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FIRE COALESCENCE AND MASS SPOT FIRE DYNAMICS: EXPERIMENTATION, MODELLING AND SIMULATION

Annual project report 2019-2020

Jason Sharples[1,4], James Hilton[2,4], Andrew Sullivan[3,4], Rachel Badlan[1]

[1] UNSW Australia, [2] CSIRO Data61, [3] CSIRO Land and Water & [4] Bushfire and Natural Hazards CRC

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EXECUTIVE SUMMARY

This report outlines the progress of the *Fire Coalescence and Mass Spot Fire Dynamics* project, which is one of the projects within the Next Generation Fire Modelling cluster. Specifically, the report summarises progress of the first two years of the second phase of the project, which has been extended over 2018-2021.

All milestones from the 2015-2018 phase of the project have now been delivered, and the project is continuing to build upon this work in delivering important insights into the dynamics of fire behaviour and fire line interaction. Phase 2 of the experimental program is in progress, and will extend recently published work from Phase 1. The project continues to yield important and significant insights into the behaviour of coalescing fires, and these insights are enhancing our understanding of the processes driving fire propagation and the way we model dynamic fire behaviours.

In particular, the research has continued to develop the pyrogenic potential model by incorporating firebrand dynamics. This has resulted in the world's first capability to model dynamic modes of fire propagation such as vorticity-driven lateral spread using a two-dimensional simulation framework with a spotting module. This means that explicitly modelling such effects in operational timeframes is now a feasible option. The research has also examined how wind-terrain interaction influences ember trajectories and the likely distribution of spot fires down wind of complex terrain.

In the past year, the project team have delivered a number of research outputs, including conference presentations and posters and journal publications. Still more publications are in preparation. The project team has also delivered on a number of key utilisation activities. These have mainly involved discussions with key end users about the prospects of the research being incorporated into education materials and training resources for firefighters and fire behaviour analysts. The project has also begun working on a dedicated utilisation project aimed at development of spot fire spatial mapping tools.

After providing some background information on the project's aims and methodology, this report provides details on the progress of the project to date. In particular, this includes:

- Milestone delivery;
- New research developments;
- Utilisation project activities;
- Details on presentations that have been delivered by members of the project team;
- Details on publications and publications in preparation;

At the time of writing, the project is on-schedule.

Prof. Jason Sharples
Project Leader
School of Science,
UNSW Australia

END USER STATEMENT

Brad Davies, *New South Wales Rural Fire Service, NSW*

The project continues to apply an innovative multi-streamed approach to better understand and efficiently model dynamic fire behaviours associated with fire coalescence and mass spotting. In particular, the project team have developed computationally efficient approaches to model dynamic fire behaviours such as spot fire coalescence, fire line merging and vorticity-driven lateral spread. The project is now well into developing ways in which the research can be incorporated into operational practice.

Over the past year, the project team has engaged with end users through seminars, forums, workshops, online events and direct discussion with the Project Leader. The project continues to produce excellent research publications, and project members are consistently available to assist end users in their interpretation. Discussions around research utilisation, including the development of operational products, and education and training materials have progressed, and additional ways this exciting work can be utilized are continuing to emerge as the research evolves. The research is directly relevant to many of the issues encountered in managing catastrophic fires and is strongly enhancing our understanding and predictive capacity of dynamic fire behaviours.

INTRODUCTION

Fire behaviour in dry eucalypt forests in Australia (and in many other vegetation types to a lesser extent) is characterised by the occurrence of spot-fires—new fires ignited by the transport of burning debris such as bark ahead of an existing fire. Under most burning conditions, spot-fires generally play a minor role in the overall propagation of a fire, except perhaps when spread is impeded by breaks in fuel or topography which spot-fires enable the fire to overcome. However, under conditions of severe and extreme bushfire behaviour, spot-fire occurrence can be so prevalent that spotting becomes the dominant propagation mechanism and the fire spreads as a cascade of spot-fires forming a 'pseudo' front (McArthur 1967).

It has long been recognised that the presence of multiple individual fires affects the behaviour and spread of all fires present. The convergence of separate individual fires into larger fires is called coalescence and can lead to rapid increases in fire intensity and spread rate, often in directions at odds with the prevailing wind. This coalescence effect is frequently utilised in prescribed burning via multiple point ignitions to rapidly burn out large areas.

The zone between two coalescing fires is known as the convergence or junction zone and can be a very dangerous place to be for firefighters and may lead to highly erratic fire behaviour as witnessed during the 2003 Canberra fires. Fire behaviour under such conditions may be dominated by dynamic feedback processes between the energy released by each fire and the coupling of that energy with the atmosphere.

All existing operational fire behaviour models assume that a fire will burn at an approximately constant (quasi-steady) rate of spread for a given set of environmental conditions. While recent work showed that an individual fire starting from a point accelerates to this steady state, little research has been undertaken into the behaviour of multiple simultaneous adjacent ignitions under wildfire conditions or the effects of the dynamic feedbacks involved. No operational fire spread models currently account for the dynamical aspects of fire spread, particularly fire-fire interactions. This inability to accurately predict the behaviour of mass spotting events and the interactions of multiple adjacent fires places firefighters at risk and the general public in danger. With the projected climate change impacts expected to produce more extreme bushfires and a prevalence of mass fire behaviour, this deficiency in our understanding and operational systems represents a considerable knowledge gap.

The effects of dynamic processes on fire spread cannot be calculated using tables, spreadsheets or simple calculators. To comprehensively account for the effects of dynamic fire spread it is necessary to model the phenomenon using a physics-based model that incorporates complete descriptions of the key processes, including interactions between the fire, the fuel, topography and the surrounding atmosphere (e.g. WFDS (Mell et al 2007), FIRETEC (Linn et al 2002)). Unfortunately, such a modelling approach is computationally intensive and expensive, with associated model run-times that prohibit operational application (Sullivan 2009).

