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SIMULATIONS OF THE WAROONA FIRE WITH THE ACCESS-FIRE COUPLED FIRE ATMOSPHERE MODEL

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ABSTRACT

SIMULATIONS OF THE WAROONA FIRE WITH THE ACCESS-FIRE COUPLED FIRE ATMOSPHERE MODEL

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The Australian Community Climate and Earth-System Simulator (ACCESS) Numerical Weather Prediction (NWP) model has been coupled to a fire spread prediction model called ACCESS-Fire (Monash and Melbourne universities, publication in preparation). The ACCESS-Fire model presents a coupled fire-atmosphere modelling capability that is linked to the Australian Bureau of Meteorology's operational weather forecasting system.

The fire spread code in ACCESS-Fire is implemented by a level set solver and includes several fire spread models, including options for Rothermel, McArthur and CSIRO forest and grassland. It uses high-resolution topography and detailed fuel maps can be included as available. The sensible and latent heat energy fluxes from the fire are passed back to the atmospheric code through the land-surface scheme JULES. The fire model has been built into the ACCESS high-resolution nested suite using an advanced graphical user and scheduler interface.

ACCESS-Fire simulations have been run on the Waroona fire, which burnt over 68,000 ha south of Perth in January 2016. Over 160 homes were destroyed and there were two fatalities. During the first two days of the fire, there were four episodes of extreme fire behaviour. Two separate pyrocumulonimbus events developed and two evening ember storms occurred. The fire behaviour at the Waroona fire was driven by three dimensional fire-atmosphere interactions, and such processes can be examined using a coupled fire-atmosphere model.

This paper will describe key features of the coupled fire-atmosphere model ACCESS-Fire and present results from simulations of the Waroona fire. Features of the simulations include fire-modified winds in the environmental flow, dynamic plume effects near steep topography and exploration of pyrocumulonimbus processes.

EXTENDED ABSTRACT

INTRODUCTION

Bushfires are a part of the Australian landscape. Periodically, during significant fire events, they burn with devastating consequences to the community and environment. Such fires release significant amounts of energy during the combustion process, and this energy modifies the structure of the surrounding atmosphere. The local three-dimensional wind fields surrounding the fire are altered from their background state, and this can then affect how the fire evolves. The vertical atmospheric stability structure will also influence the depth of the fire plume and the circulation within it, as well as development of pyro-convective cloud.

Traditional approaches to assessing fire risk and anticipating fire behavior do not take into account the atmospheric structure and feedback processes. Internationally, evidence suggests that fires are increasing in size and frequency, with greater impacts to human populations. Consequently, there is a growing emphasis on understanding the underlying science driving fire and atmosphere interactions, with investment towards developing predictive tools that will assist fire managers to anticipate and mitigate against the impacts of large, dynamic fires.

Coupled fire-atmosphere models are one mechanism through which this can be achieved. Coupled fire-atmosphere models link an empirical (or dynamical) fire spread model to a numerical weather prediction system. Several coupled models are in use internationally and, in view of the impacts of fire on the Australian community, an Australian coupled modelling capability is prudent and consistent with the objectives of other countries with fire-prone landscapes.

The aim of our project is to develop an Australian capability for coupled fire-atmosphere modelling that lies on the same platform as our operational numerical weather prediction systems, and to test the model on a set of case studies of actual events.

COUPLED FIRE-ATMOSPHERE MODELLING

Coupled fire-atmosphere models link an atmospheric model with a fire spread model. There are two main approaches in use, the first is a numerical weather prediction atmospheric models linked to an empirical fire spread model, as in WRF-Fire (Coen et. al, 2013). ACCESS-Fire follows the same approach as WRF-Fire, with a different NWP framework. The second approach to coupled modelling employs dynamical rather than empirical fire spread (e.g. FireTec (Linn et. al, 2007) and ForeFire (Filippi et. al, 2018)). The dynamical approaches are currently limited to a research capability due to the computational requirements, however future upgrades and refinements may reduce the current restrictions. Dynamical approaches have had limited uptake in Australia to date, however investigation of this method would be worthwhile.

An advanced international application of coupled fire modelling has been implemented in the USA state of Colorado, where their operational fire prediction project uses the WRF-Fire model (Coen et. al, 2013) as a component of the system (WRF-Fire has a similar operational NWP and empirical fire approach as ACCESS-Fire).

