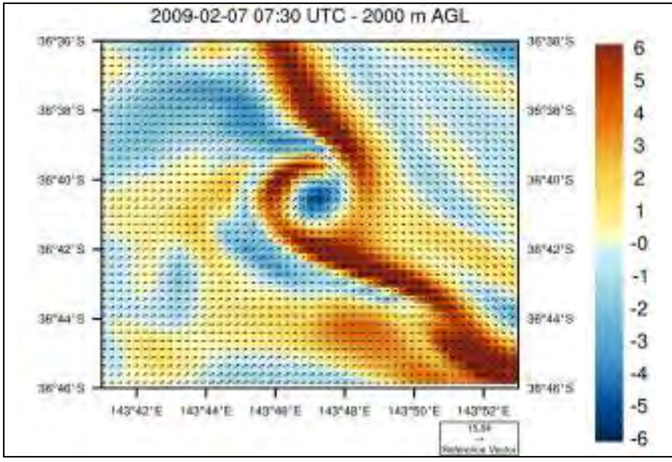


Fig. 7: Vertical velocity at 2000 m above ground level (shading, m s^{-1}) and horizontal wind at 10 m above ground level (vectors) in one of the vortices along the wind change at 1830 EDT Black Saturday.

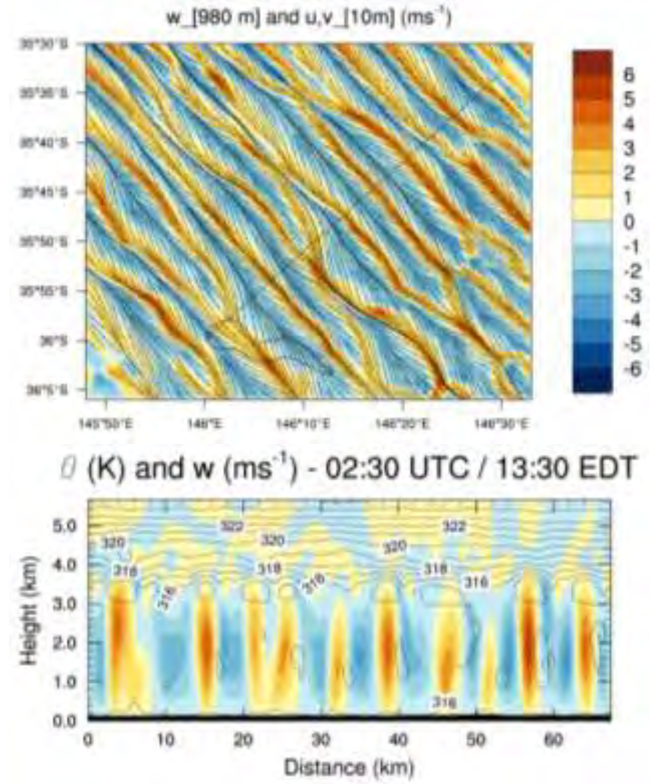


Fig. 8: Boundary-layer rolls at 1330 EDT (0230 UTC) on the afternoon of Black Saturday. Top: 10-m wind (streamlines) and vertical velocity at 980 m (shading). Bottom: Cross-section along the line indicated in the top panel, of vertical velocity (shading) and potential temperature (contours, K). The top of the boundary layer is where the significant potential temperature gradient begins, near 3-km height.

The meteorology of the Margaret River fires of November 2011.

The Margaret River fire was due to a prescribed burn that escaped, with the impact including the destruction of some 30 houses and damage to others. The case is of scientific and operational interest because the fire, which had been reluctant to burn the previous day, intensified during the night and crossed the containment lines shortly after sunrise, before burning southwards during the day under the influence of hot, gusty northerly winds. The crucial re-intensification of the fire occurred during the night when fire behaviour is usually at a minimum, and fire crews had departed the scene after observing the fire's decline the previous afternoon and expecting further decline as per the normal diurnal trend. This case thus stands in contrast to our work on Black Saturday: while there we were seeking to understand the details of what was already clearly extreme fire weather, here we were trying to understand why unexpectedly strong fire behaviour occurred under what were expected to be benign conditions.

Modelling of the meteorology revealed the following features, all of which would have contributed to increased fire behaviour.

- A mass of dry air was advected from the interior of Western Australia to the Margaret River region during the early morning prior to the escape, replacing the moister maritime air mass previously over the fire ground. Evidence from observations and the model suggests that the fuels experienced the drying effect of this air for about six hours before the escape.
- Beginning in the early evening, strong downslope winds developed in the lee of the hill that occupied the northeastern portion of the prescribed area, due to a gradual strengthening of the pressure gradient and the formation of a nocturnal inversion. These winds would have reinvigorated the fire, pushing it towards the west (i.e. towards the coast) and then southwest, from whence it escaped. The modelling suggests that the winds over the southwest portion of the prescribed area were the strongest over-land winds in the region. Figure 9 shows a plan view of the 10-m wind speed and direction at 8 am LST, showing the strongest winds in the lee of the hill, while Fig. 10 displays cross-sections of potential temperature, vertical velocity and wind speed showing the strong descent in the lee of the hill associated with the strong surface winds. While the dynamics of such flows are reasonably well understood, this case was unusual for the modest size and height of the hill on which they occurred. This case-study is one of the first to show a strong connection between nocturnal downslope winds and enhanced fire activity.
- A strong low-level wind maximum developed over southwest WA during the night, apparent in the model and the upper air observations from Perth, and apparent in Fig. 10. This maximum likely contributed to stronger winds during the early morning and afterwards, since the downslope winds would have transported this momentum to the surface. During the day, turbulent mixing would also have intermittently transported this momentum downwards, contributing to the marked gustiness noted by the fire crews.
- Hills to the north of the fire ground developed a strong linear wake which passed across the fire ground around midday. This may have contributed stronger winds and dryer air to the fire, at about the time of its observed peak intensity due to increased vertical transport, although other evidence for the wake is lacking due to the sparse observational network.

Given the very small size of the region affected, it will be difficult to predict similar cases in the future. The relevant atmospheric dynamics, however, are reasonably well understood and are not uncommon. We therefore recommend that due caution be exercised with fires on lee slopes overnight; such caution should take account of expected wind direction changes.

A full report of this research is available in Kepert et al. (2012a) and Kepert and Fawcett (2013a,b).

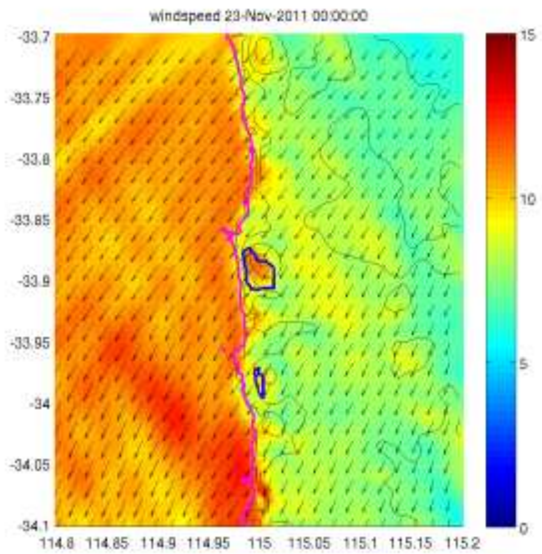


Fig. 9: Surface wind speed (shading, m s^{-1}) and direction (arrows) at 0800 WST (0000 UTC) on November 23 in the 400-m ACCESS simulation. The topography is shown by the black contours at 50-m intervals, the coastline by the magenta line, and the two prescribed burn areas are outlined in blue, with Ellenbrook being the northern one. The coincidence of the strongest winds with the burn area is clear.

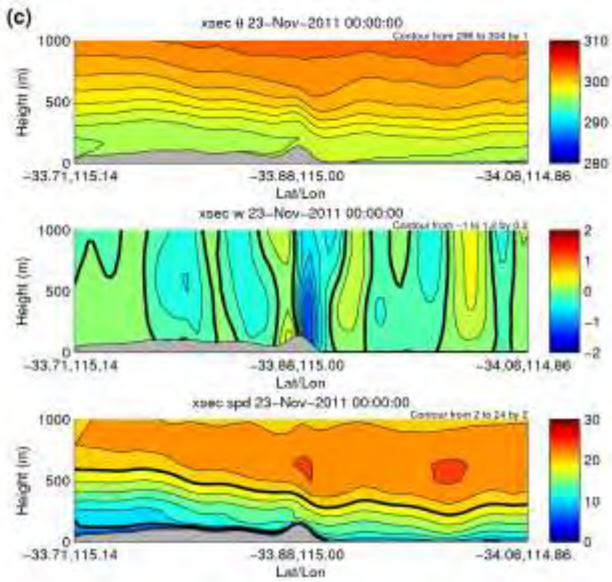


Fig. 10: Cross-sections through the Ellenbrook fire ground at 0800 WST (0000 UTC) on November 23 2011 from the 400-m ACCESS simulation. Top: potential temperature (K). Middle: Vertical velocity (m s^{-1}). Bottom: Wind speed (m s^{-1}). The cross-sections are aligned with the wind direction at 200-m height, approximately north-east to south-west, and are 50 km long. Contour intervals are indicated at the top right of each panel.

The meteorology of the Wangary fire, 11 January 2005.

A significant bushfire broke out on the Lower Eyre Peninsula (LEP) in South Australia on 10 January 2005, not long after 1500 CDT (Central Daylight Time = UTC + 10.5 hours). Under favourable conditions for bushfire spread, it burnt some 1800 hectares of swamp, scrubland and pasture paddocks that day. The following morning strong northwesterly winds caused the fire to break out of containment lines established overnight. By 1300 CDT on the 11th, the fire had changed direction under the influence of southwesterly winds behind the wind change and reached North Shields, 35 km from the original fireground. The fire caused 9 deaths and 115 injuries. 77,964 hectares of land were burnt, with 47,000 in stock losses and around $100 million in total property damages

Similarly to our reconstruction of Black Saturday, the simulation of the wind change timing was very accurate, within 45 minutes and mostly within 30 minutes of the analysis, as shown by isochrones of frontal position (Fig. 11). In contrast with the Black Saturday simulation, the model tended to be early, rather than late, with the timing. The change showed marked structural changes as it made landfall; over sea, the structure was that of an undular bore, propagating on the shallow stable marine boundary layer. As it made landfall, it moved into a deeper, well-mixed daytime continental boundary layer, and transformed into a structure similar to a density current. Prior to landfall, the change had several parallel updrafts a few kilometres apart at its head, while afterwards, there was just a single updraft. The direction of this structural transition was opposite to that on Black Saturday, from a bore-like structure to a density current rather than the reverse. Another difference was that the updraft over the fire was weaker and possibly less able to support ember transport.

Another similarity to Black Saturday was the development of a region of boundary-layer rolls in the hot northwesterlies preceding the change. These were located well to the north of the fire ground and would not have affected this fire. However, they similarly caused significant fluctuations in the instantaneous values of fire danger indices, wind direction, and vertical motion, which we expect would have affected any fires in that region.

Previous work on this event demonstrated that a period of marked drying, lasting several hours, occurred prior to the change. This dry air would have contributed to the fire intensity through its affect on fine-fuel dryness, and was attributed to a narrow band of subsidence followed by strong vertical mixing within the boundary layer (Mills 2008). An additional shorter drying occurred following the change. Our simulation captures the timing of the first drying well, but at lower amplitude, while the second is not represented.

A fuller account of this research is available in Fawcett et al. (2012b, 2013b).

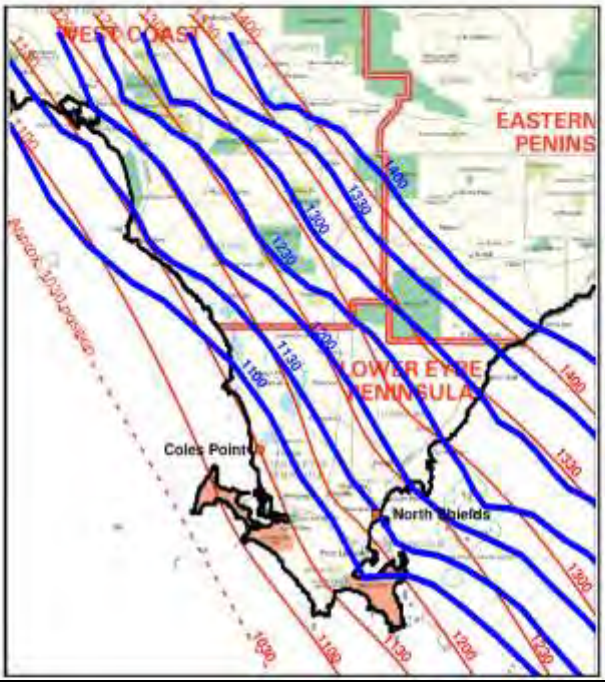


Fig. 11: Comparison of modelled (blue lines; 0.012°-resolution model run) and analysed (red lines) wind-change isochrones at half-hour intervals across the Lower Eyre Peninsula from 1100 to 1400 CDT (0030 to 0330 UTC) on 11 January 2005.

The meteorology of the Warragamba / Mount Hall fire, 24 – 25 December 2001.

Of the fire weather cases investigated so far, this one is the earliest (December 2001), has the most orography, and is the least successful in terms of the accuracy with which the simulations reproduced observations. Significant aspects of the AWS observations (see below) are missed or otherwise inadequately represented. These include the nocturnal moistening at many sites (e.g., Sydney Airport) in the early hours of the morning of 25 December, the overnight cooling at some sites (e.g., Richmond RAAF), and the period of dry air during the afternoon of 24 December at some sites (e.g., Canterbury Racecourse) (Fawcett et al. 2012c,d).

The relatively poor simulation is possibly due to the quality of the ERA-Interim (ECMWF Interim Reanalysis) initial condition, although we tried initialising from several different times without significant improvement from our original simulation. We note however that an ERA-Interim initial condition was also used in the later and more successful Eyre Peninsula simulation for January 2005, discussed in the previous section. The complex topography may be another factor, since the forecast wind direction in the Warragamba valley was not consistent with the reconstructed fire spread. A third may be that the synoptic forcing in this case was weaker than for the Black Saturday or Wangary simulations, although the Margaret River simulation was successful in the absence of such forcing, but with much simpler topography.

Unfortunately, because the event occurred so far in the past, it was not possible to examine the sensitivity to initial conditions from other sources. While this simulation is probably of insufficient quality for research into the fire behaviour, it should not be concluded that all events of similar age will present such problems. Rather, it illustrates the importance of thorough verification before the fields are used.

On the afternoons of 24 and 25 December 2001, the 0.004°-resolution simulation shows winds from the westerly quadrant crossing the simulation domain from west to east (see Fig. 12). There is an impression of the orography of the Blue Mountains causing “streamers” (coherent patterns of variation in 10-metre wind direction) to trail across the domain, although with more downstream disturbance on the 25th. These look a little like the boundary-layer rolls seen in the Black Saturday simulations, but appear to be too fixed in their positions to be boundary-layer rolls, so instead are considered to be similar to the wakes apparent in the simulations of the Margaret River event.

Further details of this simulation can be found in Fawcett et al. (2012c,d).

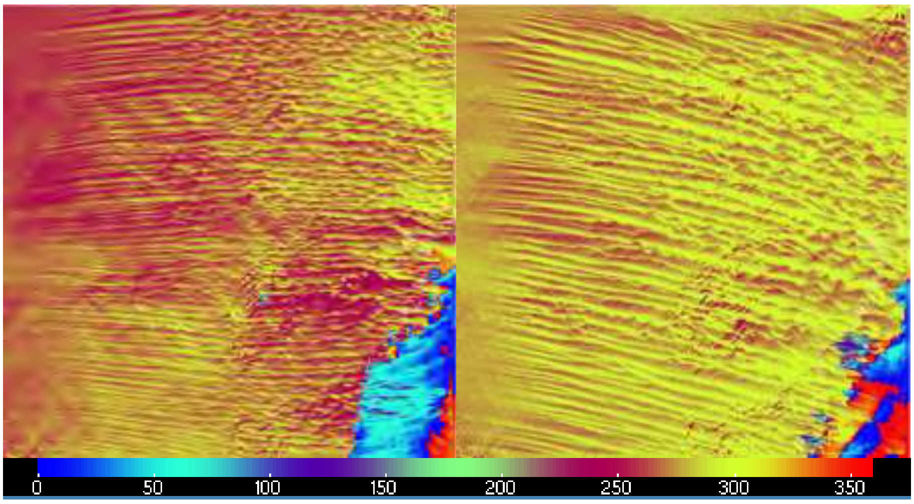


Fig. 12: Wind direction at 1400 EDT (0300 UTC) on 24 December (left) and 25 December (right), from the 0.004°-resolution simulations.

Other events

In addition, simulations were prepared for the weather of a number of other severe fire danger days, for which the analysis is still in progress. Several of these were notable events that were simulated shortly after their occurrence. A brief description of each these extra simulations follows.

- *Boorabbin, 30 December 2007.* This fire occurred in the Western Australian goldfields region, near the main east-west road. Several trucks were engulfed in flames, resulting in three fatalities. The highway was closed to traffic for over a week. Analysis of this simulation is ongoing, initial results show that the wind change prior to the fatalities was well captured.
- *Canberra, 18 January 2003.* These fires resulted in several deaths, over 490 injuries, severe damage to the outskirts of Canberra, and the destruction of the Mt Stromlo observatory. They were notable for the formation of an intense tornado. Analysis of the simulation for this event has not yet commenced.
- *Coonabarabran, 13 January 2013.* This event occurred in the Warrambungle National Park in north-east NSW. The weather featured exceptionally strong temperature gradients associated with a strong wind change which moved through from the southwest. The pre-frontal winds and the change itself showed similar features to our Black Saturday simulations, including boundary-layer rolls and fine-scale vortices. The situation also featured sea-breeze penetration inland, and the formation of some marked deep convective cells. Further details can be found in Fawcett et al. (2013c).
- *Dereel, 27-28 March 2013.* Simulations were prepared for this fire event in central Victoria that destroyed at least 16 homes. Verification showed that the simulations were of good quality. Figure 13 shows a model verification plot for Hopetoun Airport in western Victoria from these simulations.
- *Dunalley, 4 January 2013.* This fire occurred in south-eastern Tasmania on a day of record heat, and destroyed at least 100 properties and isolated 2700 people. The simulations showed that the heat was partly due to a Foehn effect in the north-westerlies off the Tasmanian central highlands. A wind change propagating from the southwest developed a complex structure as it encountered the numerous islands and peninsulas in that region. Verification was generally quite good on our initial analysis, with timing of wind changes and maximum temperatures being well captured. Further details can be found in Fawcett et al. (2013f,g).
- *Melbourne Dust Storm, 8 February 1983.* This day was not a severe fire event, although fires were present on the day and the overall synoptic situation features a strong wind change similar to those of severe fire days in south-eastern Australia. The simulation was performed partly to examine the utility of reanalysis data for studying old events, and partly to try to determine why this event was not a severe fire day.

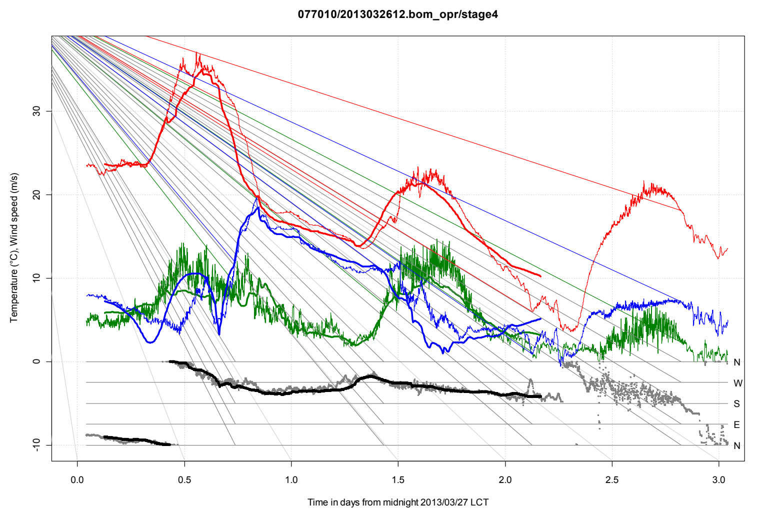


Fig. 13: Comparison of modelled (thick lines, black dots 0.012°-resolution model run) and observed (thin lines, grey dots) air temperature (red lines), dewpoint temperature (blue lines), wind speed (green lines) and wind direction (dots) for Hopetoun Airport in the Dereel fire case study. At this site, there is a high degree of consistency between the model and observations

Summary

Very high resolution simulations of the meteorology associated with nine significant fire events and the Melbourne dust storm have been made, using the Bureau of Meteorology's new ACCESS numerical weather prediction system. Validation of these simulations shows that, with the exception of the Warragamba fire, they are of high quality. Features important to fire behaviour such as the timing of wind changes and the maximum temperature are very well predicted. Humidity is not quite so good, consistent with extensive experience suggesting that this is a more difficult variable to forecast. Wind speed has a systematic low bias which can, however, be statistically corrected.

Detailed analyses have been carried out on three of the cases, Black Saturday, Eyre Peninsula and the Margaret River fires. Analysis of the remainder is ongoing. One important finding was the development of a range of small-scale phenomena that likely impacted the fire behaviour, including boundary-layer rolls, fine-scale vortices on wind changes, and strong downslope winds on relatively small hills. We presented strong evidence that the latter was the likely cause of the escape of the Margaret River fire. Another important finding was the variety of different forms that a wind change could take, which may mean that its impact on a fire is not always the same. A third was a range of processes that could cause significant near-surface updrafts in the absence of a fire, and in the presence of a strong fire plume could enhance the ember transport and spot-fire potential.

The ability to run both recent and historical events at high resolution is an important development for future research. As well as continuing to learn from major events of record, our research contributed to the rapid determination of “lessons learned” from the Margaret River fire in particular.

We note, however, that the resolution used for these studies will not be available operationally for some years because of the very high computational cost, and even then will not be available for the whole of Australia. Hence there is a need to develop techniques to forecast the phenomena described herein from much coarser resolution NWP. We regard such work as an important avenue for future research.

We note also that errors in weather forecasts that may be small by meteorological standards may nevertheless have a significant impact on the course of a fire. For example, meteorologists would generally regard a forecast of a wind change with a timing error of only

30 minutes as being very good. That error, however, leads to a substantial error of 7.5 – 10 km in predicting the spread of a grass fire moving at 15 – 20 km/hr. While weather forecasts will continue to improve, they will never be perfect. It is therefore incumbent upon fire agencies to join the growing body of forecast users who are actively and explicitly accounting for forecast uncertainty in their operations, through the use of technologies such as ensemble prediction.

This paper has focussed on the possible impact of meteorological phenomena on fire behaviour. We note that other factors are also important, including fuels and topography.

The research described here was undertaken as part of the FIRE-DST project and was partially supported by the Bushfire CRC. All publications resulting from this project are available at http:/www.bushfirecrc.com/category/projectgroup/2-risk-assessment-and-decision-making.

References

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2012a: Modelling the fire weather of Black Saturday. *Extended abstracts, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2012b: Modelling the fire weather of the Eyre Peninsula fire of January 2005. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2012c: *Blue Mountains case study – December 2001*. Project report to the Bushfire CRC.

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2012d: *Blue Mountains case study – December 2001. Additional material*. Project report to the Bushfire CRC.

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2013a: The meteorology of Black Saturday: a high-resolution ACCESS modelling study. *CAWCR Technical Reports*, in review.

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2013b: Modelling the fire weather of the Eyre Peninsula fire of January 2005. *Extended abstracts, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Melbourne, September 2 to 5.* In preparation.

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2013c: Modelling the fire weather of the Coonabarabran fire of 13 January 2013. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Melbourne, September 2 to 5.* In preparation.

Fawcett, R J B, W Thurston, J D Kepert and K J Tory, 2013d: Modelling the Weather on Black Saturday. *Poster, Australian Meteorological and Oceanographic Society, Melbourne, February 11 to 13.*

Fawcett, R J B, A J Wain, W Thurston, J D Kepert and K J Tory, 2013e: The Melbourne dust storm revisited: an ACCESS case study. *Extended abstracts, 20th International Congress on Modelling and Simulation, Adelaide, December 1 to 6.* Submitted.

Fawcett, R J B, M Webb, W Thurston, J D Kepert and K J Tory, 2013f: Modelling the fire weather of the Dunalley fire of January 2013. *Extended abstracts, 20th International Congress on Modelling and Simulation, Adelaide, December 1 to 6.* Submitted.

Fawcett, R J B, M Webb, W Thurston, J D Kepert and K J Tory, 2013g: Modelling the fire weather of the Dunalley fire of January 2013. *Papers presented at the Science to Wervices Workshop, Bureau of Meteorology, Melbourne, August 15 - 16.* Submitted.

Gellie, N, J D Kepert, K Tolhurst, C Rudiger and S Harris, 2012: Conceptual Framework for Assessing Seasonal, Daily, and Hourly Landscape Moisture and Fuel Energy. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Kepert, J D, 2011: Weather Forecasting: A long way since Tropical Cyclone Tracy, Invited presentation. *Extended Abstracts, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Sydney, August 29 to 31.*

Kepert, J D, L W Logan and K J Tory, 2011a: Modelling the fire weather on Black Saturday, *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Sydney, August 29 to 31.*

Kepert J D, P J Steinle, C I W Tingwell and K J Tory, 2011b, Verification of High-Resolution Forecasts from ACCESS. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Sydney, August 29 to 31.*

Kepert J D and K J Tory, 2011c, Using Numerical Weather Prediction to Forecast Wind Direction Variability. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Sydney, August 29 to 31.*

Kepert, J D, R J B Fawcett and M Peace, 2012a: Meteorological Aspects of the Margaret River Fires on 23 November 2011. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Kepert, J D, A Wain and K J Tory, 2012b: A comprehensive, nationally consistent climatology of fire weather parameters. *Extended abstracts, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Kepert, J D, R J B Fawcett, W Thurston and K J Tory, 2013: Applications of very high resolution atmospheric modelling for bushfires. *Extended abstracts, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Melbourne, September 2 to 5.* In preparation.

Kepert, J D and R J B Fawcett, 2013a: Meteorological aspects of the Margaret River fires on November 2011. *Extended abstracts, 20th International Congress on Modelling and Simulation, Adelaide, December 1 to 6.* Submitted.

Kepert, J D and R J B Fawcett, 2013b: Meteorological aspects of the Margaret River fires on November 2011. *Poster, Australian Meteorological and Oceanographic Society, Melbourne, February 11 to 13.*

Mills, G.A., 2008: Abrupt surface drying and fire weather. Part I: overview and case study of the South Australian fires of 11 January 2005. *Aust. Meteorol. Mag.,* **57**, 299-309.

