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DETERMINING THRESHOLD CONDITIONS FOR EXTREME FIRE BEHAVIOUR

Annual project report 2016-17

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Cover: Prescribed fire (photo by Thomas Duff 2017)

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ABSTRACT

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Organisations that manage bushfires are expected to deliver scientifically defensible decisions. However, the limited availability of high quality data restricts the rate at which research can advance. The nature of bushfires contributes to this; they are infrequent, complex events, occur with limited notice and are of relatively short duration. Some information is typically collected during bushfires however it may not be of an appropriate standard for research. In the past year we have focused on the information that is typically collected during fires. First we reviewed the information routinely collected during fire events across Australia. Secondly, we reviewed research methodologies that may be able to supplement existing data collection. Based on the results of these surveys, we developed a recommended list of attributes for routine collection during bushfires. We also suggest standards of data collection from bushfire events to enhance the advancement of fire behaviour research and make research findings more internationally relevant. In a research field typified by scarce data, improved data collection standards and methodologies will enhance information quality and allow the advancement in the development of quality science (1). In addition to the fire data review, we investigated embers, including their production and how they burn (2,3).

END USER STATEMENT

Dr. Simon Heemstra, *Operational Services, Rural Fire Service, NSW*

This is a great summary of the current state of data collection and a starting point for agencies to try to collect more useful data for fire reconstruction and research. Improvement of data collection will facilitate providing leverage on data collected and allow robust conclusions to be reached sooner and with less expense. This would include improving systems and processes in use today, as well as considering new technologies than can help information to be collected more efficiently. These results will serve a foundation for further analysis the frequency of extreme fire behaviours in the context of landscape scale fire behaviour.

INTRODUCTION

Bushfires can result in substantial social, economic and environmental impacts and recovery activities may take many years. Fires in Australia have resulted in mass house loss in the state Victoria in 2009 (4), Western Australia in 2011 and New South Wales and Tasmania in 2013 (5). The total annual economic cost of bushfires in Victoria is estimated to be approximately 180 million Australian dollars (6). These costs have been forecast to double over the next 40 years to $378 million (7). It is important to develop strategies that are able to reduce the risk of loss and thereby decrease the economic and social impacts of bushfire.

Fire simulation systems have been developed as part of management decision support systems vital to reducing the risk to people and property (8–11). However, most of these simulation tools are based on empirical fire forward rate of spread (FROS) models and do not necessarily emulate physical processes. Empirical FROS models were predominantly developed using observations of experimental fires burning in conditions that allow the fires to be safely managed. As a result, data representing the conditions under which damaging bushfires occur were rarely included. Indeed, current operational fire spread models assume that fires burn at an approximately constant (quasi-steady) rate of spread under a specific set of environmental conditions (e.g. Rothermel (12), Canadian FBP system (13), VESTA (14), CSIRO Grassland fire behaviour model (15)). However; under extreme weather conditions, there are emergent forms of fire behaviour that can rapidly change fire progression and intensity, including phenomena such as plume dominated spread and mass spotting events (16). Consequently, simulation tools that utilise these FROS models are not able to emulate these dynamic bushfire behaviours.

Fire behaviour and management research cannot develop fully without better quantification of the various fire behaviour phenomena that occur under moderate and extreme weather conditions. To do so requires comprehensive and accurate data. Experimental research into intense fire behaviour cannot be undertaken as these fires cannot be safely managed; as a result alternative sources of data are required and the only opportunity to collect information about fires under moderate and extreme conditions is to collect observations at bushfires as they occur. Case-study fires are commonly used in research (4,17,18) however, the data is usually collated from various sources post event, hence data availability and quality is highly variable. There is currently no formal procedure for ensuring the data collected during and post-fire is appropriate for meeting research requirements. Without new data regarding bushfire behaviour, fire research, the future development of fire simulation tools and the associated decision support systems will be unable to improve significantly.

Fire information collected by management agencies varies by jurisdiction and fire size. In small fires, agencies may record simple details such as ignition location (19–22), final fire size and fire area (23). For large fires that have substantial impacts, data may be extended to include fire severity (24–27), fire progression (28,29) and impact (30–32). However, much of this information is collected and collated post event. During fires there are many transient fire behaviour phenomena that cannot be easily reconstructed post event. These include spotting/fire storms, fire tornado/whirls, lateral vortices, junction zones (jump fires), eruptive fires, independent crown fires (Van Wagner 1977), conflagrations, downbursts, pyro-convective events (16).

Information about fire behaviour is best collected as fires occur, however, there is currently no agreed set of standards or methodologies that define a) what information needs to be collected during fires and b) when collected, what data standards are appropriate (23). Data generated during a fire may be discarded if it is not required by an organisation. As a result, data that is saved will only be a subset of the information available during an incident.

As an outcome of our recent research, we suggest data collected during bushfires be standardised. Doing this would enable fire behaviour phenomena to be documented and analysed. Furthermore, if such data collection were to be undertaken in a standardised manner across Australia or worldwide, it would enhance interagency collaboration, increase the research potential of datasets and make research findings more broadly relevant. To evaluate potential standards, we reviewed the information routinely collected during fire events for most states in Australia. We also reviewed existing research methodologies that have the potential to be routinely used for observations during fires. The outcomes of these were used to develop some initial recommendations of attributes that could be considered for routine collection during bushfires. While we focus primarily on Australian agencies, the recommendations are relevant for agencies worldwide (1).

