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Meteorological aspects of the January 2003 south-eastern Australia bushfire outbreak

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Summary

The severe fire outbreak in south-eastern Australia in January 2003 caused much devastation, with well over one million hectares of National Parks, State Forests and grazing land burnt. There was significant economic damage in terms of loss of dwellings (over 500 in Canberra on 18 January), buildings and stock. Tragically four people lost their lives in Canberra on 18 January. The conditions preceding the 2002–2003 fire season resulted in an abundance of dry fuel. Thunderstorm activity on 7–8 January initiated the wildfire activity that was not completely brought under control until early March. The meteorological conditions contributing to the severe fire outbreak in south-eastern Australia during early 2003 are discussed with particular attention to critical days during the period. Diurnal changes affecting fire weather are also discussed, in addition to stability and its effect on fire plumes.

Keywords: weather; meteorology; fire weather; climate; Australia

Introduction

South-eastern Australia is renowned for wildfire activity during the summer months. Large wildfires have occurred in January 1939 (Black Friday), February 1983 (Ash Wednesday), January 1994 (Speer *et al.* 1996) and January 2002, to name a few. During a fire outbreak that began in January 2003 well over one million hectares of National Parks, State Forests and grazing land were burnt in the south-east of Australia. Nearly 500 houses were destroyed in Canberra, and four people lost their lives on 18 January. In Victoria no lives were lost that were directly attributable to the fires. However, 41 houses, 213 other buildings and more than 9000 commercial stock were lost (Country Fire Authority 2003).

Taylor and Webb (2004) note that in the eastern Australian states a common progression of the fire season is for initial outbreaks of severe fire activity to occur in north-eastern NSW and south-eastern Queensland during late winter and spring, as temperatures begin to rise under the influence of a climatologically-common dry westerly wind regime. The fire weather season then progresses south and finally west as a predominantly westerly wind regime retreats south of the continent and is replaced by relatively moist sub-tropical easterlies.

The 2002–2003 fire season had these characteristics. Taylor and Webb (2004) describe the outbreak of wildfire activity in north-eastern NSW during the spring of 2002, gradually extending south during summer and culminating in the large fires in south-eastern Australia in January 2003. This paper summarises the meteorological conditions contributing to the severity of the south-eastern fires of 2003 with a particular focus on the antecedent conditions, the meteorological conditions contributing to the initial outbreak, and significant days of fire weather which prolonged the event.

Antecedent conditions

Fuel flammability, an important factor affecting fire behaviour, is influenced by the weather conditions the fuel is exposed to. The conditions leading to the severe outbreak of fire weather were influenced by a persistent El Niño event during 2002. Such events generally lead to below-average rainfall and higher than average temperatures in south-eastern Australia (Jones and Trewin 2000).

Rainfall

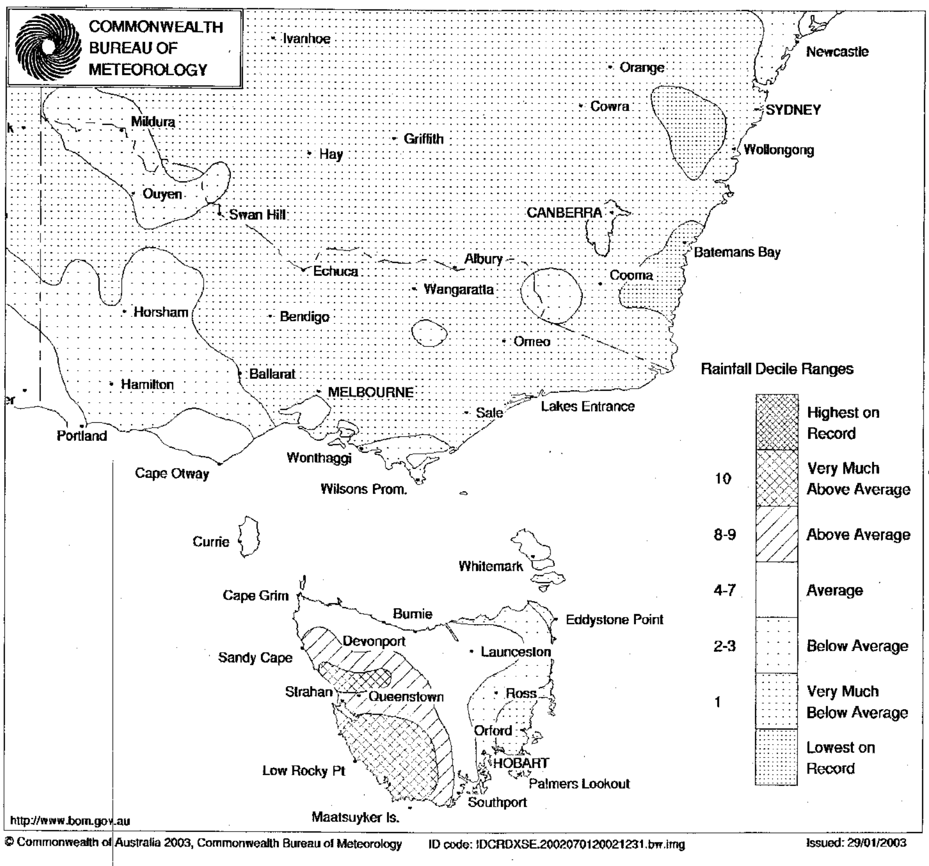
Rainfall statistics over south-eastern Australia for the period leading up to the fires of January 2003 reveal a consistent pattern of below-average totals over wide areas. The longer-term rainfall deciles for the six-month period ending 31 December 2002 can be seen in Figure 1(a). Extensive areas of the south-east received rainfall within decile 1, the lowest 10% of all records.

In the shorter term, the three-month decile map (Fig. 1(b)) for the period October–December 2002 displays a similar scenario, with very much below-average rainfall experienced in the south-east of the continent. Some areas received their lowest rainfall totals on record for this period.

Another way to view rainfall totals is to compare the accumulated rainfall for a given period to the median accumulated rainfall totals. It is clear from Table 1 that the accumulated rainfall was extremely low compared with the median rainfall for both Canberra and Omeo. In both cases only half the median rainfall was recorded for the period July to December.