This project addresses these issues by investigating the processes involved in the coalescence of free-burning fires under experimentally controlled conditions, quantifying the physical mechanisms involved in these, and investigating the potential of geometric drivers of fire line propagation with the aim of developing a physically simplified proxy for some of the more complicated dynamical effects, particularly those driven by pyroconvective interaction between different parts of the fire(s). This approach enables development of models that are able to effectively emulate the dynamics of fire spread without the need to explicitly model fire-atmosphere or fire-fire interactions in a computationally costly manner.

PROJECT BACKGROUND

To enhance our knowledge of the effects of intrinsic fire dynamics on fire spread this project employs sophisticated mathematical modelling techniques in combination with fire experiments spanning laboratory and landscape scales. In particular, the project will develop computationally efficient fire spread models which include physically simplified proxies for complicated dynamical effects.

The overarching analytical approach adopted in this project is to treat fire as an evolving interface. This is not new – many researchers have treated fire in such a way, but the methods they have used have often been confounded due to the changes in topology that can be encountered when fire lines merge or when pockets of unburnt fuel develop (Bose et al. 2009). Such occurrences are rife when spot fires coalesce (see Figure 1), and so employing a methodology that is able to successfully deal with these types of behaviours is crucial to effectively and efficiently model spot fire development. We therefore employ a level set approach, which is well known to be able to deal with such complexities (Sethian, 1999).

In addition to its ability to deal with topological changes, the level set method also allows for the easy inclusion of additional dynamic drivers, which we aim to include as two-dimensional proxies for more complicated three-dimensional effects.

Phase 2 of the project builds on work completed in phase 1 by members of the project team, who have investigated the use of potential flow to simulate instances of dynamic fire propagation such as fire line merging (Sharples et al. 2013; Hilton, 2014).

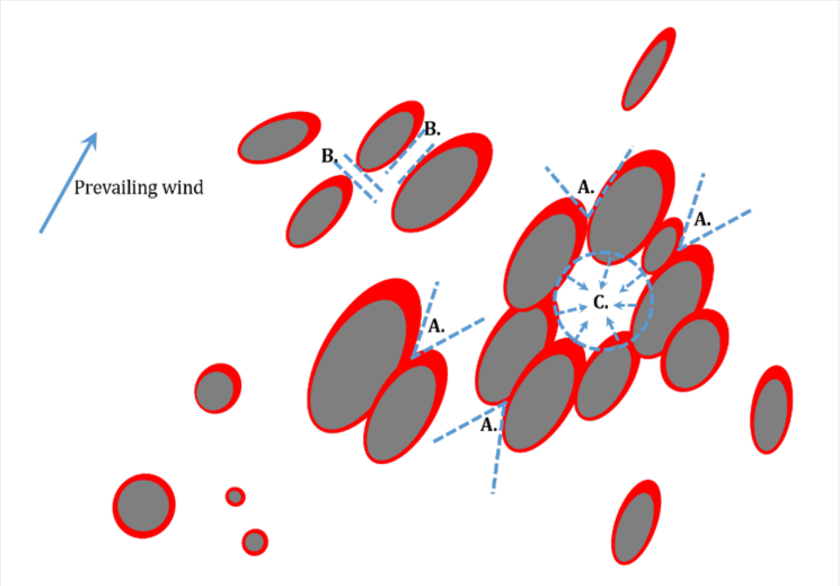

Figure 1: Schematic representation of coalescing spot-fires and forms of interaction between individual spots. Examples of fire line interactions include (A) intersecting oblique lines, non-intersecting converging fire edges (B) and collapsing or constricting perimeters (C). These can be oriented at any angle to the prevailing wind.

To complement model development the project also includes a targeted experimental program. This will involve analysis of experimental fires burning under controlled laboratory conditions, analysis of available field experiments and numerical experiments using couple fire-atmosphere models.

LEVEL SET METHODS FOR INTERFACE MODELLING

Level set methods provide a feasible method for dealing with the types of behaviours encountered when spot fires coalesce. Figure 1 shows a schematic representation of coalescing spot fires and the types of topological issues that can arise due to the discontiguous nature of spot fires.

Fire simulation incorporating pyrogenic potential

A main focus of the research has been the continued development of the 'pyrogenic potential' model. This model adopts the notion that the pyroconvective interactions between different parts of the fire line (or fire lines) arise due to development of pyrogenic indrafts. These indrafts are modelled as a two-dimensional surface flow with a sink everywhere along the fireline. This is shown schematically in Figure 2. The figure shows that the air flowing horizontally into a fire's plume can be treated as an two-dimensional incompressible flow everywhere except along the fire line, where it becomes a purely vertical flow (the two-dimensional flow disappears along the fire line, which is then treated as a 'sink' for the flow).

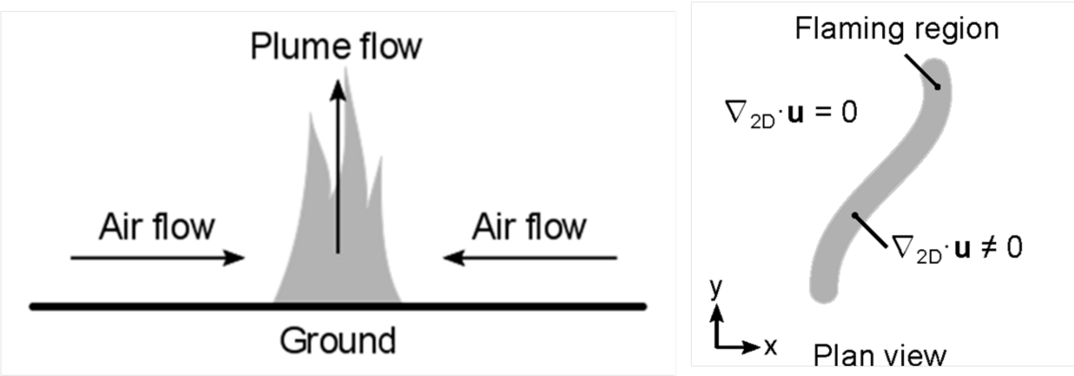

Figure 2: Left: Schematic view of the indraft into a fire plume. Right: Schematic view of a fire line as a sink for the horizontal indraft into the fire's plume.

