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

Annual project report 2014-2015

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Cover: Extreme fire behaviour during the 2014 Grampians, Victoria, bushfire.

Photo: Wayne Rigg, CFA.

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EXECUTIVE SUMMARY

This report outlines the progress of the *Fire Coalescene and Mass Spot Fire Dynamics* project, which is one of the projects within the Next Generation Fire Modelling cluster.

Project contracts were only finalised in March 2015 (with the subcontract between UNSW and CSIRO finalised in May 2015), so this report only covers a portion of the reporting period. Nevertheless, progress has been made in a number of areas, including:

- Drafting of the Science Plan
- Presentation at meetings
- Preparation of publications
- Engagement of a PhD scholar

These developments are described in more detail within this report along with general project background and some details on the methods that will be employed to complete the project.

A/Prof. Jason Sharples

Project Leader
School of Physical, Environmental and Mathematical Sciences,
University of NSW, Australia

END USER STATEMENT

Simon Heemstra, *New South Wales Rural Fire Service, NSW*

Jason and his team have made excellent progress getting the project up and running after signing the contracts in the past couple of months. I am pleased with the level of engagement so far, including consultation on the science plan, and look forward to seeing interesting experimental and modelling results in the future.

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 spotfires—new fires ignited by the transport of burning debris such as bark ahead of an existing fire. Under most burning conditions, spotfires play little role in the overall propagation of a fire, except where spread is impeded by breaks in fuel or topography and spotfires allow these impediments to be overcome. However, under conditions of severe bushfire behaviour spotfire occurrence can be so prevalent that spotting becomes the dominant propagation mechanism and the fire spreads as a cascade of spotfires forming a 'pseudo' front.

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. 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 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. Unfortunately, such a modelling approach is computationally intensive, expensive and model run-times not conducive to operational application.

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 geometric drivers of fire line propagation (e.g. fire line curvature) with the aim of developing a physically simplified proxy for some of the more complicated dynamical effects. 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 will employ 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, and so employing a methodology that is able to successfully deal with these types of behaviours is crucial to model spot fire development. We therefore employ a level set approach, which is well known to be able to deal with such obscurities (Sethian, 1999).

In addition to its ability to deal with topological changes, the level set method also allows for the easy inclusion of variables such as fire line curvature, which we aim to include as a two-dimensional proxy for more complicated three-dimensional effects.

This project builds on initial work by members of the project team, who have investigated the use of curvature-based models in probes related to fire spread such as fire line merging (Sharples et al. 2013; Hilton, 2014).

To complement model development the project will also include a targeted experimental program. This will involve analysis of experimental fires burning under controlled laboratory conditions as well as analysis of field experiments.

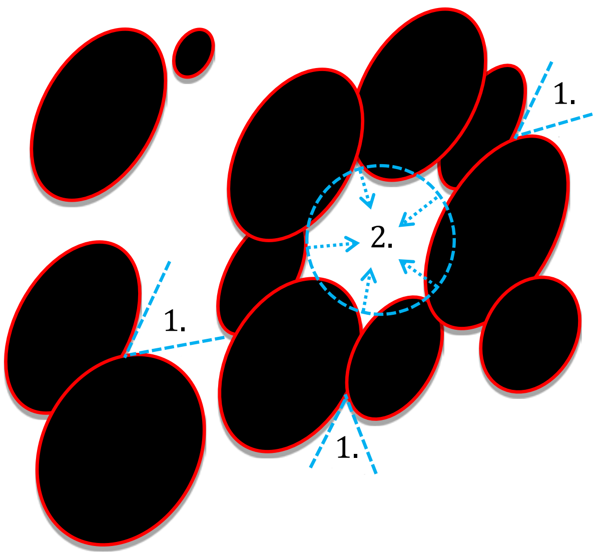

Figure 1: Schematic representation of coalescing spot fires. Examples of fire line merging are marked with a 1, while an example of perimeter collapse is marked with a 2. Both phenomena involve changes in topology.

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.

Curvature dependence

Viegas et al. (2012) noted that when two obliquely intersecting fire lines merge, their point of intersection will advance more rapidly than what would normally be expected. This is due to dynamic interations that enhance radiative and convective heat transfer in a way that causes the fires to burn faster in regions surrounded by fire. Such regions can be characterized as having negative fireline curvature. Sharples et al. (2013) showed how using fire line curvature dependent rate of spread can successfully emulate the types of behaviour observed by Viegas et al. (2012). This approach allows for the effect to be modelled in two-dimensions despite the complicated three-dimensional processes that are actually driving it.

The level set method employed is formulated as follows:

$$\frac{\partial \varphi}{\partial t} + \alpha \nabla^2 \varphi + N(\varphi) = 0,$$

where

$$N(\varphi) = \alpha \frac{\nabla \varphi}{|\nabla \varphi|} \cdot \nabla(|\nabla \varphi|) + \beta |\nabla \varphi| + \boldsymbol{u} \cdot \nabla \varphi.$$

In this model as simple affine dependence of rate of spread on fire line curvature has been assumed; that is,

$$R = \alpha\kappa + \beta,$$

where R is the rate of spread (normal speed), κ is the fire line curvature and α and β are model parameters. The wind vector is denoted by $\boldsymbol{u}$.