During the summer months, fine fuels commonly become well cured. However, the significantly drier than normal conditions in

(a)



(b)

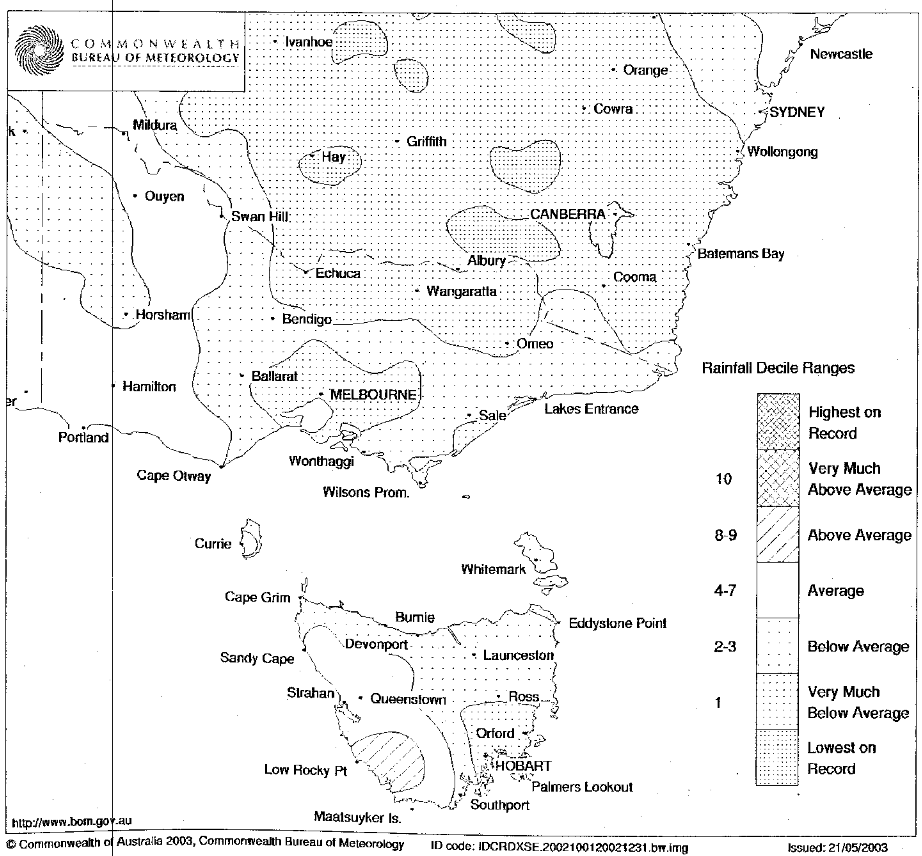


Figure 1. (a) Rainfall deciles over south-eastern Australia, 1 July 2002 – 31 December 2002, based on gridded data from National Climate Centre; (b) rainfall deciles over south-eastern Australia, 1 October 2002 – 31 December 2002, based on gridded data from National Climate Centre

Table 1. Comparison of accumulated rainfall depth to the median accumulated rainfall depth at Canberra and Omeo, July–December 2002

Month	Canberra		Omeo	
	Accumulated rainfall 2002 (mm)	Median accumulated rainfall (mm)	Accumulated rainfall 2002 (mm)	Median accumulated rainfall (mm)
July	16.8	36.9	10.0	43.2
August	39.6	82.5	43.4	95.5
September	98.0	136.0	85.4	154.0
October	109.6	191.45	109.0	224.5
November	120.0	246.95	154.2	284.3
December	138.2	286.35	173.4	340.6

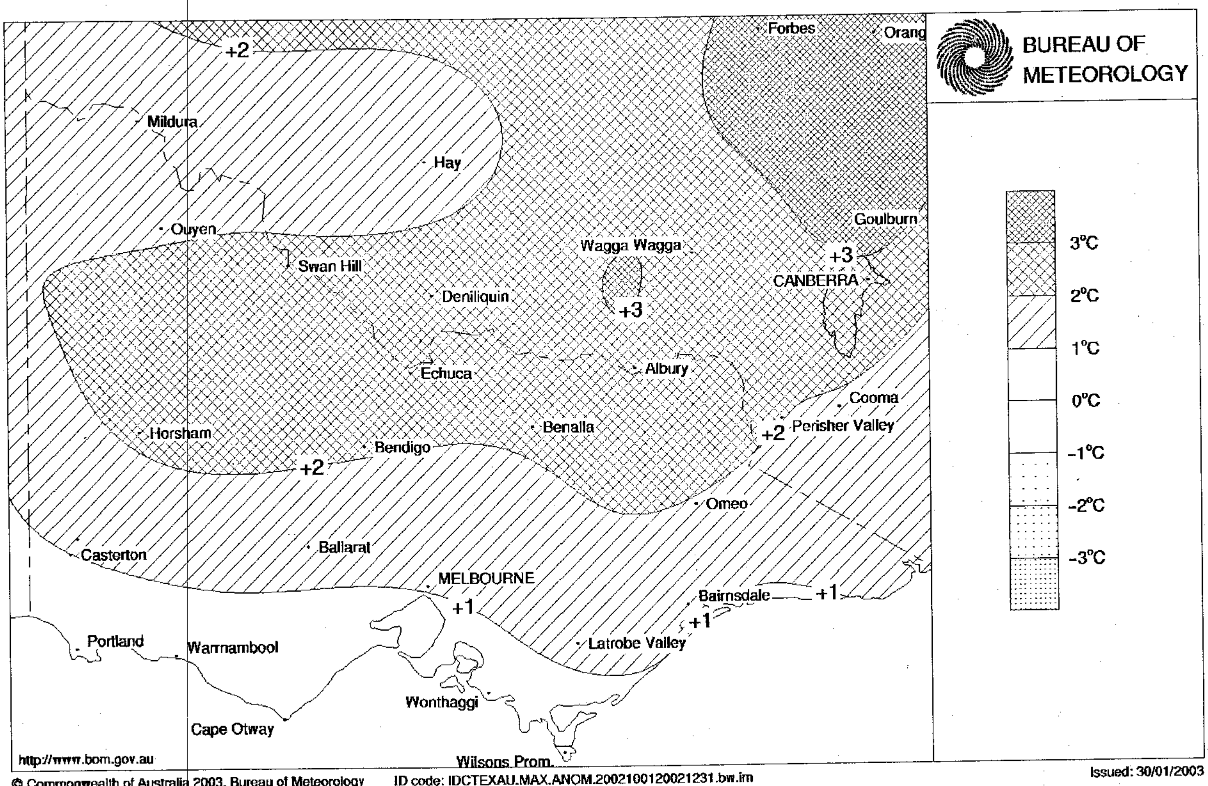


Figure 2. Average maximum temperature anomaly for Victoria and southern NSW for 1 October 2002 – 31 December 2002, courtesy of National Climate Centre

the months prior to the fire outbreak ensured heavy fuels were also well cured. When this fuel state is coupled with fire ignitions and severe fire weather conditions, the potential for severe fire outbreaks is clear.

