Aust. Met. Mag. 55 (2006) 3-18

A climatology of extreme fire weather days in Victoria

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(Manuscript received November 2003; revised November 2005)

A study of extreme fire weather days (EFWD) in Victoria for the twenty-nine fire seasons (November to April) from 1970/71 to 1998/99 inclusive was carried out in order to provide objective information about:
(a) the frequency of EFWDs; and
(b) the synoptic patterns and wind directions associated with EFWDs.

Data from East Sale, Melbourne Airport, Mt Gambier and Mildura were used to calculate the fire danger rating using the McArthur Mark 4 grasslands fire danger meter and the McArthur Mark 5 forest fire danger meter. Days that had a fire danger rating of 50 or greater were labelled EFWDs. The number of EFWDs per year was compared to the number of high risk Haines Index days (HRHID), another fire risk indicator. It was found that EFWDs occur most in the northwest and central parts of Victoria while Melbourne Airport had the largest number of extreme days. Extreme fire danger ratings usually occurred at 1500 h local time, however at Melbourne Airport, extreme grass fire danger ratings usually occurred at 1200 h local time. Most extreme events occurred in north to northwesterly flow. HRHIDs were found to be well correlated with EFWDs.

Introduction

Bushfires are common during the Victorian summer. The role of the Bureau of Meteorology in providing fire weather estimates and forecasts to the Country Fire Authority (CFA) and the Department of Sustainability and Environment (DSE) is a vital one and for this reason a study of extreme fire weather days (EFWD) was carried out. The purpose of the study was to provide objective information about the frequency of EFWDs and the synoptic patterns and wind directions associated with extreme days in order to assist forecasters to recognise potential danger days and thus enable preventative action to be taken by the relevant agencies. It is acknowledged that a very limited number of stations were analysed for this study and that stations in the mountainous northeast of Victoria are not represented. It is also acknowledged that the coarse temporal coverage of three-hourly observations combined with the limitations of the McArthur fire danger indices and non-meteorological influences on fire behaviour further limit the outcomes of the study. Despite these limitations, the study highlights some interesting and useful information about EFWDs in Victoria.

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Background

A number of significant fire events have occurred in Victoria, the most well known being Black Friday (13 January 1939) and Ash Wednesday (16 February 1983). A list of some of the significant fires appears in Table 1 (Esplin 2003). Fire behaviour and fire spread are influenced by three main factors: fuel, weather and topography. To gain a better understanding of fire behaviour, fire growth models have been developed and modified over the years with various parameters representing the fuel, weather and topography of a given situation. From these models, such as the McArthur Fire Danger Indices, the fire danger on a particular day at a given location can be determined. Fire fighting agencies and the general public can then be informed of the expected fire danger and plan their activities accordingly.

Due to the devastation caused by fires, there is a wealth of international literature relating to fire weather forecasting and the impact of meteorological conditions on the generation and development of fires. Fire-risk indices based solely on meteorological factors have been shown to be an effective tool in providing useful information on fire risk potential (Palmieri et al. 1996). Some studies have gone further than a qualitative risk index and have proposed a model for forecasting the number of fires likely to occur on a given day using the previously determined daily fire risk (Diez et al. 1994). In the interest of improving the usefulness of fire weather forecasts, Brown and Murphy (1987) conducted a study in which operational forecasters quantified their perceived uncertainty in their own forecasts. In Australia, a number of regional fire weather studies have been conducted including an analysis of fire danger indices in the Mallee shrubland of Victoria (Krusel et al. 1993), an investigation of the skill in fire weather forecasts in central Australia (Love and Downey 1986), and a climatology of EFWDs in southern Western Australia (Bannister and Hanstrum, personal communication). The bushfires affecting New South Wales in January 1994 have also been investigated (Gill and Moore 1994, 1996 and 1998).

Surface meteorological conditions in conjunction with certain synoptic patterns have been shown to be favourable for enhanced fire danger in both the eastern United States and southeastern Australia. A case study by Brotak (1980) concluded that ‘The meteorological conditions which produced major fires in North and South Carolina were comparable to conditions associated with disastrous bush fires in Tasmania, Australia. Surface weather conditions consisted of abnormally high temperatures, extremely low humidities, and strong, gusty winds. In both cases, the surface synoptic situation showed the fire area to be in the warm sector preceding a strong cyclone and attendant cold front.’

The impact of the El Niño Southern Oscillation (ENSO) phenomenon (Troup 1965) on the severity of seasonal and daily fire danger has been another area of investigation. Swetnam and Betancourt (1990) found that the fire danger-ENSO relationship is strongest during extreme phases of the Southern Oscillation Index (SOI). Williams and Karoly (1999) discovered that there is a direct association between ENSO and fire danger in Australia, especially in the southeast and at Alice Springs. This concurs with the findings of Stern and Williams (1989) who found a strong relationship between ENSO and fire danger in Victoria. In contrast to these findings, Gill (1984) found no correlation between SOI and soil dryness index, area burnt or the number of fires in a given time period in southeastern Australia.

In addition to surface-based fire danger indices, other fire risk indices have been developed. One such index is the Haines Index. As described in Haines (1988) and outlined in Table 10, this index is a measure of lower tropospheric instability and dryness. A number of papers have investigated the usefulness of the Haines Index in predicting fire activity. Werth and Ochoa (1993) found that the Haines Index performs well at pinpointing the time of the most explosive fire growth and Bally (personal communication) found that the Haines Index is about as successful at predicting fire activity in Tasmania as the McArthur Forest Fire Danger Index (McArthur 1967).