BACKGROUND

The main aim of this project is to investigate the conditions and processes under which bushfire behaviour undergoes major transitions, including fire convection and plume dynamics, evaluating the consequences of eruptive fire behaviour (spotting events, convection driven wind damage, rapid fire spread) and determining the combination of conditions for such behaviours to occur (e.g. unstable atmosphere, fuel properties and weather conditions) (33).

STANDARDISING DATA OBTAINED FROM BUSHFIRES

Data collection in Australia

Australia is a diverse continent with ecosystems ranging from tropical rainforests through to desert environments. Fires occur at varying intervals and intensities across the country (34). Land and fire management is the responsibility of state-level governments (which include are six states and two territories). The industry body AFAC (Australian and New Zealand Fire and Emergency Services Association Council) endeavours to bring together fire and land management agencies across Australia and New Zealand to provide a coordinated response to fire and emergency management. To date, there has been no national policy developed focused on data collection and management during fires.

To understand what data is collected during bushfires, we approached representatives from all fire and land management agencies in Australia. Representatives of state agencies were contacted via email and telephone and asked to complete a guided survey (Appendix 1). There were multiple agencies from each state as fire management responsibilities are typically divided by land tenure. Specifically, we asked:

- What information is collected and stored during fires?;
- How frequently is the data is collected?; and
- Does this information collection vary between fires under different conditions?

Responses (Appendix 2) were received from Australian Capital Territory (ACT), New South Wales (NSW), Victoria (VIC), Queensland (QLD), South Australia (SA) and Western Australia (WA) (Table 1). No responses were received from Tasmania (TAS) and the Northern Territory (NT). Where multiple agencies responded from the same state, if at least one of the agencies in the state collects a certain type of data the attribute was considered 'collected' by the state.

State or Territory	Agency
ACT	Parks and Conservation Service
	Rural Fire Service (RFS)
NSW	National Parks and Wildlife Service
	Rural Fire Service (RFS)
NT	Darwin Centre for Bushfire Research
	Bushfires NT
QLD	Queensland Parks and Wildlife Service
	Queensland Fire and Emergency Services (FES)
SA	Department of Environment, Water and Natural Resources (DEWNR)

	Country Fire Service (CFS)
TAS	Forestry Tasmania
	Tasmania Fire Service
VIC	Country Fire Authority (CFA)
	Department of Environment, Land, Water and Planning (DEWLP)
WA	Department of Parks and Wildlife (DPAW)

TABLE 1. LIST OF FIRE MANAGEMENT AGENCIES THAT WERE APPROACHED IN RELATION TO THE COLLECTION OF DATA DURING FIRES

As fires are complex events and there are many sources of data, in the surveys we classified fire data into broad groups (Table 2).

Data type	Definition
Incident type	The level of Incident Scale as determined by the AIIMS/ICS system*
GPS tracks	Global Positioning System records recorded by transponders mounted on firefighting vehicles. This may include ground based vehicles or aircrafts
Suppression strategies	Details pertaining to the methods and strategies of firefighting used
Containment	Details relating to the effectiveness of fire containment lines at different times during the fire
Final perimeters	Maps or surveys of the final burned area
Ignition point/points	Details about where the fire started
Situation reports	During a fire, firefighting agencies routinely report on the status of the fire (including fire behaviour and area affected).
Fire behaviour observations	Information from firefighters and ground observers recorded
Private property losses	The losses of private property (e.g. houses, fences)
Local weather observations	Information recorded at or near the fire using portable weather stations
Urban infrastructure	Details relating to infrastructure impacted by the fire
Response structures	Details relating to the command and coordination of the fire suppression effort
Fuel condition	Observations relating to the condition of the fuel at the fire, including the nature and whether there is evidence of prior fires
Weather radar	Data collected by the Australian Bureau of Meteorology rain radar illustrating the nature of fire smoke plumes
Progression isochrones	Archives of maps created at different times during the fire as part of firefighting efforts
Post fire impacts	Details in relation to fire impacts to values at large
Satellite images	Satellite images from around the time of the fire (include before, during and after)
FLIR	Images and video from low altitude aircraft mounted FLIR (Forward looking infrared) cameras**
Linescans	Images from high altitude aircraft mounted Infrared linescan systems***

TABLE 2. CATEGORIES AND DEFINITIONS USED IN FIRE DATA COLLECTION SURVEYS

*AIIMS IS THE AUSTRALASIAN INTER-SERVICE INCIDENT MANAGEMENT SYSTEM (AUSTRALASIAN FIRE AND EMERGENCY SERVICES AUTHORITIES COUNCIL 2013). THE CORE OF THE AIIMS IS THE INCIDENT CONTROL SYSTEM (ICS) THAT AIMS TO PROVIDE AN INTEGRATED STRUCTURE TO MANAGE THE RESPONSE TO ANY EMERGENCY INCIDENT THAT CAN BE USED BY ANY ORGANISATION INVOLVED IN THE RESPONSE.

**FLIR CAMERAS ARE ELECTRO-OPTICAL THERMAL IMAGING DEVICES THAT DETECT HEAT AND PROVIDE A VISUAL REPRESENTATION OF SMALL PARTS OF A FIRE.