Initial limitations of the model, which required the indraft flow to be irrotational, have been overcome through use of a near-field approximation via the Helmholtz decomposition. In this sense we assume that the we can write it as the gradient of a pyrogenic potential function ψ. In the presence of an ambient wind, the fire's propagation is then driven by the sum of the ambient wind and the pyrogenic indraft $\nabla\psi$. This gives rise to the upgraded level set formulation, in which fire line curvature has been removed, and instead the level set equation is coupled with a Poisson equation for the pyrogenic potential:

$$\frac{\partial \varphi}{\partial t} = s\|\nabla\varphi\| + \left(\boldsymbol{u}(\gamma) + \boldsymbol{U}_p\right) \cdot \nabla\varphi, \qquad \boldsymbol{U}_p = \nabla\psi + \nabla \times \boldsymbol{\eta} \tag{3}$$

where $\nabla^2\psi = \rho$ and $\nabla^2\boldsymbol{\eta} = \boldsymbol{\omega}$.

Here $\rho = kf(R, \varphi, \nabla\varphi)$, where k can be considered a tuning parameter, and f is a function of the local rate of spread R, and the level set function and it's derivative. The term $\boldsymbol{\omega}$ represents sources of vertical pyrogenic vorticity.

We refer to the model in equation (3) as the '*pyrogenic potential* model' or the 'near-field model'.

Note also that the advective effect of the ambient wind on fire propagation is modeled as follows:

$$\boldsymbol{u}(\gamma) = \begin{cases} \gamma(\widehat{w}\cdot\hat{n})\widehat{w} & \text{if } \widehat{w}\cdot\hat{n} > 0, \\ 0 & \text{if } \widehat{w}\cdot\hat{n} \leq 0. \end{cases} \tag{4}$$

Here $\widehat{w}$ and $\hat{n}$ are the unit vectors pointing in the direction of the wind and normal to the interface, respectively. The model defined by (3) and (4) has been applied to a number of different fire behaviour scenarios. It has successfully reproduced the observed behaviour of a number of experimental fires (across scales from 1metre to 10s of metres), and is able to emulate expected dynamic fire behaviours, such as fire line merging.

More recently, the near-field model has been applied to modes of dynamic fire propagation such as vorticity-driven lateral spread.

Laboratory experiments

Phase 2 of the laboratory experiments using the CSIRO Pyrotron facility will be conducted. These experiments will be broken down into the following three categories:

- Parallel fire line experiments
- Ring fire experiments
- Multiple spot fire experiments

The ring fire experiments are currently in progress.

Field experiments

In addition, the project will draw upon data collected by Portuguese Researchers as part of Project Firewhirl: Vorticity Effects in Forest Fires (on which Sharples is a co-investigator).

Numerical experiments

Development of the near-field model will continue to be informed by a number of targeted numerical simulations using a coupled fire-atmosphere model.

In particular this work will consider the fundamental indraft patterns produced by small fire sources to investigate the scalability of the near-field model.

SPOTFIRE SPATIAL TOOLS – UTILISATION PROJECT

An extreme bushfire is the most dangerous manifestation of a fire and is defined as "a fire that exhibits deep or widespread flaming in an atmospheric environment conducive to the development of violent pyroconvection. All fires start small, and so extreme bushfire development is driven by factors that can cause small fires to rapidly escalate in size and intensity. Extreme fires exhibit expansive areas of active flaming – referred to as 'deep flaming'. Deep flaming has also been referred to by other authors as 'areal fires' or 'mass fires'. These include change of wind direction, strong winds, eruptive fire behaviour, mass-spotting and fire coalescence and VLS.

VLS occurs when steep (or broken) topography and strong winds interact to produce flow separation, creating horizontal vorticity such as a lee slope eddy. The fire's updraft may then stretch and tilt this horizontal vorticity into intense vertical vorticity, which may then cause the fire to spread laterally along the ridge line. The intense vorticity associated with the lateral spread can enhance ember generation. These embers are then transported laterally and downwind due to the combined influence of the vertical vorticity and the prevailing wind, potentially resulting in mass spotting and fire coalescence.

This aim of this utilisation project is to create an operational mapping overlay that highlights areas of high VLS risk. This will begin with static overlays that indicate a single wind direction for an area and then progress to using real-time wind vectors to calculate filters that reflect the changing, dynamic conditions that affect VLS.

The original research into the identification of VLS-prone regions used a 250 metre DEM to determine that a minimum slope of 10.5 degrees was necessary for VLS occurrence. However, there are issues with how slopes scale with DEM resolution. This is because slopes get smoothed (i.e. the angle of slope reduces) with decreasing resolution. The threshold for the flow separation required for VLS is usually cited as 20 degrees and this raises the question of what minimum slope is required to implement the mapping overlays using different resolution DEMs?