Temperature

The anomalous conditions leading up to the January 2003 outbreak of bushfires were not confined to rainfall. The maximum temperatures were also significantly above average over parts of the fire area. Figure 2 shows the anomaly in maximum temperature over south-eastern Australia for the three-month period October–December 2002. Vast areas were over 1°C above average, and in NSW and northern Victoria this figure reached 2–3°C above average.

Webb *et al.* (2004) discuss the conditions experienced in the ACT leading to the devastating January bushfires. In this case the monthly average maximum temperatures from April 2002 to January 2003 were significantly above the long-term average. In November 2002, the monthly average maximum temperature was 5°C above average, a very significant figure for an entire month.

Keetch–Byram Drought Index

In NSW and Victoria, the Keetch–Byram Drought Index (KBDI) (Keetch and Byram 1968) is used as a measure of soil dryness and, in combination with the drought factor (Griffiths 1999) and other weather parameters, is used to calculate fire danger. The KBDI incorporates maximum temperature and rainfall and is the theoretical amount of rain required to bring the upper layers of the soil to saturation.

The combination of anomalously warm and dry conditions in 2002 resulted in the KBDI rising rapidly to reach very high values by the end of December. Figure 3 shows the daily KBDI at Canberra,

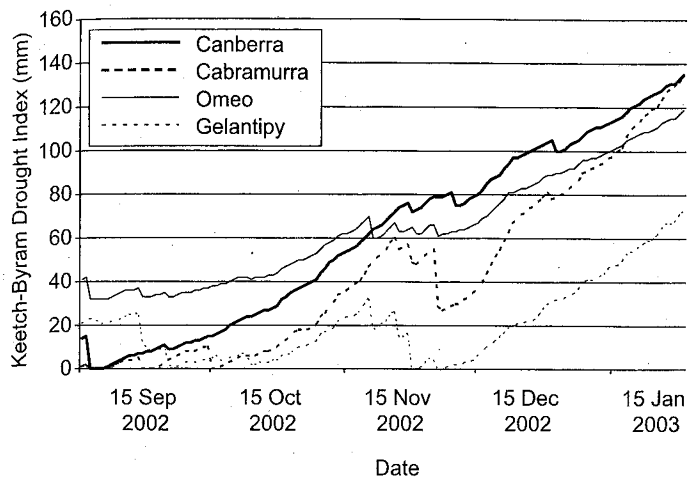


Figure 3. Keetch–Byram Drought Index for the period 15 September 2002 – 31 January 2003 at Canberra, Cabramurra, Omeo and Gelantipy

Cabramurra, Omeo and Gelantipy. Figure 4 indicates the locations and altitudes of places referred to in this paper. By January, three of these stations had reached a KBDI of 100 mm. Gelantipy had 80 mm of rainfall over the 48 hours to 9 am on 1 December 2002 that reduced the KBDI to zero. However, the dry period that followed later in December 2002 and January 2003 at Gelantipy resulted in a quick rise in the KBDI. Given the accumulated rainfall deficiencies indicated in Table 1, and the relatively warm conditions, it is not surprising the KBDIs for Canberra and Omeo reached such high values.

Webb *et al.* (2004) compare the KBDI values at Canberra with the long-term median KBDI values (Fig. 5). The KBDI rose very rapidly from October 2002 onwards in response to the very warm and dry conditions. Such a comparison of existing conditions to the normal conditions can be a useful indicator of the potential severity of the oncoming fire season because it provides some context to the existing conditions, particularly as the KBDI is prone to climatological differences. For individuals who have responsibility for large areas or those who are visiting different locations, information such as is contained in Figure 5 can be used to benchmark local conditions.

Meteorological conditions — common problems

A number of factors contribute to the severity of particular fire events. For example, temperature, relative humidity and wind speed may be combined with the underlying fuel conditions to provide fire authorities with estimates of fire behaviour. Important additions to this information are the diurnal changes in each of the elements, the stability of the atmosphere, and the differing meteorological conditions associated with fires burning at differing altitudes. A brief discussion of these aspects provides further insight into conditions experienced during 2003.

Diurnal changes in meteorological conditions

Temperature and relative humidity typically follow a regular diurnal pattern, with temperatures falling overnight and relative humidity correspondingly increasing significantly. Figure 6 shows the temperature and relative humidity at Cabramurra for the period 7 January – 2 February. On many occasions, the temperature dropped significantly overnight and humidity reached values > 60% — sometimes close to 100%. However, on a number of notable occasions, namely 18 January, 21 January, 26 January and 30 January, the relative humidity remained very low overnight, sometimes staying below 35%. Low relative humidity overnight may increase fuel flammability — earlier than would otherwise occur — the next day. Under such conditions the overnight absorption of moisture by fuel is reduced, and hence fuels can dry more rapidly once temperature and wind speed increase. Large fire growth and long fire runs occurred on most days where low relative humidity had been recorded the previous night (Bureau of Meteorology 2003).

Stability

Another factor influencing the development of the fires was atmospheric stability. Atmospheric stability, a measure of the