Data and calculations

The fire season in Victoria is generally defined to have begun when high or very high fire dangers are expected on consecutive days. Although this can vary from year to year, the season generally commences in November and lasts through the summer months (Bureau of Meteorology 2005). In this study, the fire season is defined as the six-month period from November to April inclusive. EFWDs for the twenty-nine fire seasons 1970/71 to 1998/99 inclusive were identified using three-hourly synoptic data from Bureau of Meteorology field offices at Melbourne Airport, Mildura, East Sale and Mt Gambier. A map of these locations is presented in Fig. 1. Data at 0900 h, 1200 h, 1500 h and 1800 h local time were used. There is some variability in the time zones at each station throughout the period of the study. So, for consistency, local time has been used. Classification as an EFWD required either a forest fire danger rating or a grass fire danger rating

Table 1. List of significant fires in Victoria including the date, location(s) affected and losses incurred.

Date	*Place*	*Losses in Victoria*
Black Thursday 6 February 1851	Wimmera, Portland, Gippsland, Plenty Ranges, Westernport, Dandenong districts, Heidelberg	12 people 1 million sheep Thousands of cattle 5 million hectares burnt
Red Tuesday 1 February 1898	South Gippsland	12 people More than 2,000 buildings 260,000 hectares
February and March 1926	Noojee, Kinglake, Warburton, Erica, Dandenong Ranges	60 people Widespread damage to farms, homes and forests
1932	Gippsland	9 people Large areas of State forest
Black Friday 13 January 1939	Rubicon, Woods Point, Warrandyte, Noojee, Omeo, Mansfield, Dromana, Yarra Glen, Warburton, Erica	71 people More than 650 homes/shops 1.5 to 2 million hectares
3/4 March 1942	Hamilton, South Gippsland – Yarram (burning on a 60 mile front)	1 person 100 sheep 2 farms More than 20 homes
22 December 1943	Wangaratta	10 people Thousands of acres of grass country
14 January - 14 February 1944	Central & western districts, Morwell, Yallourn	32 people 700 homes Huge stock losses 440,000 hectares burnt in 8 hours
5 February 1952	Benalla	Several people 100,000 hectares
14-16 January 1962	The Basin, Christmas Hills, Kinglake, St Andrews, Hurstbridge, Warrandyte, Mitcham	32 people 454 homes
17 January 1965	Longwood	7 people (all from one family) 6 houses
21 February - 13 March 1965 Fires burned for 17 days	Gippsland	More than 60 homes/shops More than 4000 stock 300,000 hectares of forest 15,000 hectares of grassland
19 February 1968	The Basin, Upwey	64 homes 1,920 hectares
8 January 1969	Lara, Daylesford, Bulgana, Yea, Darraweit, Kangaroo Flat, Korongvale	23 people 230 homes 21 schools/church halls More than 12,000 stock 250,000 hectares
14 December 1972	Mt Buffalo	12,140 hectares including 7,400 hectares of State forest and 4,520 hectares of National Park

Table 1. Continued.

Date	*Place*	*Losses in Victoria*
12 February 1977	Penshurst, Tatyoon, Streatham, Creswick, Pura Pura, Werneth, Cressy, Rokewood, Beeac, Mingay, Lismore, Little River	4 people 116 houses/shops More than 236,000 stock 103,000 hectares
15 January 1978	Bairnsdale	2 people 1 house 6500 stock
December 1980 – 6 January 1981	Sunset Country, Big Desert	119,000 hectares
31 January 1983	Cann River district	250,000 hectares
1 February 1983	Mt Macedon	50 houses 6,100 hectares
Ash Wednesday 16 February 1983	Monivae, Branxholme, Cockatoo, East Trentham, Mt Macedon, Otways, Warburton, Cudgee, Upper Beaconsfield	47 people More than 27,000 stock Over 2000 homes/shops
14 January 1985	Maryborough, Avoca, Little River	3 people 182 homes 500 farms 46,000 stock 50,800 hectares
27 December 1990	Strathbogie	1 person 17 homes More than 12,000 stock
21 January 1997	Dandenong Ranges, Creswick, Heathcote, Teddywaddy, Gough’s Bay	3 people 41 houses 1 CFA fire truck 400 hectares
New Year’s Eve – 9 January 1998	Carey River State Forest	32,000 hectares
2 December 1998	Linton	5 people 1 CFA tanker 780 hectares
Big Desert Fire December 2002	Big Desert, Wyperfeld National Park	181,400 hectares 1 house
Eastern Victorian Fires 8 January 2003 Fires burned for 59 days	Mt Buffalo, Bright, Dinner Plain, Benambra, Omeo	41 homes Over 9,000 livestock 1.3 million hectares

of 50 or greater for at least one of the three-hourly observations. The forest fire danger rating was calculated using the equations for the McArthur Mark 5 forest fire danger meter as described in Noble et al. (1980). The grass fire danger rating was calculated using the equations for the McArthur Mark 4 grassland fire danger meter as described in Purton (1982). A drought factor of 10 and a curing value of 100 per cent were assigned, thus isolating the weather component of EFWDs. It is acknowledged that the actual fire danger rating at each observation time depended on the actual drought factor and curing value, which may give a lesser fire danger rating. However, it is the purpose of this study to assess only the weather components of the fire danger rating.

Fig. 1 **Map of Victoria showing locations mentioned in the text.**

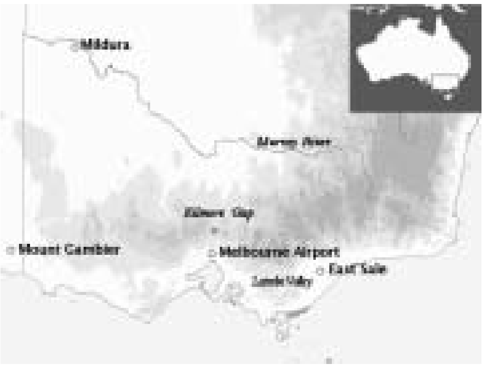
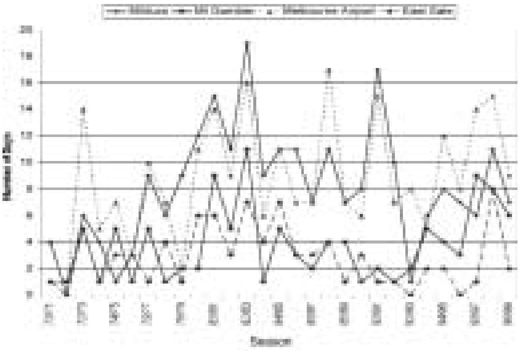