***INFRARED LINESCAN SYSTEM IS A PASSIVE AIRBORNE INFRARED RECORDING SYSTEM, WHICH SCANS ACROSS THE GROUND BENEATH THE FLIGHTPATH, ADDING SUCCESSIVE LINES TO THE RECORD AS THE AIRCRAFT ADVANCES ALONG THE FLIGHT PATH.

The responses in relation to the fire data were broken into three categories relating to incident size as determined by the AIIMS/ICS system:

- Small fire (Level 1) – characterised by being able to be controlled through local or initial response resources within a few hours of notification;
- Medium fire (Level 2) – are more complex either in size, resources, risk or community impact. May require interagency response;

- Large fire (Level 3) – are protracted, large and resource intensive. They may affect community assets and/or public infrastructure, and attract significant community, media and political interest.

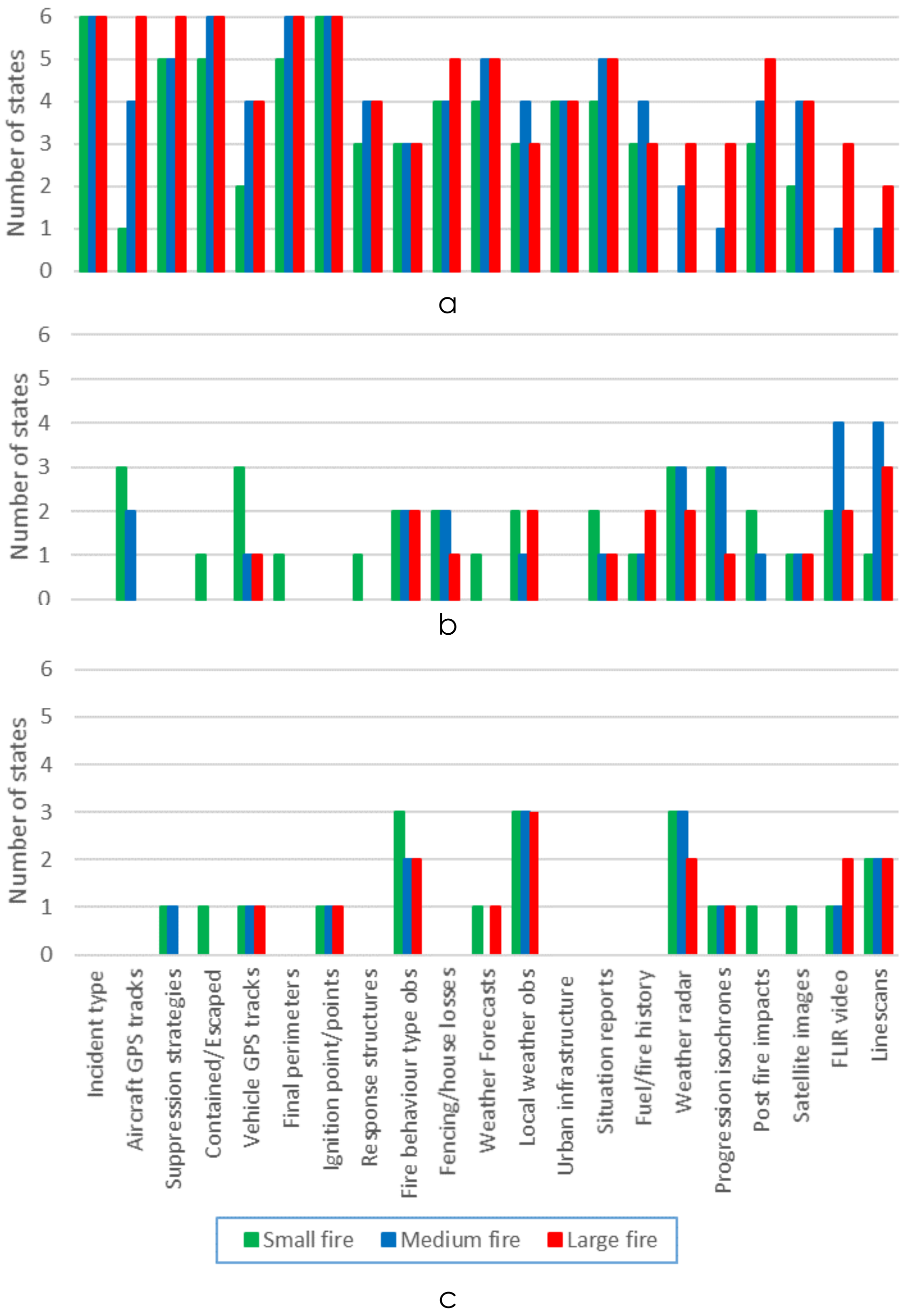

FIG. 1. RESPONSES FROM FIRE AND LAND MANAGEMENT AGENCIES IN AUSTRALIA. CLUSTERED COLUMNS SHOW THE NUMBER OF STATES, WHICH COLLECT SPECIFIC DATA TYPE ROUTINELY (A), OCCASIONALLY (B) OR SHOULD COLLECT ROUTINELY (C). THE RESPONSES ARE GIVEN FOR SMALL (GREEN), MEDIUM (BLUE) AND LARGE (RED) FIRES.

