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COUPLED FIRE-ATMOSPHERE MODELLING: ACCESS-FIRE

Annual project report 2019-2020

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Bureau of Meteorology

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Cover: Waroona fire. Source: Neil Bennett, Bureau of Meteorology.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

We acknowledge the helpful feedback from our end-users on the practical implications of what we do, and for guidance on the direction of the project. We also thank BNHCRC for the ongoing support of our work and appreciation for related outreach and operational activities.

We thank our colleagues at the Bureau and the UK Met Office for their advice on using the ACCESS/UM model. Many colleagues have helped us understand modelling developments, as well as encouraged us with the importance of our work.

EXECUTIVE SUMMARY

This project aims to improve understanding of fire and atmosphere interactions and feedback processes through running the coupled fire-atmosphere model ACCESS-Fire.

Project deliverables include: preparation of meteorological and simulation case studies of significant fire events; installation and testing of the ACCESS-Fire coupled model on the National Computing Infrastructure (NCI) and preparation of training material to support operational implementation of research findings.

The project started in March 2016, and progress over the past four years has been on several aspects:

1. ACCESS-Fire has been installed on NCI and substantial investment has been made in testing and developing the model
2. A meteorological case study of the Waroona fire has been published, which generated outreach activities across numerous agencies and jurisdictions.
3. ACCESS-Fire has been run on two fires: the Waroona fire in WA and the Sir Ivan fire in NSW. A draft of the results of the Waroona simulations has been prepared and analysis and manuscript outline of the Sir Ivan simulations is well underway.
4. Operational support was requested by fire agencies and the Bureau during high-impact events during the 2019-20 fire season. Support was provided in CFS and SES in SA, RFS in NSW and QFES in QLD during the protracted fire campaigns.
5. A draft of the paper `Lessons learned from coupled fire-atmosphere research and implications for operational fire modelling' has been prepared.

The project has continued to participate strongly in outreach activities, including media engagement through extended radio interviews and collaboration on print and online news articles. Conference presentations, high level training presentations and panel participation on topics including fire science, High Performance Computing, STEM careers and Women in Leadership have been attended.

The project has demonstrably achieved the objective of building and sharing national capability in fire research and has repeatedly applied that knowledge in critical focus during high impact events in support of end-users inside their operational centers. That outcome is not a specific project deliverable and is to some degree intangible, so not as easily measured as outcomes such as publications. However, it demonstrates successful realization of the CRC objective of building collaborations and trusted partnerships and strengthening national capability. The capability is recognized and valued across fire and land management agencies and in the Bureau; value that is evidenced by the repeated requests to provide high-level fire and meteorological interpretation inside operations.

We therefore thank BNHCRC for their understanding in allowing flexible deadlines and repeatedly negotiating project timelines and deliverables, as this flexibility to shifting priorities has enabled the project team to provide operational support when it was needed.

Our focus for the remainder of the project is to complete advanced drafts of the papers to ensure that our key findings are documented in the scientific literature and expand the body of knowledge from coupled modelling studies. We will also share the results with a range of audiences through three online presentations and recordings during which we intend to develop presenting experience in more junior members of the project team.

These objectives may be challenging, due to the need to work from home during the Coronavirus pandemic and the need to be flexible with plans.

We are confident that we will bring the project to completion and are gratified that along the way we have shared a valuable legacy of knowledge, analysis techniques and software that can benefit the field of meteorology and fire prediction and the Australian community into the future.

END-USER PROJECT IMPACT STATEMENT

John Bally, *Fire Prediction Business Manager, AFAC*

The importance of case study investigations into bushfire behaviour, supported by modelling can hardly be overstated, and the complexities faced in the effort to understand this complex multi-faceted problem are formidable. The program of work undertaken in this project has contributed significantly to that effort.

Most approaches to diagnosing and predicting bushfires assume that the weather (and other factors) drive the fire and ignore the influence the fire has on the atmosphere. This work tackles that much more difficult problem. It has taken much longer than anticipated for the project to successfully configure and run the ACCESS-Fire coupled model, due to the complexity of the task and the dependency on the base modelling system which has undergone major change during the life of the project, outside of the project's control. The model has now been run and has produced results for two important case studies.

Both case studies have shown significant modification of the weather (mostly the wind fields) driven by the heat generated by the fires. More realistic forecast wind fields generated by coupled models are a benefit in themselves, a result consistent with the benefits found in the Colorado coupled fire-weather experiment (CO-FPS).

The ACCESS-Fire runs for the Waroona fire reproduced downslope winds and fire induced turbulence, both drivers of large-scale ember transport and spotting. This is consistent with the Large Eddy Model work undertaken in the BNHCRC "Severe Weather" project which found that turbulence is a major driver of ember transport. The coupled runs were also able to develop fire induced convection consistent with in-situ observations of pyro-cumulonimbus. These results underscore the role this work can play in validating the (BoM) parameterised ember transport model and PFT work.

ACCESS-Fire runs also reproduced 3-D effects of the fire on the atmosphere which included coupling to upper winds, transient vortices and pulsing. These effects were important in the 2019-20 fires where it was common practice for FBANs to rely on experience-based estimates of which (stronger) upper wind levels to use for fire simulations. This project has shed some light on the mechanisms involved. It would be great to see the insights gained applied to developing more parameterized and other heuristic "models" which can be applied to current and emerging operational 2D (or 2.5D) simulation approaches.

The modeling framework used in this project is very computationally expensive, and spatial resolutions used are still about an order of magnitude coarser than those used in 2D models. Apart from waiting for computers to get faster, it is interesting to see some effort being put into running the fire components at a (much) higher resolution. This approach could bring forward direct use of coupled models in operations.

The coupled model runs have all used constant fuel layers. It is pleasing to see consideration being given to using the AFDRS fuel layers, as these should add more detail and accuracy to the simulations, but also to deepen the links between this and other related bodies of work.

PRODUCT USER TESTIMONIALS

Laurence McCoy, *Fire Predictive Services, Rural Fire Service, NSW*

Fire and weather are intrinsically linked. Traditionally, fire behaviour models focus on surface conditions or forecast surface conditions. New technology, integration of Meteorologists into operations and the use of observation equipment such as Portable Atmospheric Sounding units are providing greater understanding of the significance of atmospheric conditions and the importance of considering fire atmosphere interaction. Traditional models have their limitations and require a degree of interpretation, knowledge and experience to transfer these complex interactions into fire behaviour predictions.