Fig. 2 **Number of extreme fire weather days (where either forest fire danger rating or grass fire danger rating was 50 or greater) per season 1970/71 to 1998/99.**



Climatology and discussion

Frequency of occurrence of EFWDs

The average number of EFWDs for each station for the 29-year period is shown in Table 2. The highest number of extreme days occurred at Melbourne Airport (average about nine per season) with the lowest number (about three per season) being recorded at East Sale. Mildura recorded an average number of eight extreme days per season, while four days were experienced in the southwest at Mt Gambier. Mildura experienced the largest range of extreme fire days in a season with a maximum of nineteen days in the 1982/83 season and a minimum of zero days in the 1971/72 season.

The frequency of EFWDs for each station, for all seasons during the 29-year period, is shown in Fig. 2. Strong interseasonal variability is apparent and there are certain seasons in which all stations show a similar trend. The seasons 1980/81, 1982/83, 1990/91 and 1997/98 were very active fire seasons with large numbers of EFWDs, whereas the seasons 1971/72 and 1975/76 were quiet seasons with few EFWDs. The season with the most number of EFWDs was the 1982/83 season, coinciding with a devastating drought period.

Monthly distribution of EFWDs

The average number of extreme forest fire danger days per month is shown in Table 3(a). Forest fire danger ratings (from the McArthur Mark 5 meter) have a higher sensitivity to temperature and wind than to other fields. To illustrate this, Mildura, with the highest average temperatures of the stations in this study, also has the highest number of extreme forest fire danger days. East Sale, with the lowest average temperatures of the stations in this study, has the least number of extreme forest fire days. The seasonal timing of the most extreme forest fire danger days differs around the State. In Mildura, the first half of the season is the most active. In the south and east, December and January are the active months. In the southwest, at Mt Gambier, February is the most active.

The average number of extreme grass fire danger days per month is shown in Table 3(b). Grass fire danger ratings (from the McArthur Mark 4 meter) have a high sensitivity to wind speed. Melbourne Airport has the most extreme grass fire danger days whilst Mt Gambier the least. For Mildura the first half of the season is the most active. At Mt Gambier and East

Table 2. **Frequency of occurrence of extreme fire weather days (where either forest fire danger rating or grass fire danger rating was 50 or greater) per season 1970/71 to 1998/99.**

Station	*Lowest number of days per season*	*Average number of days per season*	*Highest number of days per season*
Mildura	0	8.14	19
Mt Gambier	1	3.76	11
Melbourne Airport	0	8.83	17
East Sale	0	2.86	8

Table 3(a). Average number of extreme forest fire danger days per month November to April 1970/71 to 1998/99 at Melbourne Airport, Mildura, East Sale and Mt Gambier.

	Station			
Month	*Melbourne Airport*	*Mildura*	*East Sale*	*Mt Gambier*
November	0.66	1.83	0.14	0.24
December	1.14	2.52	0.38	0.76
January	1.38	1.76	0.48	1.07
February	1.00	1.03	0.21	1.14
March	0.45	0.41	0.14	0.21
April	0.03	0.10	0.00	0.14

Table 3(b). Average number of extreme grass fire danger days per month November to April 1970/71 to 1998/99 at Melbourne Airport, Mildura, East Sale and Mt Gambier.

	Station			
Month	*Melbourne Airport*	*Mildura*	*East Sale*	*Mt Gambier*
November	1.28	1.24	0.17	0.17
December	1.59	1.31	0.69	0.66
January	1.69	0.62	0.66	0.45
February	1.66	0.52	0.31	0.38
March	1.03	0.31	0.28	0.07
April	0.52	0.07	0.21	0.10

Sale December is the most active month but Melbourne Airport is very active throughout the November to February period.

The months when each station has a combination of a high mean maximum temperature, low mean humidity and high mean wind speed are generally the months that have the highest number of EFWDs. This is the case for both forest fire danger ratings and grass fire danger ratings. The high number of grass fire danger ratings at Melbourne Airport is likely due to the funnelling effect in any northerly flow of the Kilmore Gap, a narrow gap in the Great Dividing Range just north of the Melbourne metropolitan area.

Diurnal distribution of extreme fire danger ratings

The number of extreme forest fire danger ratings at each of the four times, 0900 h, 1200 h, 1500 h and 1800 h (local time), is shown in Table 4(a). All stations show a minimum number of extreme forest fire danger ratings at 0900 h and a maximum at 1500 h. This is because maximum temperatures often occur at around 1500 h.

The number of extreme grass fire danger ratings at each of the four times is shown in Table 4(b). Most stations follow the same pattern as the forest fire danger ratings with a minimum number of extreme grass fire danger ratings at 0900 h and a maximum at 1500 h. The exception is Melbourne Airport, which has a significantly high number at 0900 h and a maximum number at 1200 h. The average wind speed on extreme days at Melbourne Airport peaks at 0900 h and gradually decreases throughout the day. Owing to the lower temperatures at 0900 h this is not the time of maximum grass fire danger rating.

Wind directions and synoptic types associated with extreme events

Treloar and Stern developed a synoptic classification scheme for southeast Australia (Treloar and Stern 1993). This classification was applied at 0900 h on days of extreme fire danger to identify the synoptic patterns that are most commonly associated with extreme fire danger. The 50 synoptic types are defined in Table 5.

