HAZARD NOTE

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TOPICS IN THIS EDITION | FIRE SEVERITY | FIRE WEATHER | FIRE IMPACTS

NEXT GENERATION FIRE MODELLING

ABOUT THESE PROJECTS

This is an overview of the *Next generation fire modelling* cluster of Bushfire and Natural Hazards CRC research projects. This cluster has four linked studies:

1. **Fire spread across fuel types –** A/Prof Khalid Moinuddin, Dr Duncan Sutherland, Prof Graham Thorpe, Rahul Wadhwani, Victoria University; Prof Andrew Ooi, Dr Daniel Chung, Michael MacDonald, Nitesh George, University of Melbourne. Contact khalid.moinuddin@vu.edu.au
2. **Fire coalescence and mass spotfire dynamics –** A/Prof Jason Sharples, University of New South Wales; Dr Andrew Sullivan, Dr James Hilton, CSIRO. Contact j.sharples@adfa.edu.au
3. **Coupled fire-atmosphere modelling –** Dr Jeff Kepert, Dr Mika Peace, Bureau of Meteorology. Contact j.kepert@bom.gov.au
4. **Determining threshold conditions for extreme fire behaviour –** Dr Trent Penman, Dr Thomas Duff, A/Prof Kevin Tolhurst, Alex Filkov, University of Melbourne. Contact trent.penman@unimelb.edu.au

CONTEXT

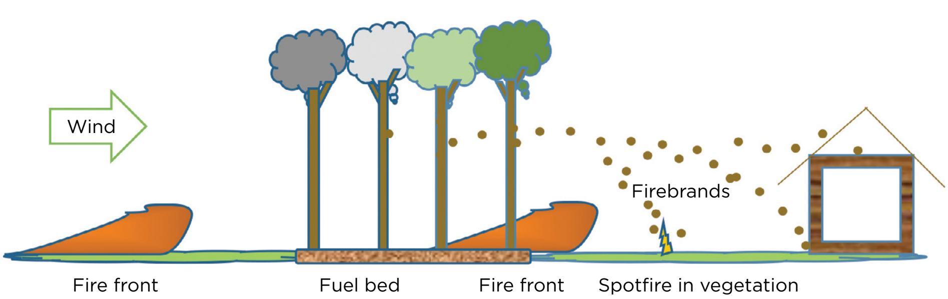
This research cluster is helping to bridge the gap between fire danger prediction systems based on the science of the 1950s and 1960s and those that exploit current research and technology. These projects take a long-term view towards developing more sophisticated fire behaviour models. All of these projects are contributing to the science that will underpin national bushfire predictive services into the future.

FIRE SPREAD PREDICTION ACROSS FUEL TYPES

BACKGROUND

This project is applying physics-based approaches to an ideal fire scenario (represented in Figure 1, right).
The project attempts to simulate the fire with unprecedented detail and in the process obtain useful application tools for end-users.

To address existing gaps in the mathematical and computational modelling of bushfire dynamics, the scenario shown in Figure 1 is subdivided into four parts. Part one is exploiting new observations about the geometric characteristics of trees and forests to determine how fire-spread rate is affected by forested areas compared with open terrain. Part two has designed and built an ember generator to investigate how embers and firebrands travel ahead of bushfires. Improved computational methods that address issues such as the turbulence around bushfires are a key focus of part three. Part four aims to develop simple-to-use formulae that will help fire behaviour analysts to calculate the flow and heat transfer over various surface features, such as buildings.



▲ **Above:** A SCHEMATIC OF FIRE SPREAD MECHANISM IN THE IDEAL FOREST SHOWING SPOTTING IN VEGETATION AND A MODEL HOUSE.

RESEARCH ACTIVITY

Modelling wind speed through tree canopies

The rate of spread of a bushfire depends both on fuel types and the wind velocity profiles at ground and tree canopy levels. Ground cover, tree trunks, branches and leaves all affect the velocity profile. This particular aspect of the project aims to understand the velocity profile within the tree canopy in order to predict the wind reduction factor, which is present in some empirical models of fire spread. This work will improve the modelling of wind-driven fire behaviour as it enters, traverses and leaves a wooded area.