Adding to this complexity, for NSW and around the globe, the number of extreme fire behaviour events such as the 2017 Sir Ivan Fire where fire and atmosphere interactions influence fire behaviour are increasing. The 2019-20 fire season saw more PyroCb events recorded in NSW that any of the preceding years.

This research is critical to providing improved forecasting ability for extreme bush fire events. Results to date are encouraging and will provide the building blocks to improved methods for predicting extreme fire behaviour. We look forward to the next steps for this project and working towards an operational coupled atmosphere fire behaviour model

INTRODUCTION

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. The changes induced by the fire can manifest as winds that are similar in speed but opposite in direction to the prevailing winds, pyrocumulus clouds and, in extreme cases, pyro-cumulonimbus clouds. The dynamic feedback loops produced by the fire-atmosphere coupling process can have a dramatic influence on how a fire evolves. Fire-atmosphere feedbacks can also be strongly enhanced by local topographic influences.

In current operational fire simulation models, simple near-surface meteorological values are provided as inputs to an algorithm for fire spread that is used to predict how a fire perimeter will evolve across a two-dimensional landscape. This approach does not incorporate any three-dimensional interactions between the fire and atmosphere and may provide a limited depiction of how a fire may evolve, particularly in a dynamic environment in complex terrain. This project explores fire and atmosphere interactions through use of a coupled model.

The project uses the operational Australian high-resolution numerical weather prediction model ACCESS, coupled to a fire-spread model (ACCESS-Fire). The ACCESS model (uncoupled) has been used to examine several high impact fire events and has provided detailed insights into meteorological processes that may occur in a fire environment. Running case studies using ACCESS coupled to a fire model builds on previous expertise in the Bureau's research team and provides opportunity for future development of a coupled modelling capability in Australia.

ACCESS-Fire has been installed and run on Australian National Computing Infrastructure (NCI) for research application and has future potential for operational use, given appropriate development and testing. Two case studies have been run, the Waroona and Sir Ivan fires.

The Waroona fire in southwest WA in January 2016 is the first case study. Over a two-day period, there were four periods of extreme fire behaviour; two separate pyro-convective thunderstorm events and two evening ember storms occurred.

The Sir Ivan fire in NSW is the second case study. The fire occurred on a day of 'Catastrophic' fire danger and produced a pyrocumulonimbus cloud near the time of a change in wind direction from northwest to southerly.

Detailed examination of these high impact events and verification against available meteorological and fire behaviour data has provided compelling evidence for the importance of assessing and anticipating the likelihood of fire-atmosphere interactions when making predictions of fire evolution. The close links of the project team with operational and training groups in meteorology, fire behaviour and fire management have provided a clear pathway for sharing relevant research findings in operational settings in advance of formal publication of results.

BACKGROUND

The project examines case studies and uses high resolution coupled modelling to better understand and predict fire-atmosphere feedback processes. Fire-atmosphere feedback is important because it often reflects a transition from steady-state fire spread to rapidly fluctuating, dynamic and more intense fire activity, which is inherently more difficult to predict. Blow-up fires, extreme fire behaviour and dynamic fire behaviour are all terms that may be used to describe fire activity that is erratic and potentially dangerous to fire fighters and destructive to communities. Coupled modelling will assist in identifying and understanding the triggers and ingredients that lead to non-linear fire activity. This knowledge will enable risk mitigation activities to be undertaken, both at bushfires and fuel reduction burns.

Coupled models (e.g. WRF-Fire) have previously been used in Australia by several researchers, and more extensively in the USA (e.g., CAWFE, WRF-Fire). This project uses the ACCESS-Fire model, which links directly to high-level operational and research Australian meteorological computing capability. ACCESS-Fire represents an important opportunity for future development, as well as potential to provide a fire prediction tool to international partners through the overarching UK Met Office Unified Model framework.

Coupled fire-atmosphere models are being used increasingly internationally in both research and operational spheres. The most progressive operational implementation is in the USA state of Colorado, where the WRF-Fire model is a component of a new capability for fire prediction. WRF-Fire also includes capability to predict particulate trajectories in fire plumes. Australia has one of the most fire-prone landscapes in the world and is already experiencing increased impacts of fire in a changing climate, therefore our motivators for developing capability in the coupled fire-atmosphere modelling space are unparalleled.

RESEARCH APPROACH

CASE STUDIES

In both meteorology and bushfire management, using a case study approach to examine events retrospectively is well established as a process that can provide insights that were not possible in real time; these insights can translate into lessons learned which may be applied during future events. It is also a tractable approach to defining the scope of a project. Therefore, our research methodology is to perform detailed analyses of high-impact fires. We do this through examination of meteorological and fire behaviour data information that was available in real time and from post-event reconstructions and reports, as well as running ACCESS-Fire and examining the output. Our ultimate objective is to understand how the energy released by the fire modified the surrounding atmosphere and infer how this process subsequently affected the fire behaviour. The two case studies are the Waroona and Sir Ivan fires.

Waroona

The Waroona fire was suggested as a case study by DPAWs end-users Lachie McCaw and Neil Burrows, who were co-authors of the Waroona case study paper (Peace et. al. 2017). The Waroona fire was selected because during the first two days of the fire there were four episodes of extreme fire behaviour: two pyrocumulonimbus events and two evening ember storms. The drivers for the extreme fire behaviour were not fully understood at the time and could not be reconciled during the fire reconstruction. The observed extreme fire behaviour did not coincide with the diurnal maximum in fire danger as calculated by traditional measures of fire risk.

Sir Ivan

The Sir Ivan fire burnt on a day of 'Catastrophic' fire risk in NSW at the end of a heatwave and during an extended drought. Fire risk was enhanced by an unstable atmosphere and a northwesterly to southerly frontal wind change during the afternoon. Pyrocumulonimbus cloud developed near the time of the passage of the front. The Rural Fire Service NSW collected a comprehensive set of observational data during the event, which provides an opportunity for detailed verification against simulation results.

ACCESS-FIRE DEVELOPMENT

ACCESS is the Australian Community Climate and Earth-System Simulator and is the primary Numerical Weather Prediction model used for climate and weather research and operations in Australia. Coupling a fire model to the ACCESS model was a project originally conceived in a collaboration between Melbourne and Monash Universities, with the objective of simulating the Kilmore East fire on Black Saturday.