The relative frequency of extreme fire weather events in each synoptic category, expressed as a percentage of the total number of events, is shown in Tables 6(b), 7(b), 8(b) and 9(b). The wind direction at the time of the extreme fire danger rating was also investigated with the results shown in Tables 6(a), 7(a), 8(a) and 9(a). As well as examining the synoptic type and wind direction on EFWDs, the number of days on which a particular synoptic type occurred was investigated. A comparison of EFWDs and all days for specific synoptic types was carried out and this is shown in Tables 6(c), 7(c), 8(c) and 9(c). A discussion of the results for each location follows.

Table 4(a). Number of extreme forest fire danger ratings at 0900 h, 1200 h, 1500 h and 1800 h at Melbourne Airport, Mildura, East Sale and Mt Gambier.

	Station			
Time	*Melbourne Airport*	*Mildura*	*East Sale*	*Mt Gambier*
0900 h	9	6	1	1
1200 h	79	121	16	42
1500 h	99	206	32	75
1800 h	59	117	5	30

Table 4(b). Number of extreme grass fire danger ratings at 0900 h, 1200 h, 1500 h and 1800 h at Melbourne Airport, Mildura, East Sale and Mt Gambier.

	Station			
Time	*Melbourne Airport*	*Mildura*	*East Sale*	*Mt Gambier*
0900 h	84	4	5	1
1200 h	171	80	48	26
1500 h	146	114	57	35
1800 h	36	62	10	11

Table 5. Definition of the 50 synoptic types (Treloar and Stern 1993). Strength of the flow is defined as light, weak, moderate or strong. The direction of the flow is defined as variable (V), north-northwest (NNW), west-northwest (WNW), west-southwest (WSW), south-southwest (SSW), south-southeast (SSE), east-southeast (ESE), east-northeast (ENE) or north-northeast (NNE). The flow is described as either cyclonic (Cyc) or anticyclonic (AC).

DIR/strength, curvature	*Weak Cyc*	*Weak AC*	*Mod Cyc*	*Mod AC*	*Strong Cyc*	*Strong AC*
Variable	1 (light Cyc)	2 (light AC)				
NNW	3	4	19	20	35	36
WNW	5	6	21	22	37	38
WSW	7	8	23	24	39	40
SSW	9	10	25	26	41	42
SSE	11	12	27	28	43	44
ESE	13	14	29	30	45	46
ENE	15	16	31	32	47	48
NNE	17	18	33	34	49	50

Melbourne Airport

About 72 per cent of events occurred with winds from the north. These are typically hot and dry, having originated over the warm land surface of central, eastern Australia. This corresponds with the synoptic pattern analysis in which 46 per cent of events occurred in synoptic types 19, 20, 35 and 36 (moderate to strong NNW flow, both cyclonic and anticyclonic). About 17 per cent of events occurred in synoptic types 21 and 37, which correspond to moderate to strong WNW cyclonic flow. Examples of this latter group are shown in Figs 3 and 4.

Table 6 (c) shows that there are many days with these synoptic types that are not EFWDs. It also suggests that a larger percentage of days with synoptic types 35 and 36 (46 per cent and 56 per cent respectively) are EFWDs compared with the number of days with synoptic types 19 and 20 (35 per cent and 25 per cent respectively). This conforms to forecaster experience that days with strong, NNW flow are the most likely to produce extreme fire danger.

Table 6(a). Relative frequency of the wind direction at the time of extreme fire danger at Melbourne Airport.

Wind direction	*Percentage of extreme fire danger ratings recorded at Melbourne Airport*
N	71.9
NNE	4.0
NE	0.4
ENE	0.0
E	0.0
ESE	0.0
SE	0.4
SSE	0.0
S	0.8
SSW	0.0
SW	0.8
WSW	0.8
W	1.6
WNW	3.2
NW	7.1
NNW	9.1

Table 6(b). Relative frequency of the synoptic type on extreme fire weather days at Melbourne Airport.

DIR/strength, curvature	*Weak Cyc*	*Weak AC*	*Mod Cyc*	*Mod AC*	*Strong Cyc*	*Strong AC*
Variable	1 0.4	2 0.0				
NNW	3 3.1	4 1.6	19 18.5	20 11.0	35 9.8	36 5.9
WNW	5 2.0	6 1.2	21 7.9	22 3.5	37 9.1	38 0.0
WSW	7 0.0	8 0.4	23 1.2	24 0.8	39 2.0	40 0.0
SSW	9 0.0	10 0.0	25 0.0	26 0.0	41 0.0	42 0.0
SSE	11 0.0	12 0.0	27 0.0	28 0.0	43 0.0	44 0.0
ESE	13 0.0	14 0.0	29 0.0	30 0.0	45 0.0	46 0.0
ENE	15 0.0	16 0.8	31 0.0	32 0.4	47 0.4	48 0.0
NNE	17 1.6	18 1.2	33 4.7	34 8.7	49 2.0	50 2.0

Table 6(c). Comparison of the number of extreme fire weather days and the total number of days for specific synoptic types at Melbourne Airport.

Synoptic type	*Number of extreme fire weather days*	*Total number of days*
19 – Moderate, NNW, Cyclonic flow	47	135
20 – Moderate, NNW, Anticyclonic flow	28	111
35 – Strong, NNW, Cyclonic flow	25	54
36 – Strong, NNW, Anticyclonic flow	15	27

Mildura

About 60 per cent of events occurred with winds from the north to northwest. Another 26 per cent of events occurred with winds from either the west-northwest or the west. Similar to Melbourne Airport, 31 per cent of events occur with synoptic patterns 19, 20, 35 and 36 (moderate to strong NNW flow, both cyclonic and anticyclonic). Examples of these are shown in Figs 5 and 6. There is, however, a wider spread of synoptic pattern types compared with Melbourne Airport. This could be due to the regular occurrence of high temperatures at Mildura, or to Mildura's inland position compared with the near coastal location of Melbourne Airport. For example, a WSW wind in Mildura has a continental origin, and so may be quite hot and dry compared with a WSW wind in Melbourne, which has a maritime origin and thus is cool and moist.