Spread and distribution of firebrands

Embers and firebrands carried ahead of the main fire front often dominate the rate of spread of bushfires. The team is harnessing its expertise in aerodynamics to design, construct and operate a firebrand generator to accurately quantify how embers disperse. Along with wind speed, bushfire spread rates strongly depend on the physical and chemical properties of vegetative materials, such as grasses, wood and leaves. To prepare for experiments using the generator, the team invested in equipment and training for measuring properties such as thermal conductivity, specific heat, density, heat of pyrolysis, heat of combustion and reaction rate constants.

Improving computational methods

Physics-based models of bushfires must consider phenomena that occur on length scales that range from a fraction of a millimetre (e.g. flame thickness) up to several hundred metres (e.g. in terrain). The researchers have addressed this challenge by considering how the average of the small-scale phenomena would affect large-scale phenomena, such as the length and intensity of flames.

Bushfire-driven airflow over surface features
This aspect of the study applies the principles of engineering science to calculate bushfire-generated airflows above buildings, structures and forests. The aim is to quantify the behaviour of airflow and heat transfer in order to calculate how the wind profiles above the surface features of variable heights changes. The approach is to calculate details of the flow and heat transfer to produce highly accurate solutions, from which simple-to-use equations are extracted for operational use.

RESEARCH OUTCOMES

Modelling wind speed through tree canopies
This aspect of the study has successfully predicted the wind velocity profiles through a set of idealised, rectangular canopies of dense vegetation, and the researchers are refining the analysis to account for sparse vegetation. The simulations demonstrate the variation in the wind reduction factor over the canopy and the presence of vortices downstream of the canopy, and will be used to assess idealised models for the wind reduction factor. Further work is required to understand the effect of canopy variability and models for non-ideal canopies over varying terrain.

Spread and distribution of firebrands
The prototype firebrand generator has been designed using computational fluid dynamics software. It projects firebrands at near-uniform velocities, which assists in the analysis. Experiments of the dispersion of cubical and cylindrical particles have been conducted, with early results showing qualitatively similar findings. Bench-scale experiments have also been undertaken to investigate the thermo-physical, flammability and kinetic properties of grasses and litter fuels. These studies will assist in understanding the propensity of grasses and litter fuels to ignite from firebrands.

Improving computational methods
The team has filtered out the small-scale phenomena from the equations that govern bushfire behaviour. This has led to the development of a rigorous, accurate and robust model of buoyancy-driven flows that show great promise for bushfire modelling.

Bushfire-driven airflow over surface features
This part of the study is well advanced and utilisation work to extract simple-to-use equations for operational use is underway.

Above: RESEARCH IS INVESTIGATING HOW TO ACCURATELY PREDICT BUSHFIRE BEHAVIOUR WHEN MULTIPLE FIRES ARE BURNING IN CLOSE PROXIMITY. PHOTO: NEW ZEALAND FIRE SERVICE.

FIRE COALESCENCE AND MASS SPOTFIRE DYNAMICS

BACKGROUND

This project addresses a significant knowledge gap about how to model the behaviour of mass bushfire spotting and the interactions of multiple fires adjacent to each other. The inability to accurately predict fire behaviour in these circumstances can exacerbate the risk to firefighters and communities. Research is investigating the processes involved in the coalescence (or convergence) of free-burning fires under experimentally controlled conditions, and quantifying their physical mechanisms. It also investigates the geometric drivers of fire-line propagation, with the aim of developing a physically simplified proxy for some of the more complicated dynamic effects.

RESEARCH ACTIVITY

As well as developing computationally efficient fire-spread models, the study will conduct a targeted experimental program that analyses experimental fires burning under controlled laboratory conditions and in the field.

The researchers will conduct four categories of experiments using CSIRO's Pyrotron facility:

- Parallel fire line experiments
- V-shaped fire experiments
- Ring fire experiments and
- Multiple spotfire experiments.

The project will also analyse data collected during field experiments, such as the CSIRO-led Project Aquarius, which examined the behaviour of point ignitions set in close proximity to each other.