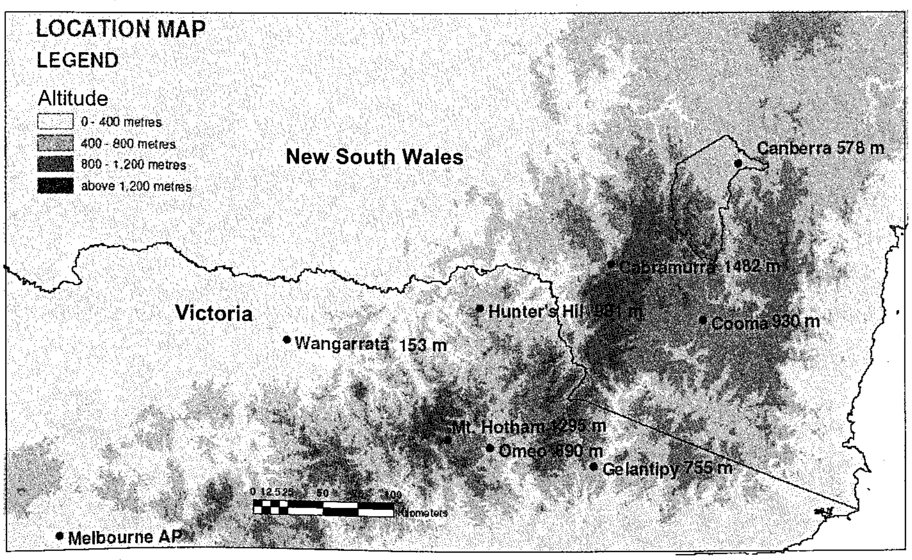


Figure 4. Location map (with altitudes) of places referred to in this paper

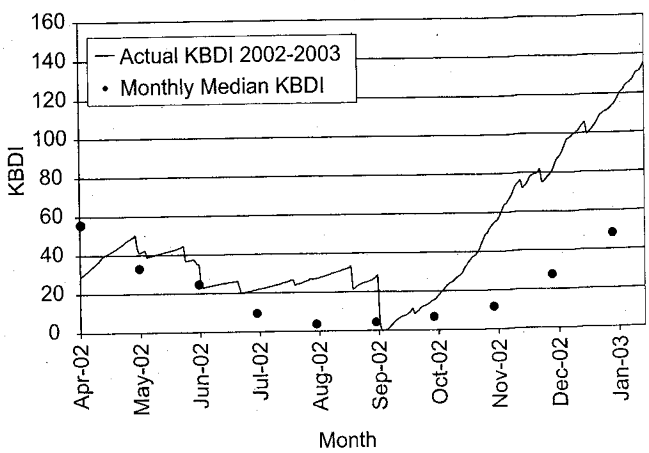


Figure 5. Keetch–Byram drought index for Canberra, April 2002 – February 2003. The dots represent the long-term median KBDI for each month (from Webb *et al.* 2004).

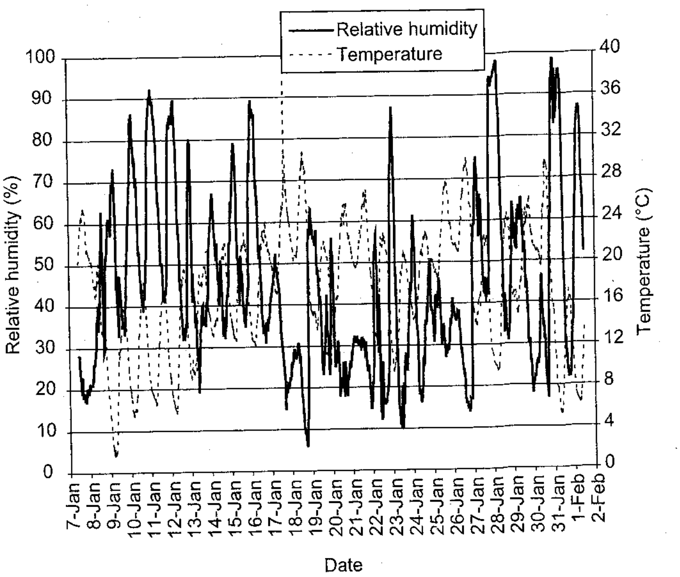


Figure 6. Temperature and relative humidity for Cabramurra (altitude 1482 m) for the period 8 January – 1 February 2003

buoyancy of a parcel of air, can affect fire behaviour. Taylor and Webb (2004) noted that large plumes, developed from the combination of an unstable atmosphere and large amounts of energy released by fires, were evident a number of times during the 2002–2003 fire season. Treloar (1999) discusses in detail the meteorology of a large plume-driven fire near Berriga, Victoria 1995. The vertical motion associated with large plumes results in stronger inflow at or near the surface in the vicinity of the fire. Fires can behave erratically under such conditions.

The Haines Index (Haines 1988) can provide a guide to the degree of instability of the atmosphere and the tendency for large-scale fires to become plume-dominated. Bally (1995) applied the index to the atmospheric environment in Tasmania. The Mid-Level Haines Index, which is most commonly used in Victoria and NSW, is calculated from temperature and dew point data in the layer between 1.5 km and 3 km. It is quoted on a scale of 2 to 6, with 6 representing the driest and most unstable conditions. The Haines Index is discussed in relation to particular days of critical fire weather later in this paper.

There is a complex relationship between the wind conditions and updraft strength that also influences the development of plumes over fires. A study of the wind shear below about 3 km can provide some insight into the likelihood that plumes will stay in the vicinity of the fire. If wind shear is relatively small and the low-level winds are not too strong, plumes are more likely to be located close to the fire. As mentioned previously, stronger inflow at the surface near the fire associated with large plumes can result in enhanced though erratic fire behaviour. This is also discussed briefly later in the paper.

Fires burning over differing altitudes

Terrain variation in the fire areas led to great variation in meteorological conditions experienced by the fires. In some cases a subsidence inversion (a very stable layer of air) descended only to the peaks of mountains, leading to vastly different conditions above and below the inversion. Air above a subsidence inversion is typically warmer and has much lower relative humidity than the air below it. Another matter of interest was the relatively regular southerly or easterly wind changes that moved over many fire areas. These changes would sometimes extend only very slowly to elevated areas, and in some cases not reach the ridgetops at all.

Meteorological conditions contributing to initial outbreak

Synoptic situation

The initial outbreak of fires in south-eastern Australia was triggered by lightning from thunderstorms associated with a frontal system that moved through the region (Bureau of Meteorology 2003). Figure 7 shows the mean sea level pressure (MSLP) chart for 17:00 Eastern Daylight Saving Time (EDST) on 7 January 2003. The prefrontal trough indicates the position of a north-westerly to westerly wind change ahead of a cooler south-westerly wind change indicated by the front. The airmass ahead of the

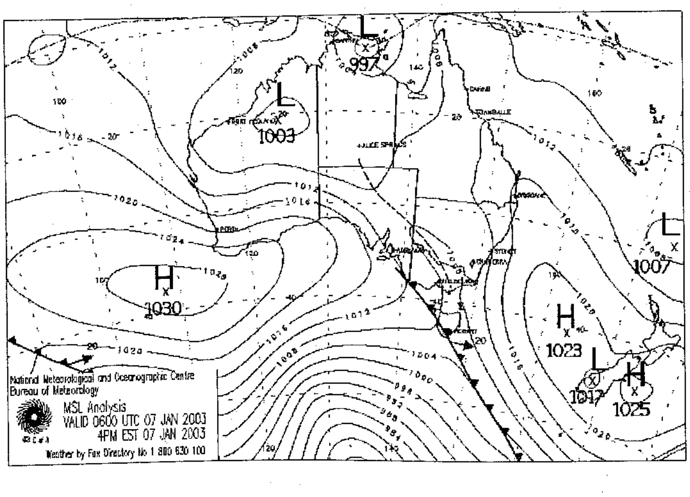


Figure 7. Mean sea level pressure analysis, 17:00 EDST 7 January 2003

prefrontal trough was too dry for thunderstorm activity, but significant middle-level (above about 3 km) moisture behind the front, combined with upward vertical motion provided by a middle-level trough and orographic lifting, resulted in thunderstorm activity in eastern Victoria developing late on 7 January. Thunderstorm activity cleared Victoria during the morning of 8 January, but south-eastern parts of NSW experienced thunderstorms into the afternoon and these ignited many fires over the area.