VLS WIND-TERRAIN FILTERS

Two filters are required for analysing VLS – a first-order differential of elevation (i.e. the slope) and a second-order differential. A first-order filter on its own would be sufficient if real topography reflected a hill such as that in Figure 3a. However, is not sufficient in rugged terrain which has 'broken' topography. Ridge lines and bluffs which adjoin VLS-prone slopes, are all part of the VLS-prone landscape. Unfortunately, these ridges are not identified by a first-order filter as this filter only captures slopes greater than a certain threshold (but not the top of the ridge, which tends to have gentler slopes (Figure 3b). Therefore, a second-order VLS filter is needed to identify the leeward ridgelines (Figure 3c).

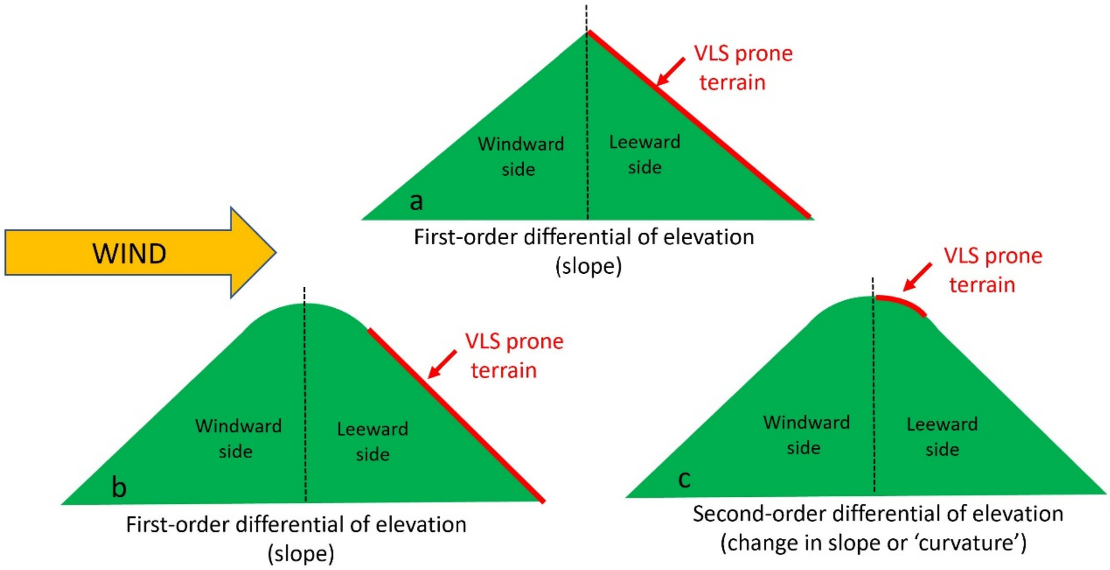

Figure 3: (a) First-order VLS filter applied to a uniform slope. (b) first-order VLS filter applied to a non-uniform slope – the part of the slope near the ridge is not identified. (c) second-order VLS filter applied to a non-uniform slope – the top of the hill near the ridge is identified.

First-order filter

VLS is dependent on the slope and aspect relative to the prevailing wind. These conditions may be expressed formally as:

$$\chi(\sigma,\delta)=\begin{cases}1 & \text{if } S\geq\sigma \text{ and } |\theta-\alpha|\leq\delta,\\ 0 & \text{otherwise,}\end{cases}$$

where S is the topographic slope, α is the topographic aspect and θ is the direction the wind is blowing to. The parameters σ and δ are the slope threshold and aspect discrepancy, respectively. In summary, the first-order filter identifies areas of the landscape with lee-facing slopes where flow-separation is likely to occur (i.e. slope greater than 20°), however the slope threshold will depend on the resolution of the DEM being used.

Second-order filter

The second-order filter depends on the second order directional derivative of the surface (DEM) and the aspect:

$$\phi(\kappa,\delta)=\begin{cases}1 & \text{if } C<\kappa \text{ and } |\theta-\alpha|\leq\delta,\\ 0 & \text{otherwise,}\end{cases}$$

where C is the profile curvature, and κ is a threshold curvature parameter. The profile curvature tool in ArcGIS Pro is used to calculate C across a landscape. This filter identifies areas of the landscape that are associated with ridge lines, whereas the first-order identifies slopes. The second-order filter will identify ridge lines like in Figure 3c.

WHAT THE PROJECT HAS BEEN UP TO

MILESTONE DELIVERY – CORE RESEARCH PROJECT

At the time of writing, the project has completed 29 of the 45 phase 2 milestones. There are 3 overdue milestones, one of which is this report. The other two overdue milestones involve end user meetings, which are hard to complete due to COVID restrictions. There are no issues that would prevent these overdue milestones from being completed soon. No delays are expected going forward.

MILESTONE DELIVERY – UTILISATION PROJECT

At the time of writing, 9 of the 26 utilisation project milestones have been completed. There is one overdue milestone. There are no issues that would prevent this overdue milestone from being delivered in the near future. No delays are expected going forward.

CORE RESEARCH PROJECT PROGRESS

The research has mainly progressed through further development of the near-field model and incorporating spotting capabilities in the model. Two main aspects of this research are worth reporting:

1. Wind-terrain effects on firebrand dynamics,
2. Incorporating firebrands and spot fires into dynamic wildfire behaviour models.

Wind-terrain effects on firebrand dynamics

Despite its importance in bushfire propagation, firebrand transport and the spotting process are still poorly understood, and there is no definitive model that can adequately emulate the spotting process in general. The dynamics of firebrands are difficult to predict due to the complex flow structure resulting from the interaction of a buoyant plume with a boundary layer wind field. Understanding the nature of this flow structure, especially for complex terrain, is essential for determining the likely path of firebrands and subsequent distributions of new spot fires and risk levels on structures downwind from the fire.