The fire code that was written during the Monash project was provided to the Bureau project team and has been installed on Bureau project space on the National Computing Infrastructure (NCI). The original code was tailored to run for a single event and was implemented in the now-retired UMUI ACCESS model interface. Significant effort has been invested in modifying the code to run on multiple events and in transitioning to the new Rose-Cylc user interface. Ongoing development work has continued to enhance the model's functionality, capability and stability, which is described in more details in the Key Milestones section.

Jeff and Mika both visited the UK Met Office (2018) and held discussions with UK researchers who are involved in development of the overarching UM (Unified Model). International interest in the project is high and offers of assistance in reviewing aspects of the model configuration and coding have been made by UK Met Office colleagues.

Progress with the coupled model ACCESS-Fire was slower than anticipated for an extended period due to several unforeseen IT and model configuration challenges. Significant testing and development has been required to adjust the settings in the meteorological boundary layer scheme to ensure model stability in response to the large fire-generated heat fluxes. The technical setbacks have been resolved and ACCESS-Fire high-resolution nested suites are now running on NCI on the new supercomputer 'Gadi' which was officially commissioned in 2019.

Importantly, the investment in developing ACCESS-Fire now means that the modelling framework can be easily re-configured to relocate and run for a 'new' event anywhere in Australia and brings the model closer to being available to other research groups.

ACCESS-FIRE SIMULATIONS

Simulations have been run on the Waroona and Sir Ivan fires. The current model configuration has a series of nested domains at 4 km, 1.2 km and 300m. Tests have been run that include another nest to 100 m however, although the 100m simulations resulted in a significant increase in computing requirements, concomitant value in output from the higher resolution runs was not seen, therefore they were not continued.

Our simulations have used constant fuel grids across the domains. The options for including variable fuel grids has been assessed and experiments with a limited domain were tested for the Sir Ivan fire. Ultimately, inclusion of variable fuel grids was deemed to be out of scope for the project. Any future development of ACCESS-Fire should incorporate variable fuels, and our investigations indicate that the grids produced for the Australian Fire Danger Ratings System (AFDRS) are likely to be the most promising option.

Current runs implement the fire grid at 1:1 on the inner atmospheric nest, and a zoom function has been developed that allows the fire grid to be run at variable resolution (ie 1:2, 1:10) within the inner atmospheric mesh.

Sir Ivan

Simulations have been run over the Sir Ivan domain with fire ignition described as a polygon taken from the RFS fire perimeter maps prior to the late morning fire 'escape'. Constant fuel settings have been used in the final simulations. The Sir Ivan case study has progressed in collaboration with partners in the Bureaus

Severe Weather section and NSW RFS. A number of features with potential to influence observed fire behaviour have been identified in the simulation results, as well as temporal and spatial processes at finer scale than are captured with current operational forecasting methods.

Waroona

Simulations of the Waroona fire using the CSIRO forest (Vesta) fire behaviour model show very good fidelity with the fire perimeter from reconstructions once the known location of spot ignitions are included. The focus of the analysis has been on two aspects of the fire activity; the pyrocumulonimbus on 6 January and the interaction between the fire plume and the downslope winds on 6 and 7 January.

FINDINGS

A number of important results have been identified through analysis of the simulation output. They are important because they represent processes that can only be reproduced through including fire-atmosphere coupling in the simulations. Key results are summarised here; longer descriptions will be included in the two papers in preparation and will be discussed in presentations that are scheduled for September 2020.

WAROONA

Key findings

- Development of deep moist convection and cloud formation is simulated that is consistent with pyrocumulonimbus cloud at the time and location of pyrocumulonimbus over the Waroona fire on 6 January.
- Very good fidelity is seen between the fire reconstruction and the simulated fire perimeter on the first day of the fire using the Vesta / CSIRO forest fuel fire spread model, when location of known spot ignitions are included.
- Downslope winds over Waroona on the first evening produce strong interactions with the fire plume and create an environment highly favourable for mass spotting.
- Simulated fire intensity increases by an order of magnitude as the fire approaches Yarloop on the second evening in the coupled simulations in response to the above-surface winds.

Abstract (draft)

The Waroona fire burned south of Perth in January 2016. 69,000 hectares were burnt, 170 homes lost and there were two fatalities in the town of Yarloop. The fire exhibited extreme fire behaviour on several occasions during the first two days, which didn't reconcile with the near surface conditions of fire risk. Two evening ember storms were reported and pyrocumulonimbus cloud (cumulonimbus flammagenitus) developed.

The coupled fire-atmosphere model ACCESS-Fire has been run to explore the processes surrounding the extreme fire behaviour at the Waroona fire. ACCESS-Fire incorporates a meteorological component and a fire spread component. In these simulations the CSIRO forest fire (Vesta) spread model is used. The meteorological numerical weather prediction model is the ACCESS version of the UK Met Office Unified Model.

In this study we report on the skill of the coupled model in reproducing surface fire spread using constant fuels in complex terrain. The periods of extreme fire behaviour that are the focus of this study are the deep moist convection as a proxy for pyroCb cloud on the first day and the fire-atmosphere interactions surrounding the ember showers, as the fire burned down a scarp beneath a diurnal low level jet on both evenings.

The simulations provide useful insights into the complex processes surrounding the periods of extreme fire behaviour, therefore suggestions are made for applying the learnings from this case to operational meteorology practices in supporting fire agencies and potential future development and applications of ACCESS-Fire.

