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Welcome from Editors

It is our pleasure to bring to you the compiled papers from the Research Forum of the AFAC and Bushfire CRC Annual Conference, held in the Perth Exhibition and Convention Centre on the 28th of August 2012.

These papers were anonymously referred. We would like to express our gratitude to all the referees who agreed to take on this task diligently. We would also like to extend our gratitude to all those involved in the organising, and conducting of the Research Forum.

The range of papers spans many different disciplines, and really reflects the breadth of the work being undertaken, The Research Forum focuses on the delivery of research findings for emergency management personnel who need to use this knowledge for their daily work.

Not all papers presented are included in these proceedings as some authors opted to not supply full papers. However these proceedings cover the broad spectrum of work shared during this important event.

The full presentations from the Research Forum and the posters from the Bushfire CRC are available on the Bushfire CRC website www.bushfirecrc.com.

Richard Thornton and Lyndsey Wright

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Modelling the fire weather of Black Saturday

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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 Victoria on Black Saturday (7 February 2009) have been performed. These simulations are described and validated against available observational data.

Introduction

Black Saturday (7 February 2009) saw many large bushfires across Victoria, resulting in the deaths of 173 people, far exceeding the loss of life from any previous bushfire (VBRC 2010). The weather conditions on that day were particularly severe, from fire-weather and public-weather perspectives. All-time daily maximum temperature records were broken in many places across Victoria, including the Melbourne Regional Office site (46.4°C) and the Melbourne Airport site (46.8°C) (BoM 2009a). Black Saturday also followed a heat-wave at the end of January 2009 (BoM 2009a) which saw the Melbourne Regional Office site's temperature exceed 43°C for three consecutive days (28-30 January). Over the period 26 January to 1 February 2009, there were 374 excess deaths over what would be expected (VGDHS 2009).

This article describes high-resolution (0.012° to 0.036° resolution) and very-high-resolution (0.004° to 0.008° resolution) modelling undertaken within the Centre for Australian Weather and Climate Research (CAWCR) to reconstruct the meteorology across Victoria and southern New South Wales on Black Saturday, as part of its contribution to the Bushfire Cooperative Research Centre's (BCRC) *Fire Impact and Risk Evaluation – Decision Support Tool* (FIRE-DST) project. Results from this modelling also feed into the BCRC's *Understanding Complex Fire Behaviour: Modelling Investigation of Lofting Phenomena and Wind Variability* project. The modelling is performed using the Australian Community Climate and Earth-System Simulator (ACCESS), and in particular the UK Met Office's (UKMO) atmospheric model (version 7.5).

Meteorological gridded outputs from the modelling will be fed into fire-spread models (e.g. Phoenix RapidFire; Tolhurst et al. 2008), to facilitate fire-spread-model upgrading from single automatic weather station (AWS) meteorological inputs to fully four-dimensional inputs. This will permit explorations of the sensitivity of fire outcomes to (i) fire-ignition location and timing relative to the "observed" weather on the day, and (ii) the timing of significant aspects of the meteorology (e.g., wind changes).

Black Saturday represents the first of several case studies to be undertaken as part of the FIRE-DST project, and analogous very-high-resolution meteorological reconstructions have been performed for the Margaret River fire (November 2011, southwestern Western Australia) and the Eyre Peninsula fire (January 2005, South Australia). The authors note that previous high-resolution and very-high-resolution simulations of the Black Saturday meteorology have been undertaken, including work by Engel et al. (2012) which uses similar modelling configurations to those described here.

The antecedent conditions and synoptic meteorology are described in Section 2. The model set-up is described in Section 3, with details of its validation against available observations given in Section 4. Aspects of the meteorology relevant to the Beechworth-Mudgegonga fire are described in Section 5, with concluding remarks in Section 6. Times are given in Universal Coordinated Time (UTC) and Australian Eastern Daylight Time (EDT = UTC + 11 hours).

Antecedent conditions and synoptic meteorology

Black Saturday occurred towards the end of a long period of drought (1997-2009), which represents the most significant period of sustained low rainfall across Victoria since 1900. 57 per cent of the State experienced rainfall at or below the 10th percentile for the 12 months ending January 2009 (Figure 7). November and December 2008 were wet months, with State-averaged rainfall totals at 134 and 175 per cent respectively of the 1961-1990 averages. January and February 2009, on the other hand, were very dry months, with State-averaged rainfall totals both at 13 per cent of the 1961-1990 averages. Several of the fires on Black Saturday were within the region of Figure 7 showing very much below average rainfall for the 12 months ending January 2009. These included the Kilmore-East, Murrindindi, Bunyip, Delburn and Churchill fires. In contrast, the Beechworth-Mudgegonga fire was outside this region.