Although several prior computational modelling studies have carried out investigations of firebrand transport, the effect of the terrain has not previously been taken into account. It is well known that topography can significantly affect ember generation. For example, the enhanced intensity of a fire running up a steep slope can generate a large number of embers. More generally, terrain-modified flows and the strong turbulence associated with leeward slopes and flow around other prominent topographic features may have a pronounced effect on the transport of firebrands. Moreover, modes of dynamic fire propagation such as vorticity-driven lateral spread and eruptive fire spread in canyons involve a coupling between the fire, the terrain and the prevailing winds and so can affect the rate at which firebrands are produced as well as their subsequent transport.

We used a coupled computational fluid dynamic (CFD) and Lagrangian particle approach to model the transport of firebrands. The model was applied to two different terrain scenarios to investigate the flow dynamics, firebrand trajectories and landing patterns resulting from the interaction with the terrain. The first scenario (Scenario A) is a line of fire on the lee slope of a ridge burning perpendicular to an incident wind flow. The second scenario (Scenario B) is a fire burning in a canyon aligned with the wind. The simulations indicated that the addition of terrain adds a further level of complexity to the flows generated by interaction between the wind and the fire. The terrain appears to modify the counter-rotating vortex pair in the plume structure. For the fire in Scenario A, the wind-terrain interaction resulted in a flattening and tilting of the counter-rotating vortex pair and enhanced regions of recirculation at the edges of the fire, which were conducive to lateral transport of embers. For the fire in Scenario B, the channelling of the winds up the canyon resulted in the formation of a single jet-like vortex transporting firebrands upwards and over the top of the canyon. We believe that this effect is caused by the shape and alignment of the canyon, which forces the vortex pair to merge into a single vortex. These findings were reported by Hilton et al. (2019a) and are summarized in Figure 3.

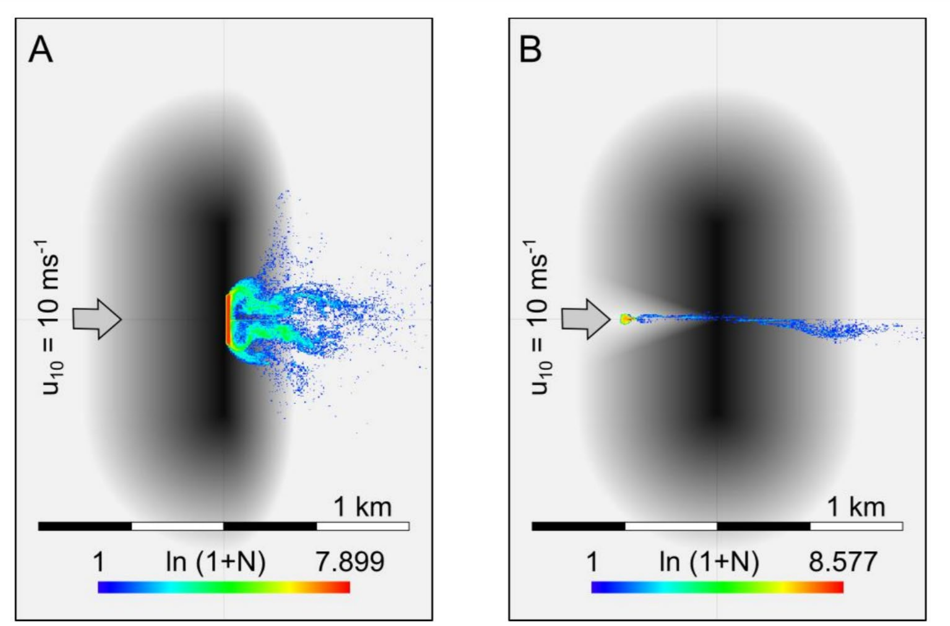

Figure 3: Density map of firebrands for scenario A and scenario B. Figure taken from Hilton et al. (2019a).

Incorporating spotting into dynamic wildfire behaviour models

Complex modes of fire behaviour resulting from local coupling between the fire and the atmosphere are a significant challenge for rapid operational wildfire spread simulations. While three-dimensional fully coupled fire-atmosphere models can account for many types of fire behaviour, their computational demands are prohibitive in an operational context. Two-dimensional fire spread models have much lower computational overhead, but are generally not able to account for complex local coupling effects and cannot provide a three-dimensional flow structure suitable for modelling the transport of firebrands. We extended two-dimensional fire spread simulations to model local coupling effects resulting from wind flow over a ridge that can result in a number of non-intuitive modes of fire behaviour. These include dynamic modes of fire propagation such as vorticity-driven lateral spread (VLS). Furthermore, we developed extensions of these two-dimensional models to incorporate three-dimensional firebrand transport and demonstrated that enhanced downwind spot fire formation can result under certain VLS conditions.

The spread of fires under VLS conditions is driven by vortices in the ground plane. A model for the production and effects of these vortices was incorporated into computational simulations using a vector potential formulation (equation 3). Firebrands were incorporated using a Lagrangian scheme to model transport through the atmosphere and a sub-scale model for spot fire creation and growth. The firebrand transport took factors such as drag, gravity and buoyancy into account. As the effect of plume buoyancy on firebrands under real-world conditions for this scenario is currently unknown, at this stage of the research the plume buoyancy is parameterised using an exponential decay model. The sensitivity of the decay parameter was examined in relation to the resulting spot fire distribution and area burnt. All simulations were carried out using Spark.

The coupled VLS and firebrand transport simulations indicated that a higher value of decay parameter, representing a higher cooling rate of the plume, acted to enhance the lateral spread as firebrands were lofted for shorter times and were caught in the vortices at the edge of the lateral spread region. In contrast, a lower value of decay parameter, representing a lower cooling of the plume, resulted in widespread downwind spot fires and larger burnt areas. This appeared to be due to longer lofting times resulting in firebrands being transported further downwind and away from the vortices within the lateral spread region. The model appears, at least qualitatively, to match observed lateral spread and 'deep flaming' fire behaviour although many of the parameters in the model require further research and experimental calibration. Further development of the model may allow these complex modes of fire behaviour to be incorporated into rapid wildfire models for operational and risk assessment usage.