Selected example figures

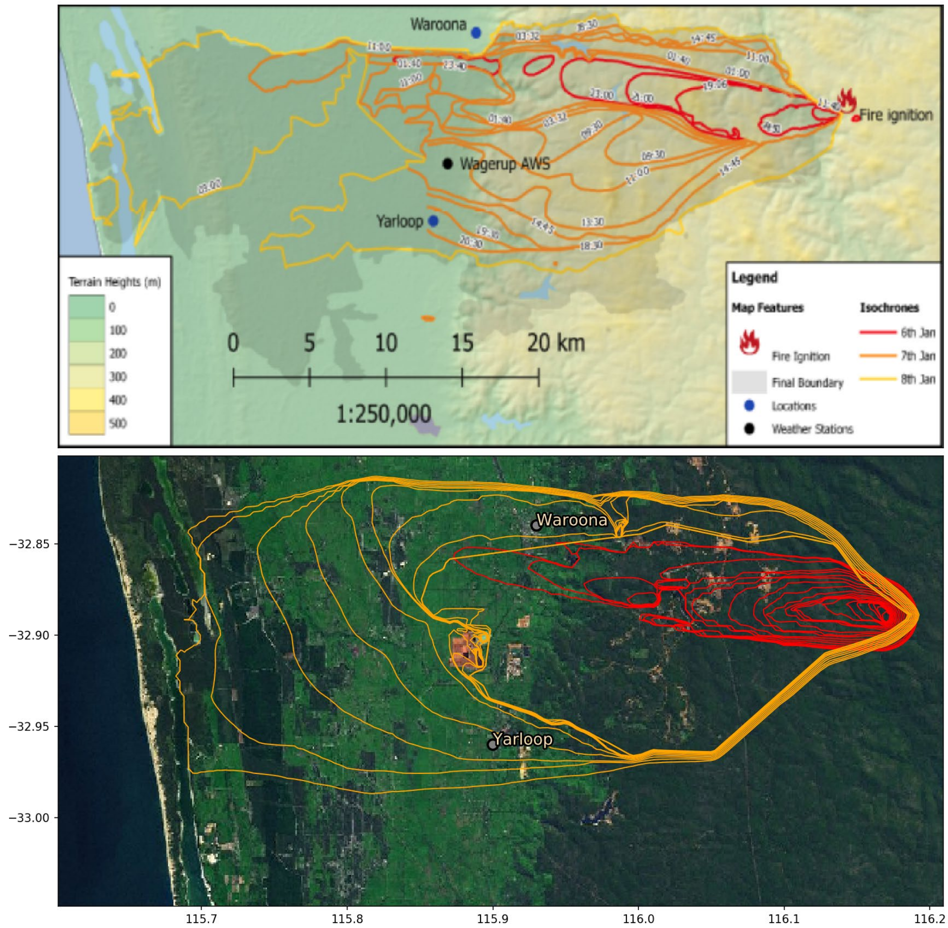

Figure 1: Reconstruction of the Waroona fire produced by DPaWS (top) and ACCESS-Fire simulations (bottom). Red isochrones show 6 January, orange isochrones show 7 January. The simulation on 7 January is initiallised from a polygon at 1445 WST.

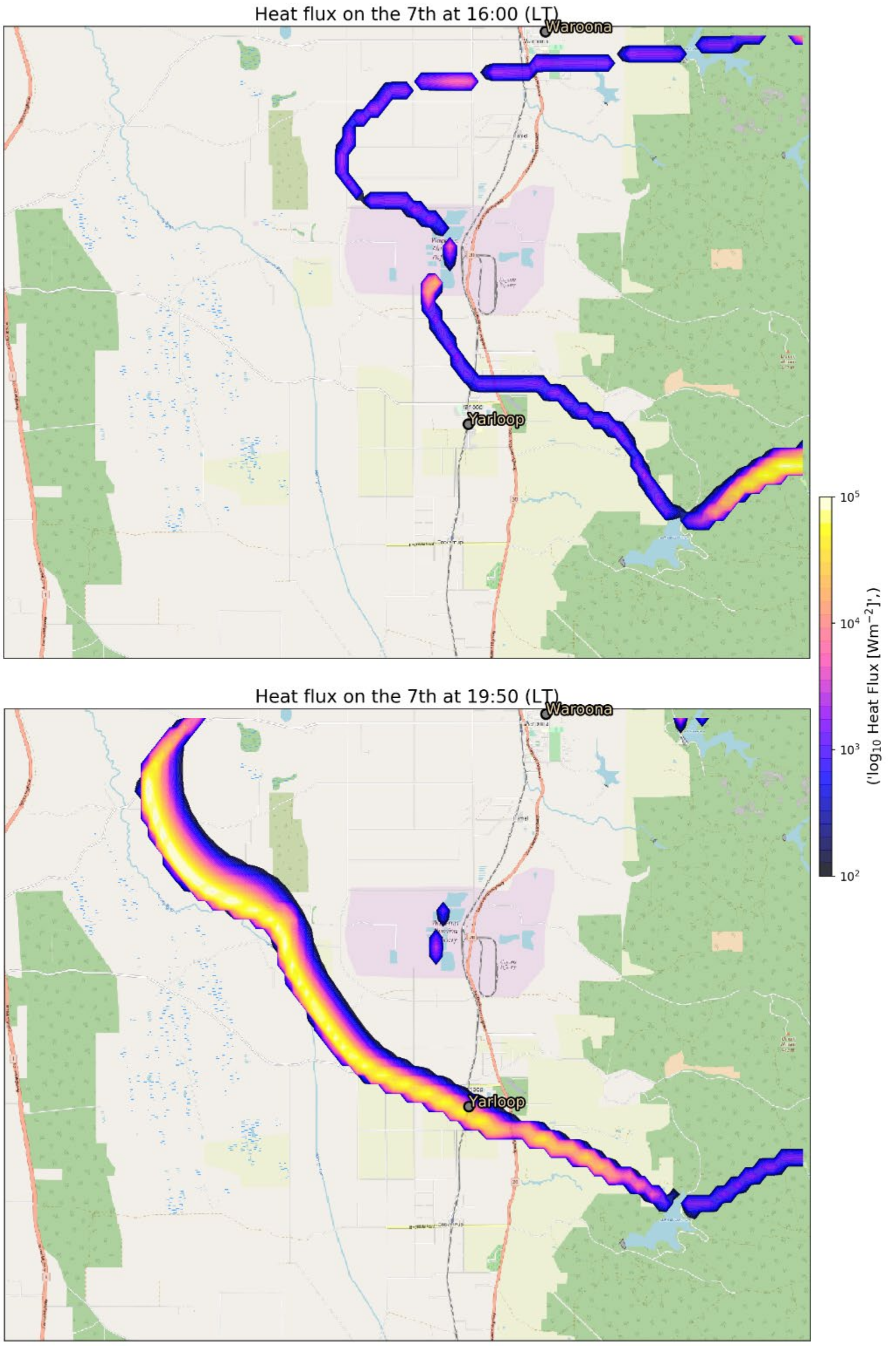

Figure 2: Heat flux on the fire perimeter on 7 January at 1600 WST (top) and 1950 WST (bottom) The 1600 WST heat flux is near the time of maximum heating and FFFDI while the evening heat flux at 1950 WST shows orders of magnitude greater flux (note log scale) in response to entrainment from the above surface winds and lesser reliance on temperature in the Vesta model.

