ACCESS-Fire report

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Contents

Abstract

This is the abstract ...

1 Introduction

Introduction to project and model. Bushfires are extremely dangerous for many reasons. Firefighters depend on accurate weather forecasting and information in order to mitigate risks both to themselves and the community in general. One issue is that fires can generate their own local weather such as vortexes [1] and storms (pyrocumulonimbus or PCB) [2] that generate lightning and wind gusts that have not been forecast by models.

Model output is examined to improve understanding of weather phenomena in the context of bushfires.

Outline The remainder of this article is organized as follows...

2 Model

2.1 ACCESS

TODO: Blurb about ACCESS

Model output are 4-dimensional: latitude, longitude, vertical level (θ or ρ), and time. Most fields are defined at their grid-box midpoints. Wind speed and direction is defined at the direction-dependent gridbox edge.

2.2 Coupled Fire Model

TODO: Details about fire model

Model output has the same latitude and longitude as ACCESS output, with more frequent time steps and no vertical component. A fire front field is produced that is negative where the fire has burnt, and positive elsewhere.

2.3 Model runs

Over the course of the project the ACCESS-Fire model has been run and updated multiple times, over two regions where large scale forest fires occurred. The model runs in a nested fashion, with three to four nests so that the highest resolution possible is produced in a reasonable manner at the site of the fires (e.g. Figure 1).

The first fire under examination occurred a few kilometers East from Waroona, a suburb South of Perth. The second occurred a few hundred kilometres North of Sydney. Both locations are modelled at high resolution using ACCESS-Fire in a nested setup (Figure 1).

This report analyses output from the latest iteration of ACCESS-Fire, earlier iterations are listed here as they may help elucidate model parameterisation decisions.

Waroona_oldold

- Run in the depths of the past (Oct 2016?)
- Output at 30 minute resolution
- Meteorology not affected by fire model

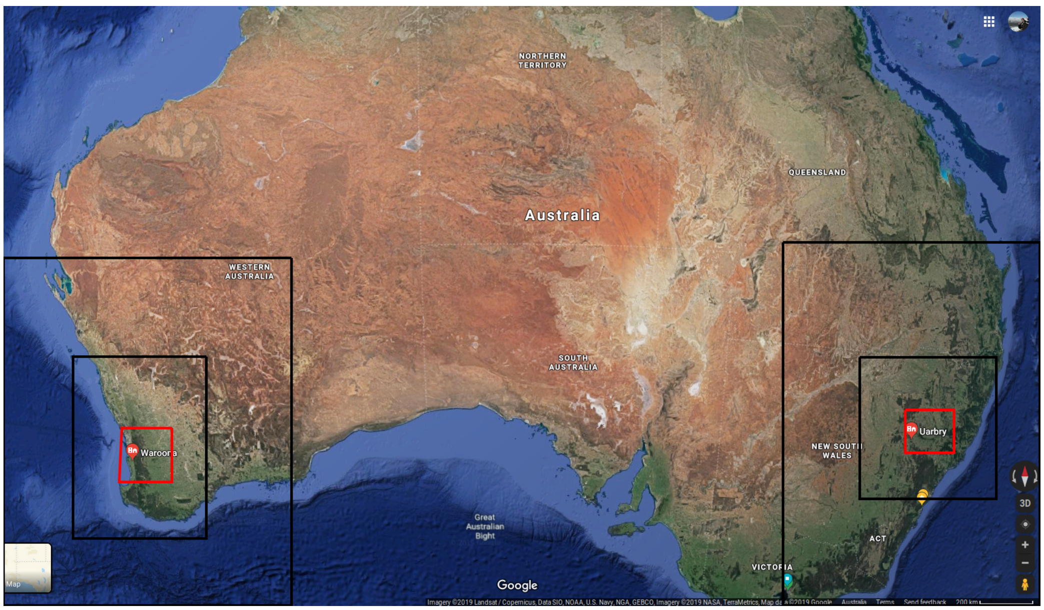

Figure 1: Three nests run by ACCESS-Fire model are shown as blackred rectangles. The outermost nest has resolution of approximately 3.5 km by 3.5 km, The intermediary Nest is at 1.0 km by 1.0 km, and the smallest nest (red) is at 0.3 km by 0.3 km. A fourth nest is sometimes added with .1 km by .1 km resolution. Fire coupling is enabled only within the higher resolution (red) nests.

- slightly different grid to other model runs

Waroona_old

- Run in Aug, 2018
- Output at 30 minute resolution
- Run crashed after 21 hours due to runaway model physics (vertical wind speeds ¿ 1km/s)
- Fast fire spread parameters
- Clear PCB creation around 1100

Waroona_run1

- Run in Aug, 2019
- Output at 10 minute resolution
- Increased boundary layer stability to prevent crash
- Slower updated fire spread parameters
- No real PCB creation seen

PCB (see Section 3) occurs in all simulations, except for Waroona_run1. PCB occurred in the real world at both fires, the absence in this model run can be explained by the different parameters used. The parameters resulted in slower fire spread, and reduced energy output.

Waroona_run2

- Run in Dec, 2019 (Raijin's last encore)
- Output at 10 minute resolution
- Increased boundary layer stability
- Fire spread parameters: Faster (older, matching Waroona_old)
- can be compared to Waroona_run2uc, which has identical settings but no fire coupling

Waroona_run3

- Run in Feb, 2020 (GADI)
- Output at 10 minute resolution
- Increased boundary layer stability
- Fire spread parameters: ?