Puri, K., G. Dietachmayer, P. Steinle, M. Dix, L. Rikus, L. Logan, M. Naughton, C. Tingwell, Y Xiao, V. Barras, I. Bermous, R. Bowen, L. Deschamps, C. Franklin, J. Fraser, T. Glowacki, B. Harris, J. Lee, T. Le, G. Roff, A. Sulaiman, H. Sims, X. Sun, Z. Sun, H. Zhu, M. Chattopadhyay, C. Engel, 2013: Implementation of the initial ACCESS numerical weather prediction system. *Aust. Meteorol. Ocean. J.,* **63,** 25-284.

Thurston, W, 2012a: *Updraft phenomena in wildfires: an annotated bibliography.* Project report to the Bushfire CRC.

Thurston, W, R J B Fawcett, J D Kepert and K J Tory, 2012b: Forecasting wind direction variability using numerical weather prediction. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Thurston, W, R J B Fawcett, J D Kepert and K J Tory, 2012c: Idealised numerical modelling of bushfire plumes. *Poster, Annual Conference of the Australasian Fire and Emergency Services Council and the Bushfire Cooperative Research Centre, Perth, August 28 to 30.*

Thurston, W, J D Kepert, R J B Fawcett and K J Tory, 2012d: *A note on the ACCESS configuration used to investigate wind variability and boundary-layer structure.* Project report to the Bushfire CRC.

Thurston, W, K J Tory and J D Kepert, 2012e: *Briefing note: choice of updraft phenomena conducive to firebrand lofting.* Project report to the Bushfire CRC.

Thurston, W, R J B Fawcett, K J Tory and J D Kepert, 2013a: Simulating boundary-layer rolls with a numerical weather prediction model. *For submission to Q. J. Royal Meteorol. Soc.*

Thurston, W, K J Tory, R J B Fawcett and J D Kepert, 2013b: Large-eddy simulations of bushfire plumes in the turbulent atmospheric boundary layer. *Extended abstracts, 20th International Congress on Modelling and Simulation, Adelaide, December 1 to 6.* Submitted.

Thurston, W, K J Tory, J D Kepert and R J B Fawcett, 2013c: *Briefing note: model configuration for investigating updraft phenomenon number one.* Project report to the Bushfire CRC.

Thurston, W, K J Tory, J D Kepert and R J B Fawcett, 2013d: *Briefing note: model configuration for investigating updraft phenomenon number two.* Project report to the Bushfire CRC.

Skamarock, W.C., 2004: Evaluating mesoscale NWP models using kinetic energy spectra. *Mon. Wea. Rev.,* **132**, 3019 – 3032.

Victorian Bushfires Royal Commission Report, 2010: *2009 Victorian Bushfires Royal Commission Final Report*. The State of Victoria. Government Printer for the State of Victoria, Melbourne, Australia.

Fire weather of a Canterbury Northwester on 6 February 2011 in South Island, New Zealand

Colin Simpson [a, b], Andrew Sturman [b], Peyman Zawar-Reza [b] and Grant Pearce [c]

[a] *School of Physical, Environmental and Mathematical Sciences, University of New South Wales at Canberra, Canberra, Australia*
[b] *Centre for Atmospheric Research, University of Canterbury, Christchurch, New Zealand*
[c] *Rural Fire Research Group, Scion, Christchurch, New Zealand*
Email: c.simpson@adfa.edu.au

Abstract

Foehn winds, known locally as the "Canterbury Northwester", occurred on 6 February 2011 and were associated with extreme fire weather in the lee of the Southern Alps and across the eastern South Island of New Zealand. A peak air temperature of 40.7˚C was recorded at Timaru, which compares with the national record of 42.4˚C set at Rangiora in 1973 during another Northwester. The primary objective of this study was to investigate the fire weather and the synoptic and mesoscale atmospheric processes associated with the Northwester. This was achieved through analysis of weather station data and a high-resolution Weather Research and Forecasting (WRF) model simulation. The fire weather was assessed through consideration of observable weather variables and New Zealand's version of the Fire Weather Index (FWI) in the Canadian Forest Fire Danger Rating System. The WRF model results suggest that internal gravity waves were present in the lee of the Southern Alps and considerably affected fire weather across the eastern South Island. The FWI was recorded at extreme values, due to a combination of high air temperatures and wind speeds, and low relative humidity. This study provides a better understanding of the mesoscale atmospheric dynamics and fire weather associated with the Canterbury Northwester.

Introduction

Foehn winds are a type of warm and dry wind that descend along the leeward slope of sizable mountain ranges. They are commonly referred to by a local name, such as the Chinook and Santa Ana winds in North America, and the Föhn wind in the Europe. Foehn winds are typically associated with a sudden increase in air temperature and decrease in relative humidity on the leeward side of the mountain range. In addition, they can be associated with orographic upwind blocking, and internal gravity waves and downslope windstorms in the lee of the mountain range. Foehn winds and their associated atmospheric processes can considerably affect fire weather near mountainous terrain (Whiteman 2000; Sharples 2009).

The South Island of New Zealand is situated in the mid-latitudes of the Southern Hemisphere and therefore experiences prevailing westerly synoptic winds. The Southern Alps mountain range extends approximately 450 km from the southwest to the northeast of the South Island and has a considerable effect on regional weather and climate (Sturman *et al.* 1999). Northwesterly foehn winds that occur on the eastern side of the Southern Alps, which predominantly affect the central South Island regions of Canterbury and Otago, are locally known as the "Canterbury Northwester", "Northwester" or "Nor'wester". The spatial and temporal characteristics of several Northwesters, and their effects on local wind systems in the Canterbury Plains and Southern Alps, have previously been studied using observational data (Lamb 1975; McGowan and Sturman 1996; McGowan *et al.* 2002).

It is understood that the Northwester can considerably affect fire weather and behaviour in the eastern South Island. For example, the 1973 Ashley Forest fire in Canterbury (Beatson 1985; Pearce and Alexander 1994) and the 1995 Berwick Forest fire in Otago (Fogarty *et al.* 1997), both exhibited high intensity fire behaviour and occurred during a Northwester. However, there has been limited research into the fire weather conditions and wildland fire behaviour associated with the Northwester (Steiner 1979).

This study aims to investigate the fire weather conditions, and the synoptic and mesoscale atmospheric processes, associated with a Northwester that occurred on 6 February 2011. Although there were no major recorded wildland fires on this day, the Northwester resulted in widespread extreme fire weather conditions across the eastern South Island. A peak air temperature of 40.7˚C was observed at Timaru, compared with the New Zealand record of 42.4˚C set at Rangiora on 7 February 1973, the same day of the Ashley Forest Fire. A combination of numerical weather prediction (NWP) modelling and weather station data are used to investigate the fire weather characteristics of this Northwester.

Numerical Weather Prediction Model

Version 3.4 of the Weather Research and Forecasting (WRF) NWP model (Skamarock *et al.* 2008) was used to simulate the synoptic and mesoscale atmospheric processes associated with the Northwester that occurred on 6 February 2011. The WRF NWP model was chosen as it is well suited to mesoscale atmospheric modelling and is widely used by the scientific research and operational weather forecasting communities. The WRF model simulation covered the five day period from 1200 NZST on 3 to 8 February 2011.

Three domains with two-way nesting were used, and the domains had a horizontal grid spacing of 18, 6 and 2 km, and a computational domain of 120x120, 193x193 and 391x391 grid points, respectively. The outer model domain covered all of mainland New Zealand and extended far out into the Pacific Ocean and Tasman Sea, whereas the two nested domains principally covered just the South Island. The three domains shared an identical configuration of 50 vertical levels, which extended from 16 m AGL to a fixed model pressure top at 10 hPa. The whole outer model domain was nudged at six-hourly intervals, with a default nudging time scale of approximately one hour, using the National Centers for Environmental Prediction (NCEP) Final Analyses (FNL).

The WRF model utilises fully compressible non-hydrostatic equations and has a mass-based terrain-following coordinate system. The microphysics were represented by a single-moment six-class scheme with mixed-phase processes. The sub-grid scale effects of convective or shallow clouds were modelled only in the outer domain using a modified Kain-Fritsch scheme. The surface layer and planetary boundary layer were represented by the Eta schemes. The heat and moisture fluxes over land were provided by the Noah Land Surface Model, which has soil temperature and moisture in four layers, fractional snow cover and frozen soil physics. A simple short-wave radiation scheme and the Rapid Radiative Transfer Model represented the radiation physics. A gravity wave damping layer was used to prevent reflection of gravity wave energy off the upper boundary.

Fire Weather Assessment

New Zealand's version of the Fire Weather Index (FWI) System, used in the Canadian Forest Fire Danger Rating System (Van Wagner 1987), is the primary operational tool used to assess fire weather in New Zealand and is a principal component of the New Zealand Fire Danger Rating System (NZFDRS) (Alexander 1992; Anderson 2005). The FWI itself is a fire behaviour index that quantifies the expected fire intensity for a reference fuel type and is derived from the near-surface air temperature, relative humidity, wind speed and rainfall. An FWI ≥ 32 generally corresponds to an "Extreme" fire danger classification for forested regions in New Zealand (Alexander 2008). The fire weather conditions are assessed using a combination of WRF model output and observational data taken from weather stations located across the South Island, as shown in Figure 1.

Synoptic Meteorology

At 1200 NZST on 6 February 2011, a high pressure system was located northwest of the North Island, and a cold front was approaching the South Island from the southwest, as shown in Figure 2. A ridge of high pressure was present over the Southern Alps, with a lee trough on the downwind side. Figure 3 demonstrates that the pressure gradient from the northwest to the southeast of the South Island was ~14 hPa, or ~2 hPa per 100 km, which is fairly typical relative to other Northwesters (McGowan and Sturman 1996). The subsequent passage of the cold front over the South Island on 7 February eliminated this pressure gradient across the South Island and brought predominantly southerly and southwesterly synoptic flow across the southern and central South Island. A visual comparison of the observed and modelled pressure differences across the South Island indicate that there are only minor differences prior to the arrival of the cold front.

The modelled wind conditions at 10 m AGL at 1200 NZST on 6 February, shown in Figure 4a, indicate limited orographic blocking of the low-level northwesterly synoptic winds by the central Southern Alps. This is in agreement with the northerly to northeasterly 10 m AGL wind direction measured at Hokitika throughout 6 February. The model results further suggest that, prior to and during the onset of the foehn winds, low-level synoptic winds were channelled through the Cook Strait, and curved inwards back towards the South Island's eastern coast due to the lee trough. This is consistent with the northeasterly 10 m AGL wind direction measured at Christchurch late on 5 February and early on 6 February, prior to the onset of the northwesterly foehn winds from 1000 NZST on 6 February. These are fairly typical characteristics of the Canterbury Northwester (McGowan and Sturman 1996, McCauley and Sturman 1999).

Gravity Waves

The modelled vertical wind velocities, at 2 km above mean sea level (AMSL), and MODIS satellite imagery from 6 February are shown in Figures 4b and 5. The vertical wind velocities at 2 km AMSL suggest that internal gravity waves were present in the lee of the Southern Alps during the Northwester. In the southern South Island, the modelled gravity waves propagated far downstream, indicating the presence of trapped lee waves. Regularly spaced gravity wave cloud formations can be seen over the southern South Island in the MODIS images, which broadly supports the model results.

Vertical cross-sections of the modelled potential temperature and wind speed at 1200 NZST on 6 February, shown in Figure 6, indicate that the atmosphere was stable upwind of the Southern Alps. These stable atmospheric conditions helps explain the presence of the low-level northeasterly barrier flow along the central western coast of the South Island. Hydraulic jump features, in which the high velocity downslope lee flow rises sharply as it encounters a low velocity flow region, were present in the WRF model results in the lee of the central Southern Alps and along the foothills of the Canterbury Plains. These hydraulic jump features were associated with modelled wind speeds exceeding 120 km h^{-1} along the foothills of the Canterbury Plains. Downwind of the internal hydraulic jumps, the modelled wind speeds were comparatively low at 0-30 km h^{-1}.

In the southern South Island, trapped lee waves were modelled downwind of the Southern Alps, which extended out across the eastern South Island and Pacific Ocean. The modelled lee waves extended from near the surface to a height of ~10-12 km, with modelled wind speeds exceeding 120 km h^{-1} above ~2 km AMSL. The modelled near-surface wind speeds were high under the lee wave troughs and on mountain lee slopes, and comparatively low under the lee wave crests and on mountain windward slopes. In contrast to the central South Island, there were no hydraulic jump features modelled in southern half of the South Island.

Fire Weather

The magnitude of the modelled warming and drying effect of the Northwester in the lee of the Southern Alps is clearly evident in Figures 7a and 7b. The Timaru station recorded the highest air temperature on 6 February 2011 at 40.7˚C, which compares with a daily maximum air temperature of 19.0˚C measured at the Hokitika station near the west coast. The WRF model did not fully capture this foehn warming effect, as demonstrated by Figure 8a, with a peak modelled air temperature at 2 m AGL of 34.8˚C in the central eastern South

Island. The observed relative humidity reached a daily minimum of 25.0 and 29.6 % at the Timaru and Christchurch stations, respectively. Both the observed and modelled relative humidity rarely dropped below 30%, as partly shown by Figure 7b, and were therefore fairly unremarkable in a fire weather context.

The modelled wind speed at 10 m AGL and the FWI were highest along the foothills of the Canterbury Plains, as shown in Figures 7c and 9a, due to the hydraulic jumps discussed above. The modelled daily maximum FWI, which is determined at hourly intervals, peaked at 75 in this region and is consistent with the daily maximum of 75 recorded at the Christchurch station. The modelled FWI was greater than 32, corresponding to an Extreme fire weather classification for forested regions, across much of the eastern South Island during the Northwester. A map of the daily FWI issued for New Zealand by the National Rural Fire Authority on 6 February 2011 is shown in Figure 9b for comparison.

The Snowdon station, which is located in the foothills of the Canterbury Plains, recorded a relatively low daily maximum wind speed and gust of 46.4 and 82.4 km h^{-1}, compared to the WRF model results (see Figure 8b). A similar daily maximum wind speed and gust of 51.3 and 85.2 km h^{-1} were measured further downwind at the Christchurch station. These combined results cast some doubt over the validity of the modelled internal hydraulic jumps in the central South Island. In the southern South Island, the WRF model results showed alternating bands of high and low near-surface wind speeds on the leeward and windward slopes, respectively, of the mountains. However, the modelled FWI was not as high in the southern South Island relative to the central South Island, due predominantly to the higher relative humidity further south.

Heavy orographic rainfall was modelled along the west coast of the southern half of the South Island, as shown in Figure 7d, with 3 hr rainfall quantities exceeding 50 mm in isolated regions at 1200 NZST on 6 February. This is in good agreement with the measured 3 hr rainfall of 55.8 mm at the Milford Sound station. Further north, there was only limited modelled rainfall along the west coast, with a 24 hr rainfall of 17.5 mm measured at the Hokitika station on 6 February. The passage of the cold front over the South Island on 7 February resulted in light to moderate rainfall across the southern and central South Island, which effectively reduced the FWI to zero.

Discussion and Conclusions

The Northwester that occurred on 6 February 2011 resulted in an Extreme fire danger classification being issued by the National Rural Fire Authority for much of the eastern South Island of New Zealand. The fire weather conditions and the synoptic and mesoscale atmospheric processes associated with the Northwester were investigated using a combination of weather station data and the WRF mesoscale NWP model. The synoptic meteorology and regional characteristics of the Northwester were broadly similar to that observed in other Northwesters (McGowan and Sturman 1996; McCauley and Sturman 1999).

The onset of the Northwester resulted in a sudden and considerable increase in air temperature, and decrease in relative humidity, across much of the eastern South Island. Timaru recorded the highest daily maximum air temperature of 40.7˚C, and air temperatures were in the high 30s across much of the central eastern and northeastern South Island. In contrast, the relative humidity was rarely below 30 % and so was fairly unremarkable in a fire weather context. However, the combination of high air temperatures and wind speeds resulted in extreme fire weather across the eastern South Island, as quantified by the FWI.

The considerable spatial and temporal variability of the FWI indicates that accurate prediction of the fire weather conditions associated with the Northwester is important for fire management decisions made during Northwester events. Although there were no major wildland fires on 6 February 2011, Northwesters are known to have contributed to high intensity fire behaviour during wildfires, such as in the 1973 Ashley Forest and 1995 Berwick Forest fires. Future work will focus on developing a climatology of Northwester events in the South Island and relate this to wildland fire occurrence and behaviour.

The WRF model results and MODIS satellite imagery suggest that trapped lee waves were present in the lee of the Southern Alps across the southern half of the South Island. These trapped lee waves were associated with alternating bands of low and high wind speeds along the upward and downward mountain slopes, respectively. The WRF model results suggest that hydraulic jump features were present in the central South Island along the foothills of the Canterbury Plains. However, the presence of these hydraulic jumps is not supported by the observational data at the Snowdown and Christchurch weather stations. The WRF model also under-predicted the peak air temperatures observed across the central eastern South Island on the order of several degrees celsius. Future work will expand the verification of the WRF model output through comparison with in-situ and remote measurements of the fire weather conditions made across the South Island. It is likely that the existing WRF model errors are due to a combination of factors, including the resolution of the high-relief terrain, model parameterisations and errors in the NCEP FNL used to nudge the outer model domain (Simpson *et al*. 2013).

Acknowledgements

This research was supported by a doctoral scholarship funded by the Bushfire Cooperative Research Centre, Melbourne, Australia. The mean sea level analyses for the South Pacific region were obtained from the Bureau of Meteorology, Melbourne, Australia. The WRF model simulation was performed on the BlueFern supercomputing system, operated by the University of Canterbury, New Zealand.

References

Alexander ME (1992) Standard specifications for Fire Weather Index System calculations. Paper prepared for discussion at the 3rd meeting of the Advisory Committee on Forest and Rural Fire Research, 21 October 1992, New Zealand Fire Service National Headquarters (Wellington, New Zealand).

Alexander ME (2008) Proposed revision of fire danger class criteria for forest and rural fire areas in New Zealand. 2nd Edition. National Rural Fire Authority (Wellington, New Zealand) in association with Scion, Rural Fire Research Group (Christchurch, New Zealand).

Anderson S (2005) Forest and rural fire danger rating in New Zealand. New Zealand Institute of Forestry, Forestry Handbook (Christchurch, New Zealand).

Beatson D (1985) 'The New Zealand weather book: a guide to the forces that shape our climate.' (Third Edition. Whitcoulls Publishers: Christchurch, New Zealand).

Fogarty LG, Jackson AF, Lindsay WT (1997) Fire behaviour, suppression and lessons from the Berwick Forest Fire of 26 February 1995. Forest and Rural Fire Scientific and Technical Series FRI Bulletin No. 197, New Zealand Forest Research Institute (Rotorua, New Zealand), in association with the National Rural Fire Authority (Wellington, New Zealand).

Lamb PC (1975) The Nor'wester's advance across the Canterbury Plains, New Zealand. *New Zealand Journal of Science and Technology* **17**, 65-75.

McCauley MP, Sturman AP (1999) A study of orography blocking and barrier wind development upstream of the Southern Alps, New Zealand. *Meteorology and Atmospheric Physics* **70**, 121-131.

McGowan HA, Sturman AP (1996) Regional and local scale characteristics of foehn wind events over the South Island of New Zealand. *Meteorology and Atmospheric Physics* **58**, 151–164.

McGowan HA, Sturman AP, Kossmann M, Zawar-Reza P (2002) Observations of foehn onset in the Southern Alps, New Zealand, *Meteorology and Atmospheric Physics* **79**, 215-230.

Pearce HG, Alexander ME (1994) Fire danger ratings associated with New Zealand's major pine plantation wildfires. Proceedings of 12th Conference on Fire and Forest Meteorology, Society of American Foresters, SAF Pub. 94-02 (Bethesda, Maryland).

Sharples JJ (2009) An overview of mountain meteorological effects relevant to fire behaviour and bushfire risk. *International Journal of Wildland Fire* **18**, 737–754.

Simpson CC, Pearce HG, Sturman AP, Zawar-Reza P (2013) Verification of WRF modelled fire weather in the 2009–10 New Zealand fire season. *International Journal of Wildland Fire* http://dx.doi.org/10.1071/WF12152

Skamarock WC, Klemp JB, Dudhia J, Gill DO, Barker DM, Duda MG, Huang XY, Wang W, Powers JG (2008) A Description of the Advanced Research WRF Version 3. National Center for Atmospheric Research, Technical Note 475 (Boulder, Colorado).

Steiner JT (1979) Meteorology and forest fires in New Zealand. Pages 30-33 reprinted from 14th Conference on Agriculture and Forest Meteorology and 4th Conference on Biometeorology, April 2-6, 1979 (Minneapolis, Minnesota).

Sturman AP, McGowan HA, Spronken-Smith, RA (1999) Mesoscale and local climates in New Zealand. *Progress in Physical Geography* **23**, 611–635.

Van Wagner CE (1987) Development and structure of the Canadian Forest Fire Weather Index System. Canadian Forestry Service, Forestry Technical Report 35 (Ottawa, Ontario).

Whiteman CD (2000) 'Mountain meteorology fundamentals and applications.' (Oxford University Press: New York)

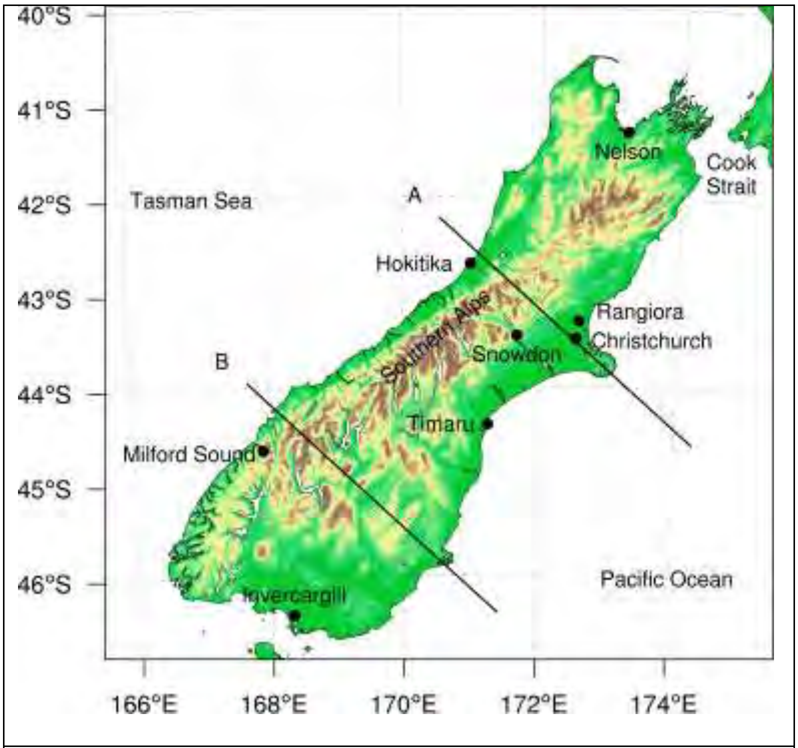


Figure 1: Map of the South Island of New Zealand showing the location of weather stations, geographical features and vertical cross-sections shown in Figure 5.

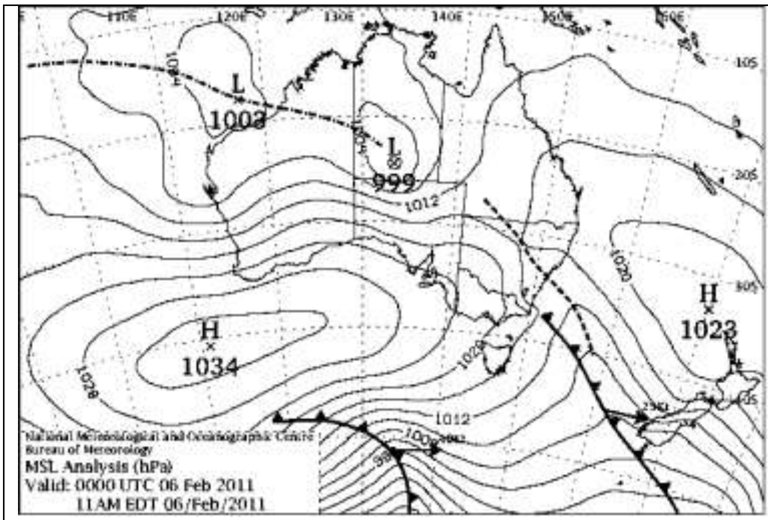


Figure 2: MSLP chart for the Australia and New Zealand region at 1200 NZST 6 February 2011, with a contour interval of 4 hPa. Originally issued by the Bureau of Meteorology, Melbourne, Australia.

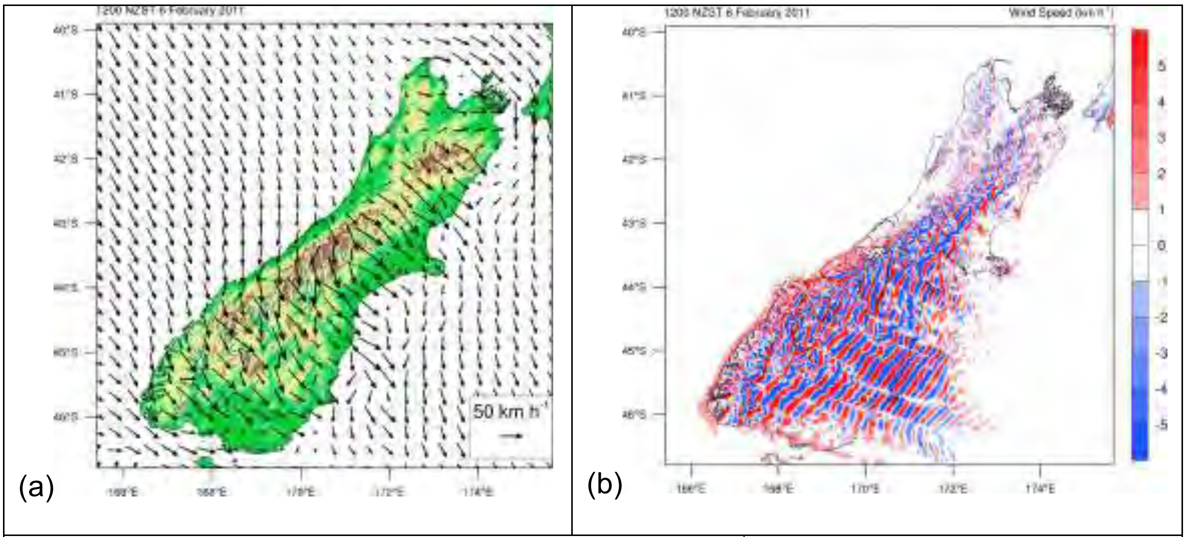


Figure 3: Modelled (a) horizontal wind conditions (km h^{-1}) at 10 m AGL and (b) vertical wind velocity (km h^{-1}) at 2 km AMSL at 1200 NZST on 6 February 2011 for the inner model domain. In (a) the reference vector in the bottom right-hand corner shows a westerly wind of 50 km h^{-1}.