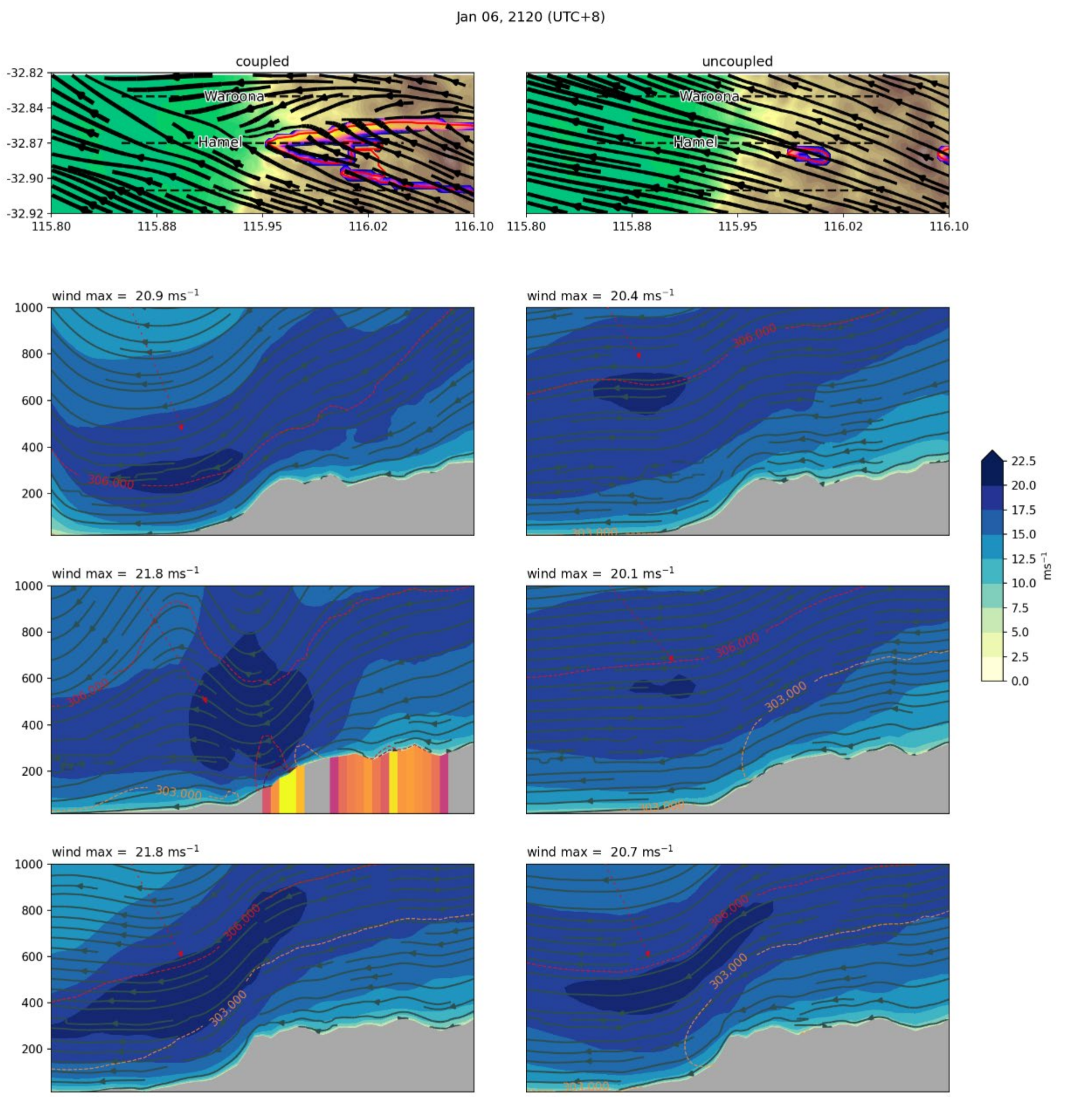

Figure 3: ACCESS-Fire cross sections (lower three plots) along the three transects shown in the top plot. Left plots show fire coupled enabled, right plots have no coupling between the fire and atmosphere. Top plot: orange-pink shaded perimeter shows fire intensity, green-brown shading shows topography and streamlines show wind direction. Lower plots: blue shading shows wind speed (m/s), black lines show streamlines and orange-pink shows approximate position of fire. Grey shows topography. The coupled model brings the jet maximum closer to the surface and enhances the maximum wind speed and the streamlines show low level wave mechanisms and turbulence favourable for ember transport.

SIR IVAN

Key findings

- Surges in fire front intensity occur in response to cellular convection embedded in the boundary layer winds.
- Deep moist convection consistent with pyrocumulonimbus cloud develops near the timing of the wind change.
- A short-lived vortex forms ahead of the fire front after the wind change consistent with observations on radar

Abstract (draft)

The Sir Ivan fire burned around 55,000 hectares in NSW on 12 February 2017. In the lead in period, record temperatures were recorded and the fire conditions on the day were described as the 'worst ever seen in NSW'. 'Extreme' to 'Catastrophic' conditions were forecast and the potential for extreme fire behaviour was identified several days in advance. The meteorological conditions were hot dry and very windy with a frontal wind change forecast during the afternoon.
The coupled fire-atmosphere model ACCESS-Fire has been run to examine the processes surrounding the extreme fire behaviour at the Sir Ivan fire. Several fire-interaction features are produced by the simulations. Comparison of linescan imagery and simulated heat flux from the fire perimeter shows response in intensity on the northern fire flank to the gradual wind shift. Temporal and spatial variability seen as pulses in fire intensity and fireline wind speed occur in the simulations in response to cellular features in the boundary layer winds. Deep moist convection consistent with the observed pyrocumulonimbus cloud develops over the fire around the timing of the frontal wind change and matches the guidance for the 'Pyrocumulus Firepower Threshold' tool which showed transient favourable conditions. After the wind change a short-lived vortex developed on the northern flank of the fire indictive of a source of organised rotation.