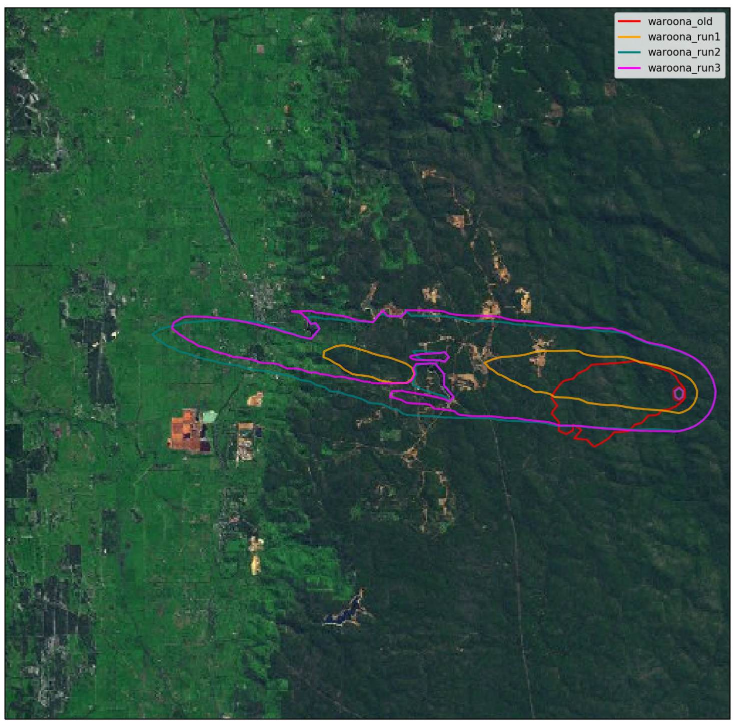

Figure 2: Model run fire fronts at start of burn and end of simulation

2.4 Modelled Weather

Weather is examined at various scales by sub-selecting extents and vertical levels, then viewing horizontal and vertical winds, cloud content, and other available metrics. This section outlines in chronological order the overall weather in the latest model run for each site.

The Waroona simulation starts 1 hour before midnight, Figure 3 shows the near-fire surface weather metrics over the first 24 hours. Winds from ESE near the surface form horizontal rolls for several hours (Figure TODO). Fire ignition occurs after about 5 hours (4AM), and progresses westwards in the easterly winds. The fire is seen to influence vertical motion a long way down-wind, before clear East-West oriented horizontal rolls occur in the vertical motion around midday. At about 2 in the afternoon, some westward winds occur at the base of the escarpment, causing updraughts and disrupting the horizontal rolls. Coincidentally the vertical motion near the fire front can be seen to have pushed into the upper troposphere leading to heightened cloud activity (Figure 4), This feature is discussed more in Section 3. Easterly winds re-establish dominance by 7PM, getting stronger especially down the escarpment until the end of the simulation. The fire spreads down the escarpment on this first evening exactly when these winds pick up, this feature is discussed in more detail in Section 4.

The Sir Ivan simulation starts at 7AM under north westerly winds, Figure 5 outlines the surface weather over 24 hours. Fire ignition occurs after 3.5 hours, initially spreading east before the wind swings around to push the fire towards the north along a long east to west fire front after about 3 hours. Northward fire spread continues for the rest of the simulation, with a marked storm cloud produced at approximately 5PM (more info on this can be found in 3.2).

