A fire danger climatology for Tasmania

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Forest fire danger indices are calculated for a number of Tasmanian locations over an extended period. Significant features of the resulting climatology include: the existence of a springtime peak in fire danger in eastern and southeastern Tasmania (although with substantial interannual variability); an apparent trend of increased severity of southeast Tasmanian springtime fire weather events; and differences in diurnal behaviour between the elevated location examined and those at lower levels.

Introduction

Fire danger indices integrate a number of weather parameters to estimate the effect on fire activity of ambient weather conditions. Climatologies of fire danger assist fire and land management agencies to plan effectively, and permit assessment of trends and variability in space and time. Tasmania is relatively small in area, but encompasses a diverse range of environments, and it is frequently the case that considerable differences in fire danger are evident across the State at any one time. There may also be substantial variability within fire seasons, and between successive fire seasons. In particular, there is the perception within the Tasmanian fire management community of a 'springtime bump', a peak of fire danger activity early in the fire season.

In order to characterise variability in fire season severity objectively and determine the existence of a springtime secondary fire danger peak, a fire danger climatology for Tasmania has recently been constructed using digitised weather data from a number of locations around the State. Where the data history is sufficiently long, the climatology has been examined to highlight any apparent trends. In particular, characteristics of springtime data are examined, as there appears to be a recent increase in the number of springtime days on which dangerous fire weather occurs. A more gradual increase over time of seasonal fire danger percentiles is also apparent. Substantial differences in fire weather behaviour are highlighted by the climatology, particularly between low-level eastern and southeastern stations and those in the north and west of Tasmania. Also, substantial diurnal differences occur between the high and low-level stations examined.

Foley (1947) provided a comprehensive overview of the state of fire weather forecasting and fire management across Australia at the time, together with a summary of significant fire events over the preceding few decades. Luke and McArthur (1978) discuss in broad terms the fire history and climatology of Australia, with sections on each State and Territory. They note that, up to that time at least, the peak fire danger period for Tasmania falls in summer and autumn.

Many other authors have developed fire danger climatologies from observational data for a variety of subject areas and purposes, both in Australia and overseas. Australian studies include that of Vines (1974), who investigated interdecadal variability in the long-term rainfall patterns of southeastern Australia, noting that significant drought occurred roughly every thirteen years, and that dangerous fire seasons were associated

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with these droughts. He does point out, however, that rigorous statistical analysis had not been conducted on this work to ensure that the variability discussed was not an artefact of the filters used in manipulating the data. Williams and Karoly (1999) examined the occurrence of extreme fire danger in Australia (including Hobart as a location) in connection with the El Niño phenomenon, noting patterns of increased fire danger during El Niño events. Verdon et al. (2004) examined long-term records of weather data in New South Wales, arguing that the effect of El Niño on the likelihood of dangerous fire weather is modulated by the influence of the Inter-decadal Pacific Oscillation. Recently, Lucas (2006) has constructed a high-quality fire danger climatology for Australia for use as a reference data-set, again including Hobart in the data-set. Smith (1998) focused on the vulnerability to fire of Hobart specifically, and addresses a number of factors, including weather, influencing the likelihood of fire occurrence. Long (2006) constructed a climatology of extreme fire weather days for Victoria, using synoptic weather observations from four weather stations around the State, and briefly analysed two events, including Ash Wednesday 1983. McCaw et al. (2007) documented the climatology of bushfire weather for four locations in southwestern Australia using the Haines index which is based on atmospheric stability and the moisture content of the lower atmosphere.

Overseas studies of fire danger climatology have focussed chiefly on North America. Flannigan and Harrington (1988) analysed the statistical relationship between raw meteorological variables with the area burned on a monthly basis in Canada, finding that long rain-free periods and days of low relative humidity were best (although only moderately) correlated with monthly area burnt. Taking a slightly different approach, Brotak and Reifsnyder (1977) examined the synoptic weather patterns associated with 52 major wildfires in the eastern United States, finding that most occurred near surface cold-frontal zones. More significantly, major fires tended to be associated with the passage of a dry trough at 500 hPa. Crimmins and Comrie (2004) examine the relationship between wildfire occurrence and longer-term climate (up to several years) in the arid southwest of the United States, arguing that fuel accumulation is a function of greater than average rainfall up to three years before fire occurrence.

Methods

The McArthur Mark V forest fire danger meter (McArthur 1967) is used operationally by fire agencies and the Bureau of Meteorology throughout much of Australia, particularly the southeast, to estimate the Forest Fire Danger Index (FFDI). Using synoptic weather observations from a number of Tasmanian stations, FFDI time series are calculated to highlight times of year, and times of day, at different locations when fire danger tends to peak, and to note any trends in FFDI occurrence. This climatology also enables areas of potential future research to be identified.