The features seen in the coupled simulations are consistent with elements of extreme fire behaviour at the Sir Ivan fire. The coupling process captures mechanisms that are not apparent in uncoupled fire predictions and are not presented in operational meteorological products.

Selected example figures

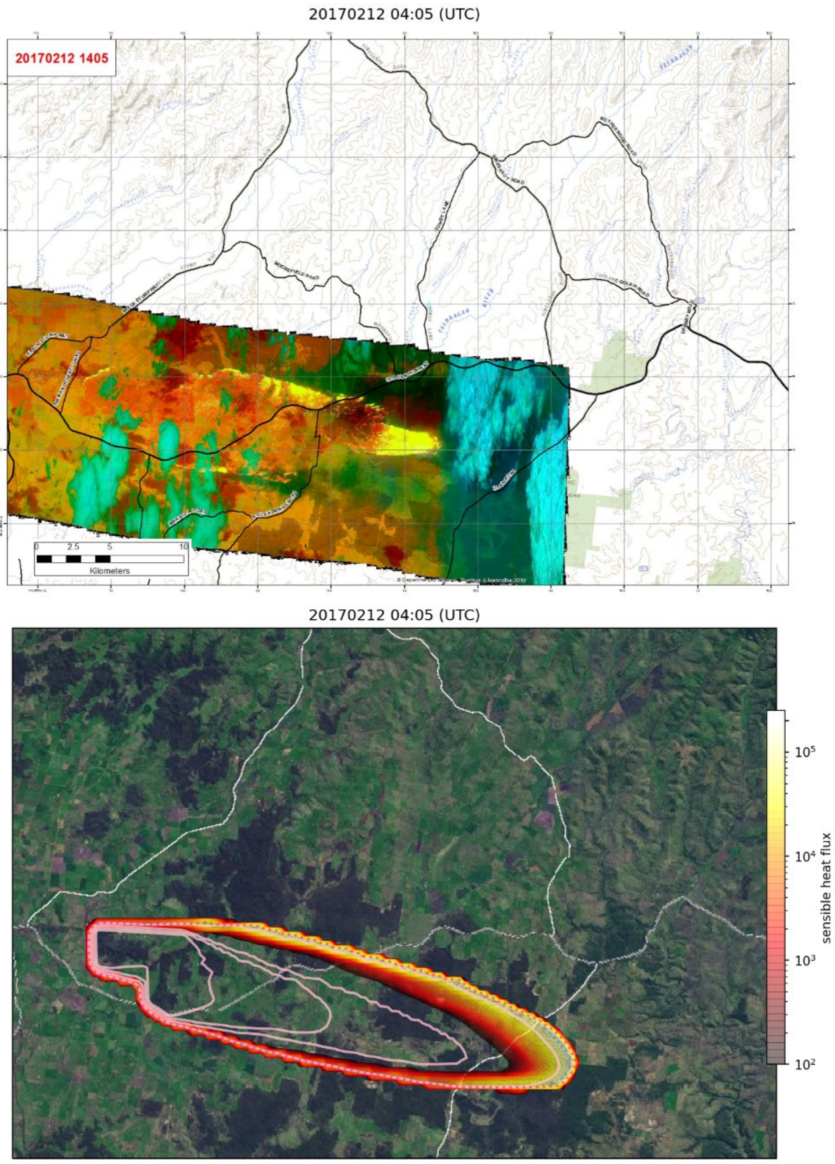

Figure 5: Comparison of the RFS linescan and simulated fire perimeter heat flux ahead of the frontal wind change, with enhanced fire activity on the northern flank in response to the gradual shift in wind direction.

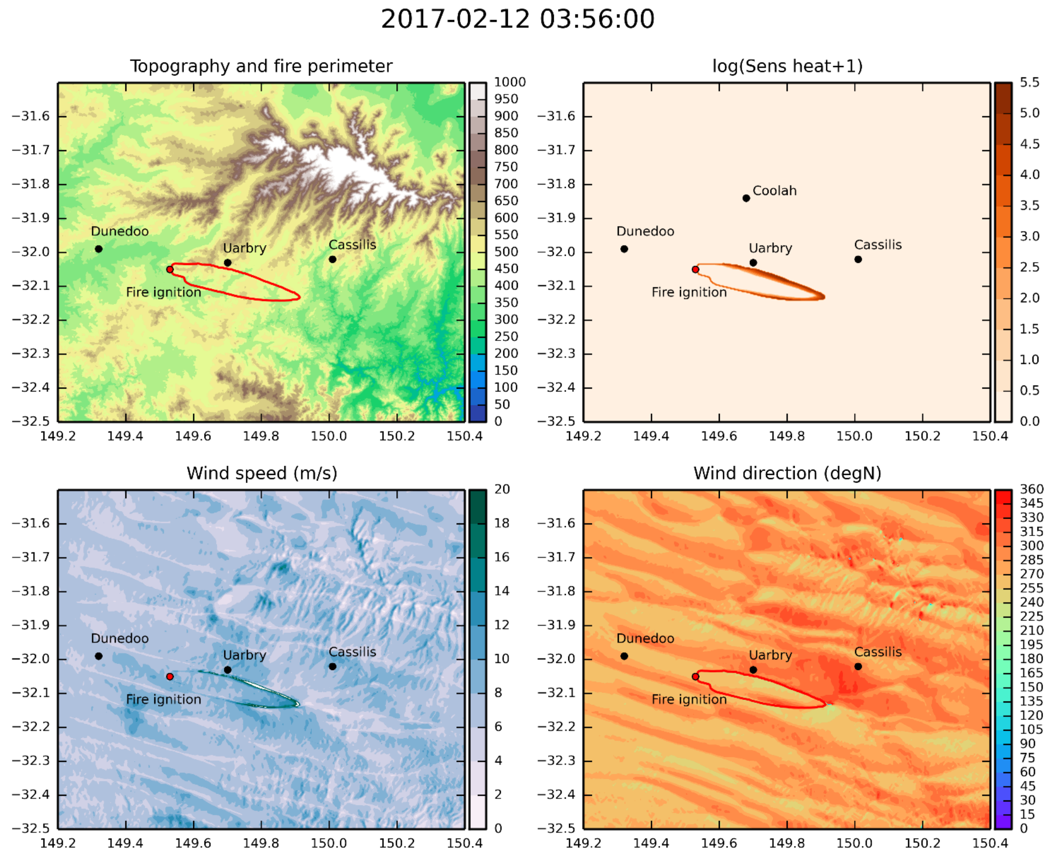

Figure 6: Simulation showing fire perimeter (top left), heat flux (top right), wind speed (bottom left) and wind direction (bottom right). Note the response in winds speed at the fir e perimeter in response to features in the cellular structure of the boundary layer winds and the shift in wind direction from the southwest which is occurring in advance of the main frontal change.