There are known limitations when using empirical approaches to calculate fire spread. However, it is beyond the scope of this project to investigate and refine the methodologies for solving fire spread.

Although there are challenging and unresolved research questions to address regarding the best approach to modelling interactions between a fire and atmosphere, previous studies using coupled fire-atmosphere (empirical and NWP) models have demonstrated that the results provide useful insights into the physical processes and reconcile well with observations (e.g. Kochanski et. al., 2013 and others). This is consistent with our initial simulations using ACCESS-Fire. Our results are promising as they capture features including plume dynamics, fire modified winds extending some distance from the fire, vorticies on the fire front, pyro-convective cloud condensation processes and enhanced vertical motion adjacent to the topographic discontinuity of the Darling Scarp.

ACCESS-FIRE

ACCESS-Fire is an empirical fire model coupled to the ACCESS framework. ACCESS is the Australian Community Climate and Earth Systems Simulator and is the national high-resolution numerical weather prediction (NWP) modelling system.

The ACCESS model operates under the UK Unified Model (UM) framework, developed by the UK Met Office. ACCESS can be considered as an Australian adaptation of the UM model.

ACCESS is Australia's premier operational weather forecasting model and is also our national model for climate simulations. Our coupled simulations are made with the ACCESS system run in research mode on the National Computing Infrastructure (NCI) supercomputer "raijin".

The fire code component of the ACCESS-Fire model was developed in a collaboration between Monash and Melbourne universities and has been provided to the Bureau of Meteorology and the BNHCRC.

The fire code interfaces with the NWP model through the land surface scheme JULES (Joint UK Land Environment Simulator) (Best et. al, 2011, Clark et. al. 2011). After each time step of the atmospheric model, wind and other required input variables are passed to the fire model, which then calculates a fire perimeter advance by level set mathematical method using empirical algorithms for fire spread. From the change in fire perimeter, the quantity of fuel consumed and resulting sensible and latent heat fluxes are calculated, which are passed back to the atmospheric model. These heat and moisture fluxes then modify the surrounding wind fields at subsequent time steps, which creates the coupling process.

The current fire model includes code for CSIRO grassland and forest, McArthur and Rothermel empirical models.

ACCESS-Fire has been configured as a high resolution 'nested suite'. Current runs include nests run at resolutions of 4 km, 1.3 km, 400 m and 100 m. The initial and boundary conditions are currently set using ACCESS-G archived grids, but may be modified to accept a range of NWP models. The fire suite is relocatable across Australia to run any new event when boundary conditions are available. Current settings use a constant value to describe fuel state, but high resolution variable fuel grids may be included. Topography data is from SRTM (Shuttle Radar Topography

Mission); the 90 m and 30 m DEM (digital Elevation Models) datasets have been tested.

Further development planned for the coming year includes: implementation of national fuel grids; steps towards inclusion of the fire model in the main UM/ACCESS release, which will make the model available to a range of users; and further refinements to the fire code to increase resolution between the inner meteorological nest and the fire grid, which can current be set at a 1:1 or 1:2 ratio.

THE WAROONA FIRE

The Waroona fire burnt 69,000 ha south of Perth on 6 and 7 January 2016, with devastating consequences for the towns of Waroona and Yarloop and the broader community of Western Australia. During the first two days of the fire there were four periods of particular interest. Pyrocumulonimbus developed over the fire on the evening of 6 January and around midday 7 January. Destructive ember showers driven by downslope winds occurred two evenings running; the first over the town of Waroona on 6 January, then the town of Yarloop was destroyed during early evening on 7 January. None of the four episodes of extreme fire behaviour matched the time of highest fire danger as measured by fire danger indices.

ACCESS-FIRE SIMULATIONS OF THE WAROONA FIRE

Simulations have been run of the Waroona fire, noting that the model is under continuing development. The results shown here are experimental and configurations are still being tested; full simulation details will be reported in due course. Three different fire models have been tested, with significant differences seen in the resulting fire spread and perimeter using the McArthur forest, CSIRO forest and Rothermel options (see Fig. 1). Rothermel produces the fastest fire spread (a known factor with this model), while McArthur and CSIRO simulations produce fire spread that is much slower than expected compared to the observations and fire reconstruction. These differences will be investigated further as the study progresses and calibrations may be included in order to facilitate investigation of dynamic processes. It is not an objective of this study to validate or improve the empirical fire-spread models that are implemented in the coupled model, therefore calibration of fire spread to match observations so that fire-atmosphere processes can be explored is considered to be an acceptable approach.