Meteorological factors

The thunderstorms formed in air of relatively low moisture content and hence were associated with little rainfall, allowing lightning from the thunderstorms to serve as ignition sources. The west to north-westerly winds during 8 January across south-eastern Australia were around 35 km h^{-1}, with temperatures rising into the mid 30°Cs and relative humidity dropping to 15–20%. The combination of these factors created Forest Fire Danger Indices (FFDIs), calculated using the McArthur Mark V Fire Danger Meter, of the order of 35–45 for much of the afternoon for areas of south-eastern NSW, reaching 'extreme' at Wagga Wagga and Canberra (the defined 'extreme' range is for FFDI ≥ 50). The situation was ideal for fire growth. Conditions in Victoria were not so harsh. Temperatures were significantly lower as the cold front had moved through, although at lower altitudes such as Wangaratta low relative humidity and fresh winds brought the FFDI into the 'very high' range (defined as FFDI 24–49). By late on 8 January widespread wildfire activity was well established.

The period 9–16 January was characterised by a ridge of high pressure in the vicinity of the south-east of the continent with a weak but persistent trough over inland NSW. Wind speeds were generally low, with mild to warm temperatures. Over south-eastern NSW, however, some periods of stronger winds did occur at times during this period, generally from the north-east to south-east direction. Figure 8 (from Webb *et al.* 2004) shows the FFDIs for Canberra Airport for the period 8–23 January (altitude 578 m). Similarly, Figure 9 shows the FFDIs for Cabramurra (altitude 1482 m) for the period 8 January to 1 February and Figure 10 shows FFDIs for Wangaratta (altitude 153 m) and Hunters Hill (altitude 981 m) for the period 8 January to 1 February (from Bureau of Meteorology 2003).

It can be seen from Figures 8–10 that, for the period 9–16 January, FFDIs were mostly below very high, apart from Wangaratta where temperatures were consistently in the high 20s to low 30s and the diurnal drop in relative humidity was consistently around 20% or less. One feature of note during this period was a cold front that moved through Victoria overnight on 13 January and during 14 January. Very high fire danger was experienced ahead of the front on 13 January, mainly at altitudes below about 800 m in Victoria. The fire situation began to significantly deteriorate on 17 January.

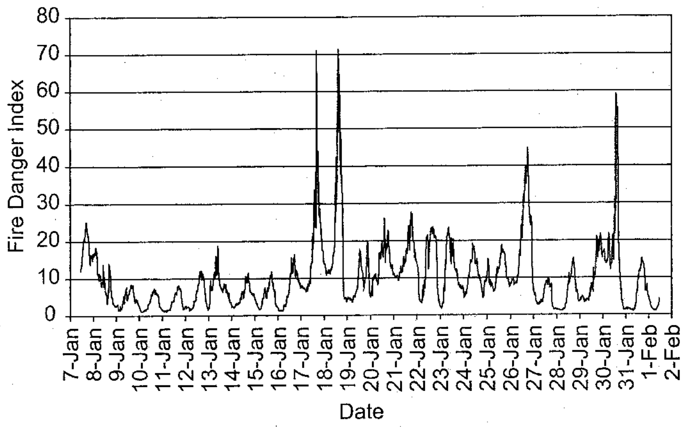


Figure 9. Forest Fire Danger Index at Cabramurra, 8 January – 1 February 2003 based upon 10-minute average data

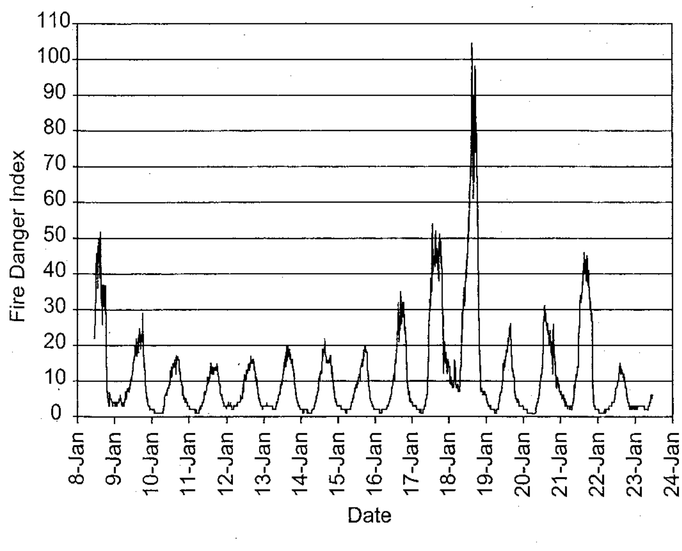


Figure 8. Forest Fire Danger Index at Canberra Airport, 8 January – 23 January 2003, based upon 10-minute average data. The maximum Fire Danger Index reached on 18 January based upon this data was 104 (from Webb *et al.* 2004).

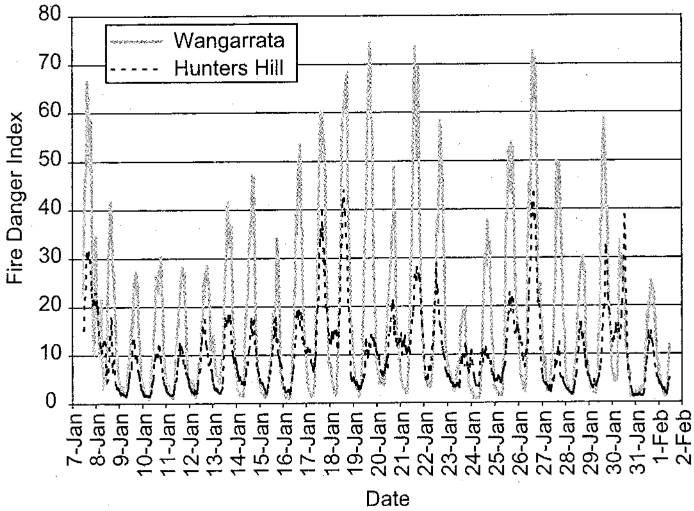


Figure 10. Forest Fire Danger Index at Wangaratta and Hunters Hill, 8 January – 1 February 2003 (from Bureau of Meteorology 2003)

Days of critical fire weather

It is very difficult to select any single location and/or altitude to illustrate the weather conditions across the wide area over which the fires were burning. However, to simplify the description of the weather, the general conditions across southern NSW will be illustrated by data from the automatic weather station at Cabramurra. Although this station is at an altitude of >1400 m, the data provide insight into trends in the meteorological conditions.

Figure 11 shows the wind speed and temperature at Cabramurra for the period 8 January – 1 February 2003. Figure 11, combined with Figures 8–10, helps to highlight 17–18, 21, 26 and 30 January as critical days of fire weather.