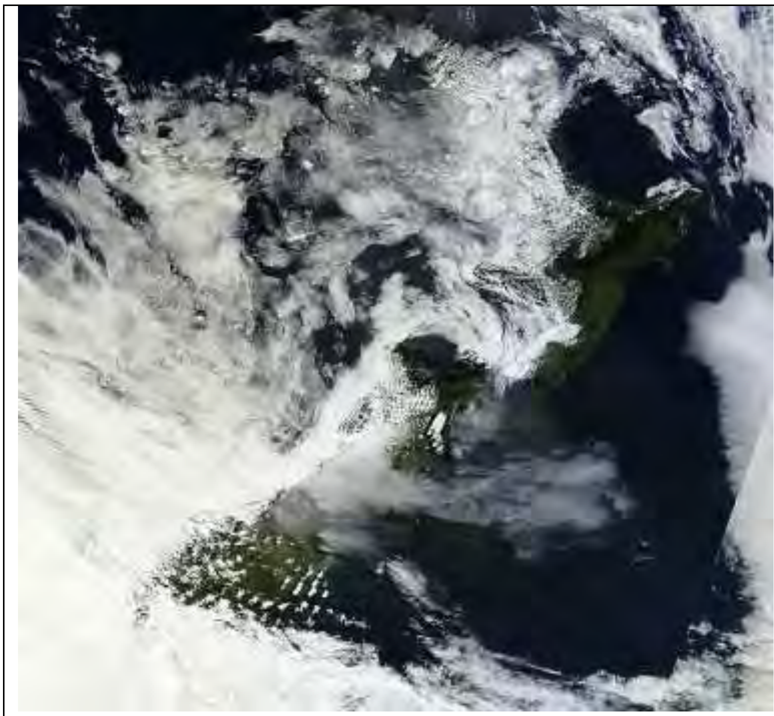


Figure 4: MODIS satellite composite images of New Zealand taken at (a) 1415, 1550 and 1555 NZST on 6 February 2011.

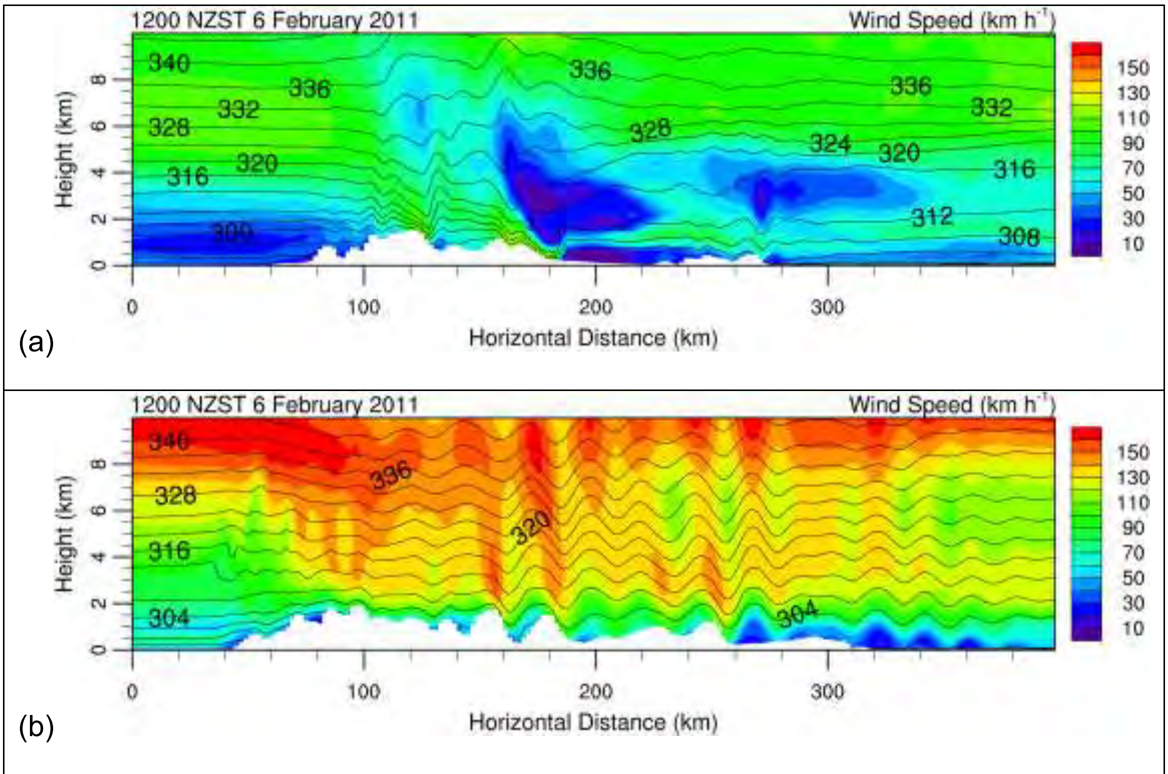


Figure 5: Vertical cross-section of the modelled potential temperature (K), which has a contour line interval of 4 K, and wind speed (km h^{-1}), which is colour shaded. The two cross-sections correspond to lines (a) A and (b) B in Figure 1a.

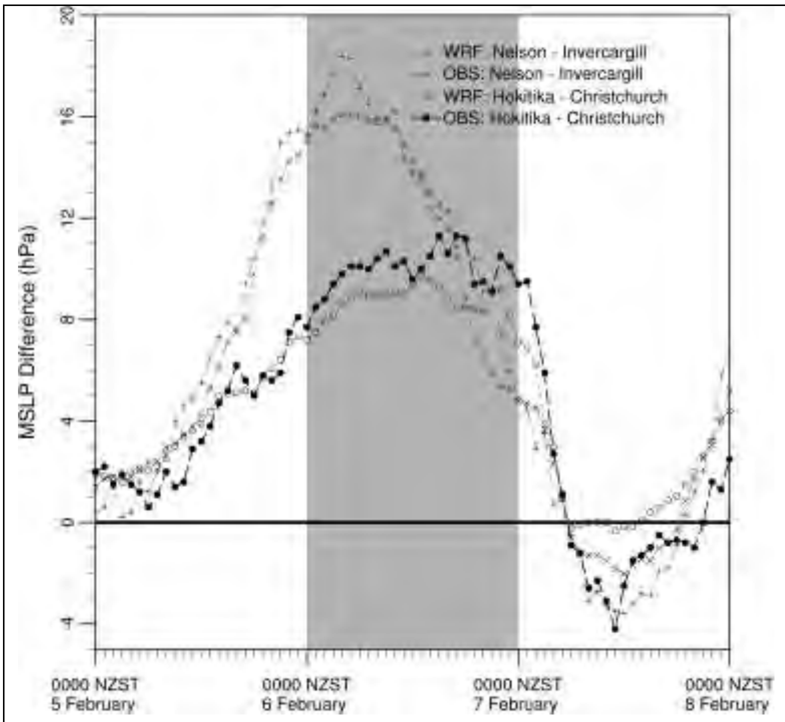


Figure 6: Time series of observed (OBS) and modelled (WRF) MSLP (hPa) difference between Nelson and Invercargill, and Hokitika and Christchurch. The horizontal black line indicates a pressure difference of 0 hPa.

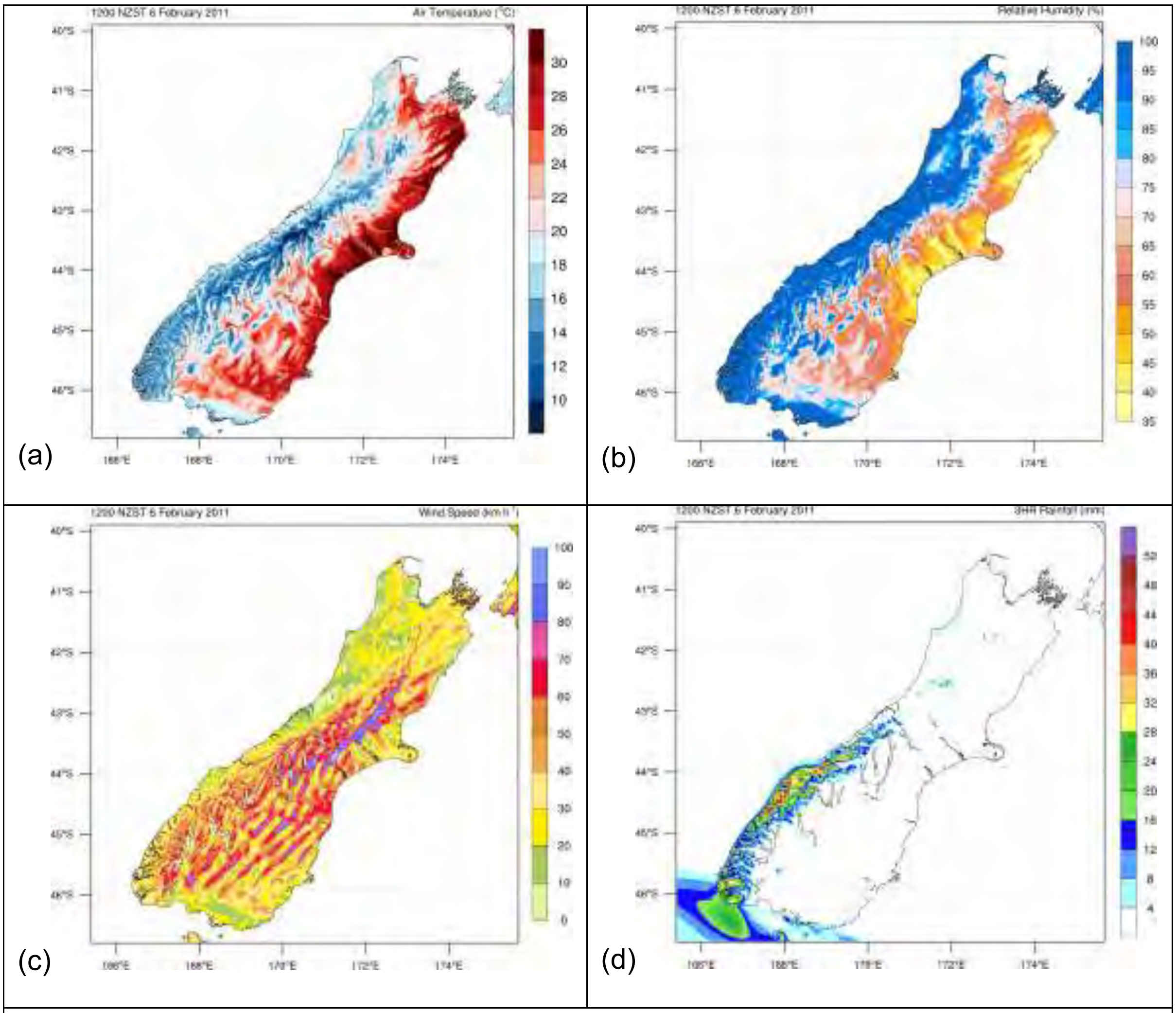


Figure 7: Modelled 2 m AGL (a) air temperature (˚C) and (b) relative humidity (%), (c) 10 m AGL wind speed (km h^{-1}), and (d) 3-hr rainfall (mm) at 1200 NZST on 6 February 2011 for the inner model domain.

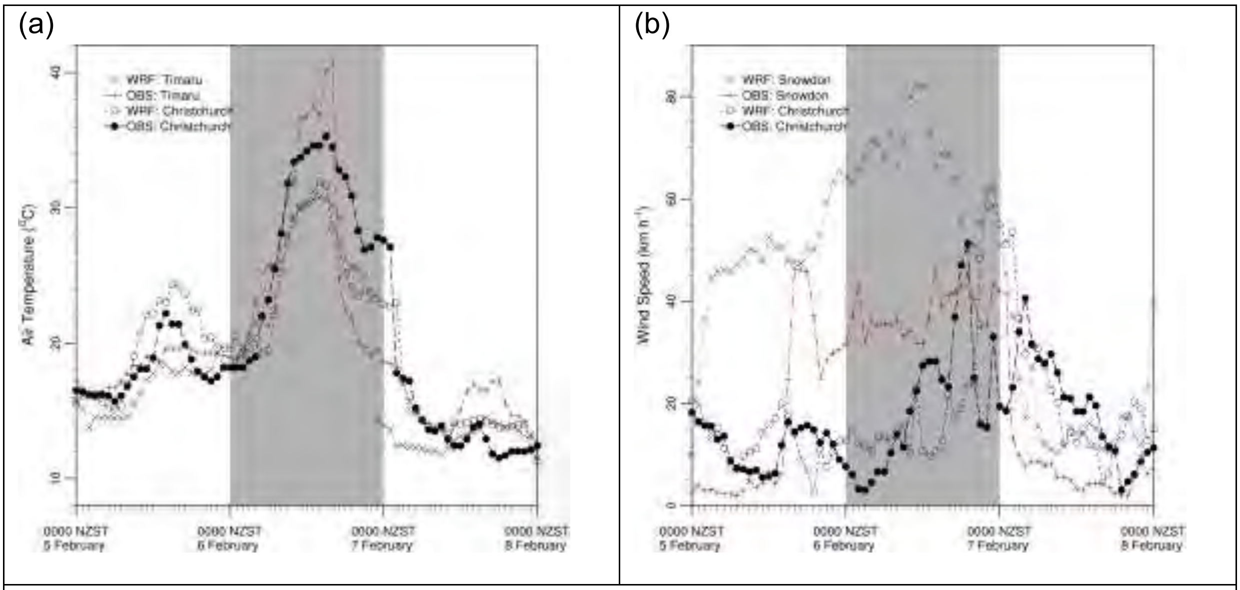


Figure 8: Time series of the observed (OBS) and modelled (WRF) (a) 2 m AGL air temperature (˚C) at Timaru and Christchurch, and (b) 10 m AGL wind speed (km h^{-1}) at Snowdon and Christchurch.

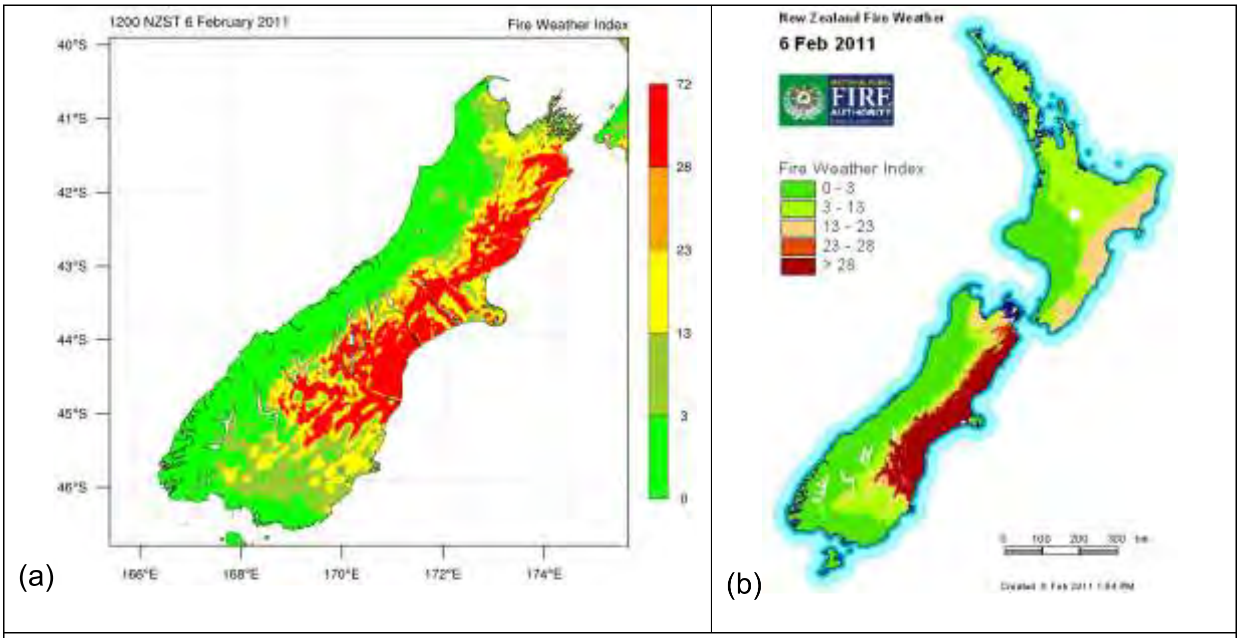


Figure 9: Daily FWI on 6 February 2011 (a) derived from WRF model results for the inner model domain and (b) issued by the National Rural Fire Authority for mainland New Zealand.

Fire-atmosphere coupled numerical simulations show a fire changes the local meteorology

Mika Peace* Trent Mattner† Graham Mills‡

Abstract

The idea that a fire 'creates its own weather' is supported by observations from fire grounds and results from idealised numerical simulations. We have simulated two Australian bushfires where unexpected fire behaviour occurred, using the coupled fire-atmosphere model WRF-fire. The results present new evidence of dynamical interactions between a fire and the surrounding atmosphere. The simulations are of two fires that burnt on Kangaroo Island, South Australia in December 2007, the D'Estrees fire and the Rocky River fire. In the D'Estrees simulations, fire-atmosphere interactions produced a long-lived fire-induced vortex. In the Rocky River simulations, fire perimeter was sensitive to the local fire-modified winds that arise from interactions between the fire, atmosphere and local topography. A simulation of the Rocky River fire at high temporal resolution produced pulses in the rate of spread of the fire front coincident with the passage of mesoscale convective cells. The simulation results suggest that the potential for extreme fire behaviour arises from interactions between the fire and the atmosphere. These results add to the body of research showing that feedback between a fire and the atmosphere can play an important role in shaping both fire behaviour and micro-scale meteorology. As a consequence, we affirm that a comprehensive risk assessment at a fire-ground should consider the three-dimensional structure of the atmosphere and the possibility of dynamical feedback processes occurring.

*Bushfire CRC; Applied Mathematics, Adelaide University; Bureau of Meteorology
†Applied Mathematics, Adelaide University
‡Applied Mathematics, Adelaide University

1 INTRODUCTION

Fire-behaviour simulation models are increasingly being used by fire managers in real time, and in future years this use will grow. Operational simulation models presently in application in Australia predict fire spread and other elements of fire behaviour using simple weather variables as input (as well as topography and fuel information), but they do not include direct feedback from the fire to the atmosphere. However, it is well recognised that the heat and moisture generated by a fire can affect the local meteorology. This often manifests as pyro- convective cloud development and modification of wind strength and direction in the fire's vicinity. Perhaps the most dramatic recent example of a fire creating its own weather is the fire tornado generated in the 2003 Canberra fires, documented by McRae et al. (2013). Their study is just one of many showing that the interactions between a fire and the surrounding atmosphere can change the local meteorological environment, with subsequent dramatic impacts on fire behaviour. Factors that are less well understood are the physical processes that lead to these feedback loops, how and when such feedbacks will occur, and of what magnitude they will be. Yet these factors could be of critical importance to fire-ground operations and to firefighter safety. Therefore they should be considered in the context of firstly, pertinent information in fire weather forecasts and secondly, appropriate inputs to fire simulation models.

In order to further current understanding of fire-atmosphere interactions, we have run coupled simulations of two Australian bushfires using the coupled fire- atmosphere model WRF-fire. WRF is described by Skamarock et al. (2008) and the fire component of WRF-fire is described in detail by Mandel et al. (2011). Coen et al. (2013) give a comprehensive description of the model's applications and capabilities. WRF-fire is similar to other numerical simulation fire behaviour models in that the underlying fire spread is formulated using an empirical method, in this case that of Rothermel (1972). However, WRF-fire differs from other operational models because it captures the interactions between the fire and atmosphere. It implements this by calculating a heat flux (sensible heat) and moisture flux (latent heat) from a quantity and type of fuel burnt at each time step of the simulation. These fluxes are passed back into the atmospheric model at the following time step, and the atmospheric response to the fire fluxes is by modification of the local wind fields. Thus, the surrounding atmosphere responds to the energy released by the fire and interactions between the two can be examined. Our simulations have been run in 'feedback on' and 'feedback off' mode. The difference in the two modes is that in the feedback off simulations, no heat and moisture fluxes are passed from the fire model to the atmospheric model, so the atmosphere is effectively unaware of the fire's presence. Comparing the two results allows insights as to the impact of a fire on the surrounding atmosphere and the impact the coupling process has on the fire's evolution. Using a coupled model in this way supplements the observational dataset, which is limited due to the difficulties associated with obtaining detailed three-dimensional observations of wind and temperature in the vicinity of a real fire. Our choice of WRF-fire was due to it being the most accessible and well supported model available for fire-atmosphere simulations and it matches our particular interest in bushfires and mesoscale atmospheric processes.

In this paper we show a selection of preliminary results from the WRF-fire simulations and then discuss some implications of the findings. The work presented here is in progress and a more complete version for publication is in preparation. The prepared work includes detail of the WRF-fire configuration, it discusses the limitations of the simulations, presents a more complete set of references and contains substantially more results. The meteorology and fire behaviour of the D'Estrees and Rocky River fires are described in the case study of Peace & Mills (2012).

2 Results

The simulation results show changes to mesoscale atmospheric structure as a result of the energy released by a fire, and a number of interesting features have been identified. The aim of these simulations was to examine fire-atmosphere interactions arising from the coupling process, rather than verify the simulated fire perimeter against observations. However, we note that the simulated fire isochrones provide a reasonable representation of fire spread against the limited available observations.

Figure 1 shows a series of time steps of the D'Estrees fire. During the event dramatic fire behaviour occurred and satellite imagery showed a well developed smoke column extending to the southwest. Of particular interest was that the fire activity was distinctly different from three other fires burning nearby. In the simulations, a complex sea-breeze frontal wind change moved over the fire ground and a long-lived vortex developed adjacent to the head fire in an area of wind shear associated with the front. The simulated vortex was 1-2 km wide and 500-600 m high and persisted for over five hours of simulation time. When feedback from the fire to the atmosphere was turned off, no vortex developed. Further detail on the simulated vortex is included in the paper in preparation.

The Rocky River fire moved rapidly up a gully in southwest winds and extreme fire behaviour was observed. Figure 2 shows the final fire perimeter for the Rocky River fire simulations. The difference in fire area on the northeastern flank arises from fire-atmosphere coupling and wind convergence along a ridge top. Note that the fire perimeter is smaller for the feedback on case. In comparison (not shown), the fire perimeter for the D'Estrees fire was smaller for the feedback off case.

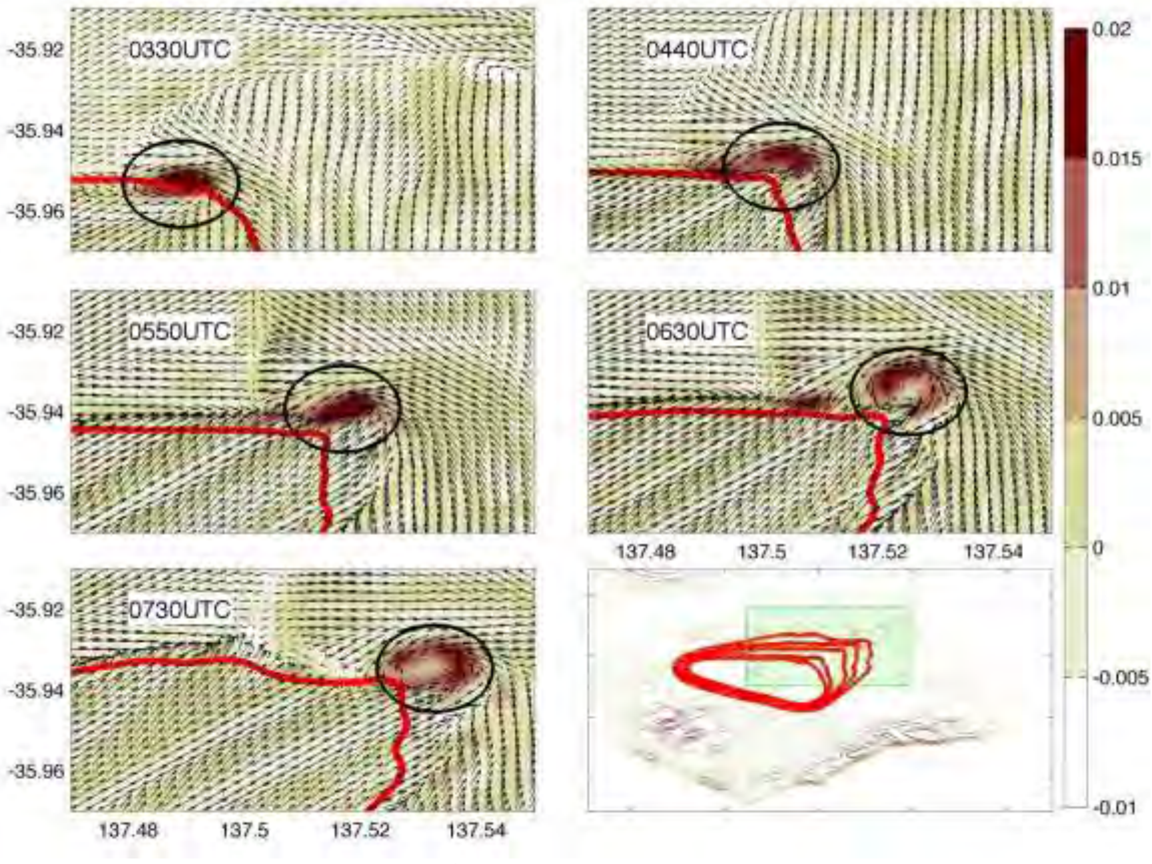


Figure 1. Wind vectors and vorticity (s^{-1}) (shaded, with vorticity about the vertical axis) at 10 m. Fire-line (feedback on) in red. Initialisation with ERA-interim meteorological grids. Lower right plot shows georeference and fire line reference for plots 1-5.

Figure 2. Simulated fire perimeter for the Rocky River fire at 1200UTC. Feedback on in red and feedback off in green. Shading shows fuel areas used in the model.

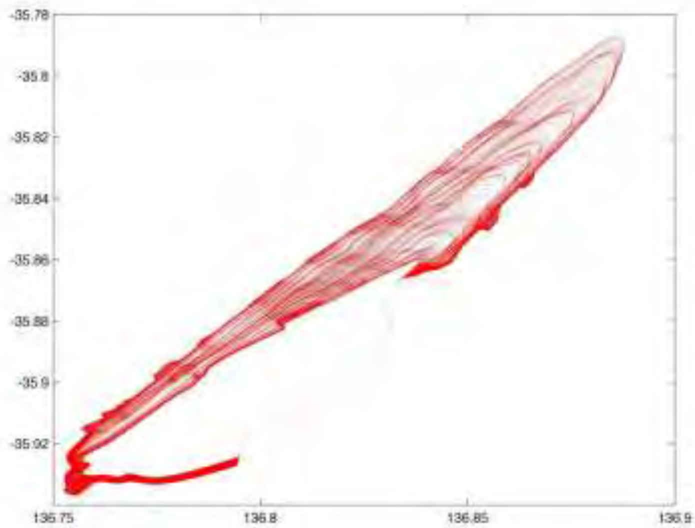


Figure 3. Fire isochrones for the Rocky River fire at one-minute intervals. Simulation from 0600UTC to 0830UTC.