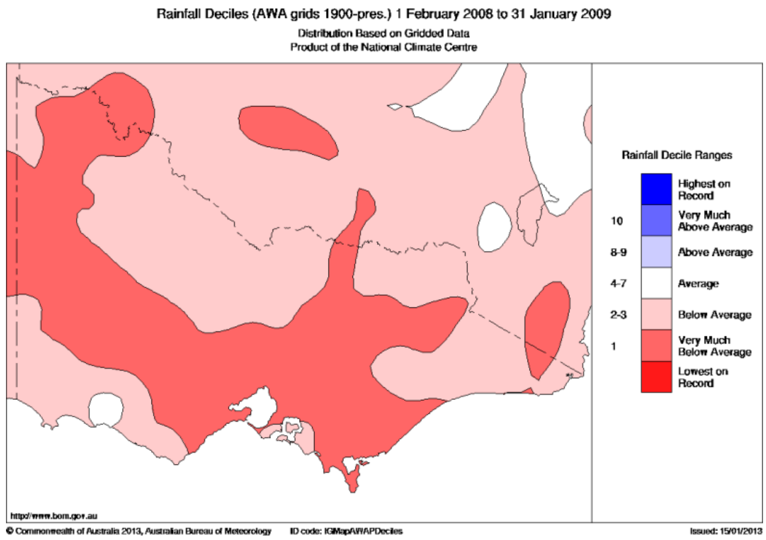


Figure 7. Rainfall deciles for Victoria, for the 12-month period February 2008 to January 2009. Based on the gridded monthly rainfall analyses of Jones et al. 2009.

State-averaged daily drought factors for Victoria are shown in Figure 8, calculated from the gridded national fields of Dowdy et al. 2009. These are non-dimensional numbers, ranging from 0 (very moist conditions) to 10 (very dry conditions), and are used as indicators of fuel dryness in forest fire danger index (FFDI) calculations (see for example the discussion in Lucas 2010). State-averaged values across Victoria rose from around 7 at the start of 2009, to around 9.5 in the first week of February. December 2008's rainfall across Victoria was concentrated into a small number of days, which resulted in the rain having little lasting impact on the drought factor, and in consequence the drought factor was higher at the end of December than at the beginning of the month. Large swings in the drought factor such as that seen in December 2008 are not unknown for this time of year; similar swings were seen in January and December 2007, and January 2008.

 R.P. Thornton & L.J. Wright (Ed) 2013, 'Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum' 28 August 2012, Perth Australia, Bushfire CRC

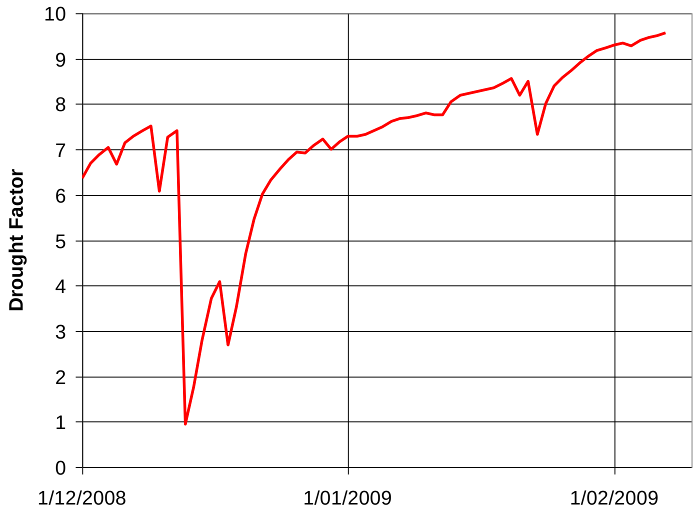


Figure 8. State-averaged daily drought factor for Victoria, for the period 1 December 2008 to 7 February 2009.

Synoptic mean-sea-level pressure (MSLP) analyses from the Bureau of Meteorology on Black Saturday (Figure 9) show a high-pressure system in the Tasman Sea off the west coast of New Zealand, together with an approaching low-pressure system located well to the southwest of Tasmania. The low-pressure system has an embedded cold front, but the principal relevant feature of the synoptic meteorology is a pre-frontal trough (indicated by the dashed line in Figure 9) which crosses Victoria through the course of the day (bringing rapid falls in temperature and significant wind changes). Wind changes such as these constitute major risks for fires in the Victorian summer.