We found that the amount of information collected increases with increasing fire size (Figure 1). Basic information that is simple to collect such as ignition location, incident type and final perimeters are recorded by at least one agency in all states. Data types that are more complex to collect (such as fire perimeters) or have technological requirements (such as FLIR) are collected in fewer states. This is due in part to the differing technical capabilities of the states (for example, some states lack of aircraft with linescan and infrared equipment). There more detailed quantitative data (which is important for conduction analysis of fire behaviour) such as weather radar, progression isochrones, FLIR video, linescans, are generally only collected occasionally (Figure 1b). Apart from fire sizes, it is unclear what stimulates the collection of such data. If these data are only collected from fires of a specific nature, it may result in biases that affect analysis and interpretation of the frequency of extreme fire behaviour.

When asked what kind of data should be collected routinely in the future, almost all interviewees noted that for all groups of fires it would be ideal to start recording fire behaviour type, weather radar and local weather (Figure 1c). From our surveys, we also identified that there is a high degree of variation in the way data is curated. While we were unable to conduct quantitative analysis, it is evident that stored in a variety of ways (e.g. hard copies, local servers, online data repositories). Databases are not shared between states and rarely between agencies within the same state, and information storage is not centralised; i.e. different categories of fire data may be stored in different systems or at different physical locations. For example in South Australia data is stored in an Incident database, logbooks, a fire behaviour analyst server, a Corporate GIS database, the Critical Resource Incident Information Management System Online Network (CRIIMSON), the SA Computer Aided Dispatch (SACAD) system, the Australasian Incident Reporting System (AIRS), and Incident Management Teams reports (IMTs). For access to each data source, separate permissions are typically required. Even if data is of high quality and correctly scoped, difficulty in access may hinder fire behaviour science.

Innovation in data collection

The management of information during active bushfires is an undoubtable challenge to managers. However, with recent technological developments, it is likely to become simpler to collect some information. There are a wide range of methods that have been developed in the research space that have not yet been adapted for operational use by fire management agencies. Research will always produce more methods than agencies will adopt, however methods that can be demonstrated to efficiently provide meaningful data are likely to be considered. For a new method to be adopted ideally there will be 1) a tangible immediate benefit to the agency utilising it and 2) a long term benefit to the agency through improved decision support as a result of research outputs. Researchers and agencies need to work more closely to identify such methodologies and develop strategies for data collection that ensure the quality of the data recorded while minimising cost and disruption to the agencies. In this section, we review a number of recent innovations that have the potential to assist with both management and science. Some of these are already in use in parts of Australia.

Perhaps the greatest recent advancement in fire behaviour research is data derived from remote sensing before, during and after the fire. Remotely sensed data give researchers a means to quantify patterns of variation in space and time. The utility of these data depends on the scale of application. Satellites and aircraft are the main sources of these data. Multi-temporal remote sensing techniques based on space and airborne sensors have been effectively employed to assess and monitor landscape change in a rapid and cost-effective manner (36,37). Remotely sensed data have been used to detect active fires (38,39); map fire extents (40–43); estimate surface and crown fuel loading (44,45); assess active fire behaviour (46–48) and examine post-fire vegetation response (49,50).

One of the more developed remote sensing approaches is the mapping of metrics that can be used to derive fire severity. Fire severity is a retrospective measure of the environmental impact of a fire (24). Such approaches include assessing changes in indices such as Normalized Burn Ratio (dNBR) (51,52), and the Normalized Difference Vegetation Index (NDVI) (53–55). Severity maps can be used to determine the relative importance of factors including fuels, weather, terrain and disturbance history to fire post event (27,56–58). Recording the sequence of satellite derived metrics over time can provide valuable data to understand a range of issues such as fuel accumulation, ecological response and vegetation change. A fire severity map can also be used as a detailed map of the burned area and an indirect measure of fire behaviour.

Fire behaviour and measures of the fuel consumed have been quantified through the analysis of thermal infrared imagery (59–61). Infrared (IR) sensors and Infrared Line Scanning Systems on aircrafts allow land managers to detect actively burning areas, spot fires, estimate the energy radiated from the fire as it burns and to analyse fire behaviour. These approaches allow for the determination of key parameters of the fire, such as intensity, size, rate of spread, hazards and other factors relevant to suppression activities and logistics. Line Scanning Systems have been used for many years for fire mapping for firefighting purposes (62). However, to date the systematic use of them to collect fire behaviour data has been limited. When routinely collected, progression isochrones will significantly simplify the process of fire reconstruction and improve fire simulation tool validation. Mapped data will also provide an understanding of how spatial processes like climate, topography, and vegetation dynamics influence fire behaviour and regimes. Combining these data with information on fire behaviour type and evidence of "unusual" behaviour, such as extreme fire behaviour, is vital. Routinely collecting information about fire intensity, fire front depth, spotting ignitions and "unusual" fire behaviour will help to better understand fire behaviour and improve operational and physical models.

