The Eyre Peninsula Fire of 11 January 2005: an ACCESS case study

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Abstract:

As part of The Centre for Australian Weather and Climate Research's contribution to the Bushfire Cooperative Research Centre's Fire Impact and Risk Evaluation – Decision Support Tool project, high-resolution and very-high-resolution simulations of the meteorology across the Lower Eyre Peninsula (LEP) in South Australia on 11 January 2005 have been performed. These simulations are described and validated against available observational data.

A significant bushfire, commonly known as the Wangary fire, broke out on the LEP in the afternoon of 10 January 2005 and continued to burn under severe weather conditions on the 11th. The most significant feature of the meteorology in relation to the fire on the 11th is the passage across the LEP of a cold front and associated wind change in the late morning to early afternoon. This feature is well modelled in the simulations, with timing errors of only 15 to 30 minutes. The simulations show the wind change transforming from an undular bore in the stable maritime boundary layer to a density current over land, accompanied by a weakening of the updraft as it passes over the location of the fire. Boundary-layer rolls are simulated further up the peninsula.

1. Introduction

A significant bushfire broke out on the Lower Eyre Peninsula (LEP) in South Australia on 10 January 2005, not long after 1500 CDT (Central Daylight Time = UTC + 10.5 hours). Under favourable conditions for bushfire spread, it burnt some 1800 hectares of swamp, scrubland and pasture paddocks that day. The following morning strong northwesterly winds caused the fire to break out of containment lines established overnight. By 1300 CDT on the 11th, the fire had changed direction under the influence of southwesterly winds behind the wind change and reached North Shields, 35 km from the original fireground (Schapel 2007).

The fire caused 9 deaths and 115 injuries. 77964 hectares of land were burnt, with 47000 in stock losses and around $100 million in total property damages (Schapel 2007). Figure 1 shows the fire-scar boundary across the LEP as of 13 January 2005. The meteorology of this fire was studied in detail by Mills (2008) using the Bureau of Meteorology's (hereafter, "the Bureau") operational LAPS analyses and forecasts of the time. A significant meteorological factor was an observed extreme reduction in the near-surface humidity, in association with a band of dry mid-tropospheric air (Mills 2008).

The present study aims to reconstruct the meteorology across the LEP on 11 January at very high resolution (0.012° and 0.004° latitude/longitude grid spacings), using a state-of-the-art numerical weather prediction (NWP) system, the Australian Community Climate and Earth-System Simulator (ACCESS). ACCESS includes the UK Met Office Unified Model as its atmospheric component. The model is run in research mode, at grid spacings much higher than those currently available (0.036°) for operational activity within the Bureau, and in consequence much more fine-scale detail is evident in the results.

2. Synoptic meteorology

The meteorological situation on 11 January 2005 consisted of a high-pressure system in the Tasman Sea, an- other high-pressure system to the west of the continent and a low-pressure system with an embedded cold front between them crossing the Southern Ocean (Figure 2). The cold front crossed the Eyre Peninsula in the late morning to early afternoon. The change in the wind direction associated with the passage of the cold front had the expected consequence of broadening the fire front and sending the fire in a north-easterly direction, as can be inferred from the fire-scar map (Figure 1).

Figure 1: Fire-scar map for the January 2005 fires on the Lower Eyre Peninsula (obtained from Schapel 2007).

3. Model details

To reconstruct the weather conditions across the LEP on 11 January 2005, a sequence of nested model runs was employed. There were five stages and the nesting was one-way, which means that meteorological information only passed from the coarser resolutions to the higher resolutions. The first stage was a global model run, with a longitude spacing of 0.5625° and a latitude spacing of 0.375°. The second stage had a latitude-longitude grid spacing of 0.11° for a wide region covering Australia and surrounding waters, while maintaining a 20° buffer to the south, 35° to the east and 35° to the north. The third stage (hereafter G36) had a grid spacing of 0.036° (approximately 4.00 km in the north-south direction and 3.29 km in the east-west direction at the latitude of Port Lincoln, 34.722°S). The fourth stage (hereafter G12) had a grid spacing of 0.012° (approximately 1.33 × 1.10 km), with the last stage (hereafter G04) having a grid spacing of 0.004° (approx. 0.44 x 0.37km). The third-stage, fourth stage and fifth-stage domain boundaries are shown in Figure 3.