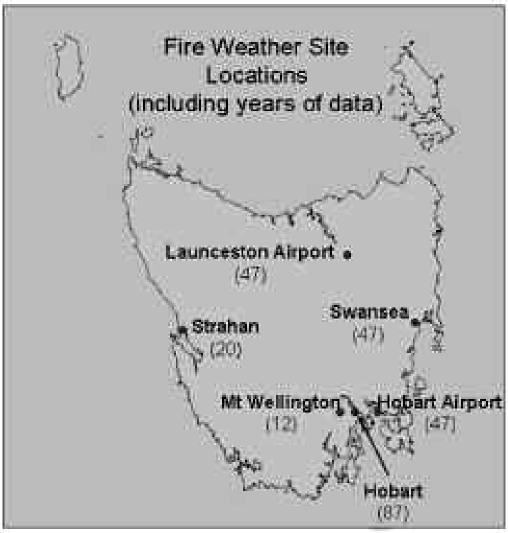
A number of fire danger rating categories are defined from ranges of FFDI values. Here, 'Low' fire danger rating is assigned to values 0-4, 'Moderate' 5-11, 'High' 12-23, 'Very High' 24-49 and 'Extreme' to FFDI of 50 or more. In Tasmania, forecast Very High (VH) fire danger (FFDI >=24) is generally used as the trigger for the issue of a fire weather warning by the Bureau of Meteorology. At a higher level of alert, the Tasmania Fire Service will usually, depending on a number of factors, consider imposing a Total Fire Ban when forecast fire dangers exceed Very High 38.

The Mark V McArthur FFDI is calculated as a function of observed temperature, humidity and wind speed, as well as a 'drought factor' that combines the effects of soil moisture deficit and recent rainfall on fuel moisture. The meter was adapted to allow computer calculation (Noble et al. 1980) and more recently modified to ensure a smooth transition between fuel moisture categories (Griffiths 1998, 1999). In Tasmania, for many years the Mount Soil Dryness Index (Mount 1972) has been used as a ground moisture input (or indicator of longer term drying) to modulate the drought factor input to the fire danger index.

In this study the FFDI values were calculated from synoptic observations, generally available at three-hourly intervals. A standard 12.5 tonnes/hectare of available fuel was assumed. Drought factors were calculated using the method of Griffiths (1998), and were updated with each synoptic observation (reflecting the practice used in the Tasmanian fire weather forecast service).

The selection of stations is constrained by the availability of homogeneous time series. Locations included in the study are Hobart, Hobart Airport, Swansea, Launceston Airport, Strahan and Mt Wellington, and, depending on the station history, observations are available at differing numbers of times per day and over differing lengths of record. Figure 1 indicates the location of all stations. Throughout this paper times of observations are presented in Local Clock Time (LCT) to avoid any problems arising from the transition to and from Daylight Saving Time (as Tasmanian synoptic observations are made according to Local Clock Time). Daylight Saving Time was introduced in Tasmania in 1972, and operates generally between October-March. During this period, Local Clock Time changes from 10 hours ahead of UTC to 11 hours ahead of UTC.

Fig. 1 Location of stations used to derive climatology. Length in years of the data history used at each station is included in brackets.



Recently, digitisation of synoptic data for Hobart has been completed back to 1920. Prior to the 1940s, synoptic observations are available at 0900, 1500 and 2100 LCT. After a period of some years of variation during the mid-1940s, in 1947 the observation schedule settled to include 0600, 1200, and 1800 in addition to the earlier times. Variations since then have occurred only in the overnight observations (0000 and 0300 added in 1970). As has been the case with many sites, changes have occurred in the area of the Hobart City observation site since 1920. In particular, in 1967 a new Bureau of Meteorology Regional Office was constructed close to the observation enclosure, and in 1994 an automatic weather station (AWS) was installed. At this time, the anemometer mast was moved further away from the Regional Office building, and elevated by three metres to increase the exposure to winds from the west and south previously somewhat sheltered by the 1967 building.

Digitised synoptic observations every three hours are available for Launceston and Hobart Airports from 1 January 1960. Twice-daily observations at 0900 and 1500 LCT are stored for Swansea, on the central east coast, from the same start date. At these sites, there have been fewer disturbances from nearby construction than at the Hobart City site. However, instrumental changes have occurred on occasion, and at the airport sites AWS were installed in 1990 (Hobart) and 1992 (Launceston). At Swansea, wind was estimated using the Beaufort scale until 1992, when a Dwyer anemometer was installed. This in turn was removed in 1998, and estimation of wind speed recommenced.