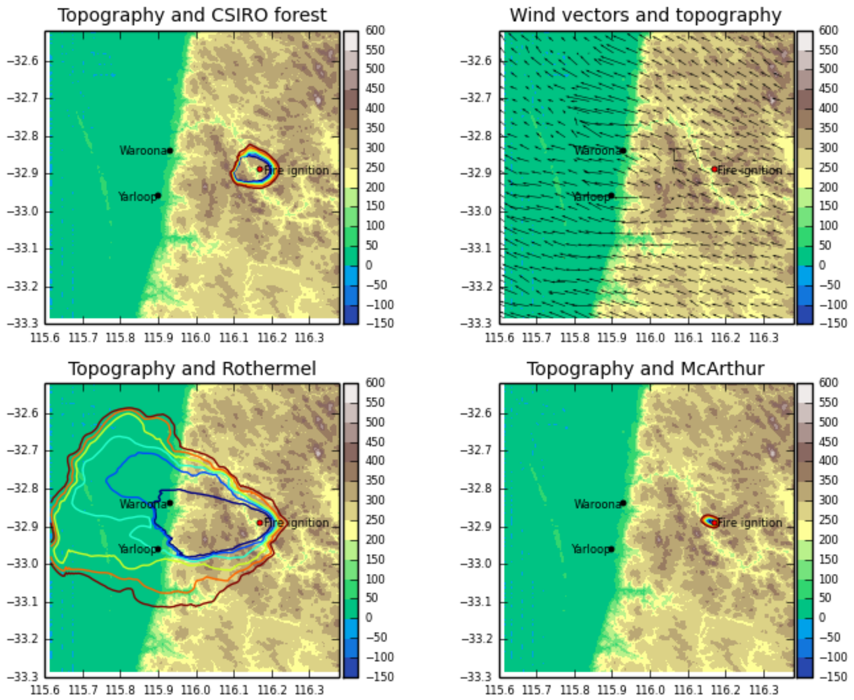

Figure 1. ACCESS-Fire simulations of the Waroona fire using the fire spread models CSIRO forest, Rothermel and McArthur forest as labelled. Simulation period varies slightly due to computational restrictions.

Following the results of the Waroona case study (Peace et. al., 2017), there are two main processes that the investigation with the coupled model may explore. These are 1) the ability of the model to resolve and develop pyrocumulonimbus and associated dynamics and 2) the interactions between downslope winds and the fire plume and resulting potential to enhance ember storms.

Experiments modelling pyrocumulus clouds have had mixed success. LES idealized studies (e.g. Thurston et. al., 2016) have produced good and insightful results, and the very highly idealized study of Cunningham and Reeder (2009) produced a pyrocumulonimbus and fire tornado. However, experiments in a real atmosphere with coupled fire-atmosphere models that attempt to reproduce observed pyrocumulonimbus in "real" cases have had more limited success (personal communications and lack of published evidence in the literature). Therefore, in setting the objective of these simulations, it has been determined to focus on the processes of downslope wind interaction with the fire plume. This approach is appropriate as the timing of downslope wind onset resulted in the greatest impacts to the community; due to loss of lives and homes destroyed. In addition, the downslope wind risk is known to affect other locations around Australia as well as other fire prone countries and evidence from simulations will make a valuable contribution towards informing operational tools.

Figure 2 shows results of the Rothermel simulations when the fire is near the base of the scarp. In the simulation shown, the temporal conditions do not match the time of the observed ember shower, however, it is encouraging that the coupled model does resolve fire-modified winds and interactions with topographic features. Also apparent are vortices along the fire front and a deeper fire line near the base of the scarp.