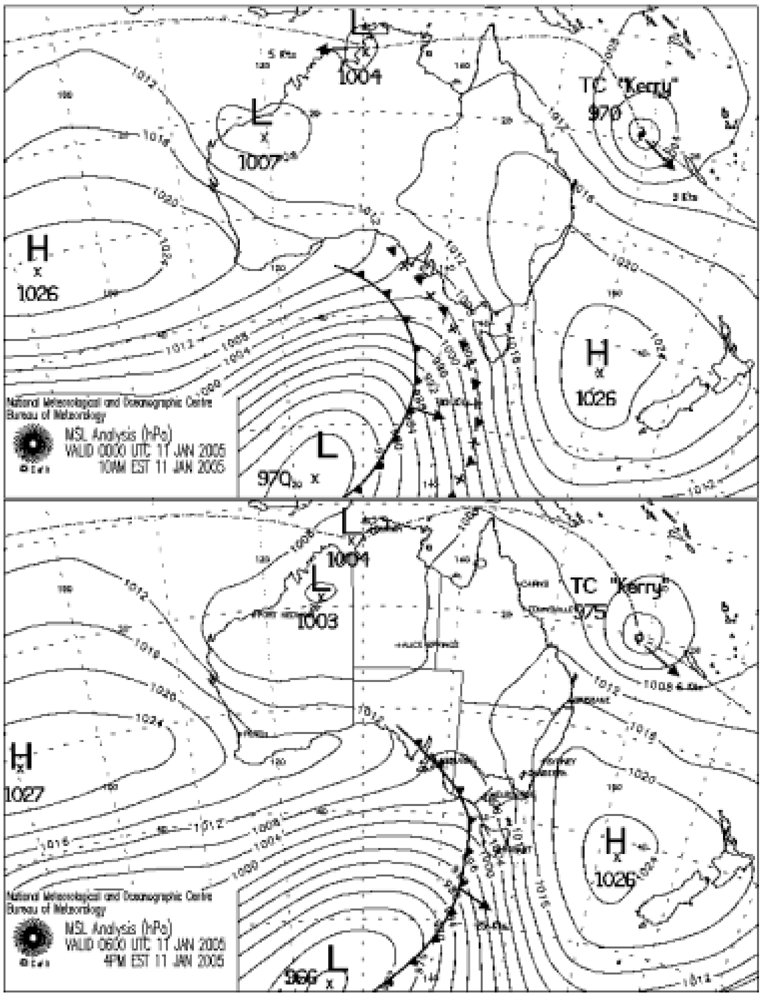

Figure 2: Synoptic pressure analyses for (upper) 0000 UTC (1030 CDT) and (lower) 0600 UTC (1630 CDT) on 11 January 2005.

The atmospheric model within ACCESS is non-hydrostatic, with an Arakawa-C grid in the horizontal and a Charney-Phillips grid in the vertical (BoM 2010). Consequently, regridding was required for the calculation of some fire-relevant meteorological quantities, such as wind speed and direction. All five stages of the modelling used 50 vertical levels, with the lowest model level being approximately 10 metres above the surface for some variables (e.g., the u and v components of the horizontal wind) and approximately 20 metres above the surface for other variables (e.g., potential temperature θ). The top level was around 60 km above sea level. The vertical aspects of the gridding were the same across all five stages; a stretched grid with 10 levels in the lowest 2000 m.

For the coarser resolutions (0.036° and above), the model used a parameterised convection scheme. The lowest 13 model levels, approximately the lowest 3000 metres of the atmosphere, were treated as being potentially boundary-layer levels. Boundary-layer mixing was parameterised using the one-dimensional scheme of Lock et al. (2000). For the finer resolutions (G12 and G04), the parameterised convection scheme was turned off. Also turned on at these finer resolutions was a sub-grid turbulence scheme applied in three dimensions for model levels 2 to 49. The whole vertical extent of the model domain was in effect treated as being potentially available for the boundary layer to grow into, and in fact boundary- layer depths of up to 5000 metres were seen in the simulations.