17–18 January

The relatively benign period following the ignition of the large number of fires ended on 17 January when conditions deteriorated. Temperatures rose dramatically, as did the recorded wind speed. Figure 12 shows the MSLP chart for 11:00 EDST on 18 January.

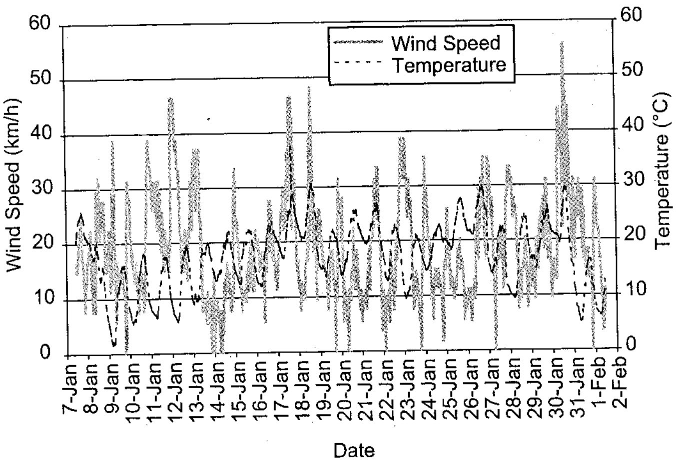


Figure 11. Temperature and wind speed for Cabramurra for the period 8 January – 1 February 2003

The passage of a broad frontal system resulted in further deterioration of conditions in NSW, although there was some easing of conditions in Victoria. A dry air mass moved over southern NSW, and fires in the ACT spread rapidly under the influence of strong winds to reach the urban interface of Canberra and destroy hundreds of homes.

Wind speeds at Canberra airport on 17 January rose during the morning and maintained average speeds of near 30–35 km h^{-1} for much of the afternoon, and the corresponding Fire Danger Index was on or near extreme all afternoon.

The average wind speed on the 18th again rose rapidly during the morning, reaching about 30 km h^{-1} by 9 am with stronger gusts. The wind speed rose even higher during the afternoon, particularly after 2:30 pm. Figure 13 (Webb *et al.* 2004) displays a summary of the temperature and moisture conditions at Canberra Airport during 18 January. The relative humidity dropped below 5% and was coupled with the strong winds and high temperatures; the Fire Danger Index rose to extremely high levels as indicated by Figure 8. Based on the 10-minute average wind, the maximum Fire Danger Index reached on 18 January was 104 just after 3 pm. This is a significant and rare value when using 10-minute wind data.

An additional by-product of the intense fire behaviour in the ACT was an intense vortex that moved towards the suburb of Chapman, leaving a path of damage some 200–300 m wide. Strong vertical motion above the fire area can intensify such vortices. In this case, winds were strong enough to snap trees and damage houses. Although small-scale vortices are not uncommon, larger vortices causing significant damage are rare.

On 18 January the Haines Index was calculated to be 6 in the ACT region, but this value is not unusual in summer in the ACT due to the hot, dry conditions that can occur in this region. The fires in the ACT developed very large cumuliform plumes above them, as indicated by photographs taken by observers in aeroplanes on the day. Weather radar surveillance suggests the plume height above fires in the ACT was >14 000 m.

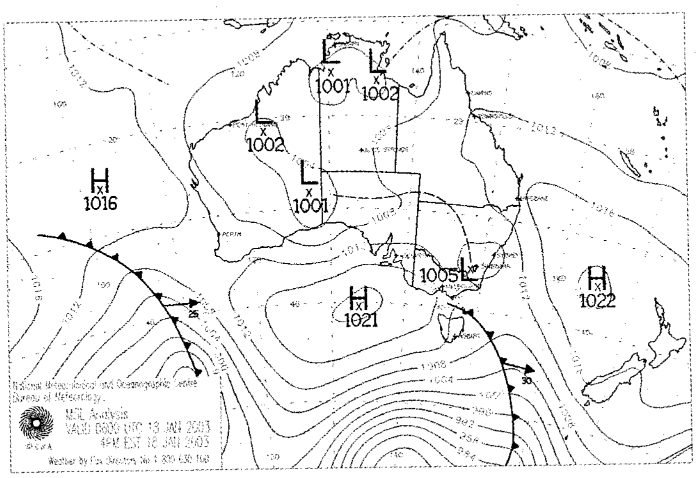


Figure 12. Mean sea level pressure chart for 11:00 EDST, 18 January 2003

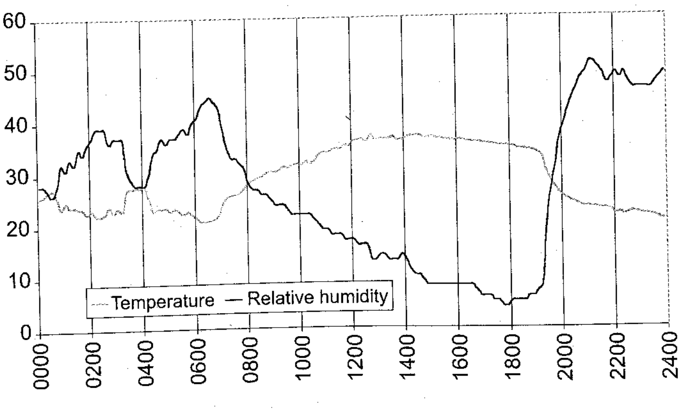


Figure 13. Temperature and relative humidity for Canberra Airport on 18 January (from Webb *et al.* 2004)