2.5 Data flow

TODO: Data flow diagram for project

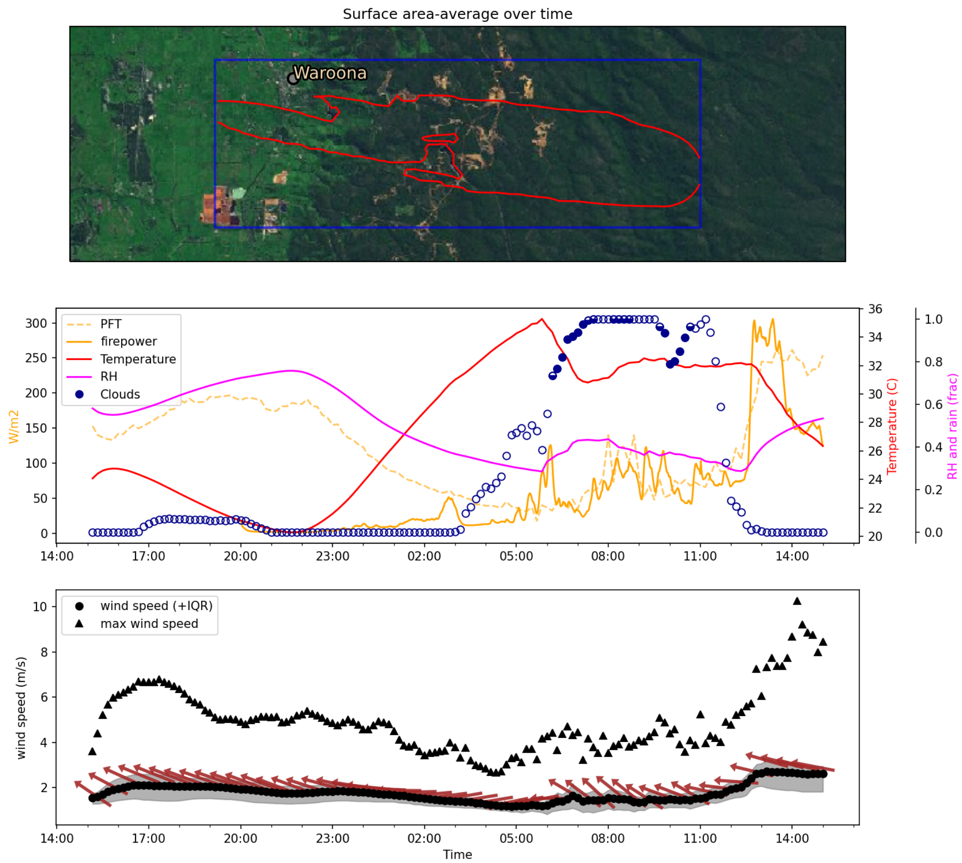

Figure 3: Top panel shows a top down satellite view near Waroona, with the fire outline after 24 hours shown in red. A blue rectangle shows the area that is averaged at each time step shown in the bottom two panels. The second panel shows several parameters over time, on 3 different y-axes, firepower and PFT share the left y-axis, cloud cover fraction and RH share the right-most y-axis. "Cloud cover" marks the fraction of the blue rectangle (top panel) where more than 0.1 gkg ice and water content in air occurs. The blue circles are filled when the heaviest 25% of total cloud content occurs, and half filled for the second highest 25%. The third panel shows surface mean wind speed and direction, including grey shading within the inter-quartile range and a triangle shows the maximum wind speed.

Figure 4: Left panels show horizontal wind speed (coloured contour map) and wind direction (arrows). Right panels show vertical wind speed (coloured contour map) and cloud content (diagonal stippling). The wind speeds are averaged into vertical bins based on height above the ground, showing lower to higher altitudes from the first row to the last row respectively. Cloud content is summed within each vertical bin, and the areas marked have at least 0.1 gkg^{-1} of water and ice.

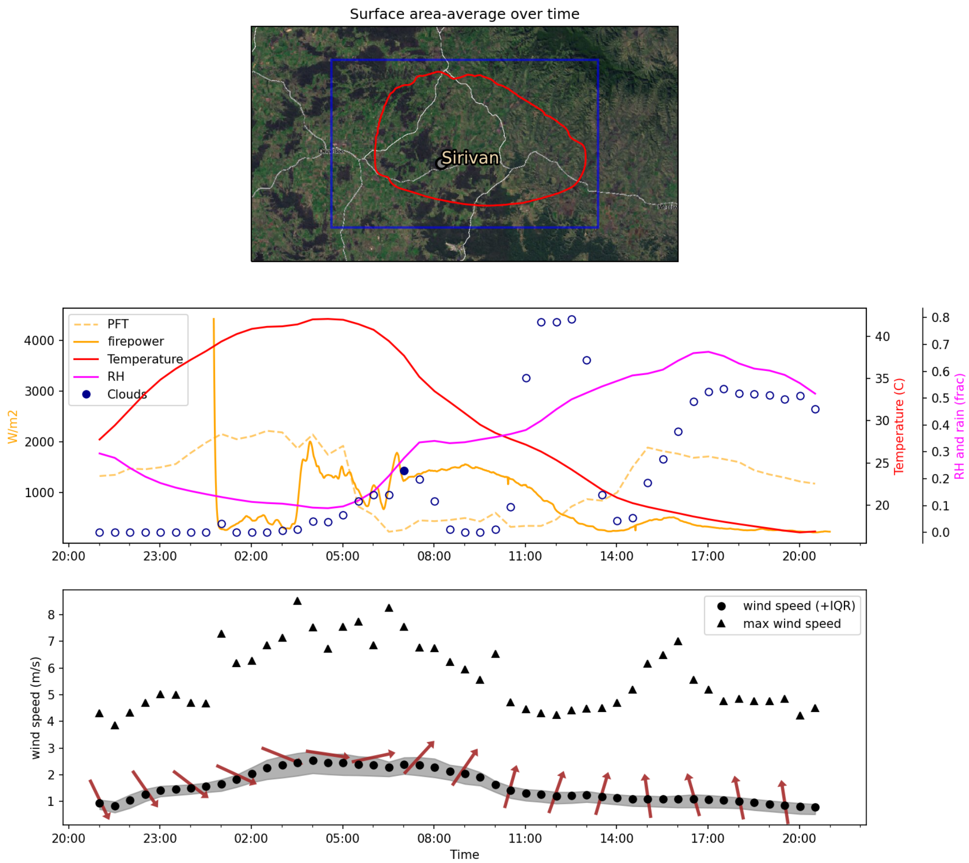

Figure 5: Top panel shows a top down satellite view near Sir Ivan, with the fire outline after 24 hours shown in red. A blue rectangle shows the area that is averaged at each time step shown in the bottom two panels. The second panel shows several parameters over time, on 3 different y-axes, firepower and PFT share the left y-axis, cloud cover fraction and RH share the right-most y-axis. "Cloud cover" marks the fraction of the blue rectangle (top panel) where more than 0.1 gkg ice and water content in air occurs. The blue circles are filled when the heaviest 25% of total cloud content occurs, and half filled for the second highest 25%. The third panel shows surface mean wind speed and direction, including grey shading within the inter-quartile range and a triangle shows the maximum wind speed.