All model runs were initialised at 0000 UTC (1030 CDT) on 10 January 2005, using an ERA-Interim initial condition for the global model run, and re-configured versions thereof for the nested regional models. Because all five nesting levels were initialised from the same time, little attention was paid to the first twelve hours of the simulations.

Surface outputs (e.g., screen-level air and dewpoint temperature, 10 metre wind velocity) where archived at five-minute intervals in these simulations, with upper air outputs on the model levels being archived at fifteen-minute intervals. Derived surface fields calculated included wind speed and direction, relative humidity, divergence and voracity of the horizontal wind, and grass/forest fire danger indices.

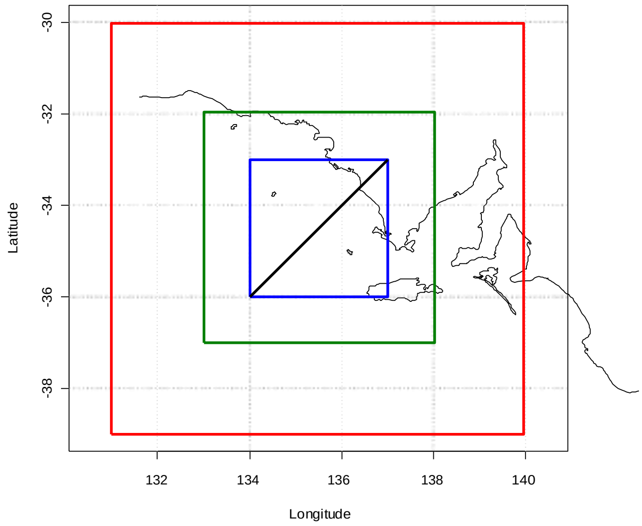

Figure 3: Boundaries of the third (0.036°, red), fourth (0.012°, green) and fifth (0.004°, blue) nesting levels for the LEP model runs. The diagonal black line represents denotes the location of the vertical cross-sections shown in Figure 6.

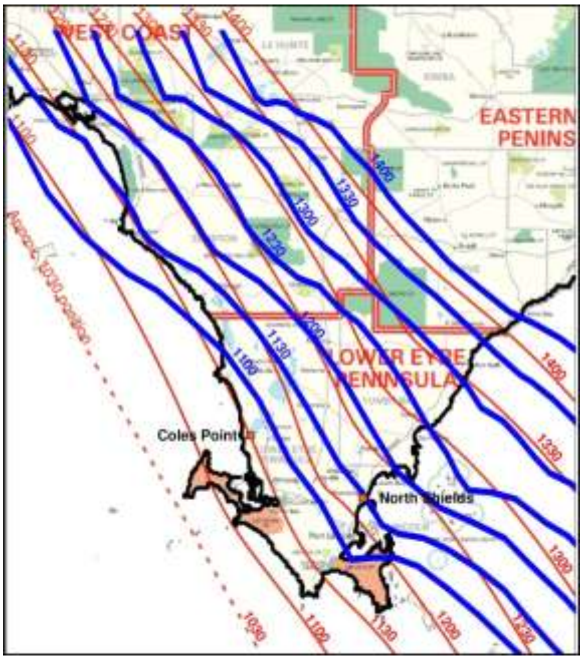

Figure 4: Comparison of modelled (blue lines; G12 model run) and analysed (red lines) wind-change isochrones across the LEP from 1100 to 1400 CDT on 11 January 2005. The locations of the two AWSs on the LEP are also shown (orange squares).

4. Model validation

The simulations may be compared directly against independent observational data from automatic weather stations (AWSs) and radiosondes. Observational data were obtained from the Bureau's Australian Data Archive for Meteorology (ADAM) database, apart from those for North Shields. The AWS data come from a network of one-minute-reporting and thirty-minute-reporting sites across South Australia. Eight AWSs (Ceduna, Minnipa, Wudinna, Port Augusta, Whyalla, Cleve, Coles Point and North Shields (Port Lincoln Airport)), are available across the Eyre Peninsula to validate the G12 simulation but only one of those (Ceduna) is a one-minute reporting site and only two of them (Coles Point and North Shields) are on the LEP itself. Additional sites are available for the Yorke and Fleurieu Peninsulas. Ten-minute reporting data for North Shields was provided by the Bureau's South Australian Regional Office.