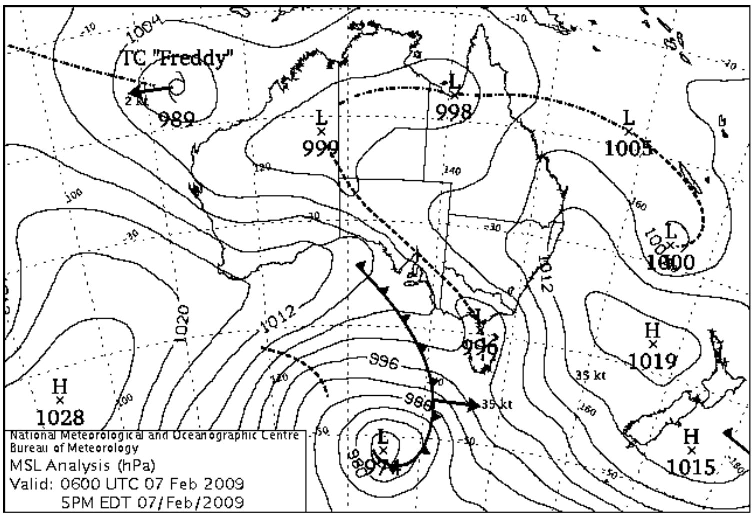


Figure 9. Mean sea level pressure at 06:00 UTC (5 pm EDT) on Black Saturday. Analysis from the National Meteorological and Oceanographic Centre, Bureau of Meteorology.

Model details

In order to reconstruct the weather conditions on Black Saturday, a sequence of nested model runs is employed. Five stages are employed, and the nesting is one-way, which means that information only flows from the coarser resolutions to the higher resolutions, and not in the opposite direction. The first stage is a global model run, with a longitude spacing of 0.5625° and a latitude spacing of 0.375°. The second stage has a latitude-longitude resolution 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 has a resolution of 0.036° (approximately 4.00 km in the north-south direction and 3.16 km in the east-west direction at Melbourne's latitude) for a region covering Victoria, Tasmania and southern New South Wales. The fourth stage has a resolution of 0.012° (approximately 1.33 × 1.05 km) and covers Victoria and southern New South Wales. The last stage has a resolution of 0.004° (approximately 0.44 × 0.35 km) and covers central Victoria. Nesting boundaries have been chosen, in so far as possible, to avoid placing them over regions of elevated topography. The third, fourth and fifth stage domains are shown in Figure 10. The fifth stage of the nesting has also been replicated at resolutions 0.008° (approximately 0.89 × 0.70 km) and 0.006° (approximately 0.67 × 0.53 km), to test the sensitivity of the results to grid resolution.

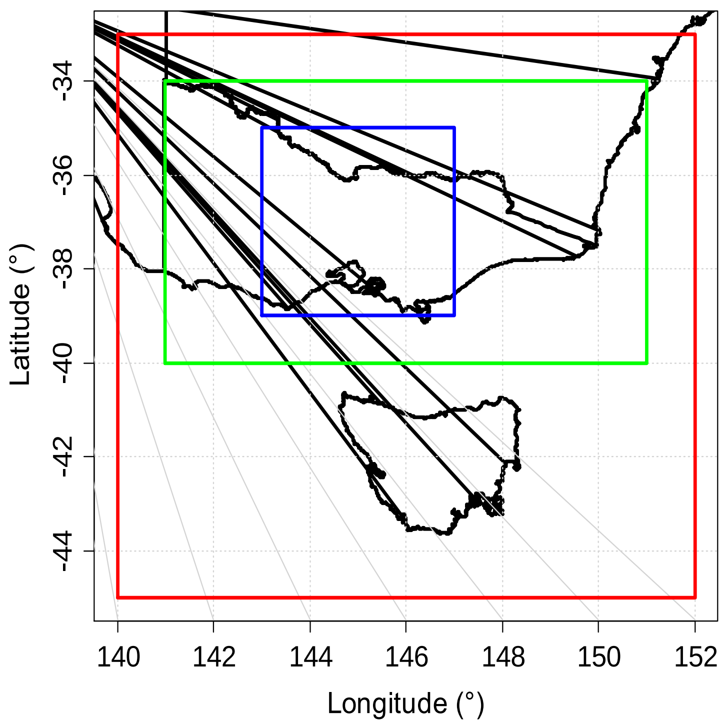


Figure 10. Boundaries of the third (0.036°, red), fourth (0.012°, green) and fifth (0.004°, blue) nesting levels for the Black Saturday model runs. Model boundaries are chosen, as far as is possible, to avoid areas of elevated topography.

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). In consequence, regridding is required for the calculation of some fire-relevant meteorological quantities, such as wind

 R.P. Thornton & L.J. Wright (Ed) 2013, 'Proceedings of Bushfire CRC & AFAC 2012 Conference Research Forum' 28 August 2012, Perth Australia, Bushfire CRC

speed and direction. All five stages of the nesting use 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 is around 60 km above sea level.