3 Pyrocumulonimbus

Pyrocumulonimbus (PCB) is the phenomenon whereby a large thunderstorm system is generated by the heat and moisture entrained and lofted by a fire. These are extremely dangerous, difficult to predict, drastically change local weather, and can lead to substantial spotting and lightning [2].

PCB Formation is driven by the massive amounts of heat energy output from fires, which can be entrained in large scale updrafts. When a fire spreads fast is when the most heat is being produced, which is when the risk of PCB formation is greatest. Near-surface atmospheric stability and dynamics affects both how the heat entrains into the atmosphere and how fast the fire spreads. This means that simulated PCB are quite sensitive to the sorts of atmospheric parameters that affect horizontal and vertical movement, and near-surface stability. TODO: Some stuff about vorticity and other metrics?

PCB Formation Threshold (PFT) Kevin's PFT - TODO: point to his publication. Weather conditions can be more or less suitable for PCB generation, one way of quantifying this is through the PFT that estimates how much energy needs to be released by a fire to create a PCB. The less energy required, the more likely we are to see PCB formation. PFT calculations can be heavily influenced by energy in the system coming from the coupled fire model, making PFT analysis unsuitable downwind of the fire. Analysis on PFT in this work therefor either uses PFT calculated somewhere upwind of the fire, or meteorological output from an uncoupled (but otherwise identical) model run.

3.1 Waroona

PFT from code developed by Kevin Tory can tell us whether PCB formation is likely. Fire output is compared to PFT calculated just upwind of the fire ignition point in figure 6. Fire power at several times exceeds the PFT, and we might expect to see PCB within the model output. This is not a sure thing as PFT calculations can vary greatly over a small distance, and upwind conditions may not represent those at the firefront.

Strong cylindrical upward motion and cloud formation over the fire front can be considered clear evidence of PCB. To home in on where PCB occur, I zoom to a subset of the horizontal region that surrounds the fire. Horizontal

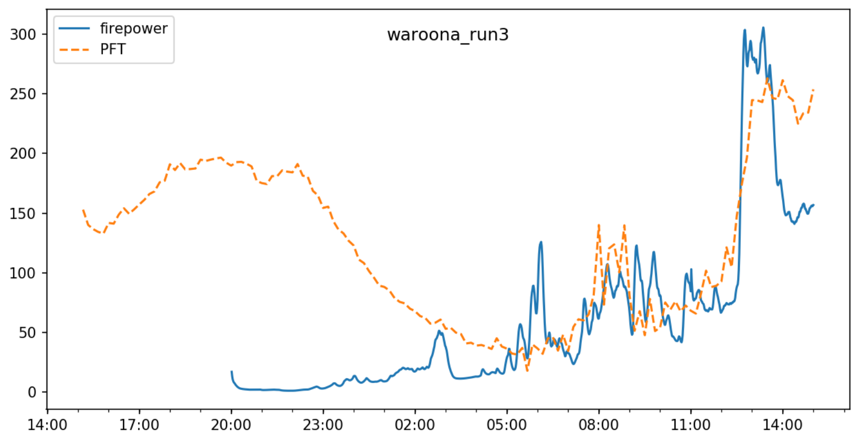

Figure 6: Fire power output, and PFT calculated approximately 1 km upwind from the fire ignition for the Waroona fire simulation.

model slices (at varying altitudes) of vertical wind motion and total cloud content show wind and cloud structures above the fire zone (Figure 7). A clear cylindrical plume occurs from around 5 km altitude all the way up to the stratosphere ($\sim$ 15 km). Cross sections show a strong internal updraft surrounded by downdrafts throughout the troposphere (Figure 8).

Visualisation in three dimensions gives a much clearer view of the PCB formation and scale. Figure 9 shows the PCB on model levels, with heat, vertical motion, and topography represented at roughly the time of formation and the peak of the storm activity. The front produces enough heat to form a huge plume that punches up into the upper troposphere, entraining moisture and leading to very strong mixing and winds locally.

3.2 Sir Ivan

The simulation over Sir Ivan showed that weather was generally unfavourable to PCB formation until about 3PM, when the PFT dropped by a couple of orders of magnitude (Fig 10). The Sir Ivan fire covered a large area, and the conditions upwind of the fire ignition are not fully representative of those near the fire front, and from other model output we see that a PCB occurs at around 5PM lasting on the order of an hour. Figure 11 shows the location