Another system in operational use for firefighting that has had limited adoption for systematic data collection is the use of low altitude IR fire observation. Operationally in Australia, aircraft use a single IR sensor which can detect fire fronts or hot spots and firebrands but not both. Most imaging techniques intended to detect the heat signature of fire are based on MWIR (Medium Wavelength Infrared) and TIR (Thermal Infrared) sensors (63). Using a single IR sensor is problematic as the signal varies with emissivity, there is considerable incident energy and only a small fraction of the pixel may correspond to the fire. Using multi-spectral methods can solve of this problem. For example, in the USA the airborne fire data gathering derived from multi-spectral data acquired by autonomous modular line-scanner sensors (AMS) operating in shortwave (SWIR), MWIR and LWIR spectral regions and providing enhanced dynamic range in support of active fire imaging (64). Using also a multispectral approach the fire radiative power, fire fractional area and temperature estimates can be estimated (64). Furthermore such systems can view through smoke, allowing the nature of ember generation and transport to be observed.

A relatively recent set of methods used in research but not yet in operational fire management is the 3D visualisation and measurement of bushfire smoke plumes and the atmosphere using LIDAR (LIght Detection And Ranging), SODAR (SOnic

Detection And Ranging) and RADAR (RAdio Detection And Ranging). These methods extract vertical profiles of the smoke plumes and also record the movement of winds and hot gases from the fire. Such information is critical for scientists to understand fire behaviour – in particular the rapid acceleration that occurs with some fires as they become large. The intensity and evolution of convective plumes is critical in the understanding of lofting and spotting of embers, where plume structure begins to play an important role in how the embers are spatially distributed. A number of studies have also characterized smoke plume behaviour using information derived from satellite data (65–67). Information on smoke-plume heights and their dynamics and these data will allow for improvements in smoke dispersion and air quality models (68–70).

Weather RADAR (71–74) and LIDAR (68–70) have also been used for visualizing active fires in context of dynamic broad scale weather events, understanding plume formation and estimation of it characteristics. As weather RADARs are maintained over large parts of Australia as part of rain monitoring, they have very broad coverage and scan at a high frequency. Extreme fire weather features like sudden wind changes, the escalation of a plume into a pyrocumulonimbus (PyroCb) or the advent of dry thunder storms and associated lightning are all important events to be considered during a major bushfire event but are rarely captured using existing methods. Ground-based scanning systems such as RADAR can be considerate an important auxiliary tool for detecting unauthorized burning and forest fires, adding significant value to the information for decision-making in monitoring, detecting and suppressing bushfires. An advantage of using weather RADAR to analyse fire is that the network is already in place and maintained for another purpose. Consequently, barriers to its adoption are low.

Remote sensing methods have provided a major step forward in data collection and understanding fire behaviour. Methods for collecting these data are also under constant development. Two major areas are worth highlighting. Firstly, as new satellites are launched the quality and quantity of data available will increase. In Australia, research and management have both used the Advanced Very High Resolution Radiometer (AVHRR) imagery and the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra (1999) and Aqua (2002) (75). The launch of the Japan Meteorological Agency (JMA) Himawari-8 satellite, with the 16-band Advanced Himawari Imager (AHI-8) onboard in October 2014 presents a significant opportunity to improve the timeliness of satellite fire detection across Australia. The near real-time availability of images, at a ten minute frequency, may also provide contextual information (background temperature) leading to improvements in the assessment of fire characteristics (Hally et al. 2016). Secondly, unmanned aerial vehicles (UAVs) as remote sensing platforms have the great potential to increase the efficiency of data acquisition, but their applications are still at an experimental stage (76–78). UAV remote sensing has low material and operational costs, flexible control of spatial and temporal resolution, high-intensity data collection, and a reduction of risk to crews. As the complexity of UAV and sensors increase, so will our ability to capture high resolution spatial data at bushfires. An additional advantage is that they can be used in conditions that would be hazardous to human health; particularly around fast moving fires or where there is unstable weather.

While there are a wide range of sources of information in relation to fires, as a starting point we recommend a focus on particular categories (Table 3). These categories are those that will provide the greatest information in relation to all types of fire behaviour, but particularly extreme fire behaviour – the phenomena that only occur at large scales and under severe conditions that cannot be safely replicated experimentally. As extreme fires are those that are most damaging to society, improved knowledge in relation to them are likely to have the greatest dividends to improved management.