Figure 3 shows fire isochrones for the Rocky River fire from output at one minute intervals for a period of 2.5 hours. During the period, winds were relatively steady across the domain in both speed and direction. In Fig. 3, surges or pulses in fire spread can be seen at the one minute interval outputs. These pulses are not associated with features of either fuel or topography. Rather, the timing of the pulses matched the passage of mesoscale convective cells at cloud height. This indicates that the surges arose from interactions between the fire and atmosphere.

3 CONCLUSIONS

The results from the coupled model show that interactions between a fire and the atmosphere can cause modification to the local winds that has consequent impacts on fire behaviour. In our simulations of the D'Estrees fire, coupling between the fire and atmosphere in the vicinity of a slow-moving front produced a large, long lived vortex adjacent to the head fire. The simulations of the Rocky River fire showed significant changes to fire spread and final fire area due to the fire- modified wind fields over topography. High temporal resolution simulations of the Rocky River fire showed a non-steady-state fire rate of spread in response to fire-atmosphere interactions.

Our results show that extreme fire behaviour may be attributed to interactions between the fire and the atmosphere. The simulations suggest mechanisms by which sudden increases in fire activity may occur and they show that wind driven fire spread at one minute intervals is not steady state due to fire-atmosphere inter- actions.

These results are thought provoking for the current approach to fire-weather forecasts and fire-behaviour predictions in Australia. Fire-weather forecasts focus on a near-surface point forecast of wind, temperature and relative humidity, following the McArthur framework. The simulation results, especially when considered in combination with case studies that examine the meteorology of unusual fire events, show that the three-dimensional structure of the atmosphere will influence how a fire behaves.

The scale of the feedbacks in the simulations shows the critical need for these elements to be incorporated into operational planning at fire events and strategic planning in the fire science community. Although the process of fire-atmosphere coupling and feedback behaviour remains poorly understood, it is essential information in order to mitigate against the impacts of bush fires and minimise risk during fuel-reduction burns.

Acknowledgements

This work has been supported by the Bushfire CRC and the Bureau of Meteorology and conducted at the University of Adelaide School of Mathematical Sciences. Simulations were run on the supercomputer Tizard at E-Research SA.

References

Coen, J., Cameron, M., Michalakes, J., Patton, E., Riggan, P. & Yedinak, K. (2013), 'WRF-Fire: Coupled Weather-Wildland Fire Modeling with the Weather Research and Forecasting Model', *Journal of Applied Meteorology and Climatology* **52**, 16–38.

Mandel, J., Beezley, J. & Kochanski, A. (2011), 'Coupled atmosphere-wildland fire modeling with WRF-fire', *Geoscientific Model Development Discussions* **4**, 497–545.

McRae, R., Sharples, J., Wilkes, S. & Walker, A. (2013), 'An Australian pyro-tornadogenesis event', *Natural Hazards* **65**, 1801–1811.

Peace, M. & Mills, G. (2012), 'A case study of the 2007 Kangaroo Island bush- fires', CAWCR Technical Report No. 53, Centre for Australian Weather and Climate Research.

Peace, M., Mills, G., Mattner, T., McCaw, L. & Kepert, J. (in prep.A), 'Coupled numerical simulations show a fire changes the weather forecast'.

Peace, M., Mills, G., Mattner, T., McCaw, L. & Kepert, J. (in prep.B), 'Coupled simulations of the Rocky River fire'.

Rothermel, R. (1972), 'A mathematical model for predicting fire spread in wild- land fires', *USDA Forest Service Research Paper* **INT-115**.

Skamarock, W., Klemp, J., Dudhia, J., Gill, D., Barker, D., Duda, M., Wang, W. & Powers, J. (2008), 'A Description of the Advanced Research WRF Version 3', NCAR Technical Note NCAR/TN-475+STR.

National Fire Behaviour Knowledge Base- Bringing together the best information for best decisions

Jim Gould[a], **Andrew Sullivan**[a], **Miguel Cruz**[a], **Chris Rucinski**[b], **Mahesh Prakash**[b]

[a] *CSIRO Ecosystem Sciences and CSIRO Digital Productivity and Services Flagship*
[b]*CSIRO Computational Informatics and CSIRO Digital Productivity and Services Flagship*
Email: Jim.Gould@csiro.au

Abstract

The estimation of fire behaviour is an important component of any fire management approach, allowing the determination of the impacts of fire on ecosystem components, public safety and warnings, and supporting bushfire management decision-making. Fire behaviour prediction combines quantitative and qualitative information based on experience and scientific principles describing the combustion and behaviour of fire influenced by topography, weather and fuel. Predictions based on mathematical models integrate these important factors in a consistent way. The National Fire Behaviour Knowledge Base (NFBKB) is a new software-based tool that consists of four primary components (fuel models, fuel moisture models, wind models, and fire behaviour models) to predict expected fire characteristics (e.g., rate of spread, flame height, fireline intensity, onset of crowning, spotting potential, etc). This paper details the current development of the fire behaviour component of the NFBKB system as well as how this will be integrated with the Australian bushfire fuel classification project currently being undertaken by AFAC. The fire behaviour component integrates a suite of models covering the main fuel types of Australia: eucalyptus forests, exotic pine plantations, grasslands, shrublands and Mallee-heath.

In the near future further CSIRO development of the National Fire Behaviour Knowledge Base will integrate the latest fire behaviour, fire weather, and fuel dynamics knowledge and science to help fire managers better predict bushfire behaviour and better plan prescribed burns. The paper also presents an overview of how these proposed future components of the knowledge base will be brought together.

Additional keywords: bushfire, fire spread, fire prediction, software development, workspace, workflow.

Introduction

Bushfires (wildland or forest fires as they are known in other parts of the world) are one of the world's most complex and dangerous natural phenomena, involving interactions of chemistry, physics and biology across a broad range of temporal and spatial scales. Bushfires affect all populated continents. In recent years devastating bushfires with a heavy human toll occurred in Australia, Russia, the USA, Greece and Spain.

In Australia, more than 300 people have been killed by bushfires in the last 50 years and in 2001 they were estimated to cause, on average, over $77M damage each year (BTE, 2001). The Black Saturday fires in Victoria in 2009 burnt more than 400,000 ha, killed 173 people (Teague et al., 2010) and caused over $1B damage (Insurance Council of Australia, 2010) with a total estimated cost of $4B (Teague et al., 2010). The largest of these, the Kilmore East fire, burnt over 100,000 ha in 12 hours (Cruz et al., 2012) and killed 121 people.

Predicting the behaviour of a bushfire is essential for the effective and timely management and control of fire in the landscape. Knowing how fast a bushfire will spread, where it will be at a given time in the future, how resistant it will be to control efforts, and what future efforts would be effective in reducing reoccurrence are essential to fire fighter safety, community protection and safety, planning and execution of fire suppression efforts. Assessment of fire behaviour potential is also essential for planning and conducting hazard reduction burns and creating fire-smart landscapes, i.e., landscapes with a low likelihood of large fire development. As such, fire behaviour knowledge provides critical situation awareness for all levels of fire management, from the front line fire fighter who needs to identify localised life-threatening conditions, the sector commander who needs to ensure the safety of fire crews, to the incident controller who is charged with looking out for the safety of all personnel on a fire ground and the general public.

In Australia, there are a number of operational fire prediction systems (Sullivan, 2009a), all of which are empirical in formulation (Sullivan, 2009b). These systems generally take the form of statistical regression models that relate a number of key independent variables that are commonly environmental in nature (e.g. fuel, weather, topography) to a range of dependent variables such as rate of forward spread, flame height, spotting distance, etc). Each is generally defined for a particular type of fuel (e.g. grassland, forest litter, forest crowns, heath) under a restricted range of burning conditions and thus has individual strengths and weaknesses. The physical forms of these systems range from circular slide rules (McArthur, 1966, McArthur, 1967) and nomograms to tables (Gould et al., 2007a, Gould et al., 2007b), spreadsheets and computer programs.

The major challenge for many operational fire behaviour prediction systems is the broad range of conditions under which wildfires occur. Being generally statistical in origin, fire behaviour models are excellent at dealing with continuously varying parameters such as weather (wind speed, air temperature, etc.) and fuel moisture. However, vegetation is much more difficult to quantify for such purposes, primarily due to the natural biological variations found in morphology and quantity, even within homogeneous vegetation.

For simplicity, vegetative fuels are frequently categorised into a set number of discrete groups that allows useful physical description and quantification. Inevitably, however, the classified groups do not match the breadth of diversity of fuels found in the natural world. Individuals making fire behaviour predictions constantly find fuel conditions that do not seem to “fit” any standard fuel classification. They are then left to guess at how to classify this fuel, with the knowledge that even when classified, the predicted fire behaviour will not match observations due to differences between the local fuel and the most appropriate standard classification. In addition to this, the new trend to “engineered” vegetation complexes through vegetation management and mitigation (to reduce fire behaviour potential) introduces a whole new suite of fuel complexes not accounted for within the current suite of fire behaviour models.

While tools have been developed around the world to automate the prediction of the behaviour and spread of fire across the landscape for various operational purposes (e.g. FARSITE (Finney, 1998), SiroFire (Coleman and Sullivan, 1996), Phoenix (Tolhurst et al., 2008), PROMETHEUS (Tymstra et al., 2010), FSPro (Finney et al., 2011)), by linking fire perimeter propagation with geographic information system databases for topography, vegetation and other landscape features, these for the most part utilise the available operational fire spread prediction models and therefore suffer the same fuel class-related issue as the less advanced systems.

The proposed solution to this seemingly intractable problem is not the development of yet another model for a particular type and arrangement of fuel. We propose the development of a fire behaviour knowledge base that supersedes existing physical forms of fire behaviour prediction systems and allows fire practitioners to view existing fire behaviour observations directly, with a richness and depth of information unachievable in traditional modelling.

A National Fire Behaviour Knowledge Base

This paper presents a proposal for a National Fire Behaviour Knowledge Base aimed at addressing the needs of fire managers in regards to improving access to critical fire behaviour information in a timely, effective and efficient manner. This includes information on fuel (type, condition, state, hazard), expected fire danger, and the prediction of site specific fire behaviour. The purpose of the system is to integrate all available and peer-reviewed fire behaviour knowledge into a single user-friendly interface that enhances the overall information quotient available to the fire manager and enables linkages to other critical sources of information such as current and forecast weather.

This system will consist of a suite of tools that can be used by fire managers to deal with fire management issues over a range of spatial and temporal scales as well as levels of decision making complexity. Such a system will enhance fuel management programs, lead to more effective and safer firefighting, improve protection of rural communities, infrastructure and other assets and reduce detrimental effects to natural resources.

The National Fire Behaviour Knowledge Base (NFBKB) is envisioned as a searchable, extendable database that allows users to:

- describe their current fuel complex and have the computer search through a database of existing fuel and fire behaviour observations to find similar conditions;
- review photos of similar fuel complex and select those that best match their current area of concern;
- review available general and detailed data concerning the weather, topography and resultant fire behaviour for each of the selected fuel complexes;
- review available images and video taken before, during and after fires burning in similar conditions;
- plot the data against existing mathematical model results to see how existing models predict parameters for selected fuel complex matches;
- access publications linked to the displayed observations for in-depth information and analysis; and
- insert data and documentation (photos, video) of their own fires in particular fuels to build the knowledge base.

The heart of the NFBKB is comprised of two distinct kernels (Figure 1): the fire behaviour models module (current work) and a fire behaviour knowledge base module (future work). The fire behaviour module is the engine of the system, providing fire behaviour predictions aimed at answering a wide range of fire management questions (Cruz and Gould, 2009). It will initially be populated with the state of the art fire behaviour models for prescribed burning and wildfire propagation. These fire behaviour models will be augmented with observational data sets derived from experimental fires as well as reliably documented case studies of wildfire events. The main fire behaviour quantities that will be determined by the fire behaviour kernel are:

- sustainability of fire spread,
- initial fire development potential (area and perimeter assuming point ignition),
- rate of forward fire spread and intensity of surface fire,
- flame dimensions (height, depth, angle) and residence time,
- spotting potential,
- onset of crowning and crown fire behaviour, and
- fine and coarse woody fuel consumption.

Ensemble calculations of fire behaviour will be carried out to incorporate the inherent spatial and temporal variability in weather and fuel conditions, providing users with measures of uncertainty associated with specific fire behaviour forecasts.

Notwithstanding the comprehensiveness of the core fire behaviour dataset (based on six decades of field-based fire experimentation and wildfire analysis), the system will still not cover all possible burning conditions (fuels, weather and topographic combinations) that may be encountered by fire managers. That is, it does not solve the problem of a user encountering a set of burning conditions that do not match any observations in the historical record, which might increase the uncertainty of the system outputs.

A unique aspect of the system architecture planned for the NFBKB is the ability for the knowledge base to be user extendable. By allowing users to document their own fuel complexes, burning conditions and associated fire behaviour observations, in as much detail as they wish, it means the NFBKB will eventually become a comprehensive crowd sourced database that is applicable to the broad range of combinations of fire conditions. The observations that users make and the knowledge they gain from making those observations will be made available (after necessary quality control) to the larger fire management community to enhance the quality of decision making. That is, the next person will be able to search the knowledge base for similar fuel complex and burning condition to review and compare previous fire events with those expected and be able to make better judgement on fire behaviour predictions and thus decisions.

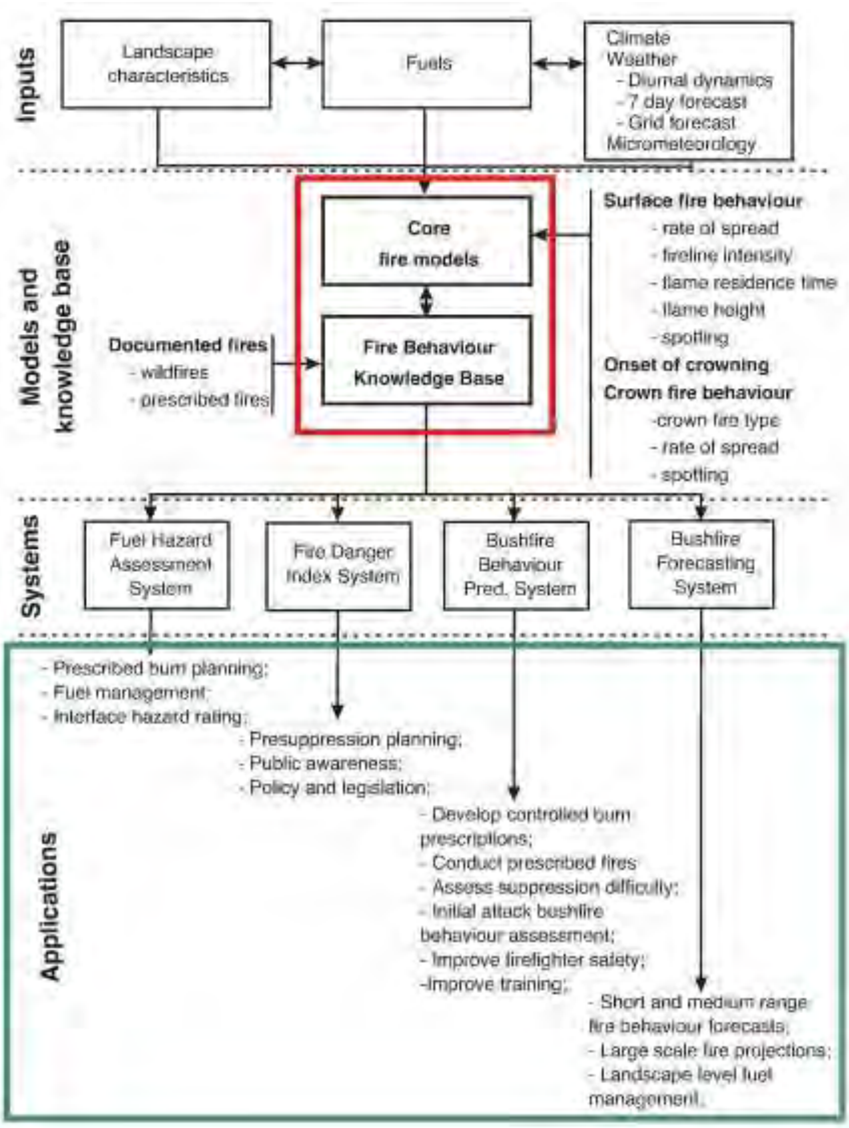


Figure 1. Flow diagram of proposed National Fire Behaviour Knowledge Base (NBFKB) structure, illustrating the link between fire drivers, the knowledge base (models and data) and output systems and potential applications (Source: Cruz and Gould, 2009).

Software development

The NFBKB will be built using the Workspace workflow environment which has been developed by the CSIRO Computational Informatics (CCI) Computational Modelling Group.

A Workspace workflow is made up of a series of "operations" (Figure 2) shows one such operation). Each operation has a series of input and output ports on its left and right side respectively. An operation can perform a calculation based on its inputs and then output some data. A user can connect a number of operations together to perform a complex series of calculations on streams of data, thus forming a workflow.

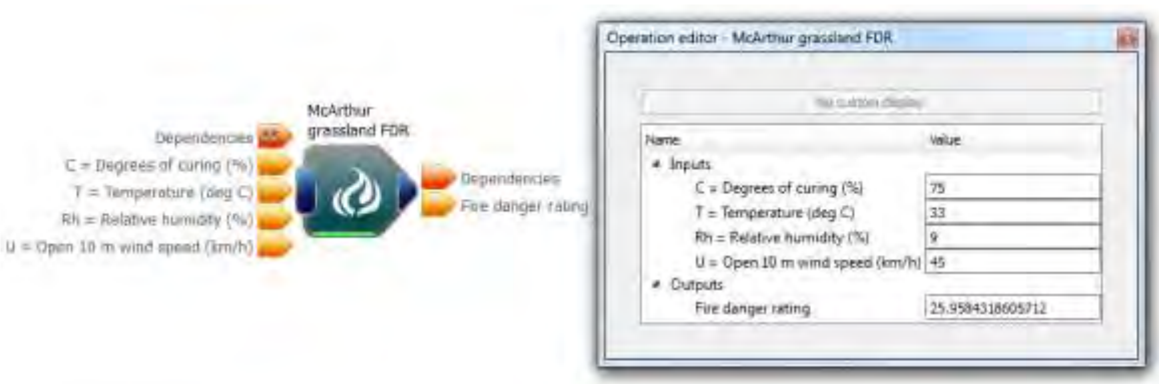


Figure 2. Workspace operation example that calculates the fire danger rating for grasslands. Input and output values of the operation are shown in the operation editor window. This custom built operation is one of many such operations that will be part of the NFBKB (Source: Rucinski, 2013).

Workspace users may construct, modify and execute workflows using an intuitive graphical editor (Figure 3). This editor allows users to inspect and modify any input or output on the workflow using custom built display widgets allowing interaction with workflows as they are executing.

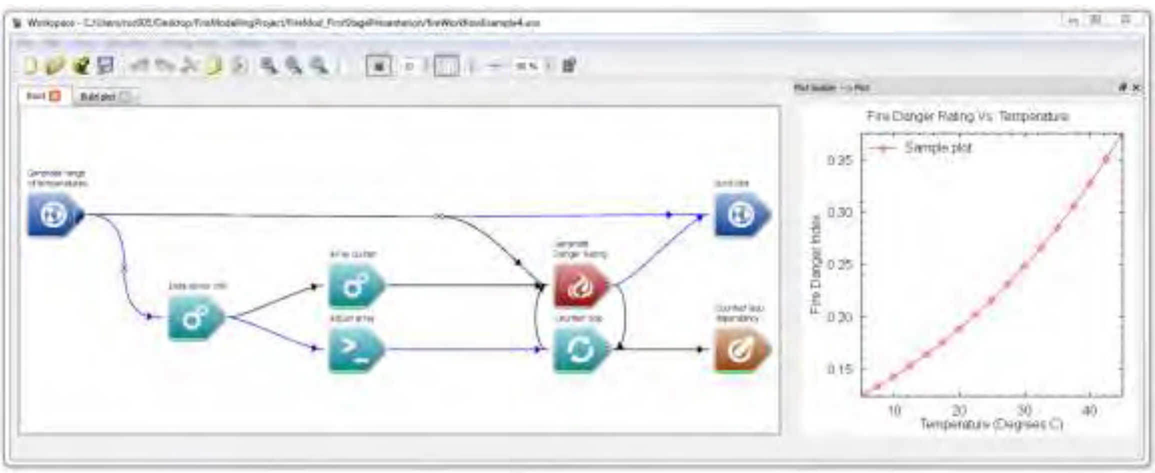


Figure 3. A workflow that plots temperatures against fire danger indices using newly developed fire model operations (Source: Rucinski, 2013).

Workspace users can access a large suite of built-in operations and data types. New operations, data types and display widgets, such as those developed for bushfire models, can be added easily. Workspace assists users in this task by providing extensive tutorials and wizards.

Workspace also supports the creation of complete custom Graphic User Interfaces (GUI) to simplify end-user interaction with workflows (Figure 4). As Workspace is built upon the Qt framework, it includes a large library of GUI widgets out of the box. Developers can also define new widgets or derive new widgets from existing ones.

Workspace is developed and maintained by a team of software engineers, all of whom have backgrounds in commercial software development and utilise software industry best practices. Software quality is a major focus of the team as well as a critical requirement in any safety system.

Workspace has been chosen as the development platform because it is a cross-platform scientific workflow engine available on Windows, Linux and OSX. Workspace is written predominantly in C++ which is inherently beneficial in terms of scalability and performance.

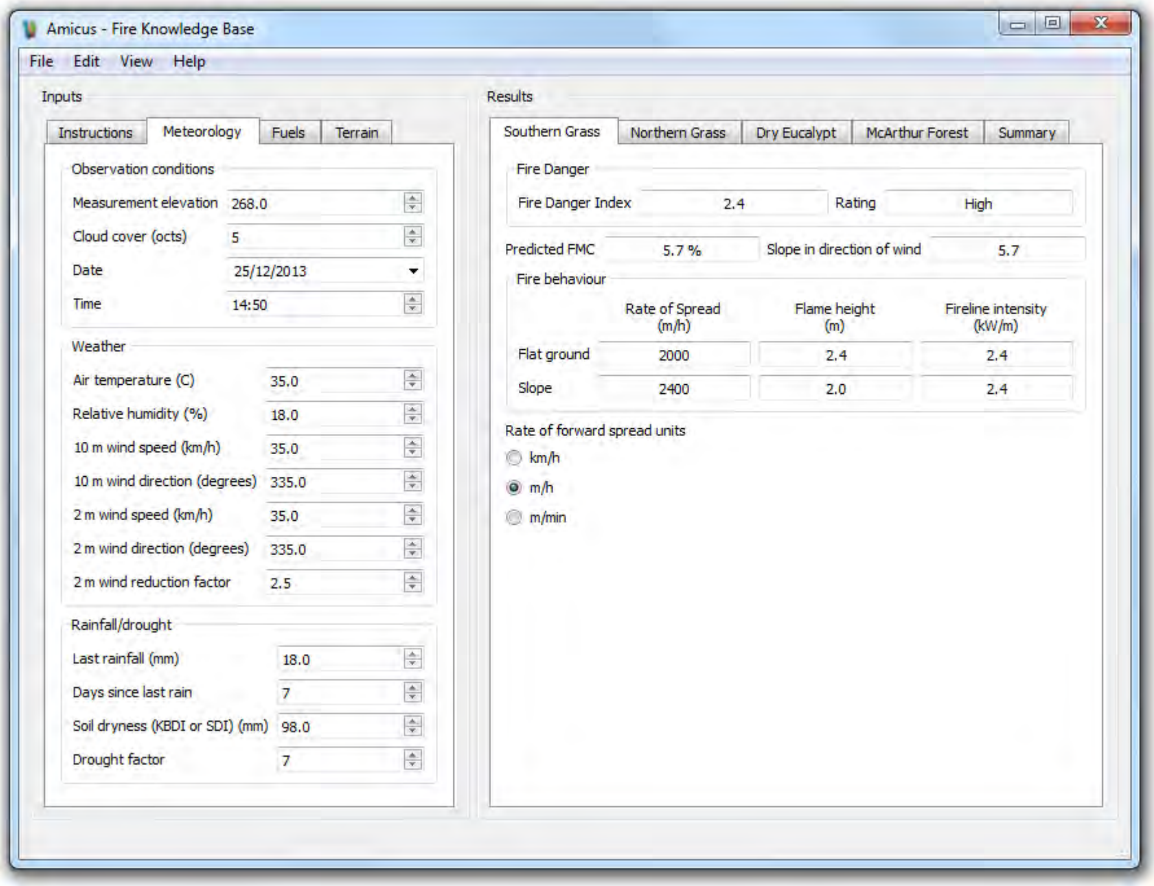


Figure 4. A preview of the NBBKB (Amicus software) application currently under development. This front-end provides a simple interface for end-users to control a workflow.

Agency Linkages and use

The NFBKB will be a powerful tool for fire behaviour analysis and prediction. However without a cohort of well-trained individuals to predict fire behaviour, the tool will enjoy little effective use. Trained and experienced Fire Behaviour Analysts (FBANs) are a critical part of any fire intelligence team reporting into an incident command team. Development and delivery of a training program for FBANs is essential for the true potential of the NFBKB to be realised. The NFBKB is first and foremost an operational tool for FBANs. As such it is expected that a multi-agency cadre of FBANs and other users and researchers would oversee database management, ensure data quality and recommend improvements to the software.

A second benefit of the NFBKB is a centralised repository of national fire behaviour data. These data will then be easily accessible to scientists for a variety of research purposes as well as to agency staff. This data set, larger than any existing single dataset, could provide powerful insights into the nature of fire in Australia and how best to manage it.

Finally, because the NFBKB has the capacity to include photo (and video) documentation of pre-, during and post-burn observations, there will be application to prescribed burning planning and preparation. Users can search or input the fuel complex of interest, view the range of post-burn results, select the appropriate post-burn consequences that they would like to obtain and then review different weather and fuel scenarios conditions required to achieve the burning objective.

Conclusions and Future Work

The development of the NFBKB is at an early stage. However its simple encompassing concept is garnering interest in many locations. Because it is not dependant on any single fire behaviour prediction system, it is seen as a complement to existing fire behaviour modelling tools and as an essential element for front line fire behaviour prediction and operational decision making.

While the fuel complexes in Australia vary quite markedly across the continent, there are some that have similar attributes or that burn in a similar manner. The merging of the fuel data from the developing National Fuel Classification System (Hollis et al., 2011, Gould and Cruz, 2012) can only improve our overall understanding and prediction of fire nationally. If the NFBKB develops beyond the implementation of the current fire behaviour prediction systems into a truly national tool integrating the large pool of observational fire behaviour data sets, the resulting knowledge base will be unparalleled in richness and depth, and vastly improve the quality of both fire behaviour prediction and decision making for all.

Acknowledgements

Thanks to Ryan Fraser and the Disaster Management stream within the CSIRO Digital Productivity and Services Flagship Government and Commercial Services Theme for funding this endeavour.