This research has been detailed by Hilton et al. (2019b). Some of the model output can be seen In Figure 4.

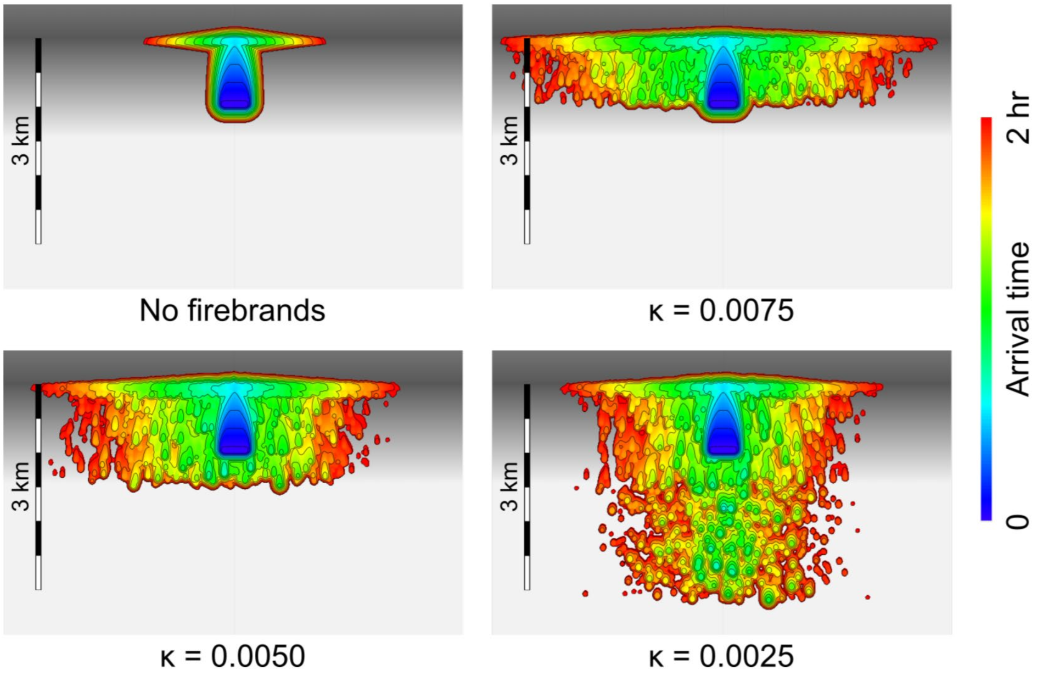

Figure 4: Lateral spread model with and without firebrands and for different values of the plume cooling parameter κ.

UTILISATION PROJECT PROGRESS

VLS plays an important role in the generation of mass-spotting, which in turn contributes to the escalation of an extreme fire. The aim of this utilisation project is to produce an operational tool to assist fire agency personnel in assessing the potential for mass-spotting associated with VLS. The main area of progress has been in phase 1, which involves refinement of a first-order and second-order wind-terrain filter, which enables the user to identify parts of the terrain susceptible to VLS through its established association with steep or broken leeward facing terrain elements. This is achieved using terrain attributes such as topographic slope, aspect, and profile curvature, as well as environmental variables such as the wind speed and direction. This builds upon the research initially undertaken as part of the original Bushfire Cooperative Research Centre. This initial research, however, was based on a digital elevation model (DEM) of 250 metre resolution, which is coarser than those currently used in operations. A key aim, therefore, was to extend the modelling to accommodate the DEM resolutions currently used.

The wind-terrain filters were refined using the GIS software "ArcGIS Pro". The first-order wind-terrain filter's parameters were manually tuned to fit a number of calibration events. This tuning was also confirmed through analyses of slope distributions over various landscape domains. These static cases were then validated with real case conditions and the filter compared to areas where VLS was known to have occurred. Scaling thresholds for the 30, 90 and 250 metre resolution DEMs were also evaluated explicitly, and a general linear model was determined to allow estimation of parameter thresholds for more general DEM resolutions.

The second-order filter was designed and tested in a similar manner to the first-order filter. The two filters were then merged into a combined operational product, which was also validated using known cases of VLS. The filters are presented - separately and as a combined product – in Figure 5.

The project is now consulting with end users to determine the best system to facilitate a nationally consistent mapping system, and how to assimilate the required data feeds on a dynamic basis (Phase 2).