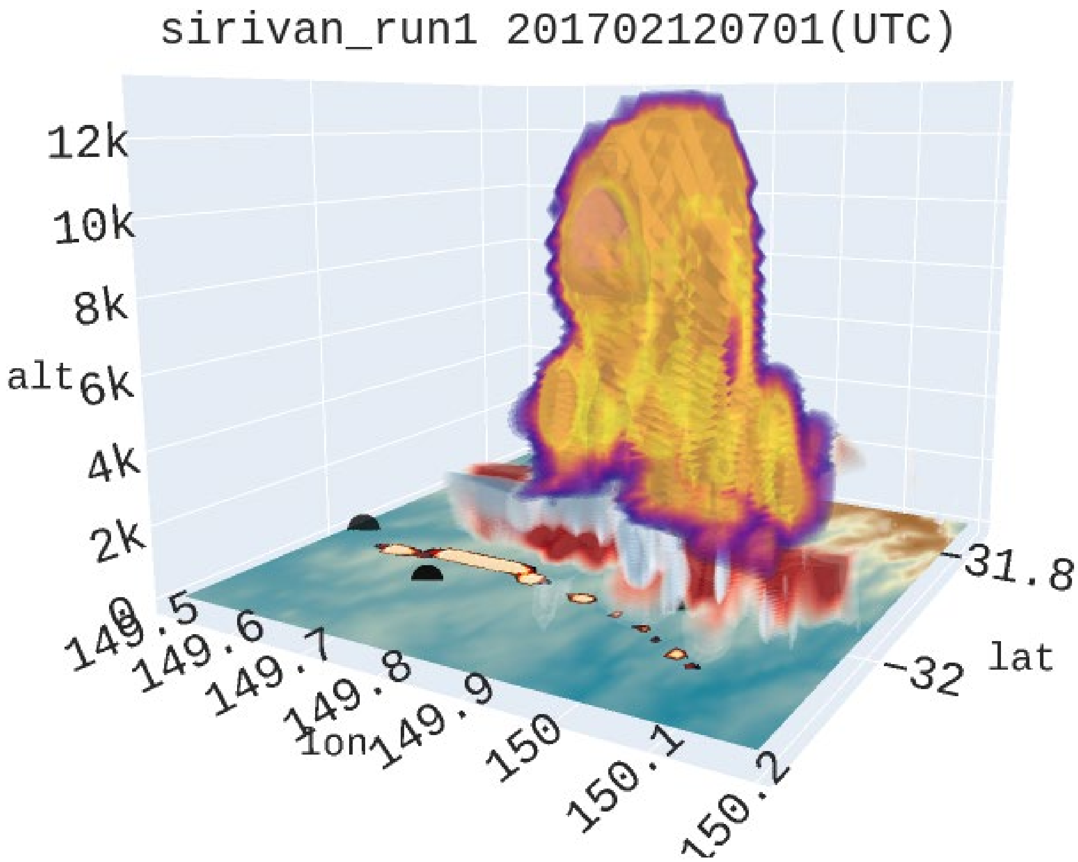

Figure 7: Three-dimensional rendition of simulated deep moist convection as an indicator of pyrocumulonimbus cloud. Further analysis will examine the sheared structure of the cloud feature in the environmental wind profile in the vicinity of the change and show the deep cloud development was transient and matched the timing of the 'PFT' prediction.

KEY MILESTONES

Key milestones in the original project plan were unavoidably delayed due to IT delays related to model stability as well as issues resulting from changes to the Unified Model framework and required developments to the fire code. Revisions to the original project plan were negotiated with end-users and the BNHCRC and a new timeline and set of deliverables were agreed. In the past 12 months a model configuration has been established that runs reliably and near-final simulations have been achieved.

The revised project plan was further adjusted in response to the 2019-20 fire season. The prolonged impacts during the season resulted in an unprecedented demand for operational staff in across multiple jurisdictions for a period of several months. Mika was requested to provide support in an Embedded Meteorologist role in several states to meet the demand for meteorological briefings and interpretation. This request was supported by the BNHCRC through an equivalent time hiatus in project deliverables of three months, which extended the due dates of deliverables from the end of June to the end of September 2020.

ACCESS-FIRE DEVELOPMENT

Considerable progress has been made by Harvey in developing components of the ACCESS-Fire framework, making refinements to the fire code and adjusting the meteorological boundary layer settings to accommodate the heat fluxes released by the simulated fire while maintaining numerical stability.

Nesting suite: Runs at 300 m have produced valuable results. Experiments at 100 m required substantial additional computational resources however, the additional computational expense was not considered to be of sufficient value to justify continuing simulations at 100 m.

The simulations have been made with constant fuel settings: The project team have held discussions with the Australian Fire Danger Ratings System (AFDRS) team regarding implementing the National Fuel Grids (as developed by the AFDRS project) in ACCESS-Fire.

The model configuration is discussed in detail in the draft manuscript on the Waroona fire simulations which contains information on the UM version and science settings, as well as the nested configuration and the methodology for the fire code interacting with the UM model component.

WAROONA CASE STUDY

A detailed paper on the Waroona fire has been published in Journal of Southern Hemisphere Earth Systems and Science (JSHESS). Engagement and training activities have been provided to a wide group of end-users in the Australian fire community.

Meteorological drivers of extreme fire behaviour during the Waroona bushfire, Western Australia, January 2016 Peace, M., McCaw, L., Santos, B., Kepert, J., Burrows, N. and Fawcett, R.

http://www.bom.gov.au/jshess/papers.php?year=2017

WAROONA SIMULATIONS AND MANUSCRIPT

The Waroona simulations have been completed and analysis has been conducted, with only revisions and improvements required to strengthen the arguments presented in the publications. A draft paper has been written and will undergo revisions and improvements in the coming weeks and we anticipate it will be ready for internal review at the project close.