For Mildura, the same four synoptic types were identified as for Melbourne Airport. Overall, fewer extreme days occurred on days with synoptic types 19, 20, 35 and 36, yet the percentage of extreme days increased when the flow was strong NNW. So Mildura displays a similar trend to Melbourne Airport.

Table 7(a). Relative frequency of the wind direction at the time of extreme fire danger at Mildura.

Wind direction	*Percentage of extreme fire danger ratings recorded at Mildura*
N	22.0
NNE	4.7
NE	0.8
ENE	0.8
E	0.0
ESE	0.0
SE	0.8
SSE	0.0
S	0.4
SSW	0.8
SW	1.7
WSW	3.4
W	14.8
WNW	11.0
NW	16.5
NNW	22.0

Table 7(b). Relative frequency of the synoptic type on extreme fire weather days at Mildura.

DIR/strength, curvature	*Weak Cyc*		*Weak AC*		*Mod Cyc*		*Mod AC*		*Strong Cyc*		*Strong AC*	
Variable	1	0.9	2	0.0								
NNW	3	2.2	4	1.3	19	12.1	20	6.0	35	8.2	36	5.2
WNW	5	3.0	6	0.9	21	5.2	22	1.7	37	6.5	38	0.0
WSW	7	1.7	8	0.0	23	3.4	24	0.0	39	0.9	40	0.0
SSW	9	1.3	10	0.0	25	0.9	26	0.9	41	0.0	42	0.0
SSE	11	1.3	12	0.0	27	0.0	28	0.0	43	0.0	44	0.0
ESE	13	0.9	14	1.7	29	0.0	30	0.0	45	0.0	46	0.0
ENE	15	0.9	16	2.2	31	0.0	32	2.6	47	0.9	48	1.7
NNE	17	3.0	18	3.0	33	5.2	34	7.8	49	4.3	50	2.6

Table 7(c). Comparison of the number of extreme fire weather days and the total number of days for specific synoptic types at Mildura.

Synoptic type	*Number of extreme fire weather days*	*Total number of days*
19 – Moderate, NNW, Cyclonic flow	28	135
20 – Moderate, NNW, Anticyclonic flow	14	111
35 – Strong, NNW, Cyclonic flow	19	54
36 – Strong, NNW, Anticyclonic flow	12	27

East Sale

About 36 per cent of events occurred with winds from the north to northwest. Another 53 per cent of events occurred with winds from either the west-northwest or the west. This westerly shift compared with other stations is apparent in the synoptic classification analysis where synoptic types 37 (strong, WNW, cyclonic flow) and 39 (strong, WSW, cyclonic flow) dominate. Examples of these are shown in Figs 7 and 8. It can be seen that anticyclonic flow is rarely associated with extreme fire danger at this location. The bias towards westerly winds at East Sale is likely to be related to the funnelling effect of the Latrobe Valley, which is situated to the west of the site.

An analysis for specific synoptic types was performed for the four most common types associated with EFWDs in East Sale (19, 21, 37 and 39). Unlike Melbourne Airport and Mildura, where strong flow was less common, strong flow (especially synoptic types 37 and 39) is more common at East Sale than more moderate flow regimes. All of the synoptic types have low percentages of extreme fire days and thus it seems that knowing the synoptic type is not a useful discriminant of EFWDs for East Sale.

Table 8(a). Relative frequency of the wind direction at the time of extreme fire danger at East Sale.

Wind direction	*Percentage of extreme fire danger ratings recorded at East Sale*
N	2.4
NNE	0.0
NE	0.0
ENE	0.0
E	0.0
ESE	0.0
SE	0.0
SSE	2.4
S	1.2
SSW	0.0
SW	0.0
WSW	8.4
W	28.9
WNW	22.9
NW	28.9
NNW	4.8

Table 8(b). Relative frequency of the synoptic type on extreme fire weather days at East Sale.

DIR/strength, curvature	*Weak Cyc*		*Weak AC*		*Mod Cyc*		*Mod AC*		*Strong Cyc*		*Strong AC*	
Variable	1	0.0	2	0.0								
NNW	3	0.0	4	2.4	19	10.8	20	2.4	35	7.2	36	1.2
WNW	5	0.0	6	1.2	21	9.6	22	1.2	37	15.7	38	30.1
WSW	7	1.2	8	0.0	23	4.8	24	1.2	39	7.2	40	0.0
SSW	9	1.2	10	1.2	25	0.0	26	0.0	41	6.0	42	0.0
SSE	11	0.0	12	0.0	27	0.0	28	0.0	43	0.0	44	0.0
ESE	13	0.0	14	0.0	29	0.0	30	0.0	45	0.0	46	0.0
ENE	15	0.0	16	0.0	31	0.0	32	0.0	47	0.0	48	0.0
NNE	17	1.2	18	0.0	33	0.0	34	0.0	49	1.2	50	0.0

Table 8(c). Comparison of the number of extreme fire weather days and the total number of days for specific synoptic types at East Sale.

Synoptic type	*Number of extreme fire weather days*	*Total number of days*
19 – Moderate, NNW, Cyclonic flow	9	135
21 – Moderate, WNW, Cyclonic flow	8	135
37 – Strong, WNW, Cyclonic flow	13	81
39 – Strong, WSW, Cyclonic flow	25	260

Mt Gambier

About 58 per cent of events occurred with winds from the north to northwest and 29 per cent of events occurred with winds from the west-northwest or west. About 32 per cent of events occurred with synoptic types 19, 20, 35 and 36 (moderate to strong NNW flow). An interesting result is that 30 per cent of events occurred with synoptic type 34 (moderate, NNE, anticyclonic flow). Examples of synoptic types 20 and 34 are shown in Figs 9 and 10.

A synoptic type analysis was performed for the four most common types associated with extreme fire danger: 20, 34, 36 and 50. As in the case of East Sale, there are low percentages of extreme days for all of these synoptic types. So at this station also, the synoptic type is not a very good indicator of potential for an EFWD.