References

BTE (2001). Economic costs of natural disasters in Australia. Economics Report 103, Bureau of Transport, Canberra, ACT.

Coleman, J. R. and Sullivan, A. L. (1996). A real-time computer application for the prediction of fire spread across the Australian landscape. *Simulation*, 67(4):230–240.

Cruz, M. G. and Gould, J. (2009). National fire behaviour prediction system. In *Proceedings of the Biennial Conference of the Institute of Foresters of Australia, 6-10 October 2009, Caloundra, Queensland, Australia*, pages 285–291.

Cruz, M. G., Sullivan, A. L., Gould, J. S., Sims, N. C., Bannister, A. J., Hollis, J. J., and Hurley, R. (2012). Anatomy of a catastrophic wildfire: The Black Saturday Kilmore East fire in Victoria, Australia. *Forest Ecology and Management*, 284:269–285.

Finney, M. A. (1998). FARSITE: Fire area simulator–model development and evaluation. Research Paper RMRS-RP-4, USDA Forest Service, Rocky Mountain Research Station.

Finney, M. A., Grenfell, A. C., McHugh, C. W., Seli, R. C., Trethewey, D., Stratton, R. D., and Brittain, S. (2011). A method for ensemble wildland fire simulation. *Environmental Modeling and Assessement*, 16(2):153–167.

Gould, J. and Cruz, M. (2012). Australian fuel classification: Stage II. Report for Australasian Fire and Emergency Services Authorities Council. Client Report No. EP126505, CSIRO Ecosystem Sciences and CSIRO Climate Adaption Flagship, Canberra, Australia.

Gould, J. S., McCaw, W. L., Cheney, N. P., Ellis, P. F., Knight, I. K., and Sullivan, A. L. (2007a). *Project Vesta–Fire in Dry Eucalypt Forest: fuel structure, dynamics and fire behaviour*. Ensis-CSIRO, Canberra ACT, and Department of Environment and Conservation, Perth WA, Canberra, ACT.

Gould, J. S., McCaw, W. L., Cheney, N. P., Ellis, P. F., and Matthews, S. (2007b). *Field Guide: Fire in Dry Eucalypt Forest.* Ensis-CSIRO, Canberra ACT, and Department of Environment and Conservation, Perth WA.

Hollis, J., Gould, J., Cruz, M., and Doherty, M. (2011). Scope and framework for an Australian fuel classification. Report for Australasian Fire and Emergency Services Authorities Council. Client Report No. EP113652, CSIRO Ecosystem Sciences and CSIRO Climate Adaptation Flagship, Canberra.

Insurance Council of Australia (2010). Insurance Council of Australia: Year in Review 2009., Insurance Council of Australia, Sydney.

McArthur, A. G. (1966). Weather and grassland fire behaviour. Forestry and Timber Bureau Leaflet 100, Commonwealth Department of National Development, Canberra.

McArthur, A. G. (1967). Fire behaviour in eucalypt forests. Forestry and Timber Bureau Leaflet 107, Commonwealth Department of National Development, Canberra.

Sullivan, A. L. (2009a). Improving operational models of fire behaviour. In Andersen, R. S., Braddock, R. D., and Newham, L. T. H., editors, *18th World IMACS Congress and MODSIM09 International Congress on Modelling and Simulation, 13-17 July 2009, Cairns, Australia.*, pages 282–288. Modelling and Simulation Society of Australia and New Zealand and International Association for Mathematics and Computers in Simulation. ISBN:978-0-9758400-7-8.

Sullivan, A. L. (2009b). Wildland surface fire spread modelling, 1990-2007. 2: Empirical and quasi-empirical models. *International Journal of Wildland Fire*, 18(4):369–386.

Teague, B., McLeod, R., and Pascoe, S. (2010). 2009 Victorian Bushfires Royal Commission. Final report, State of Victoria, Melbourne, Victoria.

Tolhurst, K., Shields, B., and Chong, D. (2008). Phoenix: development and application of a bushfire risk management tool. *The Australian Journal of Emergency Management*, 23(4):47–55.

Tymstra, C., Bryce, R. W., Wotton, B. M., Taylor, S. W., and Armitage, O. B. (2010). Development and structure of Prometheus: the Canadian wildland fire growth simulation model. Information Report NOR-X-417, Canadian Forest Service Northern Forestry Centre, Edmonton, Alberta.

TITLE:

Winter Hazard Reduction Burning Reduces the Fuel Load in *Themeda* and *Phalaris* during Summer

AUTHORS:

Adam J. Leavesley[1]

Jennie Mallela[2]

Dylan Kendall[1]

Neil Cooper[1]

1. Fire management Unit, ACT Parks and Conservation Service
2. Research School of Biology, Australian National University

Abstract

Hazard-reduction burning is an important component of the bushfire mitigation program in the Australian Capital Territory (ACT). Burning is particularly important in grass fuels at locations that are unsuitable for slashing/mowing or grazing. Ideally grass fuels are burnt in spring however this work is constrained by weather, resource availability and ecological considerations. It would therefore be helpful if the burning season could begin on sunny winter days when grass fuels are well cured.

Previous work conducted during a high rainfall year found that winter burning reduced the fuel load and increased fuel moisture content in treated *Phalaris* fuels compared to untreated fuels. However treated fuels did not comply with ACT fuel management standards because by summer the grass was too high. In this study we expand on that work by:

1) testing across a broader geographic area;
2) testing under different rainfall conditions; and
3) including warm-season *Themeda*-dominated native grasses in the study.

We conducted a Before-After-Control-Impact study in a *Phalaris*-dominated site on the Canberra urban-rural interface and in one large native grass reserve within the Canberra urban area. Fuel load, grass cover and grass height were assessed before burning. Hazard reduction burns were completed in late winter (*Phalaris*) and early spring (*Themeda*) leaving control sectors unburnt for later comparison. All plots were re-measured in February 2013.

The fuel load in treated *Phalaris* and *Themeda* grassland was lower than in the untreated grassland in summer following fire. In addition, the treated plots were within ACT fuel management standards. Our results suggest that winter burning has good potential as a grass fuel management tool in the ACT.

Introduction

Fuel management is an important component of the bushfire mitigation program in the Australian Capital Territory (ACT Government, 2009). Fuel management standards are defined for each bushfire management zone and are implemented by slashing/mowing, grazing, physical removal, chemical treatment and burning. The choice of method is determined according to the suitability of the method at each location, cost, ecological considerations and time-of-year.

The City of Canberra was constructed in a landscape dominated by grassy fuels – Yellow Box (*Eucalyptus melliodora*)-Blakely's Red Gum (*Eucalyptus blakelyi*) Grassy Woodland (Gellie, 2005). Grassy woodland, grassland and pasture surround the city and management of these fuels is a critical component of the bushfire management program.

Six bushfire management zones are defined by the Strategic Bushfire Management Plan and of these three have associated fuel management standards (Table 1; ACT Government, 2009). These are:

1) Inner Asset Protection Zone (IAPZ): strips of land adjacent to vulnerable assets in which fuel is reduced and which provide defensible space.
2) Outer Asset Protection Zone (OAPZ): strips of land adjacent to IAPZs in which fuel is reduced.
3) Strategic Fire Management Zones (SFAZ): corridors of reduced fuel positioned to break up major fire runs.

Table 1. Bushfire management zones in the ACT and the relevant grass fuel standards. Grassland fire hazard (GFH) is determined by multiplying the grass height (m) by percentage grass cover.

Bushfire Zone	Grassland fuel standard
IAPZ	Grassland maintained at >200mm height when grassland curing ≤70%
OAPZ	Grassland fire hazard ≤35 when grassland curing ≤70%
SFAZ	Grassland fire hazard ≤50 when grassland curing ≤70%

Grass fuel in IAPZs is typically managed by slashing and ideally this will occur just at the moment that curing reaches 70%. In OAPZs and SFAZs, fuel treatment is typically by grazing, but where this is not possible or has failed to achieve the standard, burning may be employed.

Grass accumulates more quickly than other fuel types such as fine surface litter, elevated fuels and bark (Tolhurst and Kelly, 2003). Ideally, from a fuel management perspective, grass would be burnt in the spring allowing as little time for accumulation as possible. However in the ACT, spring burning work is constrained for several reasons.

1) Spring weather is wetter and windier than the rest of year (Bureau of Meteorology, 2013).
2) The ACT ecological guidelines are more restrictive in spring than other times of year (Kitchin and Matthews, 2012).

3) The seasonal fire crew program is designed to ensure that staff are available for the summer fire season so recruitment and training usually occurs in spring.

Overall, the total number of burning days available to fire managers in the ACT is relatively small, averaging 60 days per year (ACT Government, 2009). The months with most burning days are May, June and July, so it would be helpful to determine whether burns conducted during these months could deliver a fire mitigation benefit the following summer.

Previous work conducted during a high rainfall year (2011-2012) found that winter burning reduced the fuel load (5.8 ± 1.2 tha^{-1} versus 11.4 ± 3.5 tha^{-1}) and increased fuel moisture content (133% versus 93%) in treated *Phalaris* fuels compared to untreated fuels (Leavesley *et al*. 2012). However treated fuels did not comply with ACT fuel management standards because by summer the grass was too tall (Height: 0.70m ± 0.20 SD; Grass Fuel Hazard: 57 ± 15 SD). In this study we expanded on that work by:

1) testing a greater number of plots across a broader geographic area;
2) testing under different rainfall conditions - spring rainfall in 2011 was 173mm compared with 132mm in 2012; and
3) including warm-season *Themeda*-dominated native grasses in the study as a comparison.

Method

We conducted a Before-After-Control-Impact study (Green, 1979) at two sites with contrasting grass communities. One site consisted of four *Phalaris*-dominated paddocks on the urban-rural interface in the suburb of Fraser, Canberra (Figure 1, 2).

Figure 1.
The burn map for the hazard reduction burn on the urban-rural interface at Fraser. The grass species was *Phalaris* spp. The sectors were prepared for burning by slashing between them.

Figure 2.
Dense *Phalaris* dominated grassland at Fraser on 23 July 2012 prior to the burn. Fuel loads were measured at $9.1tha^{-1}$.

The other site was located in Mulanggari Grassland, a large natural temperate grassland reserve within the Canberra urban area (Figure 3, 4).

Figure 3.
The burn map for the hazard reduction burn at Mullangarri Grasslands, part of Canberra Nature Park, within the Canberra urban area. The dominant grass species was Kangaroo Grass (*Themeda triandra*), though Charlie sector also had a lot of Wallaby Grass (e.g. *Austrodanthonia* spp.) and Spear Grass (e.g. *Austrostipa* spp.).

Figure 4.
Dense *Themeda triandra* grassland on 23 July 2012 at Mulanggari Grassland Nature Reserve prior to the burn. Fuel loads were measured at 7.0tha^{-1} – 10.2tha^{-1}.

Mulanggari Grassland is dominated by Kangaroo Grass (*Themeda triandra*) but also has Wallaby Grass (e.g. *Austrodanthonia* spp.) and Spear Grass (e.g. *Austrostipa* spp.). Control plots were approximately 2500m^2 in size and located directly adjacent to the treated areas to minimise variation between them. At Fraser the control and treatments plots were established directly either side of the slashed control lines on similar slopes. Potentially confounding factors such as trees and the edges of the control lines were avoided. The maximum distance between pairs of treatments and controls was approximately 40m. At Mulanggari, the controls were established by slashing a control line within the planned burn area. The controls were located on the edges of the burn to minimise:

1) the risk of escape; and
2) the length of burn edge requiring a wet line.

Fuel load, grass cover and grass height were assessed at all plots before and after burning. Fuel load was determined by removing the fuel from five 1m^2 quadrats from each replicate. The fuel was dried at 105°C for 24 hours to obtain the oven-dried weight (Matthews, 2010). Grass cover and height were estimated from a plot of 3m radius around the fuel sample using a 1m ruler and a fuel cover guide (Hines *et al*. 2010). Grass cover and height were used to produce a Grassland Fire Hazard index (GFH; ACT Government, 2009). Hazard reduction burns were completed in late winter (*Phalaris*; Figure 5, 6, 7) and early spring (*Themeda*; Figure 8, 9) leaving control sectors unburnt for later comparison. Crews conducting the burns were briefed on the need to avoid disturbing the experimental areas. Use of fire retardant foam was not permitted. Fuel load, grass height and grass cover was re-measured in the treated and control plots in February 2013.

Assumptions of normality for data were tested using a Kolgomorov-Smirnov test. All variables were normally distributed: fuel load ($Z = 0.9$, $p = 0.4$), grass height ($Z = 1.2$, $p = 0.1$); grass cover ($Z = 1.2$, $p = 0.1$) and were analysed using a single factor ANOVA ($\alpha = 0.05$). Analyses were conducted using SPSS 19 (IBM Corp., 2010).

Figure 5.
Hazard reduction burn in *Phalaris* dominated grassland at Fraser conducted on 22 August 2012.

Figure 6.
Unburnt fuel quadrat ($1m^2$) after the burn in *Phalaris* dominated grassland at Fraser. Five quadrats were taken from each replicate to determine the fuel load. All fuel was removed from the quadrat and dried at 105°C for 24 hours to determine the oven-dried weight.

Figure 7.
Residue and re-growth of *Phalaris* dominated grassland at Fraser on 28 September 2012, 37 days after the burn.

Figure 8.
Burning the natural temperate grassland at Mulanggari Nature Reserve on 3 September 2012.

Figure 9.
Mulanggari Grasslands on 2 October, 30 days after the burn. A control plot is in the centre of the picture. The control plots were protected by slashing around them and running a wet line during the burn.

Results

In February 2013, the fuel loads in treated *Phalaris* and *Themeda* grassland were lower than in the untreated grassland (*Phalaris*: $F = 57.6$, $df = 7$, $p < 0.001$; *Themeda*: $F = 34.5$, $df = 5$, $p < 0.001$; Figure 10). Grass height (*Phalaris*: $F = 43.9$, $df = 7$, $p < 0.001$; *Themeda*: $F = 21.9$, $df = 5$, $p < 0.001$; Figure 11) and GFH (*Phalaris*: $F = 57.7$, $df = 7$, $p < 0.001$; *Themeda*: $F = 26.3$, $df = 5$, $p < 0.001$; Figure 12) were also lower.

The treated grassland in both fuel types was within ACT fuel management standards (ACT Government, 2009).

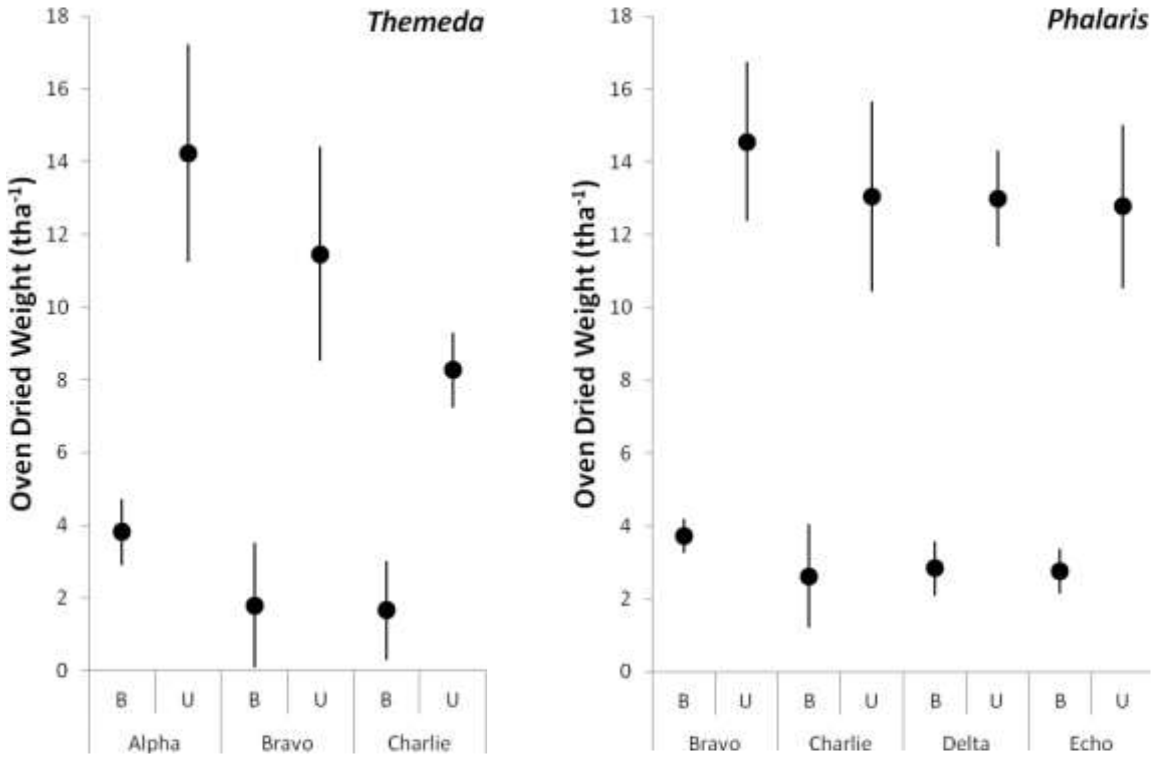


Figure 10. Fuel loads measured in February 2013 in treated and untreated grass plots. Error bars indicate the standard deviation.

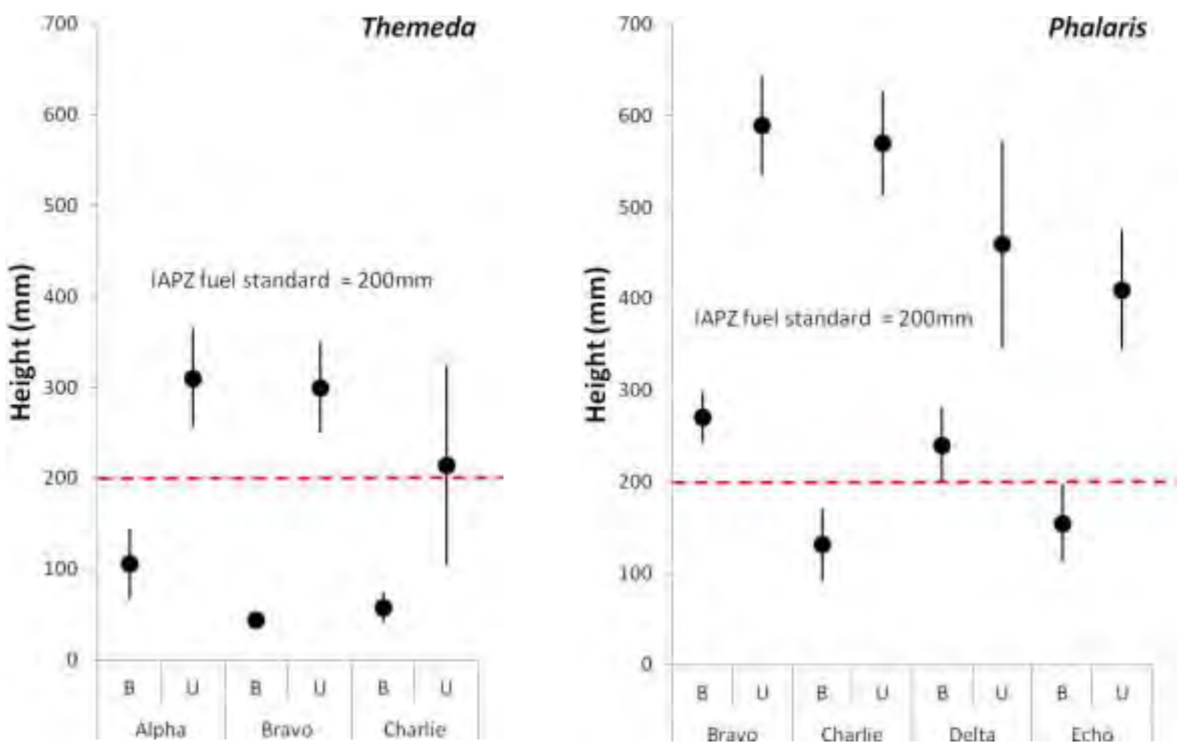


Figure 11. Height of grass measured in February 2013 in treated and untreated grass plots. Error bars indicate the standard deviation.

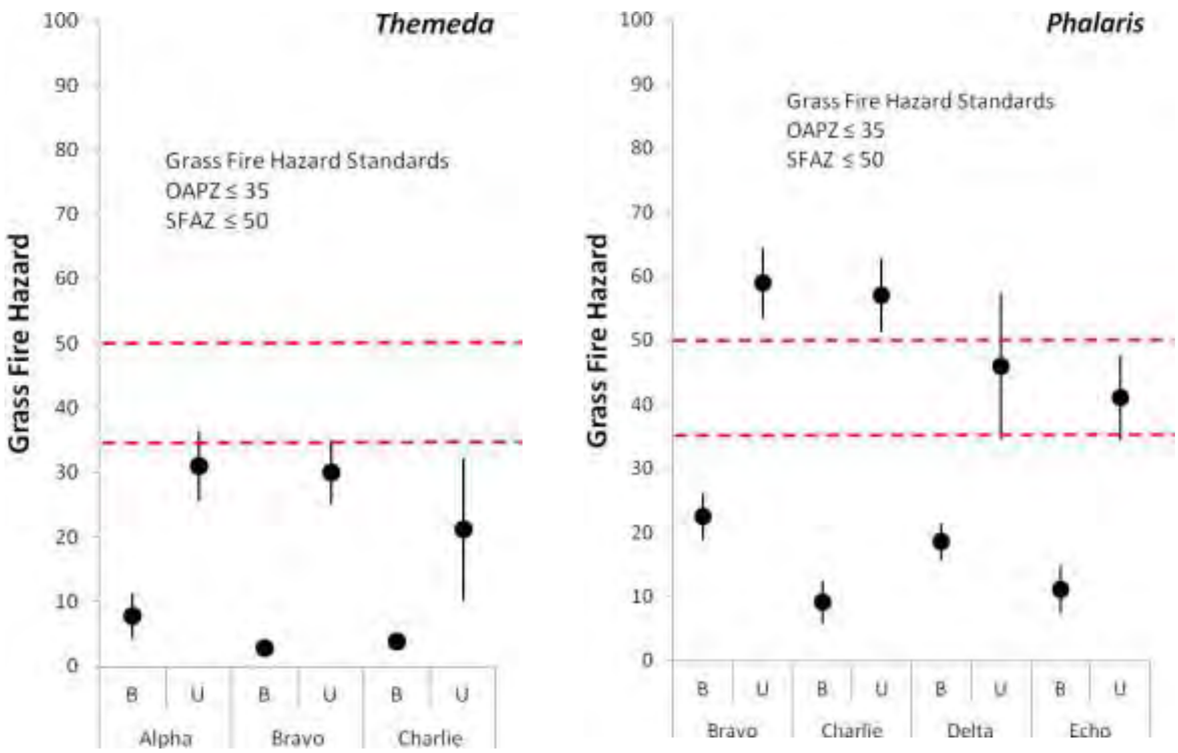


Figure 12. Grassland fire hazard measured in February 2013 in treated and untreated grass plots. Error bars indicate the standard deviation.

Discussion

Themeda grassland burnt in early spring 2012 met the ACT fuel management standard for all zones (ACT Government, 2009). In contrast, the grassland dominated by *Phalaris* grassland marginally failed the IAPZ standard, but met the OAPZ and SFAZ standards. It therefore appears that there is considerable potential for the use of early-spring and winter burning as a grass fuel management tool for *Themeda* and *Phalaris* dominated grasslands in the ACT.

The effect of burning is generally mediated by rainfall (King *et al*. 2012). *Themeda* dominated grasslands are considered to be 'warm season' and most productive in summer. Spring rain is therefore less likely to alter fuel loads until later in the fire season. In contrast, *Phalaris* dominated grassland is most productive in spring (Leavesley *et al*. 2012), so it is likely to be more sensitive to spring rainfall than *Themeda* dominated grassland. Previous work conducted in spring of 2011 in the ACT showed that *Phalaris* has the capacity to exceed fuel management standards in IAPZs and OAPZs in a single high rainfall spring (Leavesley *et al*. 2012). Potential reasons for the differential result in this study include different productivity between the sites, annual variation between years and longer period of re-growth in the 2011 study – in that study the grass was burnt in an unplanned fire in June.

Neither the *Themeda* or *Phalaris* dominated grasslands had been treated during the previous two years of above average rainfall. In both instances, the fuel loads were heavy prior to treatment but much reduced afterwards. This suggests that even in instances where burning may not deliver the required fuel management standard, it will still reduce the intensity and rate of spread of unplanned fires (Sullivan, 2010). This effect will aid fire suppression and is therefore still likely to be of benefit to bushfire management.

Acknowledgements

A number of people assisted with this research and deserve our thanks. First and foremost are the members of the ACT Parks and Conservation Service Fire management Unit who collected and processed grass samples, planned and skilfully implemented the burns. Essential technical assistance was provided by CSIRO Bushfire Dynamics. The comments of two anonymous reviewers greatly improved the manuscript, responsibility for errors is entirely ours.

References

ACT Government (2010) Strategic Bushfire Management Plan. Justice and Community Services Directorate. https://esa.act.gov.au/community-information/publications/sbmp/. Accessed 13 August 2013.

Bureau of Meteorology (2013) Climate Statistics for Canberra. http://www.bom.gov.au/climate/averages/tables/cw_070282.shtml Accessed 13 August 2013.

Gellie, N.J.H. (2005) Native vegetation of the southern forests: south-east Highlands, Australian Alps, South-west Slopes, and SE Corner bioregions, *Cunninghamia* 9: 219-254.

Green, R. H.: 1979, *Sampling Design and Statistical Methods for Environmental Biologists*, John
Wiley and Sons Inc, USA, 272 pp.

Hines, F., Tolhurst, K.G., Wilson, A.A.G., McCarthy, G.J. (2010) *Overall Fuel Hazard Assessment Guide*, Victorian Government of Sustainablility and Environment, Melbourne.

IBM Corp. 2010. IBM SPSS Statistics for Windows, Version 19.0. Armonk, NY: IBM Corp.

King, K.J., Cary, G.J., Gill, A.M., Moore, A.D. (2012) Implications of changing climate and atmospheric CO_2 for grassland fire in south-east Australia: insights using the GRAZPLAN grassland simulation model. *International Journal of Wildland Fire* 21: 695-708.

Kitchin, M., Matthews, H. (2012) 2012-13 Ecological guidelines for fuel and fire management operations. ACT Government Internal Report 2912/01. http://www.tams.act.gov.au/__data/assets/pdf_file/0011/411113/2_2012-13_Ecological_Guidelines_FINAL_for_web.pdf. Accessed 13 August 2013.

Leavesley, A.J., Mallela, J., Corrigan, A., Bretherton, S., Kendall, D., Cooper, N. (2012) Is there any point burning or grazing grass in winter? Proceedings of the AFAC Conference 2012, Perth, 28-30 August.

Matthews, S. (2010) Effect of drying temperature on fuel moisture content measurements. *International Journal of Wildland Fire* 19: 800-802.