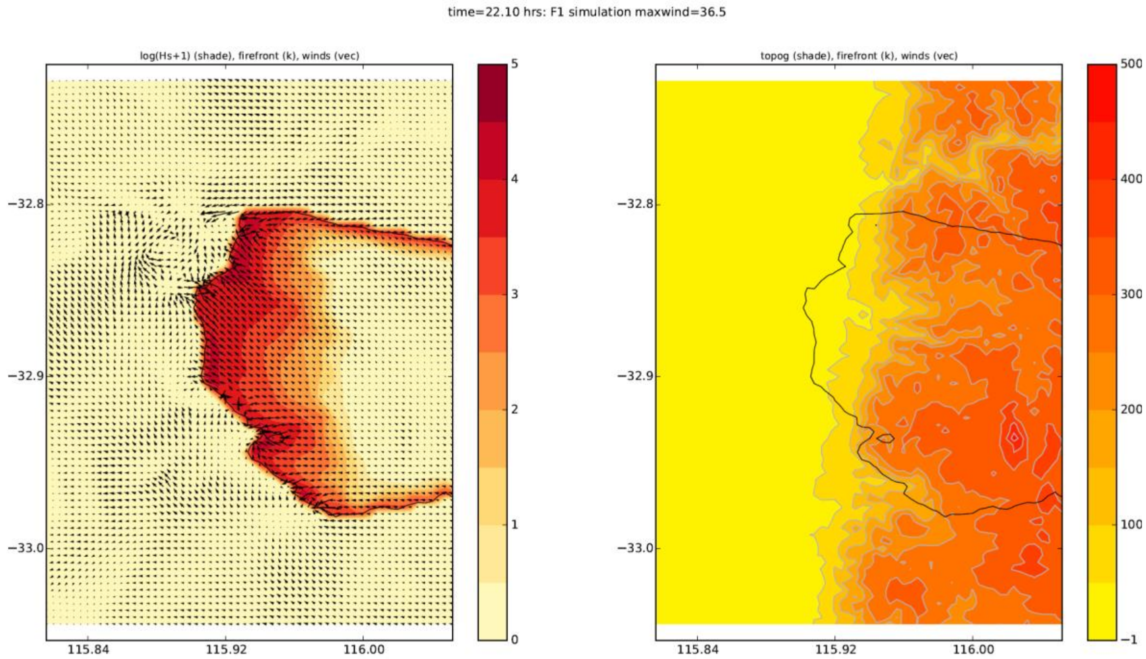

Figure 2. ACCESS-Fire simulations showing fire perimeter and (left)heat flux and wind vectors and (right) topography.

Figure 3 shows a vertical cross-section from west to east across the coastal plain and scarp. The fire is located near the base of the scarp (the edge of the topography profile) and the features and discontinuities seen in the vertical cross sections arise from the fire plume interacting with the vertical atmospheric structure. There are several features of interest. The vertical extent of the plume is considerable, extending above the depth of 4 km shown in the plots, with the plume structure showing significant perturbations from the atmospheric background state. The perturbations in potential temperature are confined to a relatively narrow column above the simulated fire, indicating limited extent of mixing and entrainment in the horizontal direction. The vertical velocity shows maximum speed near 30 m/s, with the maxima elevated a considerable distance above the surface, rather than just above the heat flux. This elevated maxima is consistent with the results of Charney et. al. (2018). Horizontal wind speed is highest over the scarp to the east of the fire, however the perturbations are highly asymmetrical with stronger winds on the (eastern) upstream side of the plume and much lighter winds on the (western) downstream plume. The cloud water is indicative of cloud development and the skill of the model in resolving these cloud processes will continue to be explored.