Comparison of EFWDs and High Risk Haines Index Days (HRHIDs)

As described in the Background section, the Haines Index is a measure of lower tropospheric instability and dryness. It is calculated using a stability score and

Table 9(a). Relative frequency of the wind direction at the time of extreme fire danger at Mt Gambier.

Wind direction	*Percentage of extreme fire danger ratings recorded at Mt Gambier*
N	20.2
NNE	5.3
NE	2.6
ENE	0.0
E	0.0
ESE	0.0
SE	0.0
SSE	0.9
S	0.0
SSW	0.0
SW	0.0
WSW	3.5
W	20.2
WNW	8.8
NW	14.0
NNW	24.6

Table 9(b). Relative frequency of the synoptic type on extreme fire weather days at Mt Gambier.

DIR/strength, curvature	*Weak Cyc*		*Weak AC*		*Mod Cyc*		*Mod AC*		*Strong Cyc*		*Strong AC*	
Variable	1	0.0	2	0.0								
NNW	3	0.9	4	2.7	19	5.4	20	18.0	35	2.7	36	6.3
WNW	5	0.0	6	1.8	21	0.0	22	5.4	37	0.0	38	0.9
WSW	7	0.9	8	0.9	23	0.9	24	0.0	39	1.8	40	0.0
SSW	9	0.0	10	0.0	25	0.0	26	0.0	41	0.0	42	0.0
SSE	11	0.0	12	0.0	27	0.0	28	0.0	43	0.0	44	0.0
ESE	13	0.9	14	0.9	29	0.0	30	0.0	45	0.0	46	0.0
ENE	15	0.0	16	1.8	31	0.0	32	0.0	47	0.0	48	0.0
NNE	17	0.0	18	4.5	33	2.7	34	29.7	49	2.7	50	8.1

Table 9(c). Comparison of the number of extreme fire weather days and the total number of days for specific synoptic types at Mt Gambier.

Synoptic type	*Number of extreme fire weather days*	*Total number of days*
20 – Moderate, NNW, Anticyclonic flow	19	111
34 – Moderate, NNE, Anticyclonic flow	33	362
36 – Strong, NNW, Anticyclonic flow	7	27
50 – Strong, NNE, Anticyclonic flow	9	92

a moisture score, which are added to give a score out of 6. Table 10 shows how the calculation is performed. The Haines Index has been used as an indicator of fire activity in the western United States of America and in southeast Australia.

The Haines Index for Melbourne was calculated on a daily basis using the 2300 UTC Melbourne Airport or Laverton radiosonde flights. A Haines Index value of 6 indicates a high risk day for fires. The seasonal number of HRHIDs (where the Haines Index equalled 6) at Melbourne was compared with the number of EFWDs at Melbourne Airport and the results are shown in Fig. 11. The seasonal number of HRHIDs is much higher than the number of EFWDs (almost three times on average) however there is a good correlation of 0.73, statistically significant at the 95 per cent confidence level, between the two. These results suggest that there is some value for the Haines Index as part of a fire weather forecasting program. Further work needs to be undertaken to compare the Haines Index and the actual area burnt or number of fire outbreaks.

Fig. 3 0000 UTC MSLP chart for 26 February 1998. Extreme fire weather day when Melbourne Airport had moderate NNW cyclonic flow (synoptic type 19).

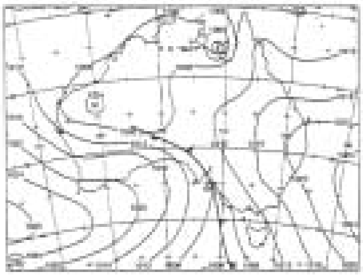


Fig. 4 0000 UTC MSLP chart for 22 December 1996. Extreme fire weather day when Melbourne Airport had strong WNW cyclonic flow (synoptic type 37).

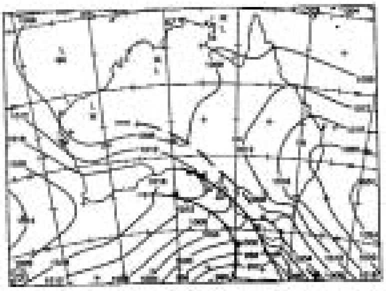


Fig. 5 0000 UTC MSLP chart for 13 October 1977. Extreme fire weather day when Mildura had strong NNW cyclonic flow (synoptic type 35).

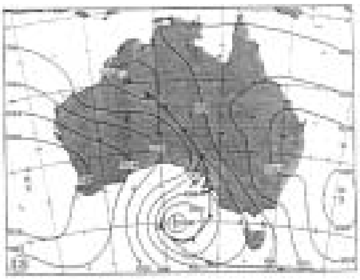


Fig. 6 0000 UTC MSLP chart for 25 November 1996. Extreme fire weather day when Mildura had strong WNW cyclonic flow (synoptic type 37).

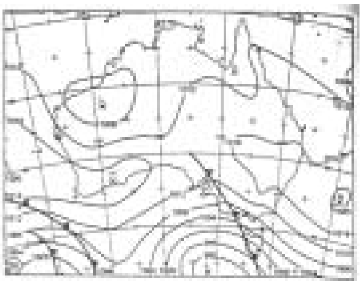


Fig. 7 0000 UTC MSLP chart for 15 January 1978. Extreme fire weather day when East Sale had strong WNW cyclonic flow (synoptic type 37).

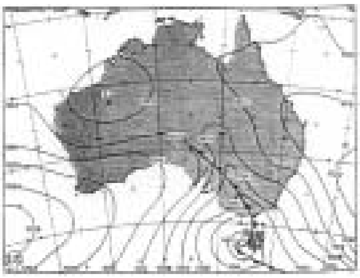


Fig. 8 0000 UTC MSLP chart for 25 November 1975. Extreme fire weather day when East Sale had strong WSW cyclonic flow (synoptic type 39).