DEFINITIONS

Coalescence – the process of how nearby fires converge together.

Coupled fire-atmosphere model – a model that combines weather and fire, which takes into account how bushfires influence the atmosphere, and therefore the weather.

Curvature – the degree to which a curve deviates from a straight line. In the case of fire modelling, it is how curved the fire front is.

Firebrand – an object that becomes airborne and has the potential to create a spotfire.

Vorticity-driven lateral spread – the rapid lateral propagation of a fire across a lee-facing slope in a direction approximately perpendicular to the prevailing wind direction.

Numerical simulations involving coupled fire-atmosphere models will be used to better understand the physical mechanisms driving spotfire coalescence, to provide information about the scale dependence of their effects and to support two-dimensional model development. The numerical simulations will also provide information about ember trajectories that are driven by an evolving heat source, which will be used to develop an end-to-end model for spotfire development. These simulations will be supported by the supercomputing facilities at the National Computational Infrastructure at the Australian National University.

RESEARCH OUTCOMES

The modelling and simulation aspects of the project have contributed strongly to understanding the processes that drive fire coalescence and dynamic fire spread.

In particular, the research has addressed the role that fire-line geometry (especially curvature) plays in the dynamic propagation of bushfires. The project team has demonstrated the performance advantages of fire propagation models incorporating curvature dependence when applied to simple wind-driven fires at both laboratory and field scales.

The research has also produced fundamental insights into how the shape of the fire line affects the dynamic behaviour of the fire as a whole. Coupled fire-atmosphere modelling was used to investigate how fire-induced air movements (pyroconvection) can produce significantly enhanced rates of spread for certain fire shapes.

END USER STATEMENT

We need better understanding and modelling of how a fire will progress and when it will impact on communities. Greater precision in predicting the size and timing of bushfires will enable fire agencies to better target their warnings and that will help to save lives. Increasing knowledge of the role and influence of weather and ember dispersion ahead of the main fire front is critical for fire agencies in warning and preparing communities under those extreme events. These projects have many benefits in improving the understanding of these issues and applying the research.

– Dr Simon Heemstra, Manager Community Planning, NSW Rural Fire Service

▲ **Above:** RESEARCH IS INVESTIGATING HOW LARGE BUSHFIRES INTERACT WITH THE ATMOSPHERE, WHICH CAN LEAD TO EXTREME FIRE BEHAVIOUR. PHOTO: GAIL WRIGHT, DEPARTMENT OF ENVIRONMENT, LAND, WATER AND PLANNING VICTORIA.

COUPLED FIRE-ATMOSPHERE MODELLING

BACKGROUND

Large bushfires release substantial amounts of energy into the surrounding atmosphere. This energy release modifies the structure of the surrounding wind, temperature and moisture profiles in three dimensions. The changes driven by the fire can manifest as winds that are similar in speed but opposite in direction to the prevailing winds, pyroconvective clouds and fire-generated thunderstorms. The dynamic feedback loops produced by the fire-atmosphere coupling process can have a dramatic influence on how a fire evolves.

In current operational fire simulation models, simple wind inputs are inserted into a linear algorithm for fire spread to predict how a fire perimeter will evolve across a two-dimensional landscape. This approach does not incorporate the three-dimensional interactions between the fire and atmosphere and, in many cases, will provide a limited depiction of how a fire may evolve, particularly in a dynamic environment in high terrain where the risk is elevated. This project explores the ability to model fire-atmosphere interactions through use of a coupled model.

RESEARCH ACTIVITY

The project uses the Australian high-resolution weather prediction model ACCESS, coupled to a fire spread model. The ACCESS model has been used to examine several high impact bushfires and has provided detailed insights into the meteorological processes impacting the fire environment. Coupling ACCESS to a fire model builds on previous expertise and provides opportunity for future development and real-time use of coupled modelling in Australia.

Case studies will be run to test and validate the model, with the Waroona fire in Western Australia in January 2016 selected as the first case study. Over a two-day period there were two separate pyroconvective thunderstorms, triggered by different processes during the diurnal cycle. In addition, analysis of Doppler radar data shows detail of the rapid plume development contributing to the ember shower that burnt over Yarloop, causing two fatalities.