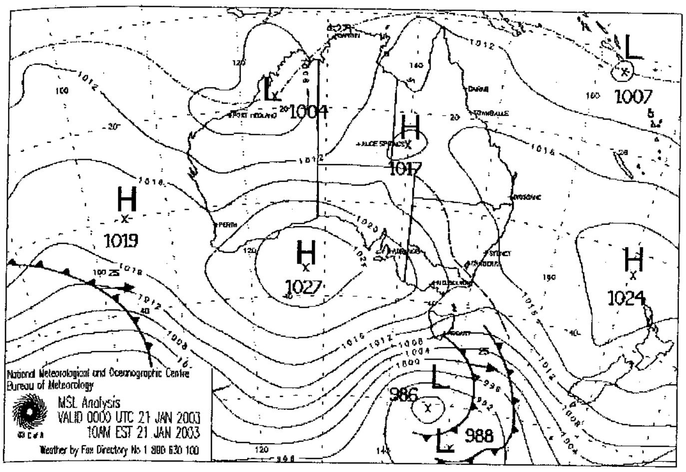


Figure 14. Mean sea level pressure chart for 11:00 EDST, 21 January

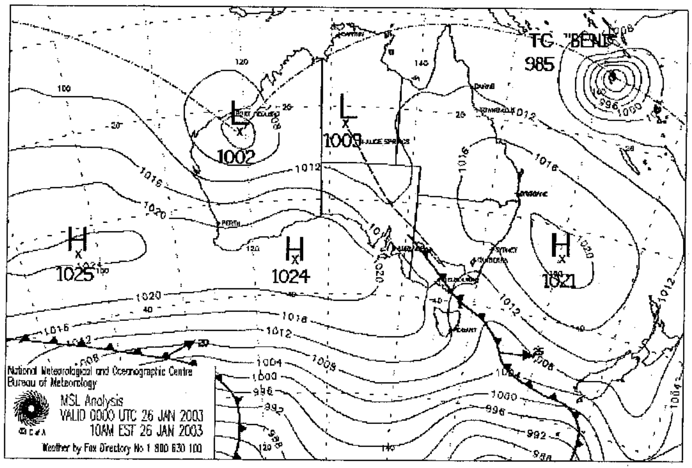


Figure 15. Mean sea level pressure chart for 11:00 EDST, 26 January

21 January

The twenty-first of January was a day of noteworthy fire runs in Victoria near Beechworth (Bureau of Meteorology 2003). Figure 14 shows the MSLP analysis for 11:00 EDST 21 January. A frontal system moved through Victoria during the morning of 21 January. West to south-west winds in the Beechworth area reached speeds of 35 km h^{-1} and temperatures reached the low 30°Cs during the afternoon. Convectively-driven vertical mixing bought very dry air to the surface, resulting in the relative humidity dropping below 10% in the area. FFDIs reached 70 at Albury and Wangaratta (the nearest automatic weather stations to the fire activity) during the afternoon, resulting in intense fire growth and long fire runs.

This day was of lesser concern at higher altitudes in eastern Victoria or south-eastern NSW. This was probably due to temperatures remaining lower, resulting in less vertical mixing, and the very dry airmass moving through later in the day. The dew point temperature at Cabramurra dropped from 4°C at 18:30 EDST to –4.8°C by 21:30 EDST, but as this occurred during the onset of nocturnal cooling the temperature was also dropping and wind speeds were easing at the same time. The result was a decrease in relative humidity of only 5%, which had a negligible effect on the FFDI.

26 January

Figures 9 and 10 show that 26 January was a day of very high FFDIs at Cabramurra and Hunters Hill, with Wangaratta reaching extreme fire danger. This was another day of major activity, as much of the south-east of the continent experienced extreme or near-extreme conditions. The MSLP chart for 11:00 EDST on 26 January, shown in Figure 15, was again characterised by a frontal system with a pre-frontal trough moving east through south-eastern Australia.

A hot airmass moved over the firegrounds ahead of the cold front that passed through eastern Victoria during the morning, and through south-eastern NSW late in the day. Temperatures rose into the mid-30s at altitudes of around 750 m, and a maximum temperature of 30°C was reached at Cabramurra. The airmass ahead of the cold front was very dry, with the relative humidity dropping to < 10% in some locations and to around 15% at ridge tops. Wind speeds were >35 km h^{-1} ahead of the change, reaching 48 km h^{-1} during the late morning at Gelantipy (altitude 755 m). The resultant FFDIs were extreme at Cooma and Gelantipy, and into the high 40s at Cabramurra. The timing of the front was significant, as the cooler and moister airmass behind the change brought some relief to the southern parts of the Victorian firegrounds by the early afternoon. It was late in the day, however, before the same relief extended through the south-eastern NSW firegrounds.

30 January

One more day of extreme fire weather occurred on 30 January. The FFDIs on this day were some of the highest recorded during the period over the south-east of the continent. Figures 9 and 10 show that at both Cabramurra and Wangaratta the FFDI reached well into the extreme range, and at Hunters Hill it pushed well into the very high level of fire danger. This day was characterised by large fire runs and downstream fire spotting (Bureau of Meteorology 2003). Figure 16 shows the MSLP chart at 11:00

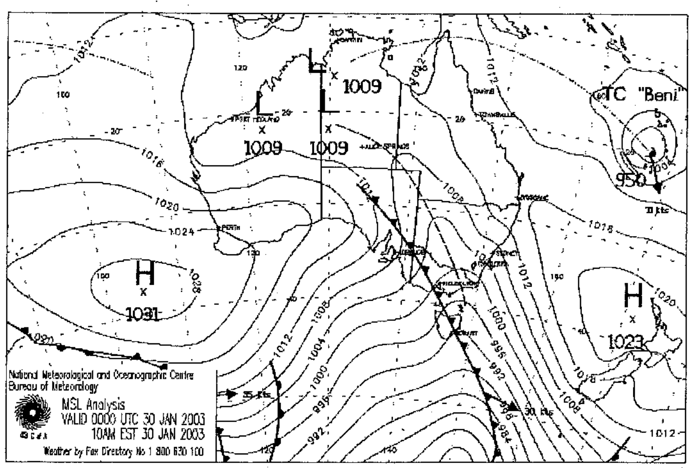


Figure 16. Mean sea level pressure chart for 11:00 EDST 30 January

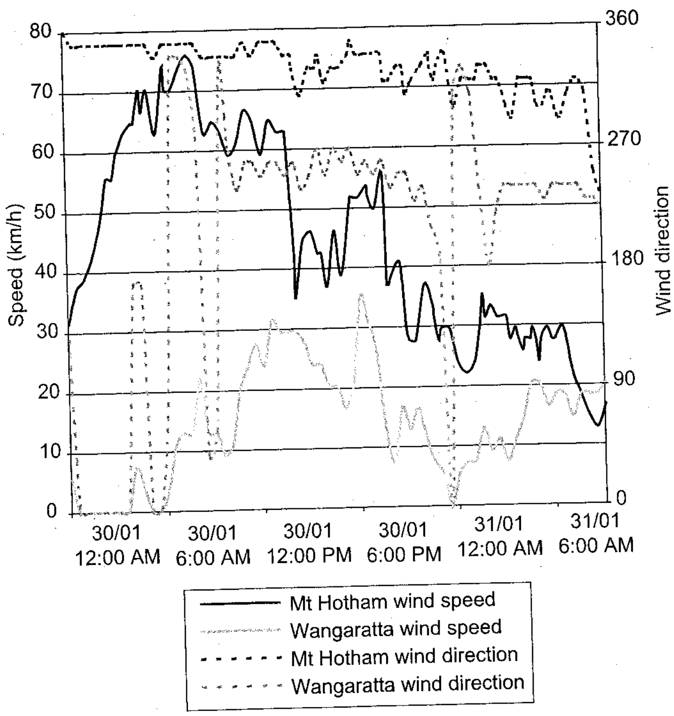


Figure 17. Mount Hotham and Wangaratta wind data for 30–31 January 2003, from Bureau of Meteorology (2003)