For the coarser resolutions (0.036° and above), the model uses a parameterised convection scheme. The lowest 13 model levels, approximately the lowest 3000 metres of the atmosphere, are treated as being boundary-layer levels. For the finer resolutions (0.012° and below), the parameterised convection is turned off. (Failure to do this in preliminary runs resulted in large-scale convection ahead of the front being modelled but not observed.) Also turned on at these finer resolutions is a sub-grid turbulence scheme applied in three dimensions for model levels 2 to 49. The whole vertical extent of the model domain is in effect treated as being potentially available for the boundary layer growth, and in fact boundary-layer depths of up to 5 km are seen in the simulations.

All model runs are initialised at 03:00 UTC (2 pm EDT) on 6 February 2009, using an initial condition obtained from the UKMO for the global model run, and re-configured versions thereof for the nest regional models. For February 2009, only one initial condition per day was available, with the next available initial condition being 03:00 UTC (2 pm EDT) on 7 February 2009 and therefore not well placed in time for the purposes of this study. Because all five nesting levels are initialised from the same time, 03:00 UTC (2 pm EDT) on 6 February 2009 as indicated above, little attention is paid to the first twelve hours of the simulations.

Surface outputs (e.g., screen-level air and dewpoint temperature, 10-metre wind speed and direction) are archived at five-minute intervals in these simulations, with upper-air outputs on the model levels being archived at fifteen-minute intervals.

Model validation

The simulations may be compared directly against independent observational data from automatic weather stations (AWSs) and radiosondes. The AWS data come from a network of one-minute-reporting and thirty-minute-reporting sites across Victoria and southern New South Wales, while radiosonde balloon-flight observations are available for five sites within the 0.036°-resolution simulation domain, two sites within the 0.012°-resolution simulation domain and one site within the 0.004°-resolution simulation domain. The radiosonde data allow a comparison between the observed and modelled vertical column data. The observational data are obtained from the Bureau of Meteorology's Australian Data Archive for Meteorology (ADAM) database.

Features of the simulations which may be validated using these data include the timing of the main wind change on Black Saturday, forecast screen-level maximum temperature and forecast maximum 10-metre wind speeds, and upper-level air temperature, dewpoint temperature and horizontal wind speed. Forecast maximum temperature errors are shown in Figure 11, with approximate timing errors in the primary wind change on Black Saturday being shown in Figure 12.

Forecast maximum temperatures in the 0.004°-resolution simulation are within 1°C of the observed values at most sites within the model domain. The timing of the primary wind change on Black Saturday in the 0.004°-resolution simulation is also well modelled, being only 30 to 60 minutes late across central Victoria, and with smaller timing errors closer to the coast. Timing errors aren't shown for the northeast of the State in Figure 12, because of difficulties in fixing the time of the change in both the simulation and the observations. A comparison of the 0.012°-resolution wind-change positions against the Bureau of Meteorology's observational analysis (BoM 2009b) not shown here gives similar results; the model wind change is slightly ahead of the analysed wind change as it crosses the southwest coast of Victoria, for the next few hours it tracks the observed wind change, but is behind the analysed wind change across central Victoria and the northwest of the State. During the evening the modelled wind change speeds up and catches up with the analysed wind change around midnight.

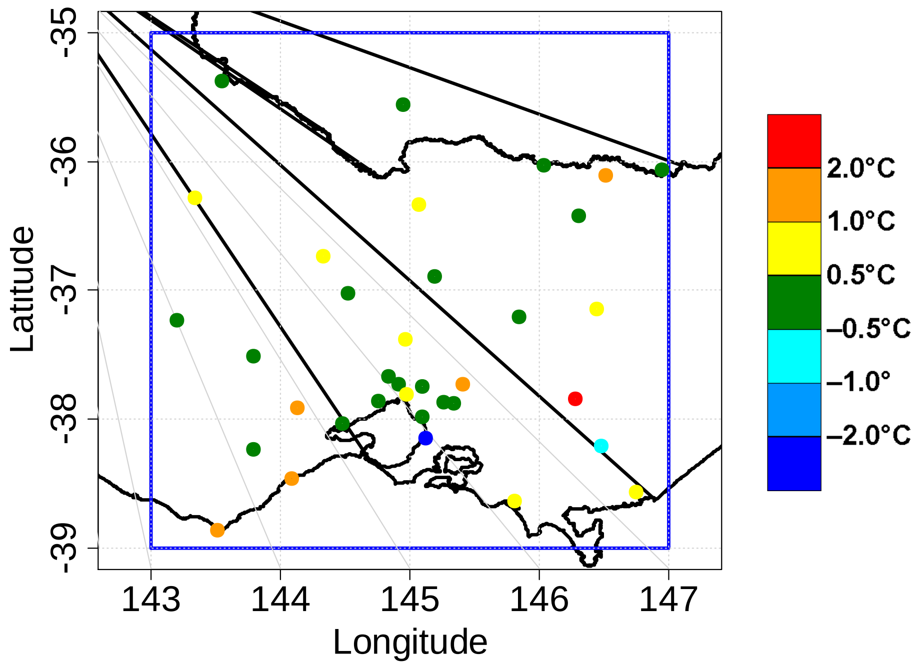


Figure 11. Forecast maximum temperature errors for the afternoon of 7 February 2009, from the 0.004°-resolution simulation. Positive (*negative*) errors mean the simulated maximum temperature is higher (*lower*) than the observed maximum temperature. The blue box denotes the model domain.