RESEARCH OUTCOMES

The coupled fire-atmosphere model ACCESS-Fire will be installed on national Australian computing infrastructure for research application, with future capability for operational use. The model will be used to run a series of case studies. Detailed examination of high impact events and verification against available meteorological and fire behaviour data will highlight the importance of assessing and predicting the likelihood of fire-atmosphere interactions in anticipating fire evolution. The close links of the project team with operational and training activities will provide a clear pathway for implementing research findings.

THRESHOLD CONDITIONS FOR EXTREME FIRE BEHAVIOUR

BACKGROUND

Particular fire phenomena occur only in extreme fire conditions. These include fire tornados, atmospheric coupling (see previous project), ember storms and vorticity-driven lateral spread (see breakout box, page three). Research into such phenomena is limited and there are no operational fire spread models that can accommodate them. The first step towards accounting for these phenomena is to describe them and the conditions under which they occur – this includes fuel conditions, surface weather and atmospheric profiles.

This project will build knowledge of the unique features of extreme fires by a) collating observations of extreme fires in Australia in recent years, and b) analysing fire phenomena in conjunction with accessory information (i.e. weather, fuel and topography).

Above: FIRE DATA, INCLUDING OBSERVED BEHAVIOUR, WEATHER FORECASTS AND WEATHER OBSERVATIONS, IS BEING COLLATED TO HELP TO UNDERSTAND UNDER WHAT CONDITIONS EXTREME FIRE BEHAVIOUR CAN OCCUR. PHOTO: NSW RURAL FIRE SERVICE.

RESEARCH ACTIVITY

This project involves three overlapping research activities:

Collating fire behaviour observations

The researchers will create a database of observations of extreme fire behaviour to use in model development and verification. They will work directly with fire and land management agencies to develop reconstructions of past fire events. This will include structuring a database, standardising data formats and processing historic reconstructions. This will involve collating both fire data and accessory data, such as weather observations and forecasts. Existing datasets will be audited, including those developed during the Bushfire CRC and outside the CRC program. This information will be useful for all projects within this cluster.

Understanding extreme fire weather and fire behaviour

This work will determine the thresholds in fire and environmental conditions (weather, fuel, topography) that lead to extreme fire phenomena.

It will use data about past fires to identify processes that lead to extreme phenomena. This will include analysing smoke plume observations from Bureau of Meteorology weather radars, three-dimensional numerical weather predictions and impact maps. These sources will be used to determine fire-related parameters, including the strength of convective winds and spotting patterns.

Factors linked to extreme fire behaviour

This aspect of the study will identify the extent to which extreme fire behaviour occurs in Australia and attempt to develop simple, statistical equations to represent dynamic fire phenomena that may be integrated into existing fire-behaviour models.

The researchers will determine relationships between specific characteristics of extreme fire behaviour and the conditions under which they occur. This will include analysing the conditions on the ground (such as fuel, temperature and relative humidity), fire properties (such as observed flame heights and rates of spread) and atmospheric conditions. Statistical methods will be used to assess whether there are thresholds for extreme fire activity and to describe its nature when it does occur.

FURTHER READING

Duff T, Penman T, Filkov A (2016), Determining thresholds for extreme fire behaviour: annual project report 2015-2016, Bushfire and Natural Hazards CRC.

Kepert J, Peace M (2016), Coupled fire-atmosphere modelling: annual project report 2015-2016, Bushfire and Natural Hazards CRC.

Moinudeen K, Sutherland D, Thorpe G (2016), Fire spread prediction across fuel types: annual project report 2015-2016, Bushfire and Natural Hazards CRC.

Sharples J, Hilton J, Sullivan A (2016), Fire coalescence and mass spotfire dynamics: experimentation, modelling and simulation annual project report 2015-2016, Bushfire and Natural Hazards CRC.

The Bushfire and Natural Hazards CRC is a national research centre funded by the Australian Government Cooperative Research Centre Program. It was formed in 2013 for an eight-year program to undertake end-user focused research for Australia and New Zealand.

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