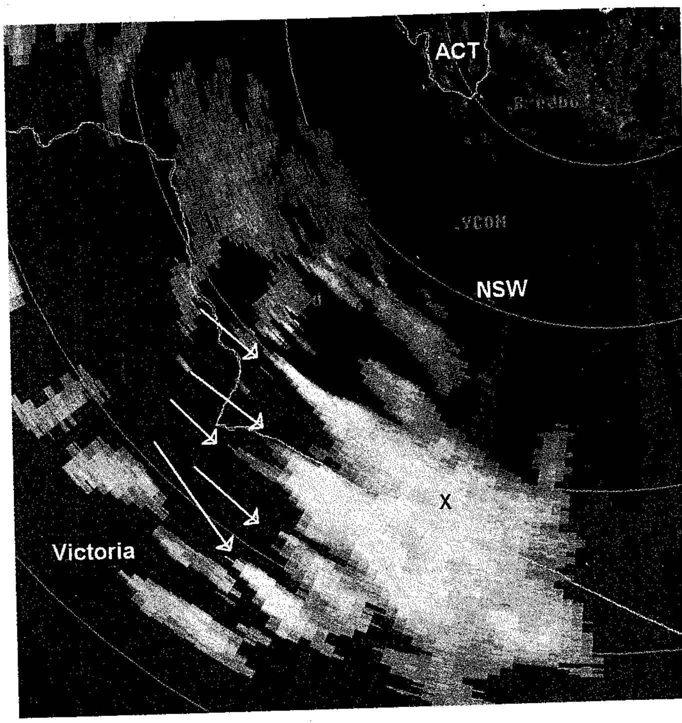


Figure 18. Radar image at 17:40 EDST 30 January 2003. The area in question is over the far eastern border of NSW and Victoria. The arrows mark some of the point sources for fire and the 'X' denotes the point where the radar-detected plume reached a height of >10 km.

EDST 30 January. A vigorous frontal system was approaching the south-east of the continent with a pre-frontal trough. Associated with the front was a band of middle-level cloud that produced rain in western Victoria but was dissipating as it moved towards the east.

Ahead of the front, north-west winds tended more towards the west as the change moved through. Bureau of Meteorology (2003) highlights the comparison between low-altitude winds and high-altitude winds on this day. Figure 17 shows the wind speeds at Mount Hotham (altitude 1849 m) and Wangaratta (altitude 153 m) on 30–31 January. The strongest winds were experienced in the early morning at Mount Hotham, with 10-minute average winds >70 km h^{-1}. These wind speeds were not experienced at low altitudes until the early afternoon, when convectively-driven vertical mixing allowed stronger winds aloft to be brought down to lower altitudes. Winds at higher altitudes were generally north-west, while the vertical mixing of winds aloft shifted winds to the west to north-west at lower altitudes.

Taylor and Webb (2004) indicate that FFDIs in south-eastern NSW were well into the extreme range on this day. Cooma experienced wind speeds to 45 km h^{-1}, while up to 55 km h^{-1} was recorded at the Cabramurra automatic weather station. Temperatures rose into the high 30s at Cooma and to near 30°C at Cabramurra, with the relative humidity falling to near 15% at higher altitudes and near 8% at Cooma. The resultant FFDIs achieved were > 70 at lower altitudes where the temperature was higher. Canberra on this day had a maximum FFDI of 91.

The atmospheric temperature and wind profile was also sufficient for large smoke plume growth with the fires. A deep dry adiabatic layer and a Haines index of 6 in eastern Victoria and south-eastern NSW indicates there was sufficient instability in the atmosphere and sufficient dryness of the air at lower levels for large-scale fires to be dominated by plumes. Additionally, wind shear below 7000 ft (2134 m) calculated using the 15:00 EDST Wagga vertical wind profile, along with the 15:00 EDST surface conditions at Gelantipy, was in the order of 30 km h^{-1}. This is relatively low shear in the low levels, which allowed fire plumes to remain in the vicinity of the fires and probably helped fires to behave erratically.

Figure 18 shows a radar image from the Captains Flat radar near Canberra. Plumes of smoke can be seen originating from a number of point sources in south-eastern NSW and eastern Victoria, some of which are marked by arrows. At X, the plume showed radar returns more than 10 km high. Such a large plume height would have affected the fires through strong inflow near the surface.

Such strong vertical motion, combined with moisture — provided by the atmosphere and as a by product of combustion — can lead to the development of thunderstorm activity associated with the fire plumes. Lightning activity was recorded in eastern Victoria associated with thunderstorms developing downstream of the fire plumes. Bureau of Meteorology (2003) indicates the thunderstorm activity was 50 km downstream from the fires, the result of the rapid vertical motion generated in the vicinity of the fires being advected downstream by the very strong winds in the upper levels (above 5 km).

Conclusion

The combination of rainfall deficiencies and above-average temperatures in the months before the 2002–2003 fire season resulted in an abundance of fuel primed for burning. Although it is not unusual for fine fuels to become well cured during the summer months, rainfall deficiencies in the months prior to the 2002–2003 fire season resulted in the curing of more heavy fuels, significantly increasing the available fuel load. The KBDIs in south-eastern Australia rose dramatically before the season. A comparison at Canberra Airport with the long-term median highlights the rapid rise of KBDI. This simple technique of comparing daily values to the recorded average can give a snapshot of the relative severity of an oncoming fire season, particularly when extensive knowledge of a particular area is lacking.

The critical days studied all had long fire runs. A common thread for these days was the presence of a strong frontal system moving through the south-east of the continent. The resultant warm to hot and windy conditions made for particularly bad fire days. Of note for the days studied is the low relative humidity on the evenings prior to critical days. It is likely that this provides an improved environment for fires to burn overnight, and during the morning allows fine fuels to dry more rapidly as the atmospheric conditions deteriorate.

Many days during January produced large plumes associated with the fires, days of particular note being 18 and 30 January. Large plumes and erratic fire behaviour were observed on 18 January, particularly in the case of the Canberra fires where plume heights were estimated using radar to be >14 000 m. On 30 January, relatively low wind shear in the lower levels of the atmosphere allowed fire plumes to remain in the vicinity of the fire, causing erratic fire behaviour. As conditions of this sort provide a dangerous environment for fighting fires, a more detailed study of stability and wind profiles is needed in south-eastern Australia to give a better understanding of the combined effects of wind and stability on fire behaviour.

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