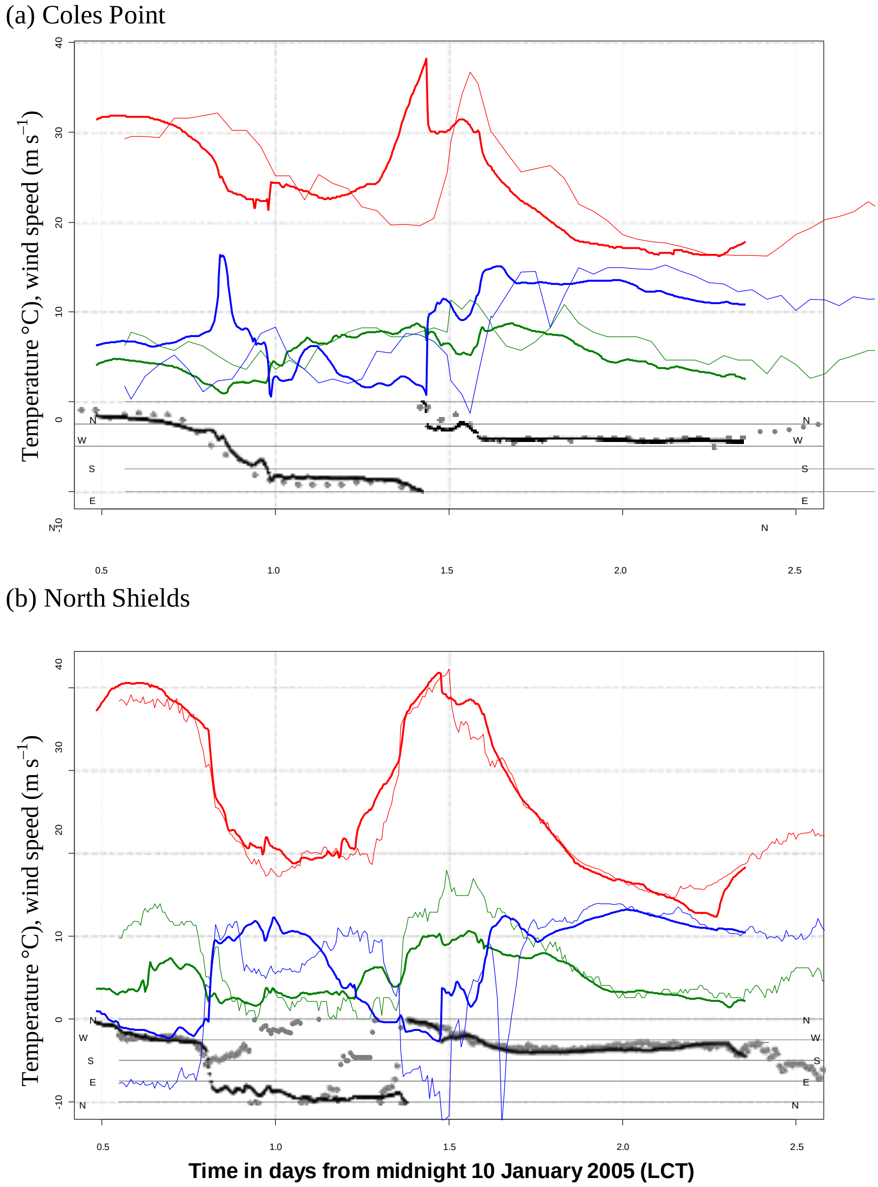

Figure 5: Comparison of AWS observational data (thin lines, grey dots) and G12 simulation data (thick lines, black dots) for (a) Coles Point and (b) North Shields. Air temperature is shown in red, dewpoint tempera- ture in blue (both in °C), 10-metre wind speed in green (in m s^{-1}) and wind direction (dots).

Figure 4 shows isochrones of the position of the cold front on the 11th. Positions analysed from observations (Nairn et al. 2005) are shown in red, while those from the G12 simulation are shown in blue. Timing errors in the simulated location of the primary wind change are around 15 to 30 minutes across the LEP, with the modelled wind change mostly being ahead of the observed wind change. A slight difference in the angle of approach is implied in Figure 4.