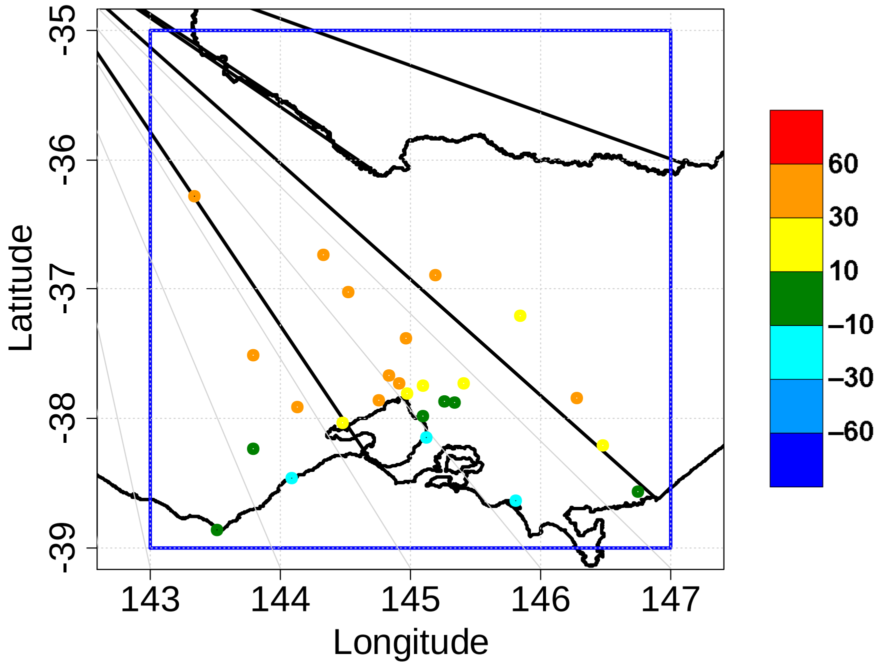


Figure 12. Approximate timing errors in minutes for the location of the primary wind change on Black Saturday. Positive (*negative*) values imply that the primary wind change in the 0.004°-resolution simulation is late (*early*) relative to the change at the indicated AWS locations. The blue box denotes the model domain.

Upper-level air temperatures are modelled very successfully in these simulations, with good results also being obtained for upper-level dewpoint temperatures and wind speeds (not shown). There is however a tendency in the simulations for 10-metre wind speeds to be underestimated, by up to 20 to 30 per cent in the periods of peak windiness on Black Saturday. The reasons for this are unclear at present and require further investigation, but may arise in part because large eddies (on the scale of hundreds of metres) and aspects of the surface roughness (trees, buildings, small gullies, etc.) simply cannot be resolved at the grid resolutions used here.

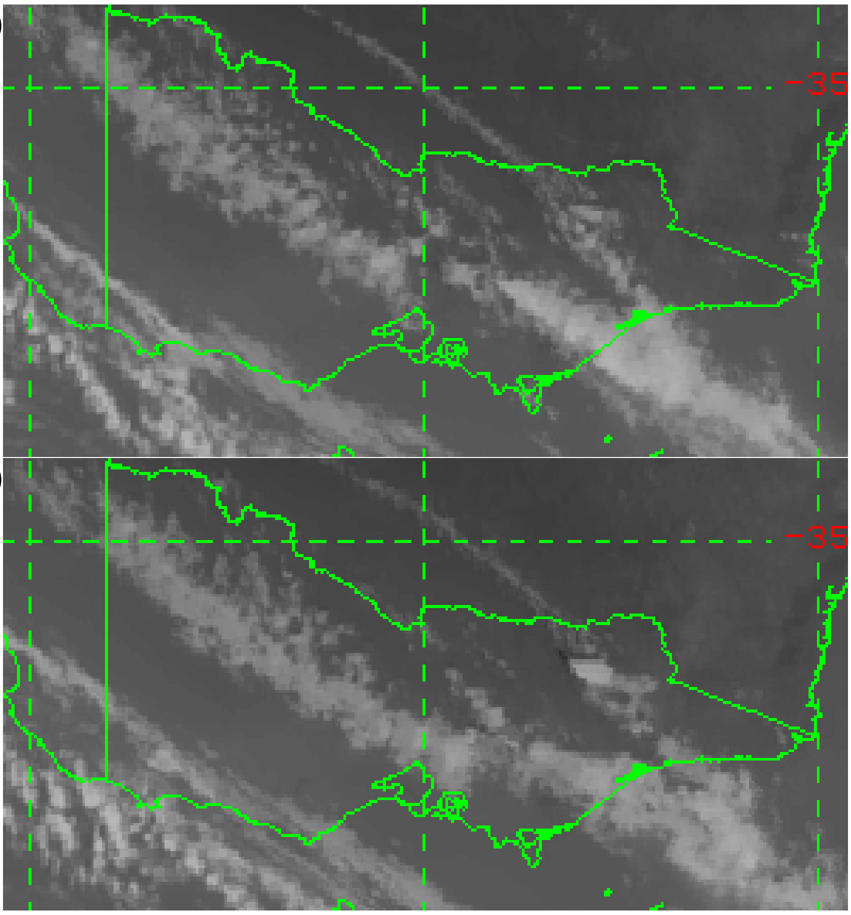
The simulations contain many interesting features, including boundary-layer rolls in the north-westerly flow preceding the primary wind change (features supported by visible satellite imagery in the form of cloud streets and data from the Yarrawonga radar), numerous small-scale vortices on the primary wind change itself, and an undular bore in the northeast of Victoria. The undular bore and the boundary-layer rolls were also seen in the simulations described in Engel et al. 2012 (although called nocturnal bores and horizontal convective rolls therein).