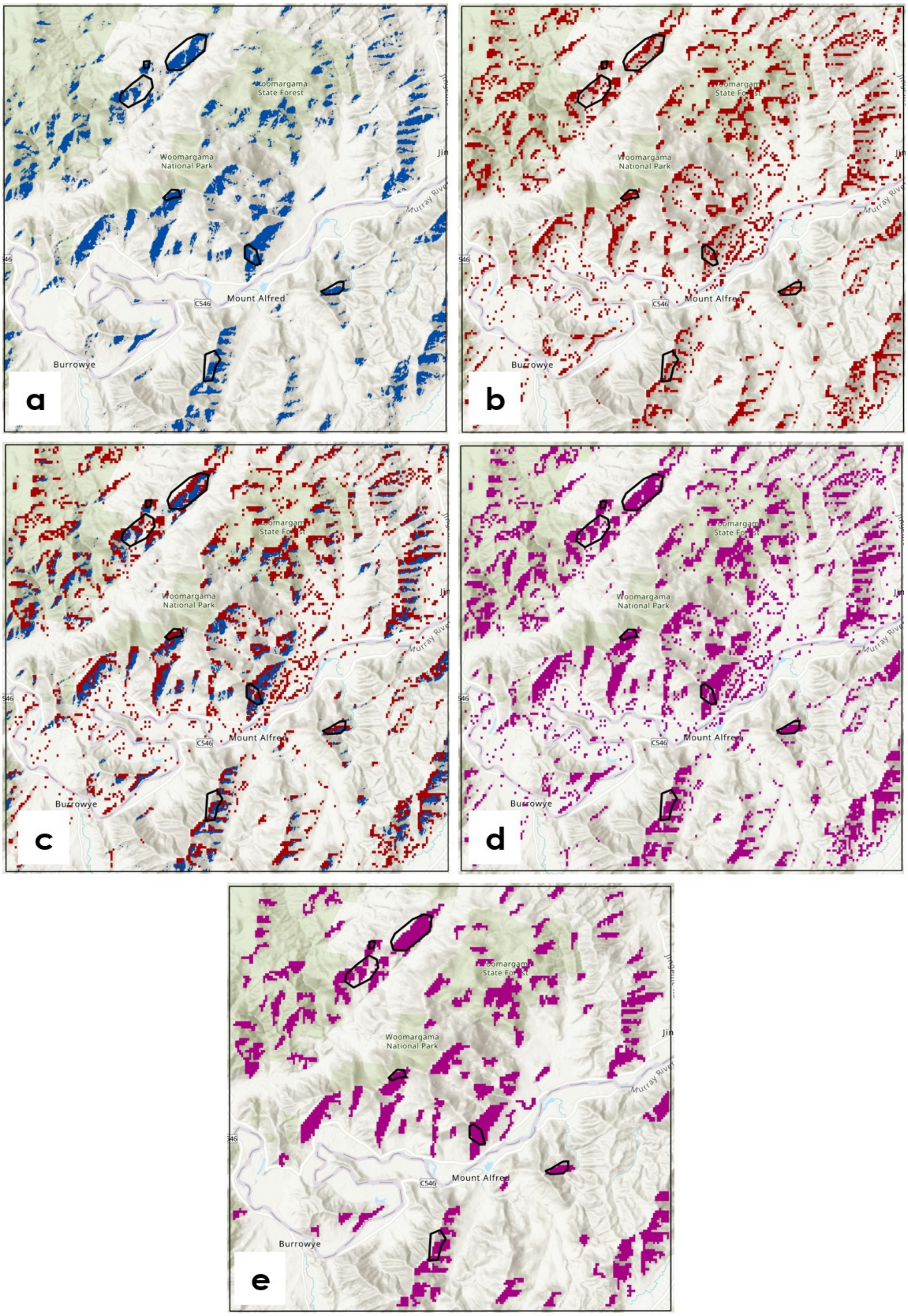

Figure 5: Various VLS wind-terrain filters for the Green Valley Fire, 30 December 2019. (a) first-order filter, (b) second-order filter, (c) first-order filter overlain by second-order filter, (d) merged first- and second-order filters, (e) merged filters with noise reduction algorithm applied. The black polygons in each panel are observed VLS events.

PRESENTATIONS

The project has delivered the following presentations and posters:

1. **MODELLING THE DYNAMIC EVOLUTION OF BUSHFIRES.** Presentation at the 2018 Australian Academy of Science – Science at the Shine Dome Symposium, Canberra, May 2018. Delivered by J. Sharples.
2. **PREDICTING FIRESTORM OCCURRENCE.** Presentation at the 2018 NSW Rural Fire Service Association Conference, Sydney, July 2018. Delivered by J. Sharples.
3. **DYNAMIC MODELLING OF EMBER STORMS.** Presentation at the 6th International Fire Behaviour and Fuels Conference, Sydney, May 2019. Delivered by J. Hilton.
4. **RAPID MODELLING TECHNIQUES FOR THE INCLUSION OF LOCAL WIND AND PRESSURE FIELDS IN WILDFIRES.** Presentation at the 6th International Fire Behaviour and Fuels Conference, Sydney, May 2019. Delivered by J. Hilton.
5. **A UNIVERSAL RATE OF SPREAD INDEX FOR AUSTRALIAN FUEL TYPES.** Presentation at the 6th International Fire Behaviour and Fuels Conference, Sydney, May 2019. Delivered by J. Sharples.
6. **EXTREME WILDFIRE DEVELOPMENT AND IMPLICATIONS FOR THE WILDLAND URBAN INTERFACE.** Presentation at the 6th International Fire Behaviour and Fuels Conference, Sydney, May 2019. Delivered by J. Sharples.
7. **FIRE-ATMOSPHERE INFLUENCES ON MEGAFIRES.** Presentation at the Science to Understand Megafire Interactions with the Atmosphere Workshop, Los Alamos, July 2019. Delivered by J. Sharples.
8. **EVALUATION OF A SIMPLE MODEL FOR FIRE SPREAD IN CANADIAN FUELS.** Presentation at the GEOSAFE 2019 Conference in Melbourne. November 2019. Delivered by J. Sharples.
9. **VLS AND ITS IMPLICATIONS FOR PRESCRIBED BURNING.** Centre of Excellence for Prescribed Burning Webinar. November 2019. Delivered by J. Sharples.
10. **THE ROLE OF ATMOSPHERIC AND LOCAL FIRE DYNAMICS IN EXTREME WILDFIRE DEVELOPMENT**. Presentation at the 8th International Fire Ecology and Management Congress. November 2019. Delivered by J. Sharples
11. **LOCAL FIRE DYNAMICS AND EXTREME WILDFIRE DEVELOPMENT**. Presentation at San Jose State University, November 2019. Delivered by J. Sharples.
12. **INCORPORATING SPOTTING IN MODELS OF DYNAMIC FIRE PROPAGATION**. Presentation at the 23rd International Congress on Modelling and Simulation. Canberra, Australia. December 2019. Delivered by J. Hilton.
13. **WIND-TERRAIN EFFECTS ON FIREBRAND DYNAMICS**. Presentation at the 23rd International Congress on Modelling and Simulation. Canberra, Australia. December 2019. Delivered by J. Hilton.
14. **UNDERSTANDING EXTREME BUSHFIRE DEVELOPMENT**. Presentation at the Australian National Botanical Gardens. February 2020. Delivered by J. Sharples.