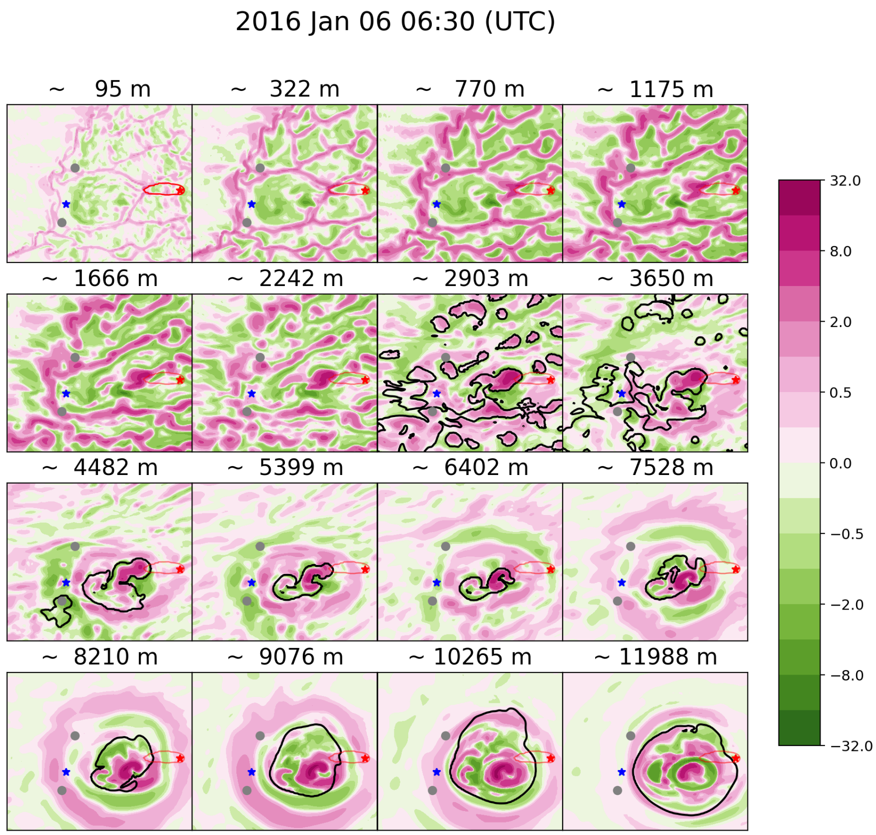

Figure 7: Top-down views of vertical motion on model levels of increasing altitude from left to right, top to bottom. Grey dots represent Waroona, and Yarloop (north, south respectively), with a blue star showing a weather station site. A red contour shows the fire front, and cloud content above the 0.1 gkg threshold is marked by stippling.

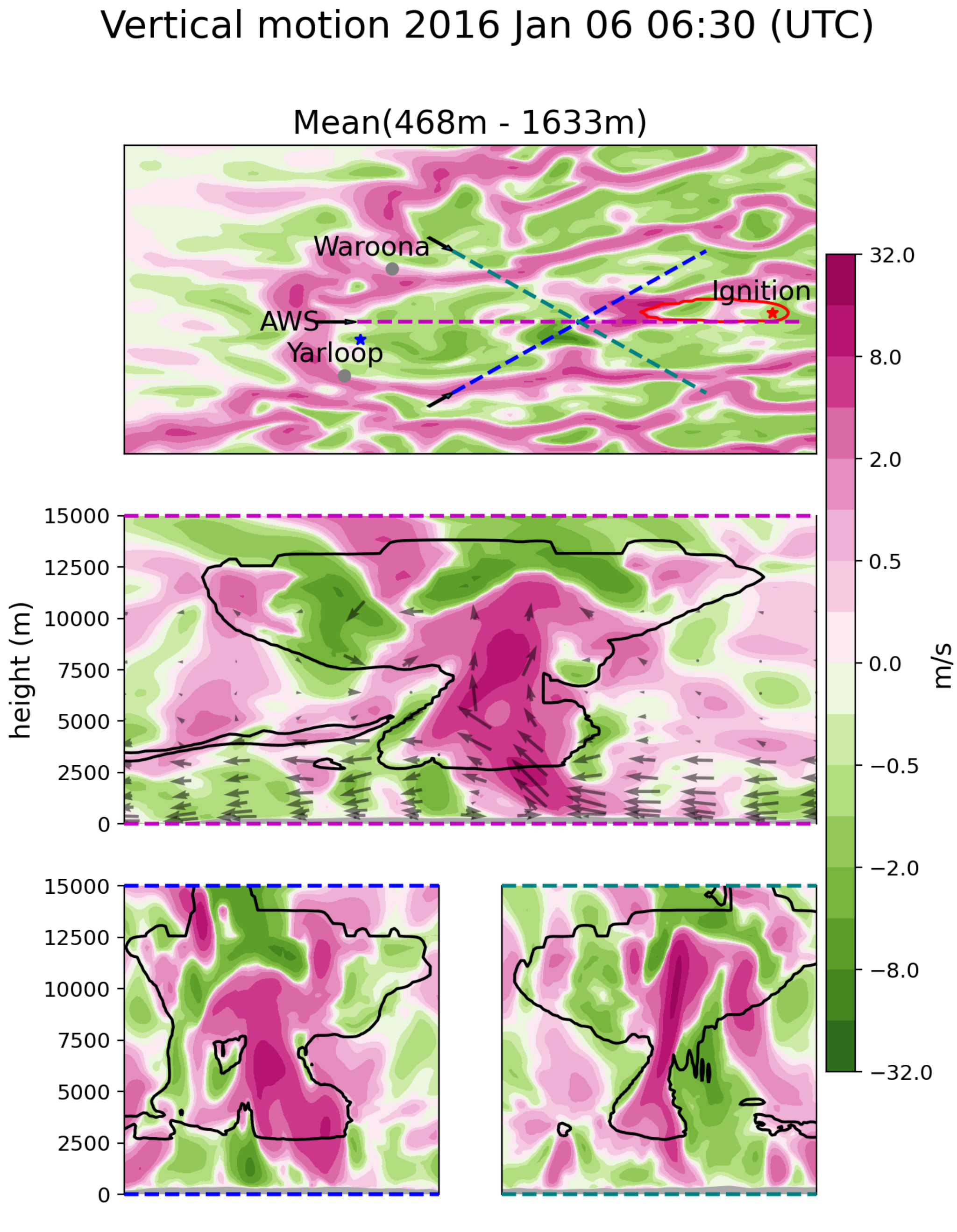

Figure 8: Top panel: top-down view showing the firefront (red contour) and vertical motion near Waroona. Bottom panels: transects (over dashed lines in Top panel) showing vertical motion, cloud content (black contour on 0.1 gkg ice and water content) and winds.