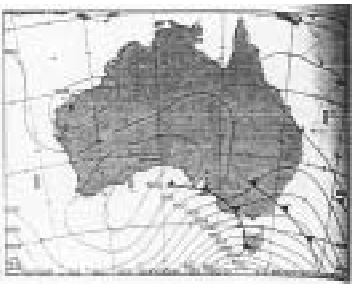


Fig. 9 0000 UTC MSLP chart for 10 December 1980. Extreme fire weather day when Mt Gambier had moderate NNW anticyclonic flow (synoptic type 20).

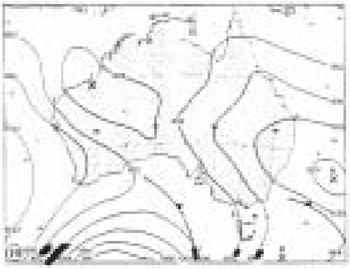


Fig. 10 0000 UTC MSLP chart for 30 January 1974. Extreme fire weather day when Mt Gambier had moderate NNE anticyclonic flow (synoptic type 34).

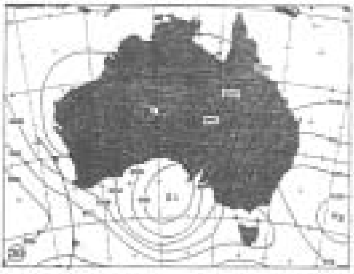


Table 10. Description of the Haines Index calculation.

Stability term (850 hPa temp - 700 hPa temp)	*Stability score*	*Moisture term (850 hPa temp - 850 hPa dew-point)*	*Moisture score*
=< 5°C	1	=< 5°C	1
6 to 10°C	2	6 to 12°C	2
=> 11°C	3	=> 13°C	3

Note: Add the stability score and the moisture score to get the Haines Index.

Fig. 11 Comparison of extreme fire weather days and high risk Haines Index days for Melbourne Airport for the 29 fire weather seasons (Nov-Apr) from 1970/71 to 1998/99.

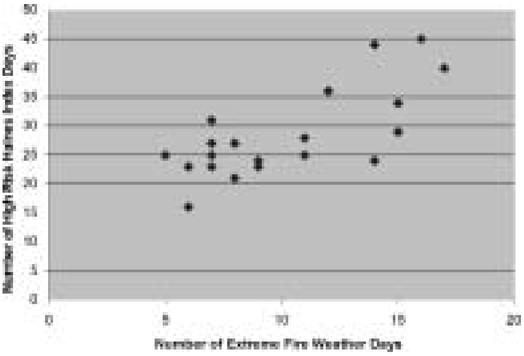
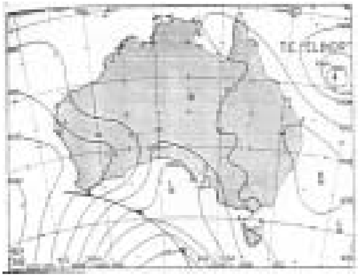


Fig. 12 0000 UTC MSLP chart for 16 February 1983 (Ash Wednesday).



Case studies

It is interesting to look at individual events more closely to see how the weather on the day affected the behaviour of the fires. Two representative case studies are now discussed.

Case study 1: Ash Wednesday (16 February 1983)
Lead up: The eleven-month period from April 1982 to February 1983 inclusive was the driest on record over most of Victoria. Very hot weather was experienced throughout the State with mean maximum temperatures on average three to four degrees above normal in February 1983 (Bureau of Meteorology 1983).

On the day: Victoria was affected by a hot, dry northerly airstream and a cold front was approaching from the west. Temperatures were high around the State and Melbourne city had a maximum temperature of 43.0°C. The 0000 UTC (1100 h local time) MSLP chart for Ash Wednesday is shown in Fig. 12 (Bureau of Meteorology 1983).

Fire danger ratings for four representative sites in Victoria (Melbourne Airport, Mildura, East Sale and Mt Gambier) are shown in Table 11. Melbourne Airport had the highest fire danger rating figures although Mildura and Mt Gambier were also extreme in the afternoon. The wind directions at the four time steps of 0900 h, 1200 h, 1500 h and 1800 h (local time) for the four locations are shown in Table 12. In this particular case, a southwesterly change had only reached Mt Gambier by 1800 h local time. Thus the change was approaching Victoria late in the afternoon and the temperatures stayed high into the evening, as indicated by the 1800 h readings in Table 11.

Case study 2: 3 January 1990
Lead up: November and December 1989 were drier than usual through most of Victoria. The Statewide averaged rainfall for the two months was 35 per cent below the 1961-90 normal, ranking 21st lowest out of the 106 years 1900-2005.

On the day: Extremely hot weather was experienced with temperatures above 40°C for much of the State. The maximum temperature of 46.9°C at Mildura was one of the highest ever recorded in

Table 11. Fire danger ratings for 0900 h, 1200 h, 1500 h and 1800 h at Melbourne Airport, Mildura, East Sale and Mt Gambier on Ash Wednesday, 16 February 1983

	Station							
	Melbourne Airport		*Mildura*		*East Sale*		*Mt Gambier*	
Time	*Forest*	*Grass*	*Forest*	*Grass*	*Forest*	*Grass*	*Forest*	*Grass*
0900 h	28	21	14	2	4	0	40	35
1200 h	85	84	67	43	3	5	80	68
1500 h	112	131	89	82	22	24	90	94
1800 h	107	115	92	86	19	14	15	53

Table 12. Wind direction and speed (km/h) for 0900 h, 1200 h, 1500 h and 1800 h at Melbourne Airport, Mildura, East Sale and Mt Gambier on Ash Wednesday, 16 February 1983

	Station			
Time	*Melbourne Airport*	*Mildura*	*East Sale*	*Mt Gambier*
0900 h	N 26	NE 4	Calm	NNE 32
1200 h	N 37	N 26	E 9	NNW 34
1500 h	N 45	NNW 37	E 32	NW 41
1800 h	NNW 41	NNW 37	E 22	SW 61