15. **FACTORS INFLUENCING VIOLENT PYROCONVECTION**. Presentation at Canberra' Volatile Summer: The New Normal? March 2020. Delivered by R. Badlan.
16. **EXTREME WILDFIRE DEVELOPMENT.** Presentation to the ANU Research School of Earth Sciences, July 2020. Delivered by J. Sharples.

END USER ENGAGEMENT

Members of the project team have engaged with the main project end user group and the AFAC Predictive Services Group. Engagement has been limited due to COVID-19 and has been restricted to phone, email and Zoom meetings. This engagement is being maintained at an appropriate level.

The 2019/20 Bushfire crisis also drove extra engagement with end users. This included:

- J. Sharples: 2020 Expert Advisor – NSW Government Independent Inquiry into the 2019-20 bushfire season
- J. Sharples: 2020 Expert Witness – Federal Parliamentary Inquiry into Lessons to be learned in relation to the Australian bushfire season 2019-20
- J. Sharples: 2020 Expert Witness – Royal Commission into National Natural Disaster Arrangements
- J. Sharples: 2019 Technical Advisor – NSW Rural Fire Service State Operations Centre, November 2019
- J. Sharples: 2019 Independent Consultant – University of Newcastle Bushfire Risk Management Planning

PROGRESS OF THE PHD SCHOLAR

The PhD scholar (Chris Thomas) was awarded his PhD in December 2019.

PUBLICATIONS LIST

1. Lahaye, S., Curt, T., Fréjaville, T., Sharples, J., Paradis, L., & Hély, C. (2018). What are the drivers of dangerous fires in Mediterranean France? International Journal of Wildland Fire, 27(3), 155-163.
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3. Raposo, J. R., Viegas, D. X., Xie, X., Almeida, M., Figueiredo, A. R., Porto, L., & Sharples, J. (2018). Analysis of the physical processes associated with junction fires at laboratory and field scales. International Journal of Wildland Fire, 27(1), 52-68.
4. Hilton, J. E., Sullivan, A. L., Swedosh, W., Sharples, J., & Thomas, C. (2018). Incorporating convective feedback in wildfire simulations using pyrogenic potential. Environmental Modelling and Software, 107, 12-24.
5. Sullivan, A.L., Swedosh, W., Hurley, R.J., Sharples, J.J., Hilton, J.E. (2019). Investigation of the effects of interactions of intersecting oblique fire lines, with and without wind. International Journal of Wildland Fire. In press
6. Thomas, C.M., Sharples, J.J., Evans, J.P. (2019). The terminal velocity assumption in simulations of long-range ember transport. Mathematics and Computers in Simulation. In press
7. Sharples, J.J., Hilton, J.E., Sullivan, A.L. (2019). Pyroconvective interactions and spot fire dynamics. Hazard Note, BNHCRC, June 2019.
8. Hilton, J.E., Sharples, J.J., Garg, N., Swedosh, W. (2019a). Wind-terrain effects on firebrand dynamics. In: Proceedings of the 23rd International Congress on Modelling and Simulation. Canberra, Australia.
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11. Di Virgilio, G., Evans, J.P., Clarke, H., Sharples, J., Hirsch, A.L. and Hart, M.A., 2020. Climate change significantly alters future wildfire mitigation opportunities in southeastern Australia. *Geophysical Research Letters*, p.e2020GL088893.
12. Cawson, J.G., Hemming, V., Ackland, A., Anderson, W., Bowman, D., Bradstock, R., Brown, T.P., Burton, J., Cary, G.J., Duff, T.J., Filkov, A., Furlaud, J.M., Gazzard, T., Kilinc, M., Nyman, P., Peacock, R., Ryan, M., Sharples, J., Sheriden, G., Tolhurst, K., Well, T., Zylstra, P., 2020. Exploring the key drivers of forest flammability in wet eucalypt forests using expert-derived conceptual models. *Landscape Ecology*, 35, pp.1775-1798.

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14. Ndalila, M.N., Williamson, G.J., Fox-Hughes, P., Sharples, J. and Bowman, D.M., 2020. Evolution of a pyrocumulonimbus event associated with an extreme wildfire in Tasmania, Australia. *Natural Hazards and Earth System Sciences*, 20(5), pp.1497-1511.
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CURRENT TEAM MEMBERS

The research team is currently made up as follows:

Prof. Jason Sharples, UNSW

Dr James Hilton, CSIRO Data61

Dr Andrew Sullivan, CSIRO Land and Water

Dr Rachel Badlan, UNSW

End-user/Advisory Committee – lead by Brad Davies, NSW Rural Fire Service.

ADDITIONAL TEAM MEMBERS

Mr Richard Hurley, CSIRO

Richard is a technical officer working at the CSIRO Pyrotron facility with Dr Sullivan. Richard is extensively involved in conducting the experimental program and as such is a crucial member of the project team.

Mr Will Swedosh, CSIRO Data61

Will is a graduate research officer working at CSIRO with Dr Hilton. Will is involved in implementing the level set models including pyrogenic potential and has bee instrumental in analyzing the Pyrotron experimental data. He has also contributed significantly to publications.

Additional assistance for experimental work in Phase 1 was provided by Dr Matt Plucinski and Mr Vijay Koul.

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