Morgan JW, Lunt ID (1999) Effects of time-since-fire on the tussock dynamics of a dominant grass (*Themeda triandra*) in a temperate Australian grassland. *Biological Conservation* 88: 379-386.

Sullivan, A.L. (2010) Grassland Fire management in Future Climate, *Advances in Agronomy* 106: 173-208.

Tolhurst, K.G., and Kelly, N. (2003) Ecological effects of repeated low-intensity fire on fuel dynamics of a mixed eucalypt foothill forest in south-eastern Australia. Research Report 59, Department of Sustainability and Environment , East Melbourne, Victoria.

Measuring forest carbon and fire emission from southern *Eucalyptus* forests: key findings and some lessons learnt

Liubov Volkova [1,2] and Christopher Weston[1,2]

1. Department of Forest and Ecosystem Science, Melbourne School of Land and Environment, The University of Melbourne, Water Street, Creswick, Victoria 3363, Australia
2. Bushfire CRC, Level 5, 340 Albert Street, East Melbourne, Victoria 3002, Australia

Corresponding author: L Volkova, lubav@unimelb.edu.au

Abstract

Managing the frequency and intensity of planned burning in forests to reduce the risk of uncontrolled wildfire as well as maximize long-term carbon storage in biomass and soil is wholly dependent on a good understanding of the impacts of burning, across a range of intensities, on forest carbon density and carbon emissions to the atmosphere. Australia's current approach for estimating State and National fire-related emissions of greenhouse gases from forests is constrained by a limited knowledge of the mass of fuels consumed and emissions from major fuel type. To assist in addressing these gaps in knowledge we describe a methodology for measuring fire impact on each of the main categories of forest carbon and discuss key findings from application of the method across a wide range of eucalypt forests in south- eastern Australia. This forest fuels and emissions dataset clearly shows that coarse woody fuels, currently not included in fuel inventories, contribute significantly to emissions. We also suggest a range of sampling intensities to improve carbon emission estimates for each major fuel category and discuss the advantages of moving towards accounting for all fuels strata in fire and emissions management at a landscape scale.

Introduction

Planned burning, or deliberate application of fire under favourable conditions, is crucial for reducing the risk of large-scale and uncontrollable bushfires that can threaten people, towns and important assets such as water catchments and commercial plantations (McCaw 2013). There are good incentives for improving knowledge of fire impacts on fuels and forest carbon as a number of studies from around the globe, including from Northern Australia, have indicated considerable potential for emission mitigation using planned fires (e.g. Hurteau and North 2009; Vilén and Fernandes 2011). Emission reductions can be considered as arising from burning only under identified optimum conditions and through a reduction in the area of forest burnt in high intensity wildfires in the future. Because estimates of emissions from biomass burning in southeastern Australia vary widely, opinion is divided on the opportunity that planned fire presents for mitigating wildfire emissions in the longer term (e.g. Adams 2013) to against any likely carbon benefits of planned fire giving high rate of planned fires and relatively low reoccurrence of wildfires (Bradstock et al. 2012). These uncertainties point to the need for land managers to strengthen the mandate for planned burning in Australia's southern eucalypt forests.

Improving the scientific basis for fuel reduction burning requires better knowledge of fuels consumed and emissions from these fuels. Fire management agencies have developed estimates of fine (litter) and elevated (shrubs) fuels in forests as a basis for planned fire scheduling and for fire behavior modeling (e.g. Phoenix), yet knowledge of all fuel categories, including fallen trees and large branches, is currently lacking for southern eucalypt forests. To assess the effectiveness of prescribed burning and emissions from planned burning, the distribution of fuels among the entire fuel strata is required. We describe here a method applicable to both measuring the components of forest biomass that become fuels during planned burning, and for calculating emissions to the atmosphere from these fuels. The aim of this report is to relate our experience gained in applying this method, to identify data gaps in knowledge of fuels, and to suggest improvements to the current AGO (2008) method for estimating emissions from forest burning.

The current approach for estimating fire emission from forest fires

Currently Australia's national approach for estimating emissions is based on a generalized equation provided by AGO (2008):

$$E_{ij=}A * EF_{ij} * F * BE * M_i \quad \text{(Eq. 1)}$$

Where E_{ij}- an emission for gas *ij*; *A*-area burnt, ha; EF_{ij}-emission factor for gas *ij* from vegetation (range from 0.0054 to 0.15 greenhouse gas dependent); *F*- fuel load, Mg C $^{-1}$; BE – burning efficiency (0.42 for planned fires and 0.72 for wildfires), M_{ij}-a conversion factor from elemental mass of species *ij* to molecular mass.

Each of the above parameters, except area burnt, is provided in the AGO methodology. Due to a lack of all fuels data, it is assumed that only fine fuels comprising dead organic material including sticks of a diameter less than 6 mm are burnt in planned fire (Tolhurst 1994a). An average fine fuel load for all forests in each State or Territory has been adopted, as shown in Figure 1 (adapted from Table 3 of AGO 2008). The AGO methodology assumes that coarse or heavy fuels only contribute to emission in wildfires, with allowance for this consumption in wildfire generally estimated as twice the fine fuel load (Tolhurst 1994a). These AGO-provided fuel loads cannot be verified in the published literature as they are based on information from State Agencies that likely reflects the experience and judgment of land managers and their operational research staff. For Australia to meet greenhouse gas emissions reporting against international treaties it is crucial that these fuel load estimates are updated with published and verifiable fuel consumption estimates. More accurate emission estimates require fuel load and emission factors that are refined for a range of forest types and burn intensities.

Table 3. Fuel loads for Prescribed Burning of Forest in Australia

State	ACT[(a)] FL_{jkl} (Mg/ha)	NSW[(a)] FL_{jkl} (Mg/ha)	NT[(a)] FL_{jkl} (Mg/ha)	Qld[(a)] FL_{jkl} (Mg/ha)	SA[(b)] FL_{jkl} (Mg/ha)	Tas[(b)] FL_{jkl} (Mg/ha)	Vic[(a)] FL_{jkl} (Mg/ha)	WA[(a)] FL_{jkl} (Mg/ha)
Load	17.6	18.2	4.1	9.7	9.6	20.0	17.9	12.0

(a) State agencies, (b) Tolhurst (1994)

Table 4. Fuel loads for Wildfires in Australia

State	ACT[(a)] FL_{jkl} (Mg/ha)	NSW[(a)] FL_{jkl} (Mg/ha)	NT[(a)] FL_{jkl} (Mg/ha)	Qld[(a)] FL_{jkl} (Mg/ha)	SA[(b)] FL_{jkl} (Mg/ha)	Tas[(b)] FL_{jkl} (Mg/ha)	Vic[(a)] FL_{jkl} (Mg/ha)	WA[(a)] FL_{jkl} (Mg/ha)
Load	35.6	36.4	7.2	19.4	19.2	40.0	35.8	33.4

(a) State agencies, (b) Tolhurst (1994)

Figure 1. A snap shot from the Australian methodology for estimating greenhouse gas emission and sinks 2006 providing fuel loads for each State and fire regime (from AGO 2008).

To demonstrate the opportunity to improve fuel load estimates we present three separate estimates for six forest sites in Figure 2, with a great variance amongst assessments of fuel loads: visual assessment (average 18 t/ha), a detailed field sampling (average 14t/ha) and the default value from the AGO (9.7 t/ha, Fig 2).

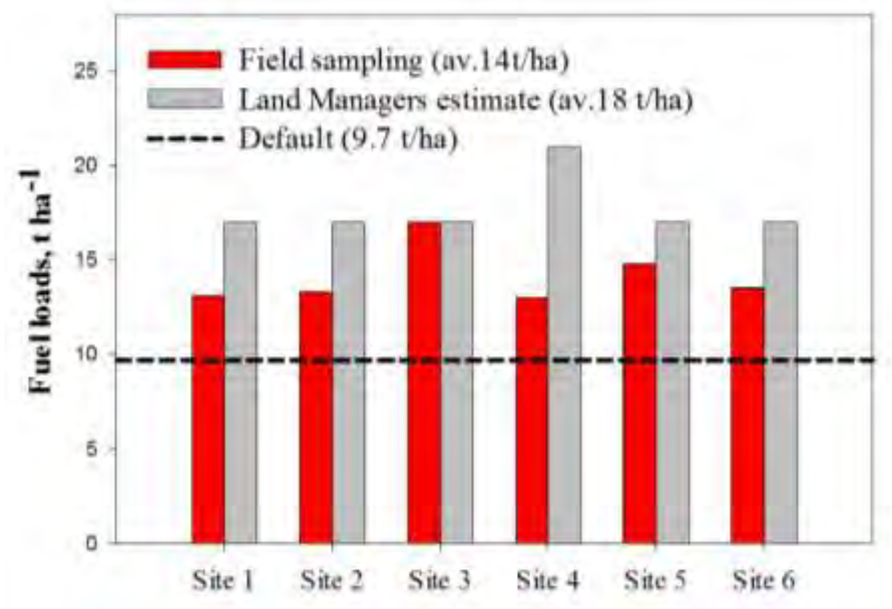


Figure 2. Fine fuel loads derived from field sampling (red bar), visual assessment by land management officer (grey bar) and default value for the State (dashed line from AGO 2008).

This example also highlights the opportunity for refining fuel loads by categorizing forest and vegetation types rather than relying on a single value for all forests across a State or Territory.

However, our main concern is that default fuel loads, which significantly influence State and National emission estimates, are not accessible or traceable in the literature. Evidence of climate change and the recognition that fuel loads are sensitive to rainfall and temperature (Matthews et al. 2012) is a further reason for improving fuel load estimates and for maintaining a rolling inventory of them to ensure accurate information for a range of purposes from fire emergency response to emissions estimates. We believe that up-to-date information on all forest fuels, derived from repeatable and transparent methodologies, is required for a range of forest types for realistically estimating fire emission and impacts on forest carbon.

We also question why only fine fuels were considered for planned fire emission estimates. Since the 1980s the literature has shown that other fuels including elevated bark, ground cover, understorey, snags and coarse woody debris are also affected by fire (e.g. Bennett et al. 2013; North and Hurteau 2011; Raison et al. 1985; Tolhurst 1994b) so that excluding those from fuel loads leads to potential significant underestimation of fire emission (Volkova and Weston 2013). Our research has found as fire intensity increases, loss from other, non-fine fuels, also increases, thus greater underestimation of emission can be from wildfires than planned fires (Volkova et al, in submission). To understand the impact of fire on forest fuels and released emission requires a field studies in a diverse range of forests where planned burning is practiced. However, the focus of recent fire-carbon research in southern Australia has been in wet sclerophyll forests where routine planned burning is not practiced (e.g. Benyon and Lane 2013; Simkin and Baker 2008). While these estimates of fire impact on forest carbon help to set the upper limit for emissions from eucalypt forests, they are of limited use for land managers responsible for planned fire operations.

Methodology and pitfalls in measuring forest carbon

We have developed, tested and improved a sampling protocol designed to accurately estimate fire impact on forest fuels in routinely burnt, open forest of *Eucalyptus* in southeastern Australia. We devised the sampling protocol based on the best advice available in technical reports developed by the Australian Greenhouse Office (e.g. Snowdon et al. 2002) in combination with our experience in forest carbon and biomass studies (Bennett et al. 1997; O'Brien at al. 2002; Bauhus et al. 2002). Given that fire impacts on all forest biomass components include duff and soil had not been measured before in Australia, we chose among a diverse range of approaches before settling on the survey protocol described here. Since developing the protocol we have been approached by a number of researchers and land management agencies seeking to implement the protocol to measure fire impacts on carbon stocks. Therefore we believe that describing our methodology along with lessons learnt will benefit agencies interested in measuring fire impacts on forest fuels. Although we have published an outline of the sampling protocol in reporting fire impacts on carbon density and emissions (Volkova and Weston 2013), our intention here is to provide greater details on the development of the protocol and commentary on its application in a wide range of forests.

After considering all published methodologies on assessing forest fuels and carbon at the time, e.g. fuel hazard assessment guide (Hines et al. 2010) and technical reports by Greenhouse

Office (2010, http://www.greenhouse.gov.au/ncas), we adapted a definition of forest carbon categories from the Intergovernmental Panel on Climate Change (IPCC 2004), and from now on will refer to forest fuels as forest carbon pools.
According to the IPCC (2004), forest biomass is divided into five carbon pools:

1) Aboveground alive
2) Deadwood
3) Litter
4) Soil organic carbon
5) Belowground biomass (live roots, not included when fire effect on forest carbon is estimated)

We measured forest carbon as four aboveground pools within circular sampling plots of 22.5 m radius (Fig.2). We prefer circular plots as they are quick and simple to set up and once center point is marked with a metal peg and its coordinates recorded, plot boundaries can be reconstructed years after if required. To estimate carbon loss, it is necessary to re-measure the same carbon pools afterwards and based on the difference, estimate fire emission from equation 1 accounting for carbon re-distribution.

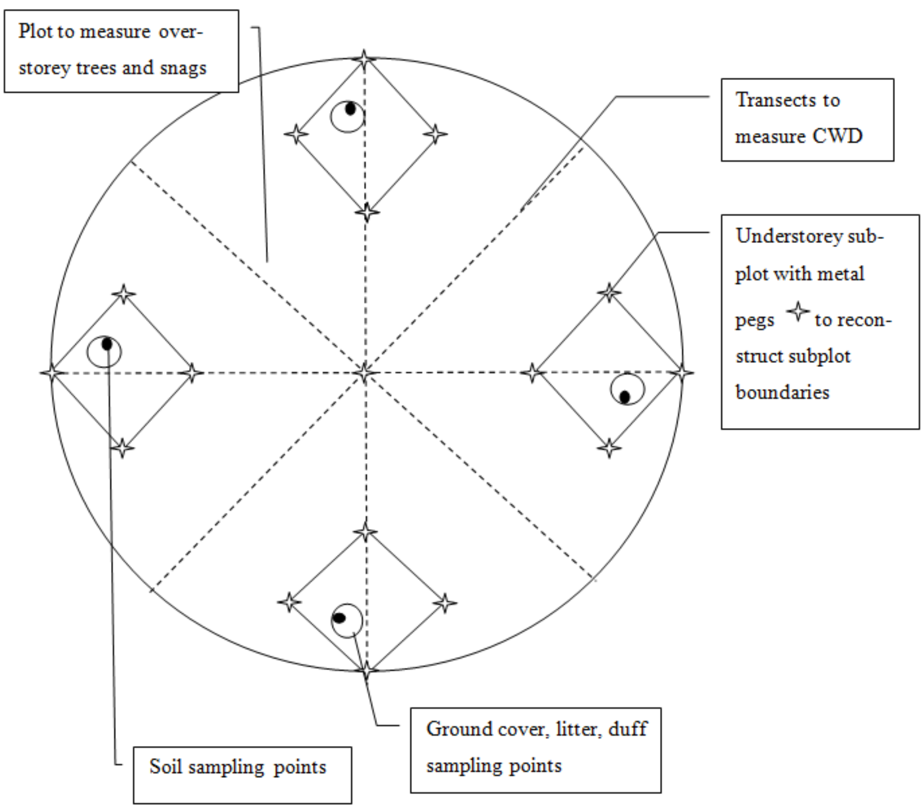


Figure 2. Circular sampling plot of 22.5 m radius to measure forest carbon pools Where ✧ indicates permanent metal pegs to reconstruct boundaries of a plot and subplots

Aboveground alive, i.e. all living biomass above the soil consist of (1) overstorey, (2) understorey and (3) ground cover. Overstorey trees can account for the half of total forest carbon to 30 cm soil depth in the southeastern *Eucalyptus* forest (based on our field data across

60 sites). Each overstorey tree should be measured at least for diameter at breast height (1.3 m) and if possible for height. Tree biomass can be estimated either from species-specific allometric equations or from a geometric equation by estimating tree volume multiplied by wood density and a conversion factor to convert stemwood biomass to aboveground biomass. Allometric equations have been developed for particular species using destructive sampling, and logically those estimates should be comparable regardless of the equation used. We caution that biomass estimates vary considerably depending on the allometric equation selected. For example, we estimated biomass for *E. obliqua* based on diameter and height measurements for >300 trees and biomass numbers varied from 145 t ha^{-1} to double this number to 357 t ha^{-1} (Table 1) depending on the equation adopted. Therefore, one should be careful when estimating biomass or comparing results with published data. For our estimates we use Bi et al. (2004), where authors reviewed 27 equations for *E. obliqua* and came up with an additive allometric equation that eliminates the inconsistency between the sum of predicted values for components such as stem, bark, branch and leaf and the prediction for the total tree (see Bi et al. 2004).

Table 1. Biomass of overstorey tree species *E.obliqua* calculated by a number of published equations.

Method to calculate biomass	Input values	AGB, t/ha	Reference
Geometric equations (stemwood volume * wood density * *e*)	DBHOB, Height	357	Snowdon et al. (2002)
Generic equation, 1/3 BA * 1.12	DBHOB, Height	366	Whiteman (1988)
Allometric equation for *E. obliqua*	DBHOB	241	Adams and Attiwill (1988)
Allometric equation for *E. obliqua*	DBHOB, Height	254	Attiwill (1966)
Allometric equation for *E. obliqua*	DBHOB, Height	145	Feller (1980)
Additive allometric equation for *E. obliqua*	DBHOB	251	Bi et al. (2004)

Where: *e*, conversion factor; DBHOB, Diameter at Breath Height Over Bark; BA, Basal Area

Bark of live overstorey trees is the most affected carbon pool of live trees during fire (Tolhurst 1994b). Loss in bark should be estimated as difference between tree biomass before fire and after fire, the latter is estimated as following:

$$M(kg) = \left(\exp(-1.870)\, {d_1}_i^{2.218}\right) + \left(\exp(-1.360)\, {d_2}_i^{1.598}\right) + \left(\exp(-9.399)\, {d_1}_i^{3.629}\right) + \left(\exp(-5.760)\, {d_1}_i^{2.326}\right) \quad \text{(Eq.2)}$$

Where ${d_1}_i$ is a diameter of a tree *i* before fire and ${d_2}_i$ diameter of the same tree after fire. Equation 2 is modified from Bi et al., (2004)

Understorey biomass (i.e. small trees and shrubs) can account for 6% of total forest biomass (based on average values from our dataset, in submission). Our research showed that understorey can be significantly affected by fire and should not be disregarded during emission estimates (as in the case of AGO 2008). Due to the potential for sampling high numbers of understorey plants in a 22.5 m circular plot, they need to be measured in smaller subplots. Their biomass can be estimated by applying the same allometric equations as overstorey, providing that trees (>5cm in diameter) are measured for diameter, while shrubs need to be destructively sampled. In our research we adopted small, 5 m radius circular, subplots established at the north, east, west and south end points of 22.5 m plot, resulting in 0.006 ha of measuring area. The difficulty was to clearly identify the boundaries of the subplot and determine understorey within the boundaries as the change in understory from pre- to post-burning can significantly affect carbon loss estimate in this pool. To avoid this, we suggest that each understorey subplot is marked with permanent metal pegs in its center and at the end points; stretching ropes between end points will make subplot boundaries visual (Fig. 2).

Ground cover of the surface vegetative layer (grasses and shrubs <0.5 m height) can account for 1% of total forest carbon and our laboratory analysis showed that its high in nitrogen, so it plays an important role when estimating N_2O emission. Ground cover can be easily estimated from destructive sampling using 0.5-1 m^2 frames.

Deadwood biomass includes dead standing trees (snags) and coarse woody debris (CWD) on the forest floor. Based on our field data, this carbon pool on average accounts for 9% of total forest carbon in south-eastern *Eucalyptus* forest and can be significantly affected by fire, its loss increases in wildfires (our data in submission; North and Hurteau 2011). Because deadwood biomass mainly burnt in smoldering combustion dominated by CO and CH_4 (Andreae and Merlet 2001), emission from this pool can be several times higher than emission from litter and ground cover that is mainly burnt in flaming combustion. The biomass of snags can be calculated using the same allometric equation, and we suggest that snag properties such as branch number and % rotten wood be noted to enable more accurate estimation of its biomass (e.g. by excluding foliage or branch components from the allometric equation).
The mass of coarse woody debris (CWD) with diameter ≥2.5 cm is commonly estimated by a line intersect method (van Wagner 1968) well-described elsewhere (e.g. Gould and Cruz 2012). Due to great variability in CWD numbers and branches fallen down during fires, the number of transects should be relatively large to assess effect of fire on this carbon pool (Table 2). In our field measurements we used diagonal transects of the plot as line transects, resulting in 8 x 22.5 m total transect length (Fig. 2), though trees that fall during the fire can make it difficult to measure CWD obscured beneath them.

Table 2. Number of plots required to detect 50%, 25% or 10% change in deadwood biomass with a probability ≥ 90% (modified from Volkova and Weston 2013).

Deadwood carbon pool	Minimal number of plots required		
	50% change	25% change	10% change
Snags	3	3	6
Coarse woody debris	8	23	131

Litter biomass can account for up to 4% of forest carbon (based on our field data, in submission) and includes dead plant material such as fruits, leaves, bark, and small branches (<2.5 cm) on the forest floor. Often the terms litter and fine fuels are used interchangeably, though fine fuels exclude sticks >0.6 cm diameter (Tolhurst 1994a). Our field sampling of litter in foothill forests of Victoria showed that those sticks can account for about 30% of litter loads and they are best separated from finer litter at the point of collection.

Soil organic carbon includes soil surface organic materials intimately mixed with soil mineral components, referred to as duff, and organic matter in soil to 30 cm depth. Our field data from 60 sites across 5 States of south-eastern Australia showed that duff ranges from being absent through to accounting for up to 10% of forest carbon. Prior to burning, duff can be difficult to separate from litter and from mineral soil. After fire fragmented and charred forest components, including litter and aboveground biomass, are deposited on the duff layer or soil surface. We chose to sample these materials as duff after fire to allow for describing changes in the nature and decomposability of surface organic materials (Volkova and Weston 2013). We recommend characterizing surface soil carbon using durable metal frames of known area as shown in Fig 3, so the fate of charred organic material can be properly accounted after burning.

To estimate loss of litter and duff after fire, the forest plot must be assessed for patchiness of the burn so loads of unburnt litter and duff can be calculated. In burnt patches, the surface of the forest floor needs to scraped and later sieved to soil, charcoal and unburnt organic matter. Depending on fire intensity, production of charcoal can account for 3 to 20% of aboveground carbon (based on field data, Volkova at el, in submission) that is important to account in emission estimates. Charcoal is often viewed as an important carbon sink because it can remain in the soil for decades, centuries and millennia due to its resistance to decomposition (Preston and Schmidt 2006).

Soil to 30cm depth is generally the second biggest carbon pool in the forest (up to 40+% of forest carbon, e.g. Grierson et al., 1991) and stores carbon semi-permanently (millennia), in contrast to trees where carbon is released back to the atmosphere during decay over decades and centuries (Adams and Attiwill 2011). To properly assess soil carbon the soil bulk density must also be accurately measured using well-engineered soil volumetric sampling equipment because forest soils can be hard, stony or even rocky; this equipment is usually expensive (up to AU$6000, Fig 3)

Figure 3. Heavy duty square sampling frame, soil bulk density corer and extraction handle developed for accurate sampling of forest floor carbon before and after fire.

Concluding remarks

Given the variability in forest fuels and burn conditions, further empirical measurements will significantly improve model estimates of forest carbon and emissions. The provision of more robust and accurate fuel estimates will also improve fire behaviour prediction and fire-risk reduction decisions. There is good scope to establish a systematic forest fuels inventory that can service these key aspects of public safety and land management and that demonstrates that Australia is addressing this challenging aspect of climate change. With clear evidence for a rising occurrence of wildfires in southern Australia (Liu et al. 2010) and the need to manage wildfire risk with planned fire, managers need access to accurate and up-to-date fuel assessments. These fuel assessments need to be verifiable and encompass the entire fuel strata.

References

Adams, M., and Attiwill, P. (2011). Burning Issues: Sustainability and Management of Australia's Southern Forests, *Book*

Adams, M. A. (2013). Mega-fires, tipping points and ecosystem services: Managing forests and woodlands in an uncertain future. *Forest Ecology and Management, 294*, 250-261.

Adams, M. A., and Attiwill, P. M. (1988). Nutrients cycling in forests of north-eastern Tasmania. *Unpublished Research Report No. 1.*

AGO (2008). Australian Methodology for the Estimation of Greenhouse Gas Emissions and Sinks 2006 - Land Use, Land Use Change and Forestry. Biomass Burning. Canberra, Australian Greenhouse Office.

Andreae, M. O., and Merlet, P. (2001). Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles, 15*(4), 955-966.

Attiwill, P. M. (1966). A method for estimating crown weight in eucalyptus and some implications of relationships between crown weight and stem diameter. *Ecology, 47*(5), 795-805.

Bauhus, J., Khanna, P.K., Hopmans, P. and Weston, C. (2002). Is soil carbon a useful indicator of sustainable forest soil management? — a case study from native eucalypt forests of south-eastern Australia. *Forest Ecology and Management* 171: 59-74.

Bennett, L.T., Weston, C.J. and Attiwill, P.M. (1997). Biomass, nutrient content and growth response to fertilizers of six-year-old Eucalyptus globulus plantations at three contrasting sites in Gippsland, Victoria. *Australian Journal of Botany* 45: 103–121.

Bennett, L. T., Aponte, C., Tolhurst, K., Low, M., and Baker, T. G. (2013). Decreases in standing tree-based carbon stocks associated with repeated prescribed fires in a temperate mixed-species eucalypt forest. *Forest Ecology and Management, 306*, 243-255.

Benyon, R. G., and Lane, P. N. J. (2013). Ground and satellite-based assessments of wet eucalypt forest survival and regeneration for predicting long-term hydrological responses to a large wildfire. *Forest Ecology and Management, 294*(0), 197-207.

Bi, H. Q., Turner, J., and Lambert, M. J. (2004). Additive biomass equations for native eucalypt forest trees of temperate Australia. *Trees-Structure and Function, 18*(4), 467-479.

Bradstock, R. A., Boer, M. M., Cary, G. J., Price, O. F., Williams, R. J., Barrett, D., Cook, G., Gill, A. M., Hutley, L. B. W., Keith, H., Maier, S. W., Meyer, M., Roxburgh, S. H., and Russell-Smith, J. (2012). Modelling the potential for prescribed burning to mitigate carbon emissions from wildfires in fire-prone forests of Australia. *International Journal of Wildland Fire, 21*(6), 629-639.

Feller, M. C. (1980). Biomass and nutrient distribution in 2 Eucalypt forest ecosystems. *Australian Journal of Ecology, 5*(3), 309-333.

Gould, J., and Cruz, M. (2012). Australian Fuel Classification: Stage II. Ecosystem Sciences and Climate Adaption Flagship, *Report*, CSIRO, Canberra Australia.

Grierson, P. F., Adams, M. A., and Attiwill, P. M. (1991). Carbon storage in soil and in forest products, *A report commissioned by the State Electricity Commission,* Victoria, Parkville, Vic. : School of Botany, University of Melbourne.