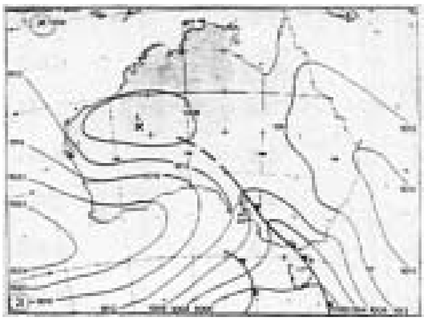
Victoria. Strong, gusty winds caused damage to trees, roofs and power lines over most of the State. One hundred and thirty-two bushfires broke out and major stock losses occurred along the Murray River. Ten million dollars of damage was done to sultana crops. Grassfires affected the outer suburbs of Melbourne although no houses were lost. The 0000 UTC (1100 h local time) MSLP chart for 3 January 1990 is shown in Fig. 13 (Bureau of Meteorology 1990).

Fire danger ratings for four Victorian representative sites, Melbourne Airport, Mildura, East Sale and Mt Gambier, are shown in Table 13. Melbourne Airport, Mildura and East Sale all had fire danger ratings greater than 100 for both forest and grassland areas at some time during the day. The highest forest fire danger rating and grassland fire danger rating values recorded using the three-hourly data from 1970 to 1999 inclusive for these three stations were recorded on this day.

The wind directions at 0900 h, 1200 h, 1500 h and 1800 h (local time) for the four locations are shown in Table 14. The wind changes throughout the day indicate that a SW change was approaching from the west.

From forecaster experience, extreme fire danger ratings often occur in a pre-frontal northwesterly flow. This is when the hottest, driest air from continental Australia moves across Victoria and the winds can become quite strong and gusty. The real danger with bushfires on these days is that when the southwesterly change moves through, the flank of the fire becomes the leading edge and a much larger area is under threat from the fire. The Ash Wednesday fires in 1983 and the Linton fire in 1998 (refer to Table 1) both occurred on days when a significant wind change moved through Victoria. From experience with major fire events such as Ash Wednesday and Linton, forecasters are very much aware of the importance of accurately timing wind changes across the State on such high fire danger days.

Fig. 13 **0000 UTC MSLP chart for 3 January 1990.**



Conclusions

A study of EFWDs for each of the twenty-nine fire seasons from 1970/71 to 1998/99 inclusive showed that EFWDs occur most in the northwest and central parts of the State. Wind speed was identified as the most important factor for extreme grass fire dangers

Table 13. Fire danger ratings for 0900 h, 1200 h, 1500 h and 1800 h at Melbourne Airport, Mildura, East Sale and Mt Gambier on 3 January 1990

	Station							
	Melbourne Airport		*Mildura*		*East Sale*		*Mt Gambier*	
Time	*Forest*	*Grass*	*Forest*	*Grass*	*Forest*	*Grass*	*Forest*	*Grass*
0900 h	73	112	55	45	7	1	5	12
1200 h	107	153	97	91	116	172	3	5
1500 h	7	11	137	177	127	173	14	20
1800 h	7	10	69	62	16	14	7	13

Table 14. Wind direction and speed (km/h) for 0900 h, 1200 h, 1500 h and 1800 h at Melbourne Airport, Mildura, East Sale and Mt Gambier on 3 January 1990.

	Station			
Time	*Melbourne Airport*	*Mildura*	*East Sale*	*Mt Gambier*
0900 h	N 54	N 32	Calm	SSW 34
1200 h	NNW 52	NNW 37	NW 55	SSW 22
1500 h	S 30	W 50	W 52	SW 35
1800 h	S 26	WSW 35	SW 41	SSW 34

and temperature combined with wind as the most important factors for extreme forest fire dangers. Melbourne Airport had the largest number of extreme days. Extreme fire danger ratings usually occurred at 1500 h local time. However, at Melbourne Airport, extreme grass fire danger ratings were most common at 1200 h local time due to prevailing stronger winds at that time.

An investigation into the relationship between wind direction and synoptic types showed that most extreme events occurred in north to northwesterly flow. Both Mt Gambier and East Sale also had a significant number of events in westerly flow. Synoptic types 35 and 36, which represent strong NNW flow, indicated the likelihood of EFWDs at both Melbourne Airport and Mildura with approximately 50 per cent of days being classed as EFWDs. The synoptic type does not appear to be as useful an indicator of EFWDs at either Mt Gambier or East Sale.

HRHIDs were found to be well correlated with EFWDs (correlation coefficient of 0.73 at the 95 per cent confidence level). HRHIDs did however occur much more frequently than EFWDs.

Further development of the climatology would be beneficial, particularly since there were significant fires in Victoria during 2003. Increasing the number of stations analysed to give greater spatial coverage across the State would enhance the climatology. This would allow comparison between elevated sites in the northeast of the State and sites at lower levels, both inland and coastal. Data of higher temporal resolution from automatic weather stations at sites around the State also provides further information to improve the climatology. Using this half-hourly information, there is less chance of an extreme fire danger rating being missed. In order to have a more realistic picture of the fire danger in each season, the state of the fuel needs to be included in the fire danger calculations. The observed curing values and calculated drought factors need to be included in the McArthur Index calculations to indicate the real fire risk at each location. A preliminary investigation of the relationship between EFWDs and the Southern Oscillation Index averaged over the six months prior to the fire season showed a correlation significant at the 95 per cent level. Further investigation of this relationship is suggested.

Acknowledgments

Special thanks to Shoni Dawkins from Climate and Consultancy Section, Victorian Regional Office of the Bureau of Meteorology, for help with finding Climate Summaries and for the database of synoptic types.

Thanks also to Tony Bannister, Jon Gill and particularly Harvey Stern, for reviewing this document and suggesting further analysis.

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