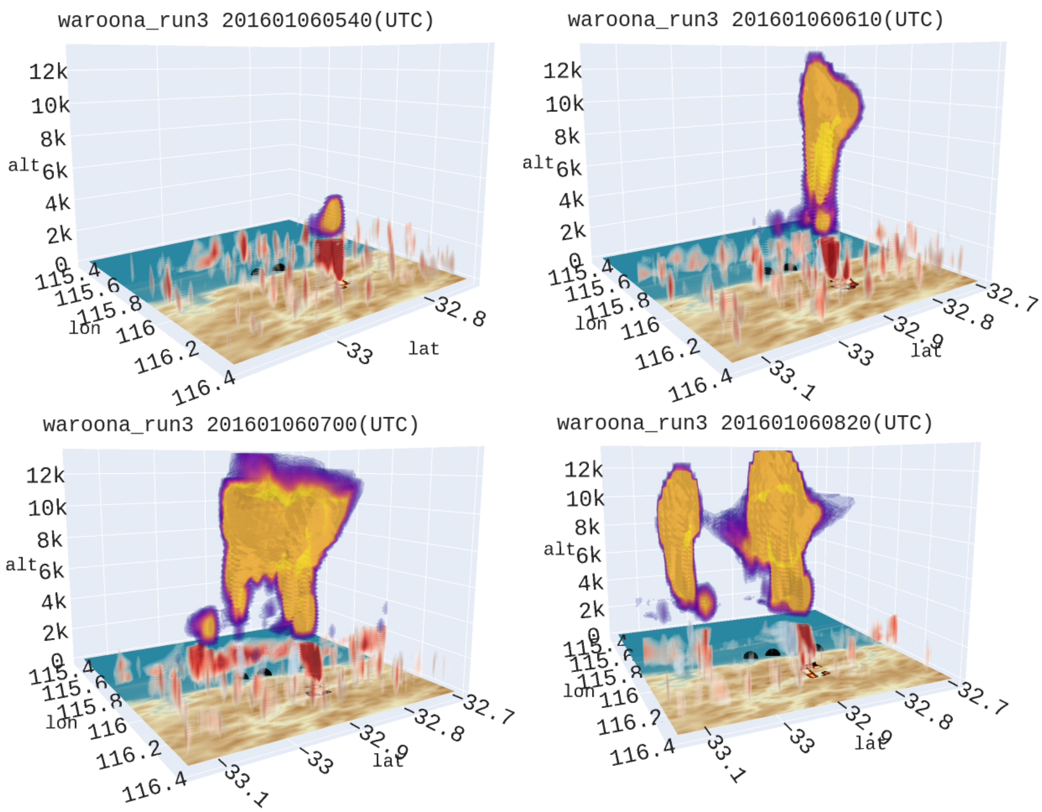

Figure 9: Three dimensional representation of meteorology near the fire over Waroona, at four times (one time per panels), with x, y, and z dimensions being longitude, latitude, and altitude above ground level respectively. Purple to yellow volumes show cloud content (0.1 gkg threshold). Red and blue volumes show vertical motion between 3-6 ms up to 2 km altitude above ground level. Near the surface a black-red-yellow volume may be visible if potential temperature is greater than 311 K, this shows where the fire is releasing the most heat. Altitude zero shows a teal to brown filled contour surface coloured by ground level altitude.

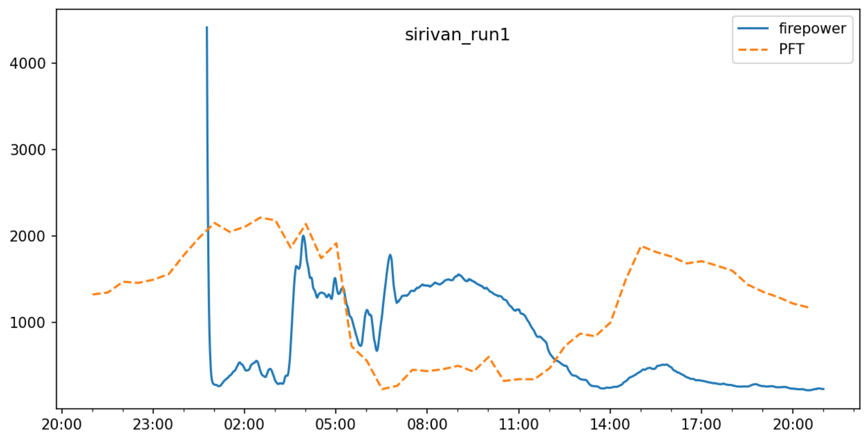

Figure 10: Time series for 24 hours of simulation firepower and PFT. PFT calculated for a vertical column approximately 1 km upwind of the fir ignition.

and dynamics of the PCB, which stretched up to the top of the troposphere, driving turbulent wind conditions and cloud formation locally.

Sir is at higher altitude, and latitude, and had a larger burn area. Figure 12 shows PCB formation in three dimensions. TODO more story here?