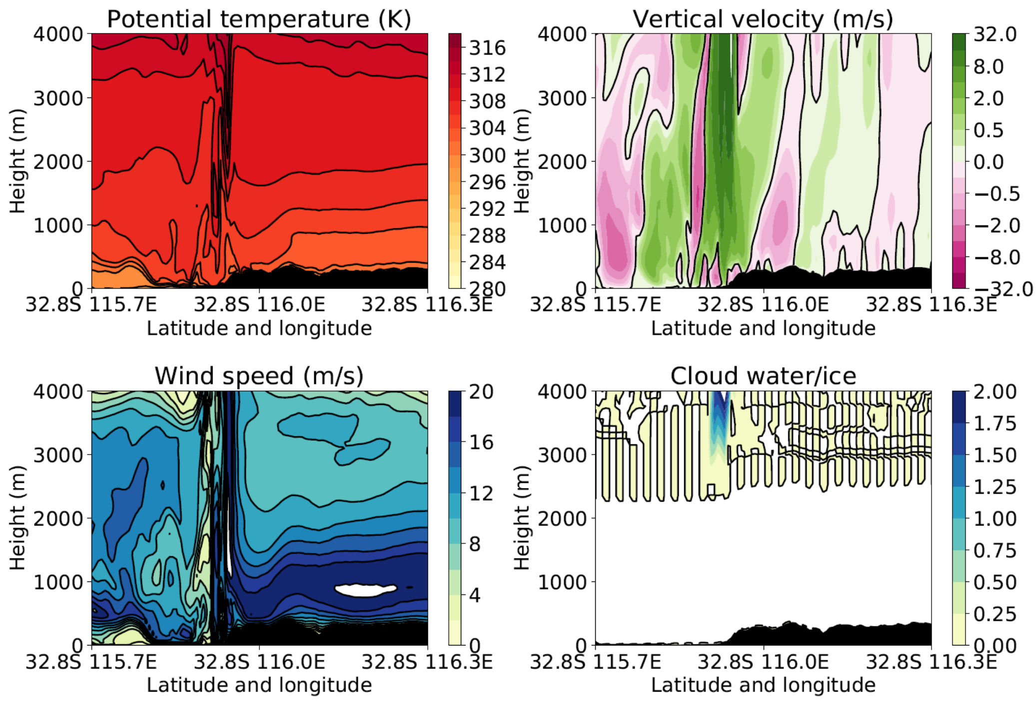

Figure 3. ACCESS-Fire simulation showing vertical cross section west to east across the Waroona fire. Top left: potential temperature. Top right: vertical velocity. Bottom left: horizontal wind speed. Bottom right: cloud water.

As this study progresses, we aim to vary initial conditions and fire-line timing in order to examine the temporal variation in fire activity near the base of the scarp with time of day. As the downslope winds, or scarp winds are a known evening and overnight process, this approach will provide a series of simulations that allow an investigation of how a fire in a particular location responds to varying atmospheric stability and vertical wind profile due to diurnal temporal conditions.

Improved understanding of the processes will inform development of predictive tools and support future fire management activities and planning decisions (e.g. Kepert et. al. 2016). Downslope winds often develop at a time of day when traditional measures of fire behaviour indicate a decrease in fire risk due to lowering of temperatures overnight. Exploring the sensitivities of downslope winds and fire behaviour as they can be captured in the model framework, will provide a theoretical basis to develop practical operational tools that will enhance decision making in similar environments and may enable mitigation of impacts in future events.

FUTURE PROJECT WORK - SIR IVAN FIRE

Parallel to these simulations of the Waroona fire, our CRC project is working on ACCESS-Fire simulations of the Sir Ivan fire. The Sir Ivan fire burnt on a day of 'catastrophic' fire risk in NSW at the end of a heatwave and during extended drought. Fire risk was enhanced by an unstable atmosphere and a northwest to southerly wind change during the afternoon. Pyrocumulonimbus developed coincident with the passage of the wind shift. RFS NSW collected an unprecedented set of observational data during the event, which presents an opportunity for detailed verification against simulation results. Simulations of the Sir Ivan fire are underway (see poster at AFAC 2018) and the continuing analysis will examine the fire environment in detail and produce a detailed comparison of the observational data and the results of simulations.

FUTURE PROJECT WORK - COUPLED FIRE-ATMOSPHERE MODELLING IN AUSTRALIA

Following the preparation of the two case studies currently in progress on the Waroona and Sir Ivan fires, the project will report on current status of coupled fire-atmosphere modelling in Australia and overseas and present an objective assessment of the various opportunities for the path forwards for this avenue of fire predictive services. The planned report will examine current capabilities internationally, the pros and cons of the varying modelling approaches, the benefits of coupled modeling, the context of current and future computing capabilities, the enhanced capability enabled by robust user interfaces, data availability, initialisation and real-time data integration. Ensuing discussion will mesh with requirements for timely operational decision making and other factors. Input will be requested from a range of Australian stakeholders; please contact the project team if you would like to contribute to the discussions.

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