The undular bore in the simulations is particularly well-supported by the available observational evidence (infrared satellite imagery, one-minute data from AWSs at Albury and Yarrawonga, and data from the Yarrawonga radar), and there is persuasive evidence in the radar and satellite data of its impact on the Beechworth-Mudgegonga fire. It will form the main focus of the following section.

The Beechworth-Mudgegonga fire

The Beechworth Mudgegonga fire caused two fatalities, twelve casualties, destroyed 38 houses and burnt 33,577 hectares (VBRC 2010). Extreme fire behaviour with significant spotting was observed 1 km from Myrtleford in northeast Victoria at 23:34 EDT (12:34 UTC) (VBRC 2010). Radar data from the Yarrawonga radar (which is located to the northwest of the fire; the radar data are available at 20-minute intervals) indicate the passage of an atmospheric disturbance travelling in a northeasterly direction and crossing the radar location at around 12:00 UTC (11 pm EDT). Its passage over the fire is coincident with an intensification of the fire, as indicated by the smoke plume in the radar data. The atmospheric disturbance is also evident in the infrared satellite imagery (available at hourly intervals), as is the intensification of the smoke plume (
Figure **13**).

(a)
(b)



(c)

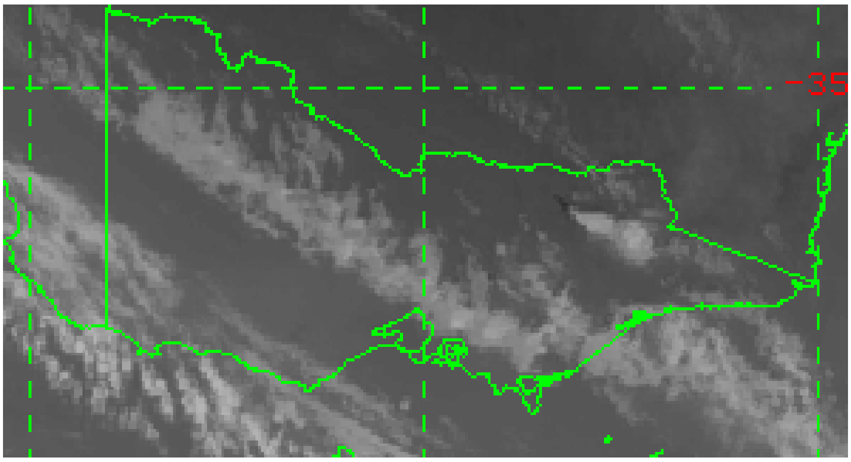


Figure 13. MTSAT infrared satellite imagery across Victoria for (a) 12:30, (b) 13:30 and (c) 14:30 UTC on 7 February 2009 (i.e., (a) 23:30 EDT on 7 February 2009, (b) 00:30 and (c) 01:30 EDT on 8 February 2009). The smoke plume from the Beechworth-Mudgegonga fire is evident on the right-hand side of the plot in each case, and is seen to intensify as the undular bore passes over it. In the first two plots, the undular bore is present in the form of a thin line of cloud.