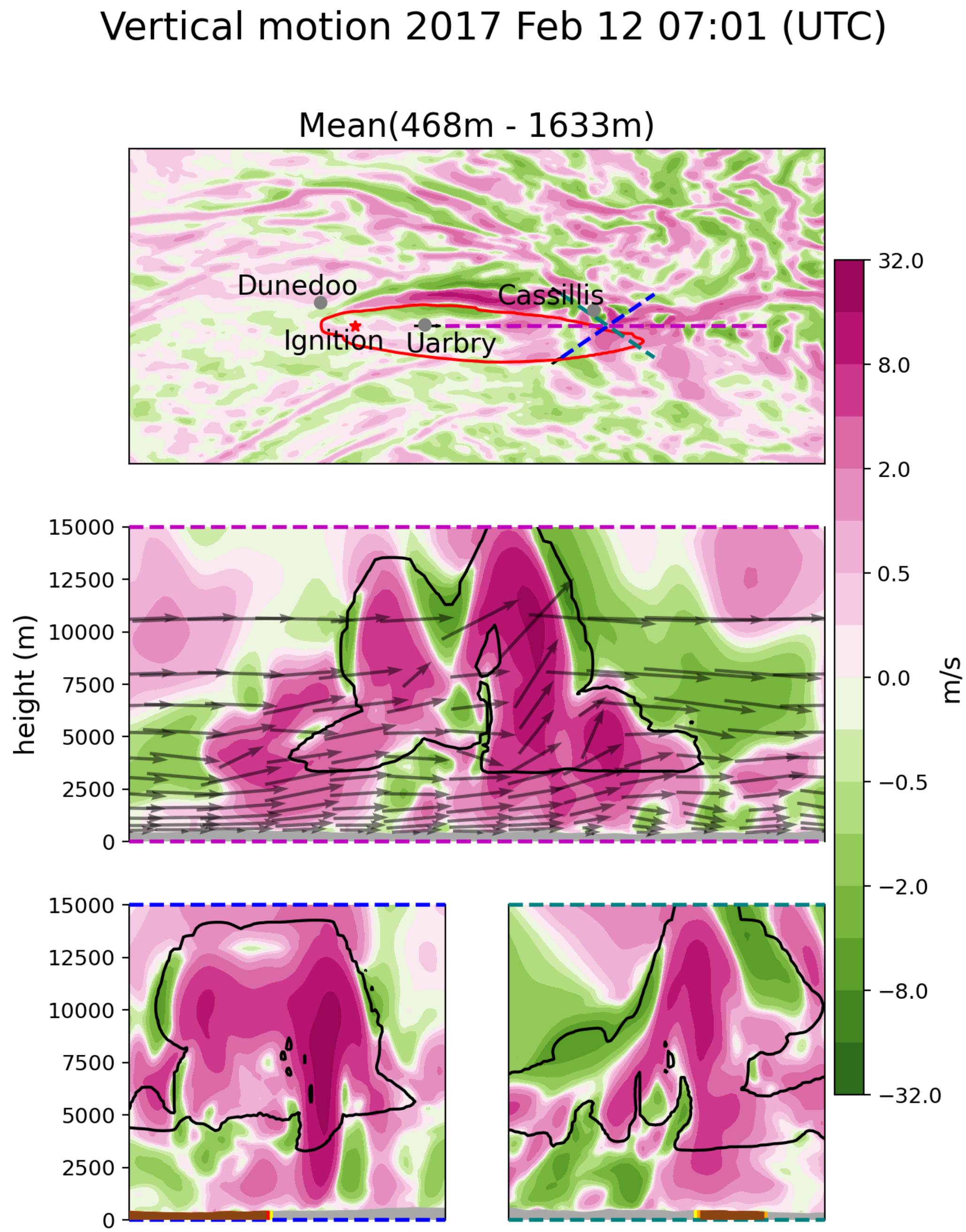

Figure 11: Top panel: top-down view showing the firefront (red contour) and vertical motion near Sir Ivan. Bottom panels: transects (over dashed lines in Top panel) showing vertical motion, cloud content (black contour on 0.1 gkg ice and water content), and winds.