SIR IVAN SIMULATIONS AND MANUSCRIPT

The Sir Ivan fire simulations are not as far progressed as the Waroona ones. Final simulations have been run and are being analysed and an outline of the paper has been drafted. The findings make for a valuable contribution to the science and considerations on how meteorological information is used for fire predictions. We are optimistic that the draft will be ready for internal review at the project close.

COUPLED FIRE-ATMOSPHERE MODELLING DISCUSSION PAPER

A manuscript has been prepared on 'Lessons learned from coupled fire-atmosphere research and implications for operational fire modelling'. The manuscript is well progressed and will be co-authored by Mika Peace, John Bally (AFAC, retired BoM) and in international collaboration with Jay Charney (US Forest Service).

Initial feedback on the breadth and depth of the draft has been favourable and we anticipate it will provide a useful document contributing to discussions on the future directions of coupled fire modelling in Australia and applications to operational interpretation. It has potential to inform the future direction for coupled fire atmosphere modelling in the Bureau and for CRC stakeholders.

The paper will be moved through internal review as soon as practicable and an avenue for appropriate dissemination will be decided.

UTILISATION AND IMPACT

SUMMARY

The project has been widely recognized for providing operational support and for outreach activities. We have a strong reputation for actively engaging with a broad range of specialist end-users and non-technical audiences. The project team regularly communicate research findings with internal and external stakeholders, local and national media and the broader community.

AGENCY OPERATIONAL SUPPORT

During the 2019-20 fire season, Mika provided operational expertise across multiple jurisdictions including CFS, QFES and RFS in a specialist Embedded Meteorologist and liaison capacity. Requests for assistance were made by both external agencies and by internal Bureau Incident Management Teams.

CFS, South Australia. - October and November 2019 and February 2020

QFES, Queensland - November 2019. Included briefings to the Prime Minister, Deputy Prime Minister and Premier**.**

RFS, New South Wales - December 2019 and January and March 2020. Included briefings to the Premier.

CONTRIBUTION TO ROYAL COMMISSION AND BUSHFIRE INQUIRIES

Mika has been working on the Bureau's team for the Royal Commission between March and August 2020, preparing the various reports and science submissions for the Royal Commission and the SA and NSW State Inquiries.

Although the appointment does not directly link to project outcomes, it draws on the capability developed and invested in by the CRC. The expertise developed through the CRC program has been applied to Royal Commission and Inquiry process.

NCI AND HPC RECOGNITION

The Australian National Computing Infrastructure and High-Performance Computing group have demonstrated great interest in the project over the past 12 months, particularly in view of the destructive impacts of the 2019-20 fire season. NCI and HPC engagement includes:

- Invited presentation to the Australian Leadership in Computing Symposium (2019)

- Reference to project work on the NCI media release for the Gadi supercomputer and interview for the NCI annual report.

- Invitation to peak at the virtual HPC – Artificial Intelligence Conference.

REQUESTED TALKS AND TRAINING

- NSW FBAns 2020 workshop (virtual) with excellent feedback received.

- South Australian Museum

OUTREACH AND ENGAGEMENT

Distribution of presentation and other research material and science support to Embedded Mets and other internal fire interests.

Extended radio interviews.

CSIRO program "STEM Professionals in Schools".

INTERNAL COLLABORATIONS

- Fire Weather Working Group
- Embedded Met Working Group
- Input to the Australian Fire Danger Rating System
- Input to internal fire meteorology training material

NEXT STEPS

The project ends on 30 September 2020, therefore current activities are strongly focused on completion of the project deliverables.

The key deliverables due by 30 September are:

Papers:

1. Draft manuscript on ACCESS-Fire simulations of the Waroona fire (ready for review)
2. Draft manuscript on ACCESS-Fire simulations of the Sir Ivan fire (ready for review)
3. Discussion paper "Lessons learned from coupled fire atmosphere research and implications for operational fire modelling" (in review)

Presentations:

1. CAWCR seminar (scheduled 9 September)
2. Video on project outcomes (rescoped from RAF presentation)
3. Presentation to AFAC Predictive Services Group

Other:

1. Final report for the BNHCRC
2. American Meteorological Society Fire and Forest Meteorology conference (this is now not a project deliverable due to timing but is an approved post project activity, dependent on travel restrictions due to covid19)

The project team are in discussions with our end-users and the BNHCRC regarding future development and use of ACCESS-Fire as the CRC transitions to a new National Research Centre for Disaster Resilience.

ACCESS-Fire is now running successfully and simulations have produced valuable and compelling evidence of some of the fire and atmosphere interactions that drive extreme fire behaviour. Impacts of fires are forecast to increase in a changing climate, which presents a need for predictive tools that include the effects of fire -atmosphere interactions. ACCESS-Fire is a capability that can contribute to this imperative; therefore, continued development is suggested particularly in view of the growing international interest in coupled fire-atmosphere models.

PUBLICATIONS LIST

1 Meteorological drivers of extreme fire behaviour during the Waroona bushfire, Western Australia, January 2016 Peace, M., McCaw, L., Santos, B., Kepert, J., Burrows, N. and Fawcett, R. Journal of Southern Hemisphere Earth Systems Science, 2017.

http://www.bom.gov.au/jshess/papers.php?year=2017

2 Extreme Fire Behaviour: Reconstructing the Waroona Fire Pyrocumulonimbus and Ember Storms., Peace, M., Kepert, J., BNHCRC Hazard Note, June 2018.

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END-USERS

Many of our end-users are also collaborators on various project deliverables or colleagues and team members during operational periods. We thank them for their ongoing support, partnership and insights.

End-user representative	End-user organisation	Extent of engagement (Describe type of engagement)
John Bally	AFAC Predictive Services (ex BoM)	Lead end-user and collaborator
Simon Heemstra	Bureau of Meteorology (ex RFS)	End-user
Laurence McCoy	RFS (NSW)	End-user
Lachie McCaw	DPAWS(WA)	End-user and collaborator
Mike Wouters	DEW (SA)	End-user
Mark Chladil	TAS Fire	End-user