Figure 5 shows a comparison of the observational data from the two AWSs on the LEP with model data from the G12 simulation extracted from the nearest model grid point to the AWS. Both sites are coastal, and neither is likely to be representative of conditions at the fire ground (M Peace, pers. comm.). At Coles Point on the west coast of the LEP (Figure 5a), the early morning minimum temperature on the 11th is over-forecast, as is the afternoon maximum temperature (although to a lesser extent), but the timing of the latter is well forecast. Unlike the previous day, the overnight cooling on the 11th and the early morning minimum on the 12th are well forecast. Wind direction is gener- ally well forecast (including the timing of the main wind change), as are wind speeds on the after- noon of the 11th, although peak 10-metre wind speeds are under-estimated, something often seen in NWP.

At North Shields on the east coast of the LEP (Figure 5b), the timings of the maximum temperature and the primary wind change are seen to be well forecast, as is the wind direction immediately after the change. Temperatures for the preceding evening are also well forecast, but although the overnight light wind speeds are well forecast, the associated variable wind direction is not well captured. Again, there is a tendency for peak wind speeds to be underestimated in the afternoon. There were two periods of extremely low dewpoint temperatures on the 11th at North Shields (Mills 2008). The first (and longer) period was reproduced by the model, although with reduced amplitude. In the simulations, it appears to arise from widespread northerly flow. The second (and shorter) period was not seen in the modelling. The reasons for this are not clear. Northwest-southeast-oriented dry slots are seen in the satellite imagery passing over the LEP after the main change. Similar features are seen in the simulations (e.g., at 720 to 980 metres of elevation in the G04 simulation), but without the observed impact at the surface.

Radar data are unfortunately not of much use in validating these simulations. The southern part of the Eyre Peninsula, including the LEP fire ground, is effectively beyond the range of the radars located at Adelaide, Sellicks Hill, Ceduna and Woomera, although the smoke plume from the fire on the 11th is seen on the Sellicks Hill radar once it drifts east of Port Lincoln over Spencer Gulf.

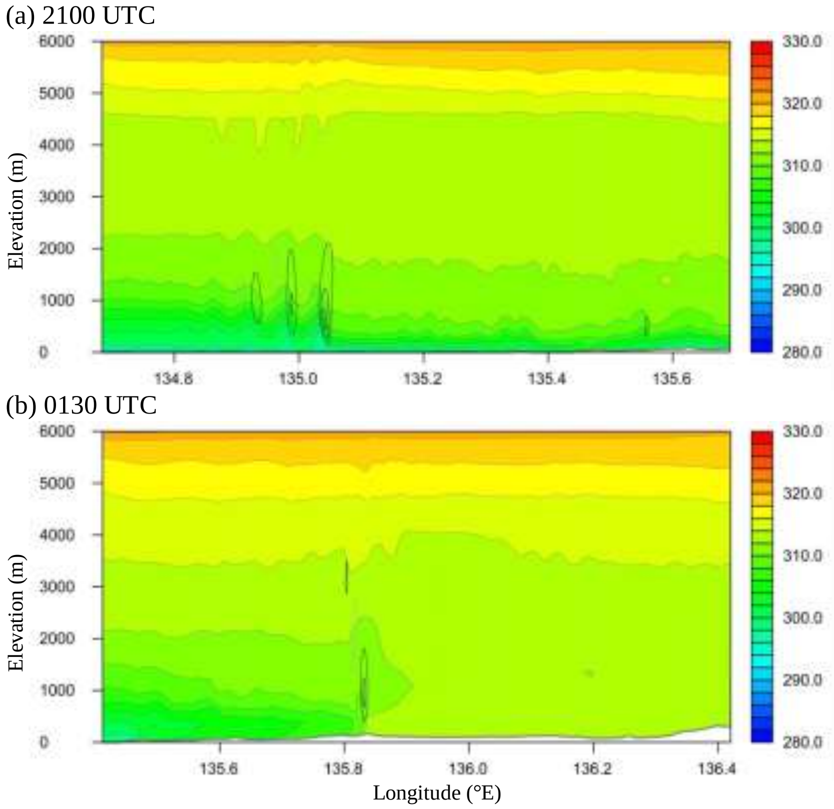

Figure 6: Vertical cross-sections of potential temperature (in K) for portions of the line shown in Figure 3, at (a) 0730 CDT and (b) 1200 CDT. Black (grey) contours denote positive (negative) vertical velocity in 1.5 m s intervals. The vertical coordinate represents elevation above 1.5 m s mean sea level (in metres). The thick grey line denotes the land surface. Data from the G04 simulation.