Data category	Data types	Protocol	Research outputs
Ground observations and operational information	▪ Building column ▪ Extreme fire behaviour ▪ Plume colour ▪ Wind entrainment ▪ Blocking plume ▪ Channelling ▪ Asset impact/losses ▪ Ignition point/points ▪ Fuel/fire history ▪ Ground weather observations	▪ Having an online system for noting significant events ▪ Periodic on-ground observations of weather ▪ Standardised data collection procedures for every data type to reduce dependence on the observer. E.g. for convective column: colour, height, sudden size/colour changes, tilt, PyroCb, downdraft, wind direction change.	▪ Understanding fire behaviour and fire-atmosphere interactions under regular/extreme conditions
Linescans	▪ Linescan images	▪ Clear metadata on linescan flights ▪ Repeated linescans of fires every 30-60 minutes minimum ▪ A focus on active parts of fires and expected fire behaviour changes ▪ Using simultaneously multispectral sensors in both MWIR and TIR(LWIR) bands	▪ Fire intensity ▪ Flame depth ▪ Rate of spread ▪ Fire perimeter ▪ Flaming/smouldering combustion ▪ Hot spots
Forward Looking IR	▪ IR/visual video and images ▪ Progression isochrones	▪ An online/digital documented process ▪ Every video and footage must have time and location ▪ Using simultaneously three sensors in MWIR, TIR(LWIR) and visual ranges ▪ Post processing of this data using specific algorithms ▪ Flight plan ▪ Targeting of spot fires ahead of moving fire fronts ▪ Opportunistic IR measurements/Guidelines on what to look for ▪ Recording of operator observations	▪ Real time fire dynamics ▪ Ember transport and ignition ▪ Suppression methodologies ▪ Actively burning areas ▪ Spot fires ▪ Energy radiated from the fire ▪ Fire intensity ▪ Flame depth ▪ Rate of spread ▪ Surface temperature ▪ Models validation
Aerial observers	▪ Atmospheric profile ▪ Plume characteristics ▪ Changes in fireground conditions	▪ Standardised data collection procedures to reduce dependence on the observer ▪ Geolocation and time stamping imagery and digitally recording times and places of noteworthy fire behaviour ▪ Weather observation	▪ Understanding fire behaviour and fire-atmosphere interactions under regular/extreme conditions
Satellites	▪ Satellite images ▪ Fire severity maps	▪ Procedure to adopt active sensors during fires ▪ System to identify and store data from satellites recording over fire areas as fires occur	▪ Fire intensity ▪ Flame depth ▪ Rate of spread ▪ Surface temperature ▪ Fire radiative power ▪ Char and ash cover ▪ Area burned ▪ Fire perimeter ▪ Flaming/smouldering combustion ▪ Smoke plume ▪ Plume injection heights ▪ Hot spots ▪ Atmospheric chemistry changes

Data category	Data types	Protocol	Research outputs
Remote weather observations	▪ Meteorological parameters ▪ Radar data	▪ Having an online system to store data	▪ Visualization of active fires ▪ Detection of dynamic effects
Unmanned Aerial Vehicle	▪ Local weather characteristics ▪ IR/visual video and images ▪ Lidar data	▪ Development and implementation of regulations to use UAVs during fires.	▪ Mapping canopy gaps and height ▪ Tracking fires ▪ Supporting intensive forest management ▪ Fire intensity ▪ Flame depth ▪ Rate of spread ▪ Hot spots/Spotting ▪ Real time fire dynamics ▪ Ember transport and ignition ▪ Suppression methodologies
Vehicle/aircraft GPS tracks and suppression strategies	▪ Aerial and ground GPS tracks ▪ Time of the water drop/suppression ▪ Vehicle type and fire size class	▪ Having an online system for data recording	▪ Optimisation suppression activities and strategy

TABLE 3. LIST OF RECOMMENDED DATA AND PROTOCOLS FOR ROUTINELY COLLECTION USING CURRENT TECHNOLOGIES.

Any system or set of measures must be accompanied by the development of a robust data storage system. The development of systems to recognise, tag, store and share fire related information could greatly reduce data discoverability issues for research and governmental inquires. Much of the information currently gathered during a fire by a fire management agency is stored in some form, however only a small proportion is centralised and can be easily accessed. A centralised and/or standardised data storage approach would streamline this process and result in better management and research outcomes. Furthermore, consistency in data storage and management should result in improved data sharing between fire management agencies and from a research perspective this should allow for more comprehensive datasets to be developed increasing the application of research results.

Summary

Land and emergency response organisations are increasingly being expected to deliver scientifically defensible decisions and to demonstrate continuous improvement in management and resource use. The limited availability of high quality data on bushfire behaviour restricts the rate at which research can advance particularly on the most damaging fires that occur. It is imperative that the losses caused by severe fires are not in vain; losses should be offset by efforts to maximise the information obtained, helping to prevent a repeat of such events in the future. Improvement of data collection will facilitate providing leverage on data collected and allow robust conclusions to be reached sooner and with less expense. This would include improving systems and processes in use today, as well as considering new technologies than can help information to be collected more efficiently. To be successful, this must be in a form of partnership between researchers and fire agencies, and ideally with a coordinated approach that standardises methods, technologies and approaches Australia wide.

INVESTIGATION OF EMBER PRODUCTION

Collaborative research was completed looking at characterising ember production during fires. This was conducted using data from experimental forest fires conducted in the New Jersey Pine Barrens, USA in March of 2013– 2015. Several preliminary techniques were tested to characterise ember production (2). Viable windblown embers were collected from three plots at the burns each year and analysed for mass and size distribution. Thermal imagery was used to measure the velocity, size and number of falling embers in 2014 and 2015. It was found that at least 70% of collected particles were bark fragments and the rest were pine and shrub branches. The proportion of embers of a particular size class decreased with increasing ember cross sectional area. The mass of the particles varied from 5 to 50 mg, and the maximum number of the particles was observed for the mass range of 10–20 mg. About 80% of embers were particles with the cross sectional area of 50–200 mm^2. Infrared video showed that starting from a distance of 13 m from fire front, an increasing number of embers were observed to be falling; up to 180 per second. Relationships describing the time-variation of the number of particles that dropped on a 1.4 m^2 surface and the number of particles that flew through a 1 m^3 volume were obtained. In addition, the velocity of the particles was found to be dependent on the wind velocity.