Hines, F., Tolhurst, K., Wilson, A. A. G., and McCarthy, G. J. (2010). Overall fuel hazard assessment guide, *Fire and adaptive management report No. 82,* Department of Sustainability and Environment; Melbourne.

Hurteau, M., and North, M. (2009). Fuel treatment effects on tree-based forest carbon storage and emissions under modeled wildfire scenarios. *Frontiers in Ecology and the Environment, 7*(8), 409-414.

IPCC (2004). Good Practice Guidance for Land Use, Land-Use Change and Forestry (GPG-LULUCF), *Report*, *Chapter 3.*

Liu, Y. Q., Stanturf, J., and Goodrick, S. (2010). Trends in global wildfire potential in a changing climate. *Forest Ecology and Management, 259*(4), 685-697.

Matthews, S., Sullivan, A. L., Watson, P., and Williams, R. J. (2012). Climate change, fuel and fire behaviour in a eucalypt forest. *Global Change Biology, 18*(10), 3212-3223.

McCaw, W. L. (2013). Managing forest fuels using prescribed fire - A perspective from southern Australia. *Forest Ecology and Management, 294*, 217-224.

North, M. P., and Hurteau, M. D. (2011). High-severity wildfire effects on carbon stocks and emissions in fuels treated and untreated forest. *Forest Ecology and Management, 261*(6), 1115-1120.

O'Brien, N., Attiwill, P.M., and Weston, C.J. (2003). Stability of soil organic matter in Eucalyptus regnans forests and Pinus radiata plantations in south-eastern Australia. *Forest Ecology and Management* 185, 249-261.

Preston, C. M., and Schmidt, M. W. I. (2006). Black (pyrogenic) carbon: a synthesis of current knowledge and uncertainties with special consideration of boreal regions. *Biogeosciences, 3*(4), 397-420.

Raison, R. J., Khanna, P. K., and Woods, P. V. (1985). Transfer of elements to the atmosphere during low-intensity prescribed fires in 3 Australian subalpine eucalypt forests. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere, 15*(4), 657-664.

Simkin, R., and Baker, P. J. (2008). Disturbance history and stand dynamics in tall open forest and riparian rainforest in the Central Highlands of Victoria. *Austral Ecology, 33*(6), 747-760.

Snowdon, P., Raison, J., Keith, H., Ritson, P., Grierson, P. F., Adams, M. A., Montagu, K., Bi, H.-q., Burrows, W., and Eamus, D. (2002). Protocol for sampling tree and stand biomass, National Carbon Accounting System, *Technical Report No. 31,* Australian Greenhouse Office, Commonwealth of Australia, Canberra.

Tolhurst, K. (1994a). Assessment of biomass burning in Australia - 1983 to 1992, In Agriculture: Workbook for non-carbon dioxide gases from the biosphere. *Book chapter*, Canberra, National Greenhouse Gas Inventory Committee, Dept. Environment, Sport and Territories, Pp. 40-65.

Tolhurst, K. (1994b). Effects of fuel reduction burning on flora in a dry sclerophyll forest. *Paper presented at the Biodiversity and Fire:* The effects and effectiveness of fire management, Footscray, Melbourne.

Van Wagner, C. E. (1968). Line intersect method in forest fuel sampling. *Forest Science, 14*(1), 20-26.

Vilén, T., and Fernandes, P. (2011). Forest Fires in Mediterranean Countries: CO_2 emissions and mitigation possibilities through prescribed burning. *Environmental Management, 48*(3), 558-567.

Volkova, L., and Weston, C. (2013). Redistribution and emission of forest carbon by planned burning in Eucalyptus obliqua (L. Hérit.) forest of south-eastern Australia. *Forest Ecology and Management, 304*(0), 383-390.

Whiteman, P. H. (1988). Growth performance of *Eucalyptus nitens* on Balook clay loam in the Strzelecki ranges. *Unpublished Technical Report*, APM Forests- Gippsland.

An Automated Operational System for Collating Field and Satellite Data for Grassland Curing Assessment

Danielle Martin, Alex Chen, David Nichols, Rachel Bessell, Susan Kidnie, Jude Alexander

Country Fire Authority, Burwood East, Victoria, Australia

ABSTRACT

Depending on the growth stage of grass, certain physiological characteristics, such as water content and degree of curing (senescence), determine the susceptibility of grass to ignite or to propagate a fire. Grassland curing is an integral component of the Grassland Fire Danger Index (GFDI), which is used to determine the Fire Danger Ratings (FDRs). In providing input for the GFDI for the whole state of Victoria, this paper reports the development of two amalgamated products by the Country Fire Authority (CFA): (i) an automated web-based system which integrates weekly field observations with real time satellite data for operational grassland curing mapping, and (ii) a satellite model based on historical satellite data and historical field observations. Both products combined will provide an improved state-wide map of curing tailored for Victorian grasslands.

KEYWORDS

Grassland curing, MODIS, Victoria.

INTRODUCTION

The chance of grass igniting and propagating a fire is dependent on the Fuel Moisture Content (FMC) (Cheney and Sullivan, 2008), which varies with curing (Anderson *et al.*, 2011; Anderson *et al.*, 2005; Barber, 1990; Dilley *et al.*, 2004; Paltridge and Barber, 1988; Tucker, 1977). Grassland curing is defined as the drying out of grasses and is measured as the percentage of dead grass in a grassland fuel complex (Cheney and Sullivan 2008). It is used to predict fire danger and to assist in fire management. In Victoria the Country Fire Authority (CFA) produces a weekly state-wide map of curing based on visual curing estimates from the field.

The 2009 Victorian Bushfire Royal Commission Interim Report recommended the Australasian Fire and Emergency Service Authorities Council and the Bureau of Meteorology (the Bureau) to collaborate with researchers to explore options for improving and revising fire danger indices and fire danger ratings (FDRs) (Teague *et al*., 2010). As part of this initiative, CFA established the Grassland Curing and Fire Danger Rating (GCFDR) project to obtain more accurate grassland curing information for increased accuracy of FDRs in grasslands. To improve the quality and production of weekly grassland curing maps, the main objective of the GCFDR project was to develop an automated system which integrates visually assessed field observations of curing with satellite data.

METHODOLOGIES – A HISTORICAL TIMELINE

AVHRR Satellite Imagery

Since the 1980s, the Bureau produced satellite-based maps of curing in south-eastern Australia using US National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) data using two successive algorithms described in Newnham *et al.* (2010). These curing maps were initially based on an algorithm developed by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and CFA that used a relationship between a modified Normalised Difference Vegetation Index (NDVI) (Rouse *et al.*, 1973) and FMC (Paltridge and Barber, 1988), and a relationship between FMC and curing (Barber, 1990). The algorithm used by the Bureau was subsequently revised by CSIRO to one that directly related the degree of curing to NDVI (Dilley *et al.*, 2004). During the 1987/1988 fire season, CFA commenced the use of AVHRR to estimate curing (Garvey, 1988). The predominant limitation of this technique was consecutive weeks of complete cloud cover (Paltridge and Mitchell, 1990) resulting in no data. This was of great concern as the drying of grass can occur quite rapidly (Paltridge and Mitchell, 1990), and any rapid changes of curing may not be captured entirely by AVHRR if complete cloud cover occurs. Consequently CFA refrained from further use of AVHRR for operational support, and has since relied solely on visually assessed field observations for mapping grassland curing.

MODIS Satellite Imagery

In the late 2000s, further research was completed by the Bushfire Cooperative Research Centre (Bushfire CRC), which resulted in the development of four Australian nation-wide satellite models based on 8-day Earth Observation System

(EOS) MODerate resolution Imaging Spectroradiometer (MODIS) satellite data and field observations using a modified Levy rod method (Levy and Madden, 1933). The Levy rod method entails counting live and dead grasses that come in contact with a thin steel rod placed vertically into the ground at several points along a transect. At the completion of the Bushfire CRC research, four (best-performing) models were developed, simply named Maps A and B (Martin, 2009; Newnham *et al.*, 2010) and Maps C and D (Newnham *et al.*, 2010). These models were tested for curing assessment throughout Australia and New Zealand, and the only agency to adopt a model operationally was the NSW Rural Fire Service (RFS) with preference for Maps A and B (Newnham *et al*., 2010). The RFS accepted primarily Map B but also Map A as a curing input for the GFDI of NSW (pers. comm. Dr Simon Heemstra, Manager NSW Rural Fire Service). However, in Victoria, these models were not implemented operationally, as CFA maintained its need for weekly updates of curing. This was not possible with the chance of cloud interference, and with the processing time of MODIS data, which was in excess of a week. CFA therefore continued to rely on weekly field observations for mapping curing until an improved and a more frequently available satellite product was developed.

In situ Visual Observations

Parallel to the use of AVHRR maps from the 1980s and onwards, CFA has maintained a growing network of volunteers across Victoria who report on the state of curing during the fire season using visual observations. Compared to the Levy rod method and relative to destructive sampling, Anderson *et al.* (2005) found visual field observations to have a ±25% error, while Newnham *et al.* (2010) found this method to under-estimate curing by 11%. Additionally, while the accuracy of the visual method varies between observers, these observations are rounded to the nearest 10% (previously 5%). The visual observation method, however, has been utilised by CFA since the 1980s. The Levy rod method entails longer sampling time than visual observations, and it is not a practicable option for weekly operational use by volunteer observers. To improve the quality of the visually assessed field data, an online training package was rolled out in the 2012/2013 fire season to ensure consistent, repeatable observations. Therefore CFA relied on weekly visual observations for frequent and consistent sampling of curing throughout the fire season (which occurs from as early as October to as late as May). Weekly visual observations are collated at CFA Headquarters and are used to produce a state-wide map of curing. The curing map is delivered to the Bureau as input into the Grassland Fire Danger Index (GFDI) for Victoria. For weekly production of the curing map, the process involves a great amount of manual processing and human interaction. With the expansion of the volunteer network, the process has become time-consuming with possibility for human error. Therefore, in October 2012, a prototype automated grassland curing online system was developed, implemented and deployed operationally for the 2012/2013 fire season.

Combination of MODIS and in situ Visual Observations

Prior to the fire season of 2013/2014, the automated grassland curing system was improved and enhanced with many functions. For example, field observers are able to upload geo-referenced photos with their observations, which can be overlaid in Google Earth® for viewing by the broader public community. In addition to the weekly field observations, MODIS satellite data have been amalgamated into the system. Since October 2013, the Bureau has established a direct downlink of MODIS data, and using CFA's new satellite-curing model, MapVictoria, the Bureau has provided CFA with a rolling 8-day satellite curing product that is updated every day. This product comprises the best quality and most recent observation for every 500m pixel across the state (pers. comm. Dr Ian Grant, Satellite Specialist, Bureau of

Meteorology). The weekly field observations and the MapVictoria product are combined to provide an improved state-wide map of curing named "Victorian Improved Satellite Curing Algorithm" (VISCA). VISCA has first been used operationally for the 2013/2014 fire season, and will be used for future seasons thereafter. The entire workflow of producing VISCA has been automated and integrated into the online system.

PRELIMINARY RESULTS

To improve and automate the production of grassland curing maps for Victoria, this section of the paper describes the development of two amalgamated products: (i) an automated web-based system which integrates weekly field observations with real time satellite data, and (ii) a satellite model based on historical (MODIS) satellite data and historical field observations.

Development of an automated web-based system

Sub-systems

CFA is heavily reliant on the grassland curing observation network to provide field curing information across the state. The GCFDR project addressed an operational workflow from data collection, analysis, to a final output. The prototype system was developed to streamline the operational workflow and automate the entire process. It comprises the following sub-systems (Figure 1):

- Online Application System,
- GIS Server, and
- Database Server.

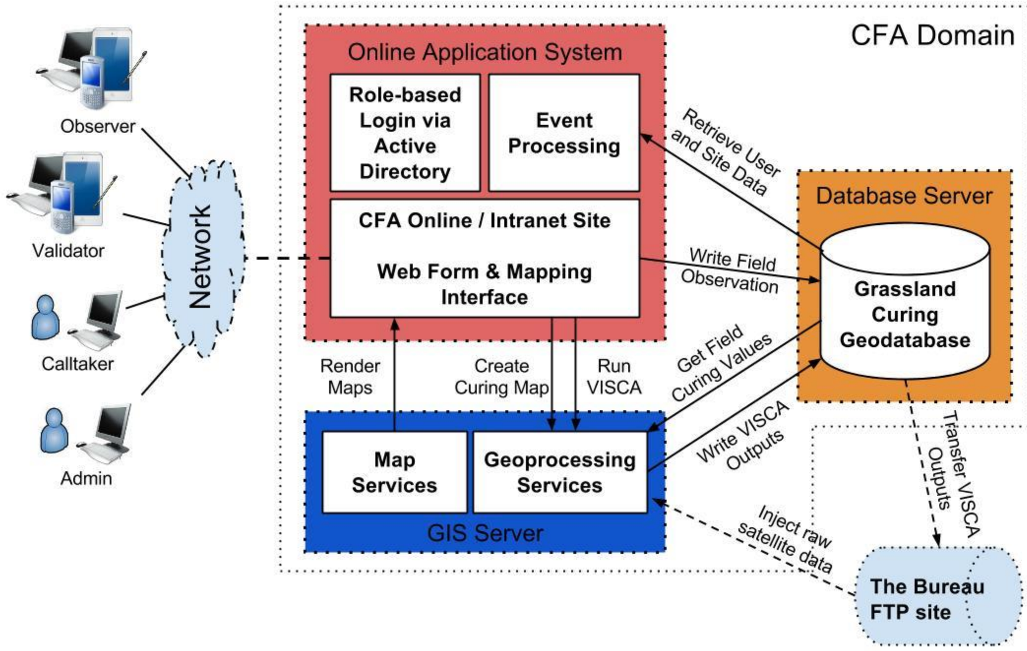


Figure 1 Overview of the design of the automated system

Online Application System

The Online Application System resides in the CFA Online website, and provides a role-based login for users to access the system via the CFA Active Directory (see Figure 1). Each role is given a different level of access to the functions of the system.

- Observers collecting field data can add and access their associated observation site(s) and report weekly observation data via the Online Application System.
- For each Victorian CFA District (see Figure 5 for district boundaries), a validator, who is usually a district-level operational manager, validates all curing values reported by observers.
- Fire and Incident Reporting System (FIRS) members are assigned the calltaker role, and assist in data entry reported from observers or validators who wish to report by phone.

- An administrator, based at CFA Headquarters, has full access to all system functions such as data validation, site and user access management, running the VISCA model and data delivery.

The Online Application System was developed to provide access from various web browsers on different platforms including desktop, tablet and smartphone. It comprises an Event Processing component (Figure 1), which mainly performs automatic email notifications for validation and data transactions such as weekly curing map distribution to the Bureau via File Transfer Protocol (FTP).

GIS Server

The Geographic Information System (GIS) Processing subsystem is powered by an ESRI ArcGIS Server 10.1, which serves a Web Mapping and Processing Service. It is accessible on the Online System for data entry. In addition, two Geo-processing web services are served from the ArcGIS Server for an administrator (via the Online System) to:

- “Run the Model” and write the VISCA output datasets to the database, and
- “Publish the Map” by generating the finalised VISCA map out of an established publishing layout template.

Database Server

The grassland curing enterprise geodatabase is established on a Relational Database Management System (Microsoft SQL Server 2008) to store all project data. It contains static datasets such as users’ login details and roles, site details, as well as dynamic information such as observations and output spatial datasets. Direct data connections were established between the database server, GIS Server and Online Application System.

Detailed Operational Workflow

The system was developed to streamline the overall workflow in operations every week during the fire season. The workflow is composed of a series of chronological processes (illustrated in Figure 2):

- Data Capture
- Data Collation
- Data Analysis and Modelling
- Data Output

These processes are described.

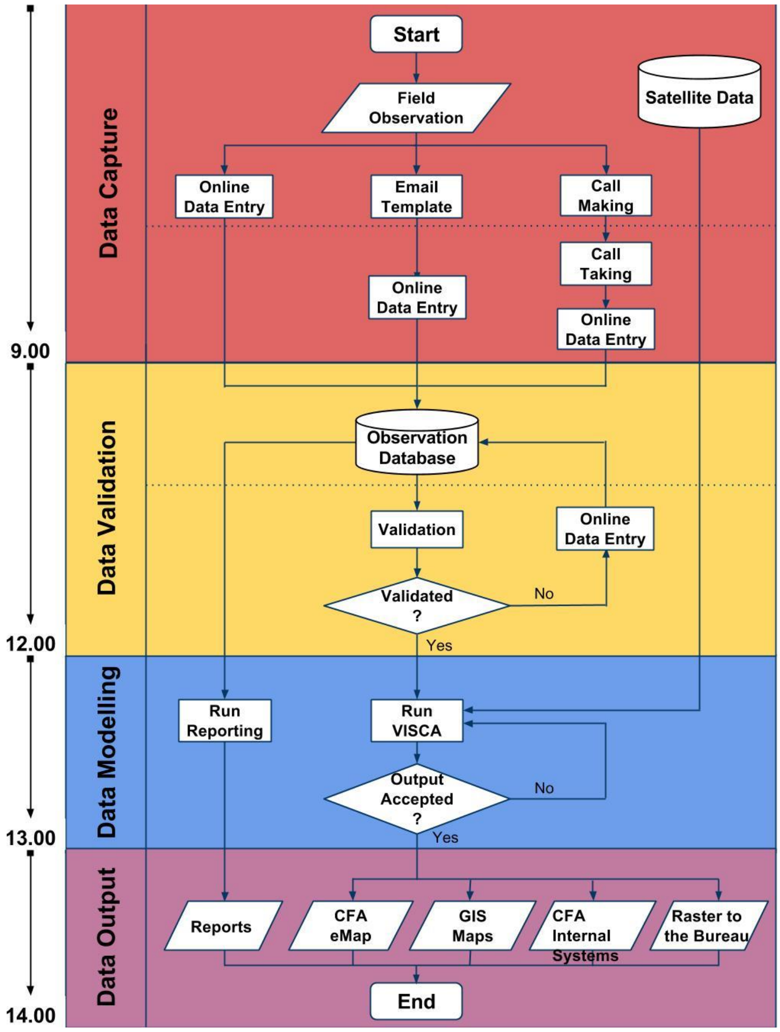


Figure 2 Grassland Curing Workflow

Data Capture

Every week throughout the fire season, field observers report observation details of their associated sites including grassland curing, height, cover, rate of drying, as well as weekly rainfall either directly through the online system data entry form (Figure 3) or via email or phone. All data are captured and stored in the grassland curing database.

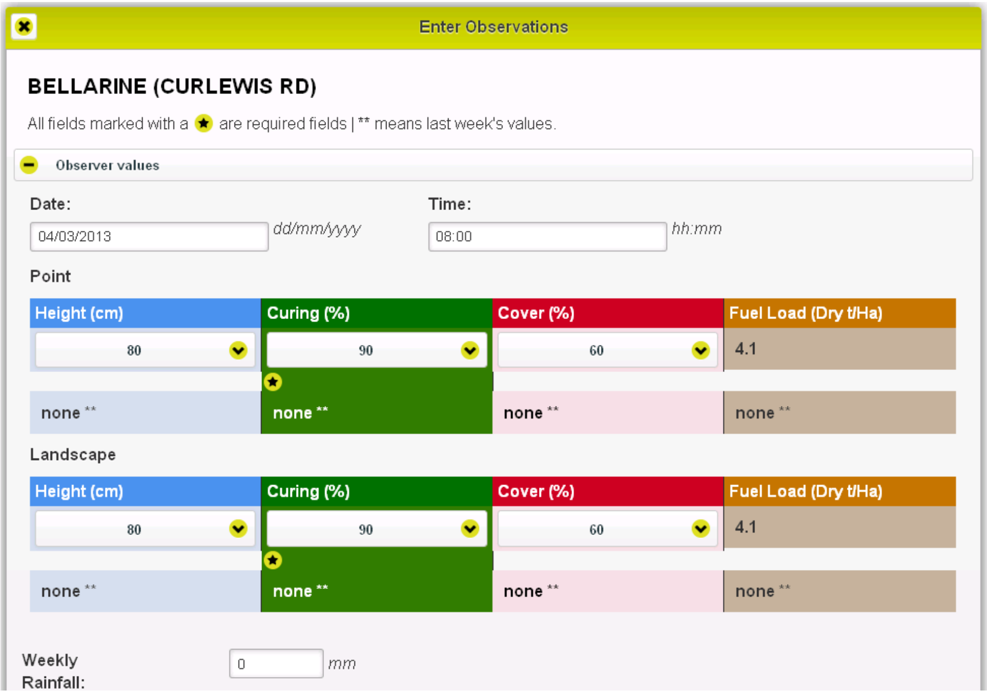


Figure 3 Example of a Data Entry Form (at the Bellarine field site, southern Victoria)

Data Collation

Once field curing values have been reported, the values are validated by CFA operational managers in each CFA district. Validation can be processed using the online system data validation form (Figure 4) or over the phone.

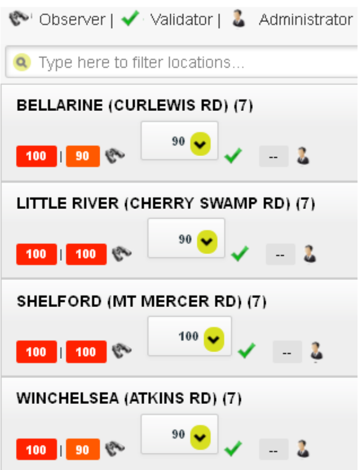


Figure 4 Example of a Data Validation Form (for District 7, southern Victoria)

When curing values from all districts have been validated, an administrator at CFA Headquarters can run the VISCA model by triggering a Geoprocessing service (Figure 1) via the Online Application System. At this stage of the processing, the model creates a GIS file locating all point curing values across the state (as shown in Figure 5). This file is stored in the Grassland Curing geodatabase and can be viewed on the Online Application System for the administrator to check for quality assurance.

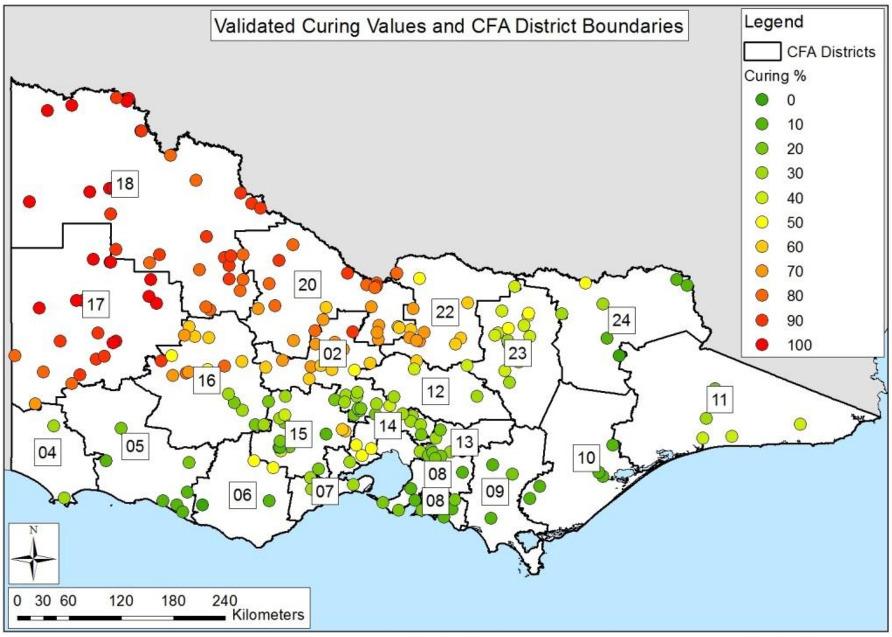


Figure 5 Map of Validated (Point) Curing Values for November 19th 2012 and CFA District Boundaries.

Development of a Satellite Model

Synchronising Satellite and Field Observations

With extensive coverage of state-wide point curing data (Figure 5), the integration of satellite data further improves the spatial resolution of the state-wide curing map. The MODIS Surface Reflectance Product, MOD09A1, has a 500m spatial resolution and comprises historical records dating back to the year 2000. The Bureau can now provide this product as rolling 8-day composites every day. MOD09A1 comprises seven bands, shown in Table 1. These spectral bands are sensitive to certain biophysical changes of vegetation such as cellular structure, changing levels of chlorophyll content, cellulose content and water content, all of which can be used to infer curing. In order to develop a MOD09A1-based model, MOD09A1 time-series, archived and processed by Paget and King (2008), were compared against field observations of curing from 2005 to 2013. Observations were taken from 211 field sites throughout Victoria as shown in Figure 5.

Table 1 First seven MODIS Spectral Bands (NASA, 2013)

Band	Spectral region	Wavelength (nm)
1	red	620 – 670
2	near infrared (NIR)	841 – 876
3	blue	459 – 479
4	green	545 – 565
5	near infrared (NIR)	1 230 – 1 250
6	short wave infrared (SWIR)	1 628 – 1 652
7	short wave Infrared (SWIR)	2 105 – 2 155

A Victorian Curing Model - "MapVictoria"

Using the synchronised field and satellite data, an extensive number of vegetation indices and multiple linear regressions (MLRs) were modelled and tested for their correlative power against observed curing values. The best performing model comprises a MLR using two vegetation indices: NDVI and GVMI, displayed in Table 2. The model was simply named MapVictoria.

Table 2 Vegetation Indices

Vegetation Index	Formulae	Reference
NDVI Normalised Difference Vegetation Index	$NDVI = \frac{(Band2 - Band1)}{(Band2 + Band1)}$	Rouse *et al.*, 1973
GVMI Global Vegetation Monitoring Index	$GVMI = \frac{(Band2 + 0.1) - (Band6 + 0.02)}{(Band2 + 0.1) + (Band6 + 0.02)}$	Ceccato *et al.*, 2002

Using field and satellite data from 2005 to 2013, Figure 6 plots observed curing (from the field) against predicted curing (estimated by MapVictoria). Supposing that observed curing has 0% error; the model was evaluated using the Root Mean Square Error (RMSE), the Mean Absolute Error (MAE) and the Mean Bias Error (MBE) (Willmott, 1982). The MapVictoria model estimates curing with an accuracy of ±11.02% (MAE). However, observed curing does not have a 0% error, but an error of up to ±25% (Anderson et al., 2005). Field observations are rounded at 10% intervals and in some cases 5%, resulting in 5 or 10% gaps in the data. Thus, the overall error of the model cannot be accurately determined. While high scatter is evident in the data, the model exhibits a slope of best fit of 0.8061, and tends to over-estimate (by 11%) at low levels of curing and under-estimate (by 11%) at high levels of curing. This is consistent with the Bushfire CRC models (Newnham *et al.*, 2010).

Having said this, the model exhibits no bias (0% MBE), and the model exhibits a lower RMSE (of 13.86%) than any other model tested in this analysis.