5. Discussion

Compared with the modelling technology available to reconstruct the weather in studies of earlier significant Australian fires, for example those of Ash Wednesday 1983 (Mills 2005a) and Canberra 2003 (Mills 2005b), the new modelling technology contained within ACCESS includes improved numerics, improved physical parameterisations, developments in analysis formulations, and assimilation of new sources of data, particularly from new satellite sounders (Puri et al. 2010). Added to this are the significantly higher grid spacings now possible.

Figure 6 shows vertical cross-sections of potential temperature along the line of cross-section indicated in Figure 3, taken from the G04 simulation. Potential temperature can be thought of as air temperature adjusted for the variation in pressure which typically decreases with increasing height above the surface, and is a useful indicator of atmospheric stability. Contours of vertical velocity are also shown, where appropriate.

As the cold front approaches the LEP, vertical cross-sections of the simulations suggest that it has the characteristics of an undular bore (Figure 6a). The atmospheric conditions ahead of the cold front, a stable near-surface layer (caused by the cool ocean) sitting underneath a deep well-mixed layer of near-constant potential temperature, are suitable for the formation of a bore

(Knupp 2006, Hartung et al. 2010). Updrafts of around 6 m s^{-1} are modelled at the leading edge of the change. In the G12 simulation, and even more so in the G04 simulation in which multiple updrafts can be seen, the cold front has a rippled appearance as it approaches the coast. Interaction with the coastline sees the undular bore transition into a density current (cooler denser air sliding in under warmer lighter air) and the temporary collapse of the updraft (Figure 6b; updrafts up to 3 m s^{-1} are shown), although the updraft does subsequently reform further up the peninsula. While large amounts of spot- ting were observed on the 11th (Schapel 2007), the simulations do not indicate strong updrafts while the primary wind change was actually over the fire ground. [This obviously does not preclude the potential for a strong updraft from the fire itself, which is not represented in the present modelling.]

Figure 7 shows notional instantaneous Grass Fire Danger Index (Mark 5; Noble et al. 1980) values for two time-steps on the 11th. As the primary wind change approaches the fire ground in the simulation, GFDI values in the 40-60 range are modelled, rising to the 60-70 range in a few more elevated locations (Figure 7a). As the wind change passes through the fire ground, GFDI values on those more elevated locations rise into the 70-90 range. Immediately behind the wind change, the GFDI values typically fall, consistent with the cooler conditions, but strengthening winds behind the change cause values to rise again into the 60-70 range across a broad area. Cheney and Sullivan (2008), citing McArthur (1966), say the following in respect of grass fires when the Mark 4 GFDI exceeds 50: direct attack will generally fail, back- burns from a good secure line will be difficult to hold because of blown embers, flanks must be held at all costs. Blanchi et al. (2010) report a Forest Fire Danger Index value of 120 for this fire.

Further up the Eyre Peninsula and beyond the fire ground, the emergence in the simulation of bound- ary layer rolls (Figure 7b) with their attendant downdrafts causes the modelled GFDI to tempo- rarily spike above 100. Embedded small-scale vor- tices along the primary wind change are also simu- lated; these too lead to spikes in the modelled GFDI (Figure 7b). The elevated wind speed is the principal contributor to the elevated GFDI here. Boundary-layer rolls (Engel et al. 2012) and embedded small-scale vortices along the primary wind change (Fawcett et al. 2013) were also seen in analogous simulations of the Black Saturday (7 February 2009) meteorology. Such features can be the cause of marked variability in wind direction in the near-surface winds, which can lead to broadening of the fire front in grass fires (Cheney and Sullivan 2008).