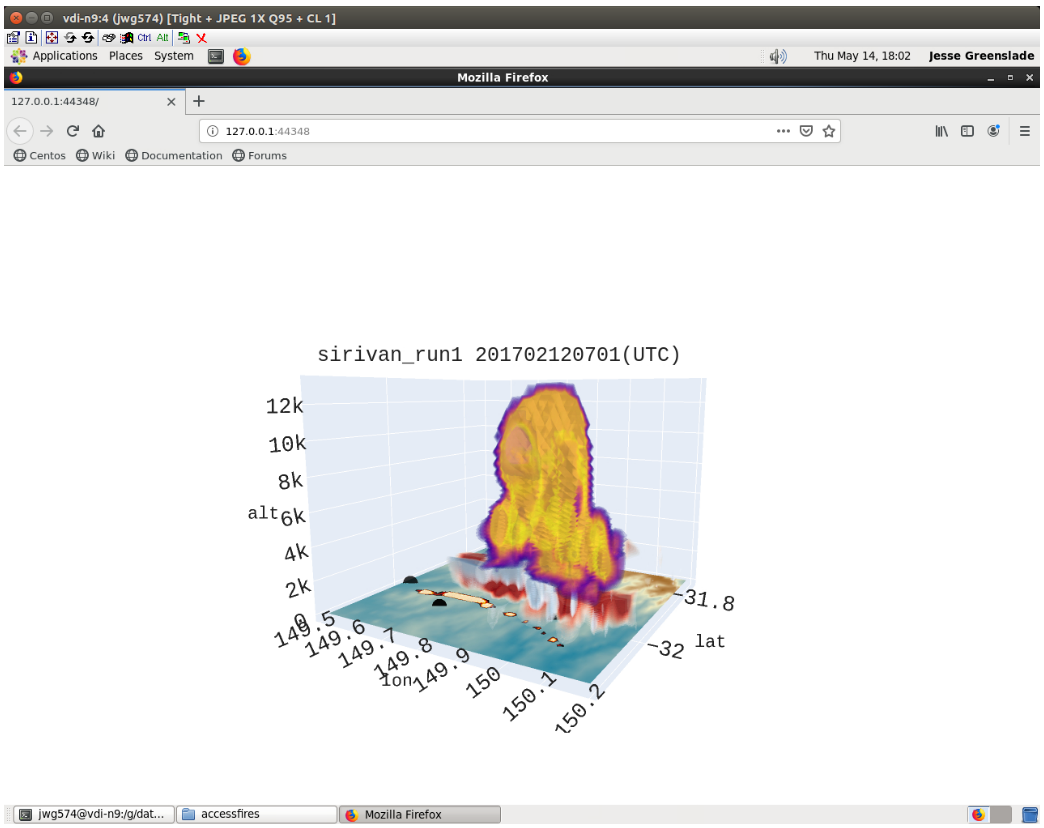

Figure 12: TODO: Placeholder until sirivan_run3 gives output - then I'll make 2x2 version of this showing pcb creation.

4 Ember storm

The Waroona fire was exacerbated by emberstorms that led to rapid downwind spotting. Spotting and ember transport is not built into the fire spread model, but atmospheric conditions do allow analysis of the contemporary meteorology. Waroona exhibited two emberstorms, the first one occurred on the first evening when the fire spread rapidly down to the base of the escarpment. The second one occurred on the second day (TODO: find out more about this one).

The first emberstorm appears to be driven by downslope winds and a jump in vertical motion at the base of the escarpment. Figure 13 shows the top-down and transectional views of winds, potential temperature, and fire front location at 10pm local time. The first feature of note is that along the nearby escarpment, rapid downward motion can be seen everywhere (blue dashed lines) except for directly in front of the fire. The transectional view shows that right as the fire spreads down the escarpment the vertical motion and wind speeds appear suited to lifting embers. This period of the model run exhibits rapid westward fire spread, which could lead to embers being entrained into the hot rising smoke plume.

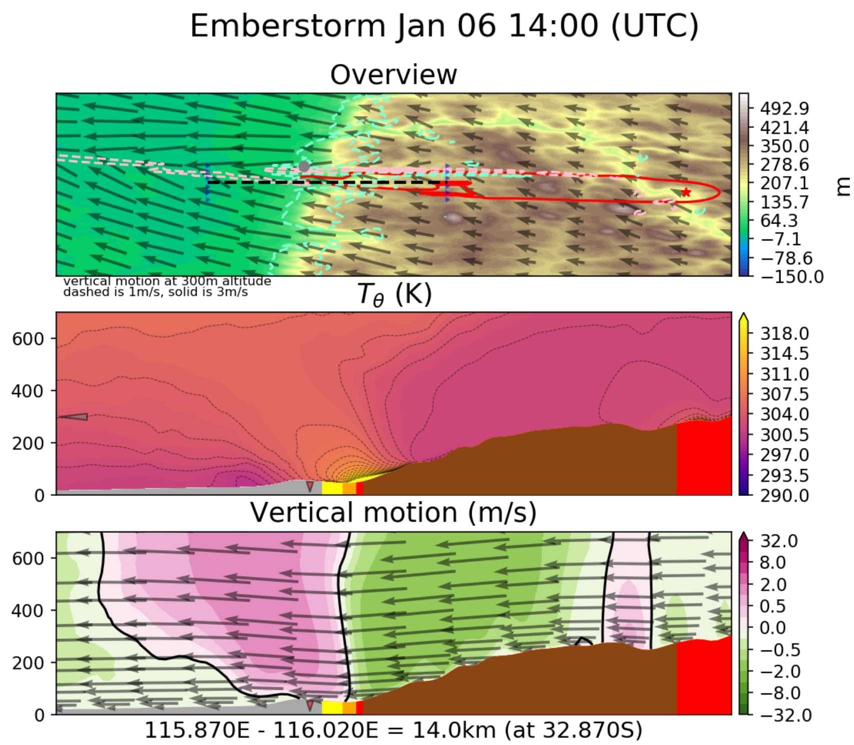

Figure 13: Top panel: Top down view of topography, surface horizontal winds (quivers), and 300m above ground vertical wind contour. Vertical winds are shown with dashed lines (at 3 m/s) upwards and downwards (pink, blue respectively). Waroona is marked by a grey dot. Middle panel: Potential temperature transect along dashed black line in panel 1. An arrow points to the X-axis depicting the west-most point of the fire front, and an arrow along the Y-axis showing the altitude of the vertical wind contours shown in the top panel. Bottom panel: Vertical motion transect (coloured) with quivers showing wind speed and direction on the east-west-vertical plane.

References

[1] Forthofer, J. M., and Goodrick, S. L. Review of vortices in wildland fire. *Journal of Combustion 2011*, Figure 1 (2011).

[2] Peace, M., Mccaw, L., Santos, B., Kepert, J. D., and Fawcett, R. J. B. Meteorological drivers of extreme fire behaviour during the Waroona bushfire , Western Australia , January 2016. 79–101.