The project will extend these initial investigations to consider more appropriate mathematical formulations of curvature dependence and also the inclusion of extrinsic factors such as wind and slope.

EXPERIMENTAL PROGRAM

The modelling techniques outlined above will be complemented by a series of laboratory and field experiments using the CSIRO' Pyrotron facility. The details of this experimental program are finally being finalised as part of the Project Science Plan.

Laboratory experiments

A series of experiments using the CSIRO' Pyrotron facility will be conducted. These experiments will be broken down into four categories:

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

The details of this experimental program are finally being finalised as part of the Project Science Plan.

Field experiments

In addition the project will analyse data collected as part of the CSIRO-led Project Aquarius, which examined the behaviour of a number of point ignitions set in close proximity to each other. Again, the approach will be outlined in more detail in the Science Plan.

Numerical experiments

A number of numerical simulations will be carried out in order to better understand the physical mechanisms driving spot fire coalescence, to provide information of the scale dependence of the effets under consideration and to provide additional information for two-dimensional model development.

Moreover, the numerical simulations will also provide information of ember trajectories that are being driven by an evolving heat source. As such they will provide information that will be used as part of the development of an end-to-end model for spot fire development.

These simulations will make use of the WRF-Fire coupled fire-atmosphere model, which will be run on the supercomputer at the NCI National Facility at the ANU.

WHAT THE PROJECT HAS BEEN UP TO

RESEARCH DEVELOPMENT

Preliminary work has shown that the inclusion of fire line curvature in models for fire spread leads to far more accurate simulations compared to those based on current operational modelling paradigms, particularly in unusual configurations. This improved accuracy is achievable with very little increase in the computation-times of these models.

Partoicular examples include applying the concept to the simple fire line merging discussed by Viegas et al. (2012) and to a number of wind-driven grassfires described by Cruz et al. (2015).

The project team has also been formulating the plan for the experimental program. This has been formalized as part of the Science Plan, which is now circulating in draft form. We hope to finalise this plan in the next month or so, with the input from the end user panel.

The project has also recruited a PhD scholar, who has begun research that complements the project aims using the WRF-Fire model.

PRESENTATIONS

The project has delivered the following presentations:

FIRE COALESCENCE AND MASS SPOTFIRE DYNAMICS: Experimentation, modelling and simulation. Bushfire and Natural Hazrads CRC Rsearch Advisory Forum, RMIT Melbourne, December 2014. Delivered by J. Sharples.

UNDERSTANDING EXTREME BUSHFIRE DEVELOPMENT. New South Wales Rural Fire Service Association Conference, Mudgee NSW, June 2015. Delivered by J. Sharples.

END USER ENGAGEMENT

The project has finalised membership of the end user panel through engagement with the Lead End User Dr Simon Heemstra and Dr Stuart Matthews, NSW RFS.

Meeting of the Advisory Committee to discuss finalising the Science Plan took place in early July.

PUBLICATIONS IN PREPARATION

A number of publications are in preparation - see the publications list.

PUBLICATIONS LIST

Hilton, J.E., Miller, C. Sharples, J.J., Sullivan, A.L. (2015) Curvature effects in the dynamic evolution of wildfires. In preparation. To be submitted to International Journal of Wildland Fire, or Combustion Theory and Modelling.

Sharples, J.J., Hilton, J.E., Sullivan, A.L. (2015) On the interaction of two oblique fire fronts. In preparation. To be submitted to International Journal of Wildland Fire, or Combustion Theory and Modelling.

Thomas, C., Sharples, J.J., Evans, J.P. (2015) Dynamic dependence of rate of spread in fire line curvature in a coupled atmosphere-fire model. Submitted to Proceedings of MODSIM 2015.

Sharples, J.J., Hilton, J.E., Miller, C., Sullivan, A.L. (2015) Nature abhors curvature – fires included! Poster presentation at AFAC/Bushfire and Natural Hazards CRC Conference.

CURRENT TEAM MEMBERS

The research team is currently made up as follows:

A/Prof. Jason Sharples, UNSW

Dr James Hilton, CSIRO

Dr Andrew Sullivan, CSIRO

ADDITIONAL/FUTURE TEAM MEMBERS

Ms Claire Miller, CSIRO

Claire is a graduate research officer working at CSIRO with Dr Hilton. Claire has been involved in implementing the level set models and has contributed significantly to publications.

Mr Richard Hurley, CSIRO

Richard is an experimental officer working at the CSIRO Pyrotron facility. Richard will be extensively involved in conducting the experimental program.

Mr Christopher Thomas, UNSW

Chris has enrolled in a PhD in Mathematics at UNSW under the supervision of A/Prof Sharples. Chris' project aligns with the spotfire coalescence project and initial steps have been made to formally include Chris as part of the project team through award of a Bushfire and Natural Hazards CRC top-up scholarship.

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