DETERMINATION OF SMOULDERING TIME AND THERMAL CHARACTERISTICS OF EMBERS

A laboratory experiment was conducted to simulate the transfer of smouldering particles produced in forest bushfires by a heated gas flow (3). Pine bark pieces with the linear dimensions L=(15; 20; 30) mm and a thickness of h=(4–5) mm were selected as model particles. The rate and temperature of the incident flow varied in the range of 1–3 m/s and 80–85 °C, respectively. The minimum smouldering temperature of pine bark was found to be 190 °C. This temperature will cause thermal decomposition of bark only at the first stage (oxidation of resinous components). In the study, the smouldering time, the temperature and the weight of samples were obtained and analysed under various experimental conditions. The data analysis showed that the increase in the particle size leads to the decrease in their rate of mass loss, and the rate change of the incident flow does not practically influence the mass change. The results have shown that the increase in the particle size leads to the increase in the smouldering time. The position of the particle plays an important role, the effect of which increases with increasing the particle size. The calculations showed that the smouldering time of bark samples is long enough for the particles to serve as new sources of spot fires.

This work was supported by laboratory work carried out on bark fragments that can be easily detached from the trunks of Eucalyptus obliqua trees– messmate stringybark. The combustion time and smouldering time of bark fragments were found to be a function of the particle dimensions, with larger particles smouldering for longer periods (79). Additionally, when stringybark forests burn, a layer of char is created on the outside of tree trunks. It was found that this char can impede tree ignition by fire, however once the bark ignites, there is no further effect on the time bark particles burn. At a broader level, the degree of char on trees is well recognised during fuel hazard assessments. However physical dimensions of the loose bark fragments are more difficult to sample with current measures.

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APPENDIX 1 – DATA COLLECTION SURVEY EXAMPLE

Data types		
1. Incident type	2. Aircraft GPS tracks	3. Suppression strategies
4. Contained/escaped	5. Vehicle GPS tracks	6. Final perimeters
7. Ignition point/points	8. Response structures	9. Post fire impacts
10. Fencing / house losses	11. Weather Forecasts	12. Local weather observations
13. Urban infrastructure	14. Situation reports	15. Fuel /fire history
16. Weather radar	17. Progression isochrones	18. Fire behaviour type observations
19. Satellite images	20. FLIR video	21. Line scans

What kind of data are you collecting during an accident?

Name	**Collect routinely**	**Collect occasionally**	**Should be collected routinely**	**Data storage (logbook/PC/Web)**
Small fire				
Medium fire				
Large fire				

APPENDIX 2 – DATA COLLECTION SURVEYS

Australian Capital Territory

		Small fire						Medium fire						Large fire					
		R		O		S		R		O		S		R		O		S	
		Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS
1	Incident type	1	1					1	1					1	1				
2	Aircraft GPS tracks			1	1				1	1					1	1			
3	Suppression strategies	1	1					1	1					1	1				
4	Contained/Escaped	1	1					1	1					1	1				
5	Vehicle GPS tracks		1			1			1			1			1			1	
6	Final perimeters	1			1			1	1					1	1				
7	Ignition point / points	1			1			1	1					1	1				
8	Response structures	1						1	1					1	1				
9	Fire behaviour type observations	1						1	1					1	1				
10	Fencing / house losses	1	1					1	1					1	1				
11	Weather Forecasts	1						1	1					1	1				
12	Local weather observations	1						1	1					1	1				
13	Urban infrastructure	1	1					1	1					1	1				
14	Situation reports	1	1					1	1					1	1				
15	Fuel /fire history	1	1					1	1					1	1				
16	Weather radar					1					1	1					1	1	
17	Progression isochrones										1						1		
18	Post fire impacts	1						1	1					1	1				
19	Satellite images							1			1			1			1		
20	FLIR video								1	1					1	1			
21	Linescans								1	1					1	1			

R – routinely, O – occasionally, S – should be collected routinely
Parks – Parks and Conservation Service, RFS – Rural Fire Service

New South Wales

		Small fire						Medium fire						Large fire					
		R		O		S		R		O		S		R		O		S	
		Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS	Parks	RFS
1	Incident type		1						1						1				
2	Aircraft GPS tracks	1	1					1	1					1	1				
3	Suppression strategies	1	1					1	1					1	1				
4	Contained/Escaped		1						1						1				
5	Vehicle GPS tracks																		
6	Final perimeters	1			1			1	1					1	1				
7	Ignition point / points	1	1					1	1					1	1				
8	Response structures	1			1			1	1					1	1				
9	Fire behaviour type observations				1	1				1	1						1		
10	Fencing / house losses		1						1						1				
11	Weather Forecasts	1	1					1	1					1	1				
12	Local weather observations	1				1		1	1					1	1				
13	Urban infrastructure																		
14	Situation reports	1	1					1	1					1	1				
15	Fuel /fire history	1			1			1	1					1	1				
16	Weather radar				1	1			1			1			1				
17	Progression isochrones				1						1				1	1			
18	Post fire impacts		1						1						1	1			
19	Satellite images		1			1			1						1	1			
20	FLIR video				1					1	1			1	1				
21	Linescans				1						1			1	1				

R – routinely, O – occasionally, S – should be collected routinely
Parks – National Parks and Wildlife Service, RFS – Rural Fire Service