When the atmospheric disturbance reaches the AWS at Albury around 1 am EDT on 8 February (Figure 14), it is evident as a slight but distinct temporary change in barometric pressure and air temperature (the change in barometric pressure, but not the change in air temperature is evident in the simulation), and a very substantial temporary change in wind direction from (near-northerly to near-westerly) lasting nearly ten minutes. The change in wind speed is much less significant. This feature is well captured in the 0.004°-resolution up to 0.012°-resolution simulations, and is even evident in the 0.036°-resolution simulation, although its speed of travel across the radar location at Yarrawonga is somewhat too fast. That speed is around 43 km hr^{-1} in the 0.004°-resolution simulation, compared with around 33 km hr^{-1} in the radar data, possibly due to the low-level stratification in the model being too strong, as indicated by the faster nocturnal cooling in the model at Albury (Figure 14) and Yarrawonga (not shown). Yarrawonga and Albury are the only two sites in the region available in ADAM reporting one-minute AWS data, and data were not sourced from outside the Bureau.

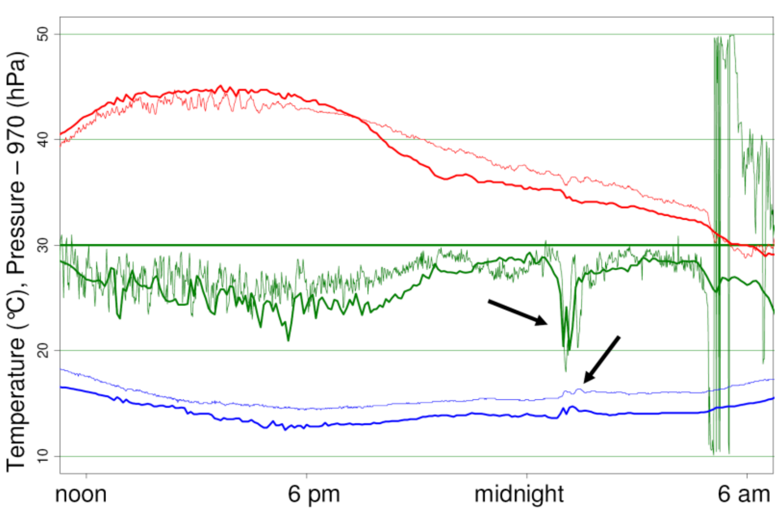


Figure 14. One-minute AWS screen-level air temperature (in °C, red, left axis), air pressure (in hPa relative to a 970 hPa base line, blue, left axis) and 10-metre wind direction (in degrees, green, right axis) for Albury 072160 (thin lines), together with five-minute nearest-grid-point data from the 0.004°-resolution simulation (thick lines), from midday EDT on 7 February 2009 to 6 am EDT on 8 February 2009. Air pressures are offset by 970 hPa. Wind directions run from southerly at the bottom of the plot, around through westerly, northerly (thick horizontal green line), easterly and southerly at the top of the plot. Black arrows indicate the undular bore.

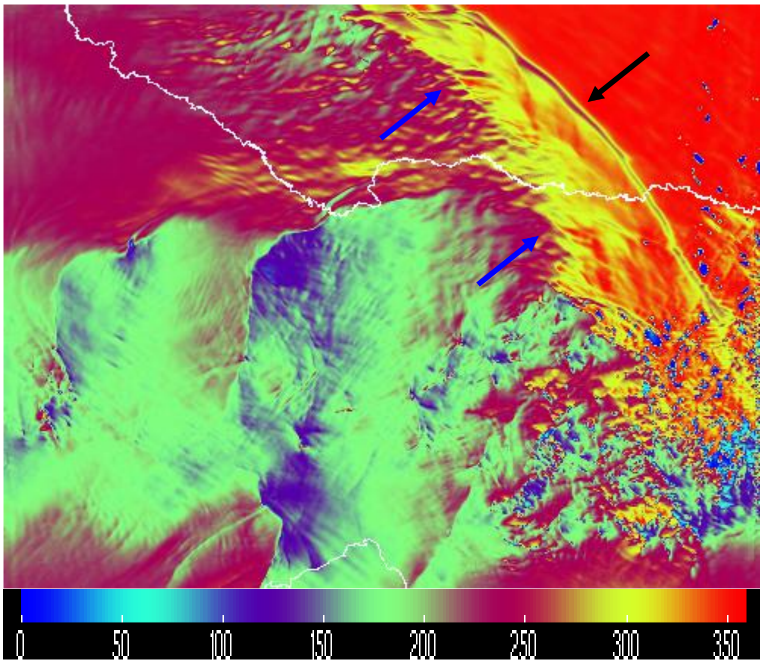


Figure 15. Wind direction in the 0.004°-resolution simulation at 13:00 UTC (midnight EDT) on Black Saturday. The primary wind change (indicated by the blue arrows) has stalled, leaving an atmospheric disturbance (indicated by the black arrow) to propagate towards the northeast into the existing pre-frontal northerly wind regime (top-right, red shades).