(a) 0000 UTC

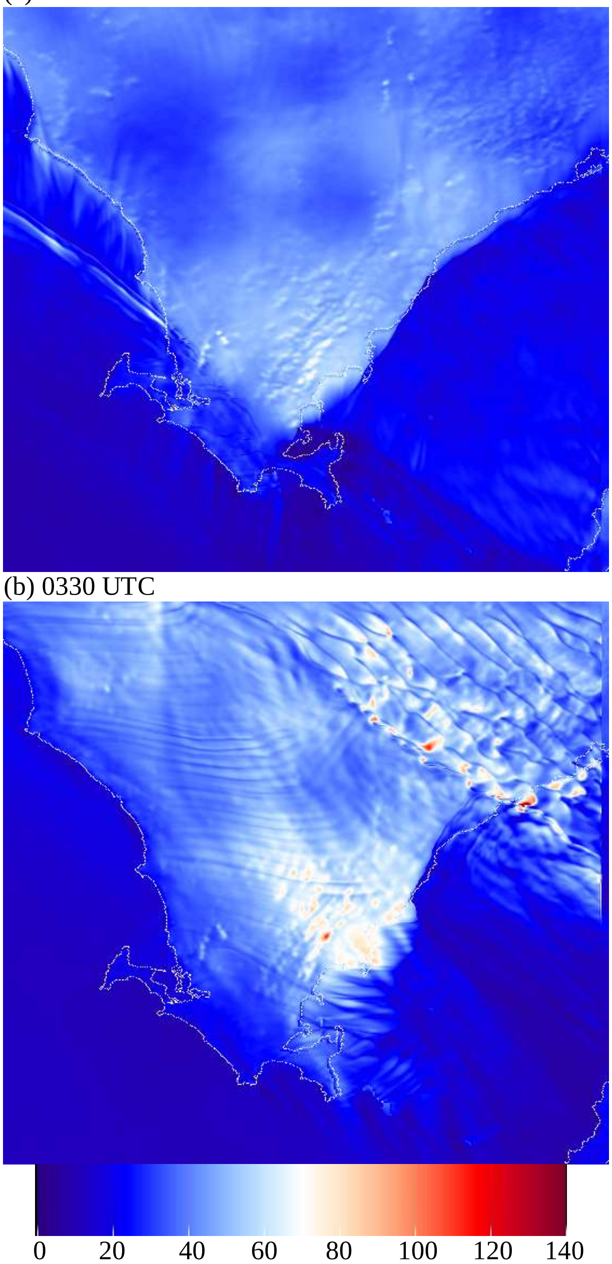

Figure 7: Notional instantaneous Grass Fire Danger Index (Mark 5) across the Eyre Peninsula at (a) 1030 CDT and (b) 1400 CDT on 11 January 2005. A notional 5 tonnes per hectare fuel load, 100% cured, is assumed in the calculation, which is based on the G04 simulation.

6. Concluding remarks

High-resolution hindcasts have been performed of the meteorology across the Lower Eyre Peninsula (LEP) on 10 and 11 January 2005, around the time of the Wangary fire, using a state-of-the-art numerical weather prediction system, ACCESS. The principal feature of the meteorology is the passage of a cold front and associated wind change across the LEP in the middle of the day on the 11th, this wind change having a significant impact on the fire behaviour. The hindcasts capture the timing of the wind change well. Although they occurred at some distance from the fire location, the simu- lations show small-scale meteorological features (vortices, boundary layer rolls) generating elevated grass fire danger index values exceeding 80 units. Such features have been seen in other simulations of fire weather in southeast Australia, and may be more common than current operational weather forecasts suggest.

7. Acknowledgements

This work is partially funded by the Bushfire Cooperative Research Centre, through its Fire Impact and Risk Evaluation – Decision Support Tool (FIRE-DST) project. The assistance of colleagues within The Centre for Australian Weather and Climate Research for their assistance in setting up the ACCESS simulations is also gratefully acknowledged. The authors wish to thank Chris Lucas and Mika Peace for their helpful comments on an early version of the paper, and Kylie Egan (Bureau of Meteorology, Adelaide) for providing the North Shields AWS data.

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