Queensland

		Small fire						Medium fire						Large fire					
		R		O		S		R		O		S		R		O		S	
		Parks	FES	Parks	FES	Parks	FES	Parks	FES	Parks	FES	Parks	FES	Parks	FES	Parks	FES	Parks	FES
1	Incident type	1	1					1	1					1	1				
2	Aircraft GPS tracks				1					1	1				1				
3	Suppression strategies	1						1						1					
4	Contained/Escaped	1						1						1					
5	Vehicle GPS tracks				1				1						1				
6	Final perimeters	1						1						1					
7	Ignition point / points	1					1	1					1	1					1
8	Response structures																		
9	Fire behaviour type observations			1			1			1			1			1			1
10	Fencing / house losses			1						1						1			
11	Weather Forecasts		1	1		1			1	1		1			1	1		1	
12	Local weather observations		1	1		1				1		1	1			1		1	1
13	Urban infrastructure		1						1						1				
14	Situation reports	1						1						1			1		
15	Fuel /fire history										1						1		
16	Weather radar				1				1						1				
17	Progression isochrones																		
18	Post fire impacts	1						1						1					
19	Satellite images		1						1						1				
20	FLIR video																		
21	Linescans						1						1						1

R – routinely, O – occasionally, S – should be collected routinely
Parks – Queensland Parks and Wildlife Service, FES – Queensland Fire and Emergency Services

South Australia

		Small fire						Medium fire						Large fire					
		R		O		S		R		O		S		R		O		S	
		DEWNR	CFS	DEWNR	CFS	DEWNR	CFS	DEWNR	CFS	DEWNR	CFS	DEWNR	CFS	DEWNR	CFS	DEWNR	CFS	DEWNR	CFS
1	Incident type	1	1					1	1					1	1				
2	Aircraft GPS tracks			1	1			1			1			1	1				
3	Suppression strategies		1	1					1	1				1	1				
4	Contained/Escaped				1	1			1	1				1	1				
5	Vehicle GPS tracks			1						1						1			
6	Final perimeters			1	1			1			1			1	1				
7	Ignition point / points	1	1					1	1					1	1				
8	Response structures			1	1			1			1			1	1				
9	Fire behaviour type observations		1	1					1	1					1	1			
10	Fencing / house losses		1	1				1	1					1	1				
11	Weather Forecasts			1				1	1					1	1				
12	Local weather observations			1	1			1			1						1		
13	Urban infrastructure		1	1					1	1				1	1				
14	Situation reports			1	1			1	1					1	1				
15	Fuel /fire history			1	1			1		1	1					1	1		
16	Weather radar			1						1				1					
17	Progression isochrones			1						1	1			1	1				
18	Post fire impacts			1						1	1			1	1				
19	Satellite images									1						1	1		
20	FLIR video										1	1					1	1	
21	Linescans									1						1	1		

R – routinely, O – occasionally, S – should be collected routinely
DEWNR – Department of Environment, Water and Natural Resources; CFS – Country Fire Service

Victoria

		Small fire						Medium fire						Large fire					
		R		O		S		R		O		S		R		O		S	
		DEWLP	CFA	DEWLP	CFA	DEWLP	CFA	DEWLP	CFA	DEWLP	CFA	DEWLP	CFA	DEWLP	CFA	DEWLP	CFA	DEWLP	CFA
1	Incident type		1						1						1				
2	Aircraft GPS tracks								1						1				
3	Suppression strategies						1						1		1				
4	Contained/Escaped		1						1						1				
5	Vehicle GPS tracks		1						1						1				
6	Final perimeters		1						1						1				
7	Ignition point / points		1						1						1				
8	Response structures																		
9	Fire behaviour type observations						1						1						1
10	Fencing / house losses				1						1				1				
11	Weather Forecasts																		
12	Local weather observations						1						1						1
13	Urban infrastructure																		
14	Situation reports				1						1						1		
15	Fuel /fire history																		
16	Weather radar						1						1						1
17	Progression isochrones						1						1						1
18	Post fire impacts						1												
19	Satellite images																		
20	FLIR video						1				1						1		
21	Linescans						1				1						1		

R – routinely, O – occasionally, S – should be collected routinely
DEWLP – Department of Environment, Land, Water and Planning; CFA – Country Fire Authority

Western Australia

		Small fire						Medium fire						Large fire					
		R		O		S		R		O		S		R		O		S	
		DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2	DPAW1	DPAW2
1	Incident type	1	1					1	1					1	1				
2	Aircraft GPS tracks										1				1				
3	Suppression strategies		1	1				1	1					1	1				
4	Contained/Escaped		1						1						1				
5	Vehicle GPS tracks			1	1			1			1			1			1		
6	Final perimeters	1	1					1	1					1	1				
7	Ignition point / points	1	1					1	1					1	1				
8	Response structures		1	1				1	1					1	1				
9	Fire behaviour type observations		1	1				1	1					1	1				
10	Fencing / house losses	1	1					1	1					1	1				
11	Weather Forecasts	1	1					1	1					1	1				
12	Local weather observations			1				1			1		1	1			1		1
13	Urban infrastructure		1	1				1	1					1	1				
14	Situation reports		1		1			1	1					1	1				
15	Fuel /fire history	1	1					1	1					1	1				
16	Weather radar										1						1		
17	Progression isochrones			1				1			1			1	1				
18	Post fire impacts			1	1			1			1			1	1				
19	Satellite images			1				1			1			1	1				
20	FLIR video			1						1				1			1		1
21	Linescans									1		1				1		1	1

R – routinely, O – occasionally, S – should be collected routinely
DPAW – Department of Parks and Wildlife