As the disturbance passes over the location of the Beechworth-Mudgegonga fire in the 0.004°-resolution simulation, it generates updrafts strong enough (of the order of 5 m s^{-1} in the simulation) to further loft any pieces of bark or other fire brands already raised to about 1000 metres by the fire plume (the fire itself not being modelled in the simulation).

There are two possible reasons for the increased fire activity and spotting as the bore passed over the fire. Firstly, the associated wind may have increased the fire intensity, due to the increased wind speed and possibly also due to the direction change pushing the fire into unburnt fuels on a temporarily broader front, although the change in wind speed was relatively small. A more intense fire would have a stronger plume, and therefore greater ability to raise embers into the strong winds aloft. Secondly, the updraft at the head of the bore, reaching 5 m s^{-1} well within 1000 m of ground level in the simulation, is itself strong enough to loft bark (Ellis 2011), although not from the surface. We propose that this updraft may have combined with the fire plume to provide strong, continuous lifting from the surface into the strong northwesterly winds aloft and thereby produced the observed major outbreak of spotting.

Discussion

Compared with the modelling technology available to reconstruct the weather of earlier significant fires (e.g., Ash Wednesday 1983, Mills 2005a; 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 resolutions now possible.

In addition to a direct comparison of the location of primary wind change in these new simulations against AWS observations (Figure 12) and observational analyses (BoM 2009b), comparisons have been also made against the results of other modelling experiments (not shown). One of these is against 0.036°-resolution (3600 m) and 0.012°-resolution (1200 m) simulations using the same ACCESS model configuration described in Section 3, but initialised from three different ERA-Interim (ERAI) global initial conditions; 00:00 UTC (11 am EDT), 06:00 UTC (5 pm EDT) and 12:00 UTC (11 pm EDT) on 6 February 2009. The other is against the real-time 0.125°-resolution (12.5 km) and 0.05°-resolution (5 km) operational MesoLAPS forecasts generated at the Bureau of Meteorology on 6 and 7 February 2009. The coarser-resolution MesoLAPS forecasts were initialised at 00:00 UTC (11 am EDT), 06:00 UTC (5 pm EDT), 12:00 UTC (11 pm EDT) and 18:00 UTC (5 am EDT, 7th Feb) on 6 February, while the finer-resolution forecasts were initialised at 00:00 UTC (11 am EDT) and 12:00 UTC (11 pm EDT) on 6 February, and 00:00 UTC (11 am EDT) on 7 February.

Amongst the ACCESS runs, the UKMO-initialised simulations generally provide a more accurate forecast for the location of the primary wind change than do the ERAI-initialised simulations, with the earliest of the ERAI simulations being up to two hours late relative to the analysed location (BoM 2009b) across central Victoria. This is not entirely unexpected, as the ERAI initial conditions (1.875°×1.25° horizontal resolution, 38 vertical levels) are less detailed than the UKMO initial condition (0.5625°×0.375° horizontal resolution, 50 vertical levels).

The operational MesoLAPS forecasts tend to be more accurate than the new ACCESS simulations with respect to the timing of the primary wind change across central Victoria, but less so earlier in the day. Also, the real-time operational forecasts were much less successful at resolving the pre-frontal boundary layer rolls and the nocturnal undular bore.

It should however be noted though that while it is indeed possible to compare two or more sets of simulations for a particular case study and decide that on balance one is better than the others, the relative merits of the various simulation approaches can only be properly assessed through comparisons across a suitably large number of examples comprising many different weather regimes.

Concluding remarks

High-resolution and very-high-resolution simulations of the meteorology on Black Saturday have been performed and validated successfully against available observational data. Many aspects of the simulated meteorology have implications for fire behaviour; the primary wind change itself, pre-wind-change boundary-layer rolls within the overall hot dry northerly flow, the bore across northeastern Victoria (and adjacent parts of New South Wales) which arises out of the stalled wind change, and the small-scale vortices on the primary wind change. In significant respects, the new ACCESS simulations perform better than the Bureau's operational MesoLAPS forecasts at the time.

These features are present at the simulation resolutions of 0.004° up to 0.012°, although the smaller-scale features (e.g., the boundary-layer rolls and small-scale vortices) are not as successfully represented in the 0.036°-resolution simulation (which is of the order of current operational high-resolution numerical weather prediction in the more densely populated parts of Australia). Integrating increasingly high-resolution simulations such as these into the fire-weather forecast process will provide an interesting challenge to the Bureau of Meteorology and fire agencies, although it should be noted that the finest model resolutions employed in this study will likely be restricted to research applications for some years to come.

High-resolution model simulations such as those used in this study provide a route to explore in great detail meteorological aspects of fire weather which are otherwise unobtainable with conventional observations, and allow for more detailed interpretations of features (such as the undular bore) seen in the observational data.

Acknowledgements

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