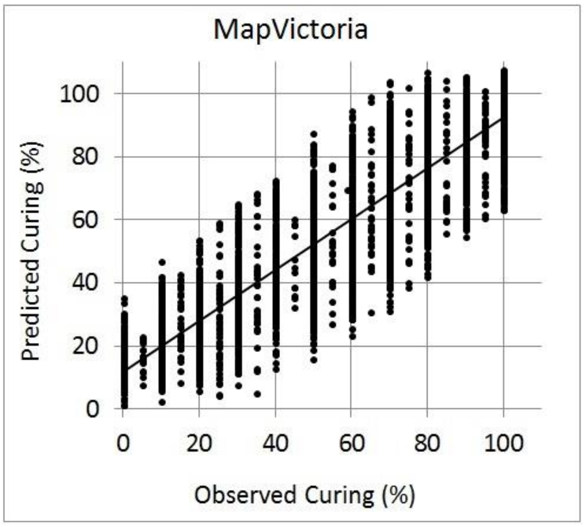


Figure 6 Predicted Curing (estimated by MapVictoria) against Observed Curing (visual observations from the field).

Since MapVictoria and the nation-wide models are all based on MOD09A1 data, it was of interest to compare the derivation of all models. Maps A and B are derived from 210 Levy rod observations from 21 field sites across Australia (Martin, 2009), and Maps C and D are derived from 343 Levy rod observations collected from 25 field sites across Australia (Newnham *et al.*, 2010). MapVictoria, on the other hand, is derived from a total of 3,938 (visual) observations collected from 211 sites across Victoria. This extensive coverage of data across the state gives confidence in using the MapVictoria model in Victoria as it is tailored specifically for Victorian grasslands.

Masking out of Water-bodies and Forests

While the measure of curing focuses on grasslands alone, curing estimates over water and forest are not valid. Therefore, preceding the calculation of curing in real time, water-bodies are masked out using a modified approach of Xiao et al. (2006). The masking of tree cover, on the other hand, does not require as frequently updated information. Tree cover is therefore masked out using a static VicMap Vegetation Dataset (Department of Environment and Primary Industries).

Victorian Improved Satellite Curing Algorithm

The satellite model is adjusted with weekly field observations (shown in Figure 5) to produce a finalised map named VISCA. To find a field value for every 500m pixel, the state is divided into regions; derived from spatial patterns from the most recent MODIS satellite image (the MapVictoria model). The median field curing value is calculated from all sites within each region within a given distance. This creates a temporary layer, named “fieldmap”, comprising a field curing value for every 500m pixel across the state. The MapVictoria values are then adjusted by the “fieldmap” values, with greater weighting for pixels closer to the field site locations. The model then processes a final map with a 3,000m spatial resolution, the required cell size for Graphical Forecast Editor (GFE) input in Victoria. The finalised map, VISCA, is stored as GIS data in the Grassland Curing geodatabase.

Once the finalised dataset (now VISCA) has been created (see an example in Figure 7), a Geoprocessing service (Figure 1) automatically generates a weekly map with VISCA set in an established template. The map is published on the CFA Grassland Curing website for all stakeholders to view. The map is also fed as an additional layer into the Victorian Emergency Map (eMap), which provides real time data for emergency management support. Finally, the Event Processing component of the Online System (Figure 1) automatically sends the VISCA dataset to the Bureau via a FTP site. It is then fed into the GFE and is utilised to calculate the GFDI for Victoria.

The GFDI values are used to calculate Fire Danger Ratings in the north-western part of the state.

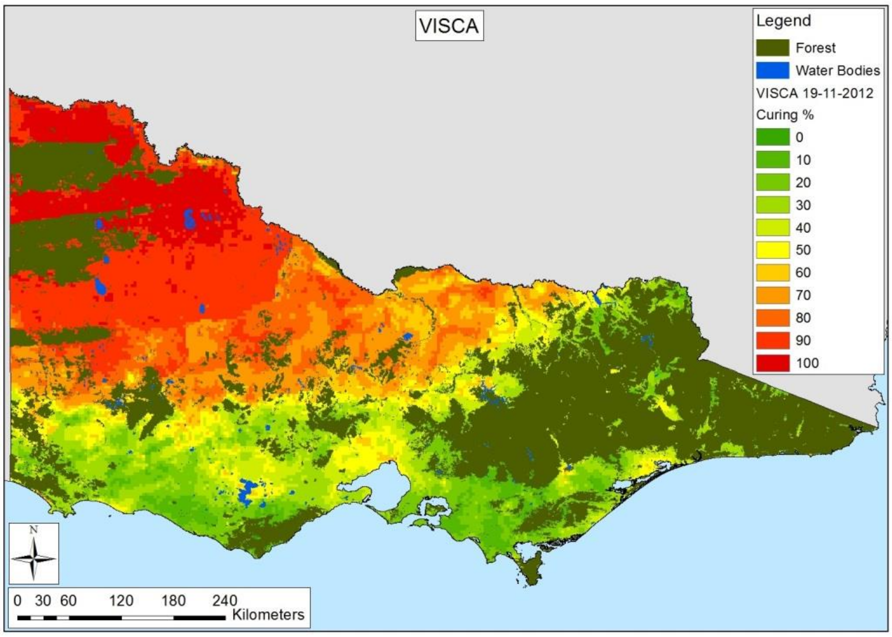


Figure 7 Example of the Finalised Curing Product - VISCA, November 19th 2012

CONCLUSIONS

For improvement of current fire danger calculations of grasslands in Victoria, CFA has developed an automated web-based system combining satellite data with visually assessed field observations of curing. Using an extensive network of 150+ field observers, CFA receives reliable state-wide information of curing every week throughout the fire season. Automation has dramatically minimised the amount of manpower required to collate field observations from across the state. These observations are used to adjust a new satellite model (MapVictoria), tailored specifically for Victorian grasslands. The combined product, named VISCA, is an improved grassland curing input for the GFDI, and hence FDRs. VISCA provides more accurate information for the declaration of the fire danger period at a municipal level, declaration of total fire bans, determination of fire suppression difficulty, fire preparedness and community warnings.

ACKNOWLEDGEMENTS

The authors acknowledge Dr Edward King and Mr Matt Paget (CSIRO) for historical mosaiced (MOD09A1) satellite data, Dr Musa Kilinc (Monash University) for assistance with statistical analyses, Dr Glenn Newnham (CSIRO) for remote sensing assistance, Dr Ian Grant (the Bureau) for reviewing the manuscript, for remote sensing assistance, and for operational satellite data processing. The authors would also like to thank Dr Paul Loto'aniu and Mr David Howard (the Bureau) for implementing much of the near-real time MODIS processing system. Last but not least, the authors thank Mr Tom Sanderson (CFA) for spatial systems and database assistance and CFA Online Services for ICT Support.

REFERENCES

Anderson SAJ, Anderson WR, Hollis JJ, Botha EJ (2011) A simple method for field-based grassland curing assessment. *International Journal of Wildland Fire* **20** (6):804-814.

Anderson SAJ, Anderson WR, Hines F and Fountain A (2005) Determination of field sampling methods for the assessment of curing levels in grasslands, Bushfire CRC Unpublished Report (Christchurch, NZ).

Barber J (1990) Monitoring the Curing of Grassland Fire Fuels in Victoria, Australia with sensors in satellites and aircraft - A Country Fire Authority study in Remote Sensing (Melbourne, VIC).

Ceccato P, Gobron N, Flasse S, Pinty B and Tarantola S (2002) Designing a spectral index to estimate vegetation water content from remote sensing data Part 1: Theoretical approach. *Remote Sensing of Environment* **82**(2-3): 188-197.

Cheney P and Sullivan A (2008) 'Grassfires - fuel, weather and fire behaviour. Second Edition.' (CSIRO Publishing: Melbourne).

Dilley A, Millie S, O'Brien D and Edwards M, (2004) The Relation between Normalized Difference Vegetation Index and Vegetation Moisture Content at three grassland locations in Victoria, Australia. *International Journal of Remote Sensing* **25**(19): 3913 - 3928.

Garvey M (1988) Country Fire Authority and remote sensing. CFA internal report (Melbourne, VIC)

Levy EB and Madden EA (1933) The point method of pasture analysis. *New England Journal of Agriculture* ***46***, 267-279.

Martin DN (2009) 'Development of satellite vegetation indices to assess grassland curing across Australia and New Zealand.' PhD Dissertation, RMIT University, Melbourne, Australia

NASA (2013) National Aeronautics and Space Administration Goddard Space Flight Center - MODIS Specifications. Available at http://modis.gsfc.nasa.gov/about/specifications.php.

Newnham GJ, Grant IF, Martin DN, Anderson SAJ (2010) Improved Methods for Assessment and Prediction of Grassland Curing - Satellite Based Curing Methods and Mapping. Published Report, Bushfire CRC Project A1.4, Melbourne, Australia. Available at www.bushfirecrc.com/managed/resource/a1-4_final_report.pdf.

Paget MJ and King EA (2008) MODIS Land datasets for the Australian region - CSIRO Marine and Atmospheric Research Internal Report No. 004. Available at https://lpdaac.usgs.gov/lpdaac/products/modis_policies

Paltridge GW and Barber J (1988) Monitoring Grassland Dryness and Fire Potential in Australia with NOAA/AVHRR Data. *Remote Sensing of Environment* **25**(3): 381-394.

Paltridge GW and Mitchell RM (1990) Atmospheric and Viewing Angle Correction of Vegetation Indices and Grassland Fuel Moisture Content Derived from NOAA/AVHRR. *Remote Sensing of Environment*, **31**: 121-135.

Rouse JW, Haas RW, Schell JA and Deering DH (1973) Monitoring vegetation systems in the great plains with ERTS. Proceedings of the Third ERTS Symposium Vol 1 (Washington DC).

Tucker CJ (1977) Spectral estimation of grass canopy variables. *Remote Sensing of Environment* **6**(1): 11-26.

Teague B (The Hon. AO), McLeod R (AM), and Pascoe S (AM) (2010) The 2009 Victorian Bushfires Royal Commission final report. Available at www.royalcommission.vic.gov.au/Commission-Reports/Final-Report.

Willmott CJ (1982) Some comments on the evaluation of model performance. *Bulletin of the American Meteorological Society* **63**, 1309-1313.

Xiao X, Boles S, Frolking S, Li C, Babu JY, Salas W and Moore B (2006) Mapping paddy rice agriculture in South and Southeast Asia using multi-temporal MODIS images. *Remote Sensing of Environment* **100**(2006): 95-113.

The Problems of Maintaining Effective Teamwork During Out-of-Scale Events

Chris Bearman[1,4], Christine Owen[2,4], Benjamin Brooks[3,4], & Jared Grunwald[1,4]

[1]Central Queensland University, Appleton Institute
[2]University of Tasmania, Faculty of Education
[3]University of Tasmania, Australian Maritime College
[4]Bushfire CRC

Abstract

The coordination of very large, complex, long duration, and multi-agency emergencies (what we refer to as out-of-scale events here) requires that teams form and work together quickly and effectively. In addition to the pressures of dealing with the emergency at the incident management team level and above emergency management teams will likely include people who do not know each other, may have very different skill sets and knowledge, and may be from different agencies that have different priorities and perspectives on the emergency. As the emergency continues new members are added to teams as shift replacements become necessary to manage fatigue. These factors exert pressure on the team and may lead to situations where the team lacks important information, leading to a breakdown in coordination and an impaired operational response. This paper provides a preliminary exploration of the problems of maintaining effective teamwork during out of scale emergencies through an examination of some of the broad causes of situations where one party has information that the other party does not have. Fourteen semi-structured interviews were conducted with emergency managers with experience at the IMT and above. All participants had recent experience of out-of-scale events in Australia and New Zealand. Key issues that emerged from these interviews were: Not getting to know the team and others, bypassing normal communication channels, disrupted coordination between different agencies, and sub-optimal take over of control from another team. The findings from this research demonstrate the need to consider team processes and to ensure effective information flow even under the extreme pressures of an out-of-scale emergency.

Introduction

Emergency management can be thought of as a series of complex, distributed teams sharing information within and between teams, up and down a chain-of-command. At a basic level (depending on the structure within the agency), information flows between the fireground and the incident management team (IMT), between the incident management teams and the regional coordination centre, and between the regional coordination centre and the state coordination centre. In very large, complex emergencies information will also need to be shared between different teams at the same level (who may sometimes be thought of as forming a meta-team) and between different agencies. Owen, Hickey & Douglas (2008) have outlined how all of these teams fit together in the operational response network and some of the information flow pathways between them. Information is used by people at each level to develop and maintain situational awareness, make decisions, develop plans and coordinate operations (Bearman, Grunwald, Owen & Brooks, 2013; Burke, et al., 2006; Endsley, 1996; Klein, 1998). It should be noted that the regional level does not simply act as a conduit for information between the incident management team and the state levels of coordination but uses information to fulfil important fire management roles (such as planning and monitoring the incident management teams; Bremner, Bearman & Lawson, in press). It should also be noted that information is not neutral and does not really flow around an emergency response network in any meaningful way. Information is perceived, comprehended and shared by people who are using it to construct an understanding of the situation they are operating in (Endsley, 1996).

During a very large, complex, long duration and multi-agency emergency (referred to as out-of-scale here), teams managing the incident at the IMT level and above will likely include people who do not know each other, may have very different skill sets and knowledge, and may be from different agencies that have different perspectives on the emergency and how to manage it. As the emergency continues in duration new members are added to teams as shift replacements become necessary to manage fatigue. Pre-planning for large events, and training/accrediting people to perform different roles can help to manage these issues, however, out-of-scale emergencies will nevertheless exert pressure on teams and may lead to situations where the team lacks important information, leading to breakdowns in coordinated decision making and an impaired operational response.

A breakdown in team coordination is a failure in coordination, cooperation or communication that leads to a temporary loss in the ability to function effectively (Bearman, Paletz, Orasanu and Thomas, 2010; Bearman, Grunwald, Brooks and Owen, 2013). At a more fine grained level individual instances of disruption between participants are referred to as *disconnects*. Bearman et al. (2010) have identified three types of disconnects: informational, evaluative and operational. *Informational disconnects* occur when there is “a difference in the information that each party possesses” (Bearman et al., 2010, pp179) and *evaluative disconnects* occur when there is “a difference in the evaluation or appraisal of information that is available to both parties” (Bearman et al., 2010, pp179). *Operational disconnects* occur when there is “either a difference between the actions of one party and actions expected by the other party or a mismatch in the plans that each party has about the physical operations of the response” (Bearman et al., 2010, pp178). Since this paper is interested in information flow, we will focus particularly on informational disconnects and some of the reasons why they occur in out-of-scale emergencies.

This paper then, provides a preliminary exploration of the problems of maintaining effective teamwork during out of scale emergencies through an examination of some of the broad causes of informational disconnects (i.e. situations where one party has information that the other party does not have). In other words, this paper identifies some of the reasons why people in the operational response don't have the information they need. This exploration does not seek to present a comprehensive list of reasons for informational disconnects in out of scale emergencies but highlights a preliminary set of issues that should be discussed by agencies. It should be noted that the research presented here does not imply any criticism of people who are operating under extreme conditions of stress, fatigue and very high workload. This research is designed to highlight some of the reasons why disruptions to teamwork occur during the response to out-of-scale emergencies and suggests some ways that we might prevent these from occurring in the future.

Method

Participants

Fourteen people from seven different emergency management agencies across Australia and New Zealand participated in the study. All participants had recent experience of out-of-scale emergencies. Participants' median age was 55 years and participants had on average (median) 28 years of experience dealing with emergencies and twelve years of experience in emergency management. All participants were male. Participants were interviewed in their chosen location (which was usually their office). Participants took part in the study during work time but were not otherwise paid for their participation.

Design and Procedure

A semi-structured interview method was used where participants were asked to recount incidents they had been involved with where there had been a breakdown in team coordination. These incidents were then probed for more information using neutral probes such as "why did you do x?" Interviews lasted for approximately 1 hour and were audio recorded using a handheld digital audio recorder and microphone. The digital recording was later fully transcribed.

Analysis

The transcribed interviews were analyzed using a thematic analysis technique. Thematic analysis is a bottom-up, data driven, qualitative analysis technique where themes are developed by placing similar extracts from the transcripts together in clusters. As these clusters develop extracts that could be placed into more than one theme or don't fit the emerging theme they are in are re-examined and the extract may be redefined or a new cluster formed. It is possible for an extract to be in more than one cluster since the emphasis of the analysis is on qualitative themes rather than independent categories. Throughout the process a name is given to the cluster that defines the essential elements of that cluster. Names are re-examined and revised as the cluster develops.

Results and Discussion

Four main themes emerged from this preliminary analysis. These themes were: not getting to know team members and others, bypassing normal communication channels, disrupted coordination between different agencies, and sub-optimal take over of control from another team. These themes describe broad causes of informational disconnects. These themes will be presented and discussed in turn.

Not Getting to Know Team Members and Others

When teams include people who are unknown to others (as they may do in an out-of-scale event) there can be an informational disconnect about the specific skills and abilities of those team members. This lack of shared information may be exacerbated when the team is overwhelmed by events and the team leaders feel like they don't have time to get to know the members of their team.

> "We didn't actually get to meet the incident controller and say who we were or what we did, there was no mating dance, none at all."

> "Everyone was too busy, we had never sat down and said 'this is what we're doing, this is what I do".

This can be a particular problem when those team members are from other agencies

> "The basic thing was that we didn't know each other's agencies, or what each other's skills or resources were."

One of the outcomes of the lack of knowledge about different team members is a disruption to information sharing throughout the team

> "it's like being at a party with a lot of divorcees that didn't want to talk to each other."

Tuckman (1965, 1977) proposed that teams pass through five stages of development: Forming, Storming, Norming, Performing, and Adjourning. At the forming stage, teams need to establish the boundaries of interpersonal and task behaviours. Once this has been done teams enter the storming stage where they need to manage interpersonal issues and conflict within the team. After the storming stage teams progress to the norming stage where members agree about roles and tasks and can start to function effectively. Following the norming stage the team enters the performing stage, where the team establishes a coherent identity that supports flexible task performance. Finally, the team goes into the stage of adjourning, where the team is disassembled. When teams don't get to know each other at the beginning of an emergency the stages of forming and storming can become protracted causing a problem for coordinated decision making.

One way of ensuring that information about the skills and abilities of each team member is shared is to get people to introduce themselves in early meetings.

> "You wanna stand up and say what your skills are and say that you're here to help. And what that did is it laid it out and I could actually work out who I was dealing with, because they did the saying."

A longer-term solution is to provide opportunities for people to get to know others through meetings, simulations or other exercises.

> "And you know really that worked very well and probably a key point in relation to why it worked well was because we have spent so much time over the past ten years

> forging relationships with those agencies. We had trained together and played together. So straight away when you walked into the facility you knew the people."

The value of such exercises is not just in forming relationships with people but also the experience of working with lots of different people and becoming familiar with other agencies and the different perspectives they can have on the emergency. According to Tuckman's theory, building knowledge of people and roles allows the team to move more quickly through the stages of forming and storming to achieve norming and performing. Such exercises can also be designed to provide opportunities for people to identify and recover from breakdowns and disconnects.

Related to informational disconnects caused by not knowing the skills and abilities of team member are informational disconnects caused by not having the right people in the team.

> "We had a manger there who actually organized all the field things. When he came in at night because we were putting the IAP together at 11 at night. He'd come and see me, that's how I knew what was going on…It was at the end of the day when we'd actually find out how his day went and how planning went for the next day. He should have been at the planning meeting, but he was never invited in."

It is important then to be able to identify people who have important information and to bring those people into the team.

Bypassing Normal Communication Channels

When people are overwhelmed or information flow is disrupted people may bypass normal communication channels. In such cases people often rely on informal or personal networks, making direct contact with people who they know. This can lead to team members or others in the operational response not getting the information they need (i.e. an informational disconnect).

> "So we had people who were in the field operations team wanting to text me first thing in the morning so that I could bring it up at the briefing, that operations needed to do something. Well that cut out, the team supervisor, the sector supervisor, the ops manager, back the and back across to the wildfire manager."

Such alternative lines of communication are especially likely to occur in an out-of-scale emergency when personnel are loaned out to other agencies.

> "So the staff they're doing a job over in the middle of the city…. They're not thinking that they're working for [organization x] or for [organization y], you know, and so they were tending to talk to our people because they know them."

When the system is placed under pressure from an out-of-scale event and people are using informal networks, there is often some attempt to try to maintain more formal channels

> "It had a lot of potential to become disjointed and muddled and we did our best to try and maintain a single channel, because we knew that you know given half a chance, it would become very confusing."

Although such attempts can become quickly overwhelmed

> "We tried to maintain some sort of line single line through a liaison person but nonetheless it sort of worked around the edges of that, that burst out in places, and we reacted to those requests as and when we got them and tried to formalize them along the way."

The reasons why people use informal networks are complex and relate to issues such as trust in people and lack of trust in the system as well as task management and information flow blockages. While there may be very good reasons why people make use of informal networks (e.g. trying to resolve an existing informational disconnect), the impact needs to be considered and strategies developed to ensure that informational disconnects don't occur where people are out of the loop and not getting the information that they need.

Disrupted Coordination Between Different Agencies

In out-of-scale events different agencies frequently need to work together to provide an effective response. The lack of understanding of the skills and abilities of people from different agencies and the use of informal networks for obtaining information by people who are 'loaned' to different agencies were discussed above. More generally cultural differences between agencies can lead to impaired information exchange and informational disconnects.

> "But at that stage of the game there were, cultural divisions between agencies, and um those sort of things restrict your ability to have those conversations…It does impact on your approach to people. You don't have the free exchange of ideas, and you don't have that free debate that you would like to have. And that impacts on the analysis and therefore that impacts on the conclusions you draw. It's just a classic blocker to any communication."

Informational disconnects can also be caused by a lack of information about the role that an agency could play in an emergency response.

> "[Organization x] and [organization y] really in my view were so overwhelmed with what they were dealing with, that they hardly noticed us…we spent a lot of time doing that, making ourselves available, and not being utilized. You know, we had the potential of being one of the most effective responders for them, but in actual fact they never fully utilized that."

While it is important to have clear roles and responsibilities that the different agencies have agreed to it is also important for people to develop a better understanding of how different agencies operate, the cultural differences and the way they are likely to react to different situations. One way of doing this is to provide opportunities for collaboration through multi-agency simulations. As discussed earlier the function of such simulation may be as much about developing an understanding of the different roles and perspectives held by people from different agencies as it is about developing relationships with individuals.

Sub-Optimal Take Over of Control From Another Team

In terms of the wider network involved in an operational response, teams need to form effective working relationships with other teams. In a sense such teams form a meta-team that also needs to coordinate effectively. The development of an effective working relationship is particularly important when a new team comes in to take over an emergency that is being run by another team. When the new team does not form a good relationship with the old team, informational disconnects can occur.

> "When the level three set up, for the life of me I can't understand how they chose what was going to be the new staging area. It was a totally inappropriate location for access and all sorts of reasons. And I can't for the life of me understand why they chose it. And they operated the [staging area] and realized it was hopeless and went to a second location which was good from the point of view of access room and that sort of thing but it was miles from anywhere. And finally after a week, they said "hang on, you guys have already got this figured out haven't you?" and moved back to the pre-planned location. Just came back to not talking to [locals], it goes back to the communication breakdown."

It is also the case that when a new team comes in and makes plans without exchanging information (an informational disconnect) with the team who were running the incident, conflicting plans (or operational disconnects) can be developed that lead to confusion for the personnel on the ground.

> "For someone to come in and write up an incident action plan and put a different set of [radio] channels in there without consulting the locals who have already set up a plan and then cause commotion when one of the [radio] channels they chose went to the aircraft which is broad area, upset a lot of people."

One participant suggested that it would be useful to receive training in how to take over the management of an incident.

> "Its probably something that I would suggest in that incident management team level… that there is actual training on how to sidle up to the locals, and actually take control in a non threatening way."

A recent development in fire management that has occurred in response to the increasing need for expertise in coordination at the IMT level and above has been to develop a pool of individuals who are available on a fly-in fly-out basis to assist in the management of out-of-scale emergencies around the country. While the merits of such specialists will not be debated here, one of the challenges that such teams will face is how to effectively take over the running of an incident to avoid informational and operational disconnects.

The study has a number of limitations that should be taken into account. Reports of situations where there has been a breakdown are retrospective and rely on the participant's memory for the events. These memories can contain inaccuracies and omissions. It is also difficult to draw causal relationships or conclusions about the prevalence of the findings based on such data. However, semi-structured interviews are widely used in human factors research (Klein, Calderwood & McGregor, 1989) and are one of the few methods of collecting data about real world emergencies. Despite these limitations the method has allowed us to develop a rich contextualized account of the way in which informational disconnects occur in teams.

Conclusion

This paper then has explored the problems of maintaining effective teamwork during out-of-scale events through a consideration of some of the reasons why people in the operational response don't have information that they need (i.e. informational disconnects). Key reasons for informational disconnects that emerged from the data were: not getting to know the team and others, bypassing normal communication channels, disrupted coordination between different agencies, and sub-optimal take over of control from another team. The findings presented here provide a preliminary set of issues that should be discussed by agencies. More broadly the findings demonstrate the need to consider team processes and to ensure effective information flow even under the extreme pressures of an out-of-scale response in order to avoid informational disconnects, impaired teamwork and a degraded operational response.

References

Bearman, C., Paletz, S.B.F., Orasanu, J. & Thomas, M.J.W. (2010). The breakdown of coordinated decision making in distributed systems. *Human Factors,* **52***,* 173-188.

Bearman, C., Grunwald, J., Brooks, B., & Owen, C. (2013). Breakdowns in coordinated decision making at and above the incident management team: An analysis of three large scale Australian wildfires. Manuscript under review.

Bearman, C., Grunwald, J., Owen, C., Brooks, B., & (2013). Information needs to support the development of accurate and appropriately situation awareness and shared mental models (Report Prepared for the Bushfire CRC Under the Project: Organizing for Effective Incident Management). Melbourne, Australia: Bushfire CRC

Bremner, P., Bearman, C., and Lawson, A. (in press). Firefighter decision making at the local incident and regional/state control levels. In Owen, C. (Ed.). *Enhancing Individual and Team Performance in Fire and Emergency Services*. Aldershot, UK: Ashgate.

Burke, C. S., Stagl, K. C., Salas, E., Pierce, L., & Kendall, D. (2006). Understanding team adaptation: a conceptual analysis and model. *Journal of Applied Psychology, 91,* 1189–1207.

Endsley, M.R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. Human Factors, 37(1), pp. 32---64.

Klein, G. (1998). Sources of power: How people make decisions. Cambridge, MA: MIT Press.

Klein, G.A., Calderwood, R., MacGregor, D. (1989) Critical decision method for eliciting knowledge. IEEE Trans Syst Man Cybern; 19:462–72.

Owen, C., Hickey, G., & Douglas, J. (2008). Mapping Information Flow During Critical Incidents.

Tuckman, B.W. (1965). Developmental sequence in small groups. *Psychological Bulletin*, **63**, 384-399.

Tuckman, B.W. & Jensen, M.A.C. (1977). Stages of small group development revisited. *Group and Organizational Studies*, **2**, 419-427.