Synoptic observations from the AWS sited near the summit of Mt Wellington are available from April 1994, but are not reliable until 1995. The FFDI values calculated from this site are of interest for several reasons. They are the only observations from a significantly elevated site in the study, and provide a point of comparison to data from the remaining stations, despite a shorter period of record than those data. Proportionally, more of Tasmania lies above 1000 m than is the case for any other Australian State, but little study has been made of different fire danger regimes pertaining to those elevated areas. Finally, the data might usefully supplement the HIGHFIRE study of alpine fire occurrence being conducted as part of the work of the Australian Bushfire Co-Operative Research Centre, being from a more southerly location than any currently under consideration within that project.

Choosing a suitable site representative of the west coast of Tasmania is somewhat problematic. Synoptic observations are available at 0900 LCT and 1500 LCT for Strathgordon from 1968, but the site is quite sheltered from the dominant westerly quarter winds. Strahan Airport observation site was opened in 1976, but there are large gaps in the record prior to October 1987, so data were examined from this time. There are still a number of minor gaps in the record used, however.

The limited time periods available for Strahan and Mt Wellington do not permit any consideration of trends in fire weather, but the longer records from the other stations do. Table 1 summarises the data availability for each station in this analysis. Occasional periods of observations from stations at non-standard synoptic times were not included in the data-set.

Results

Discussion of the fire danger characteristics of the study stations is grouped into: (a) low-level south-eastern and eastern stations (Hobart – elevation 51 m above sea level, Hobart Airport – elevation 4 m and Swansea – elevation 10.5 m); (b) northern and western stations (Launceston Airport – elevation 170 m and Strahan – elevation 20 m); and (c) Mt Wellington (elevation 1261 m), as broadly similar characteristics are evident within each such grouping.

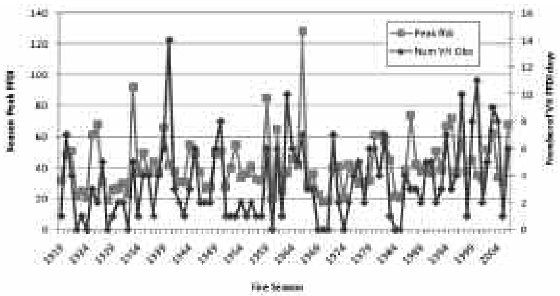
Hobart, Hobart Airport and Swansea

Data for Hobart City are of particular interest given the long record available, despite changes during the record in both observation times and instrumentation. Figure 2 shows plots of the peak FFDI recorded and the number of VH FFDI recorded at 1500 LCT in a fire

Table 1. Summary of the availability of synoptic observations from studied stations.

Site	*Dates available*	*Comment*
Hobart City	1/1/1920- 20/4/1947	0900, 1500 and 2100, with additional observations from 1/1/1944
	21/4/1947 – 31/12/1969	0600 – 2100, 3-hourly
	1/1/1970 – 30/4/2007	Full 3-hourly synoptic program
Hobart Airport	1/1/1960 – 30/4/2007	Full 3-hourly synoptic program
Launceston Airport	1/1/1960 – 30/4/2007	Full 3-hourly synoptic program
Swansea	1/1/1960 – 30/4/2007	0900 and 1500 synoptic observations
Strahan Airport	20/10/1987 – 30/4/2007	Full 3-hourly synoptic program – but numerous observations missing
Mt Wellington	30/4/1995 – 30/4/2007	Full 3-hourly synoptic program

Fig. 2 Plot of fire season activity 1919-2006 for Hobart City, based on 1500 LCT synoptic observations. Seasonal peak FFDI values are plotted in with square markers, the number of VH FFDI observations per season is plotted with smaller diamond markers.



season, where a fire season is named by the first year of a period 1 July – 30 June of the following year. Only 1500 LCT observations were used in this presentation to avoid distortions resulting from changes in the number of observations made per day across the observing history. Very High fire danger is used here and throughout this study not only as a convenient indicator of potentially dangerous fire weather but also because it is, as noted above, the fire danger level at which a fire weather warning is usually issued in Tasmania, and so has substantial operational significance.

Considerable interannual variability is evident in the series of both peak FFDI and seasonal count of VH FFDI (Fig. 2), and it is rare for there to be more than a few consecutive seasons of either low or high fire weather activity, as measured by either indicator shown.

There are noticeable differences between the two measures of seasonal severity. For example, the 1940-41 fire season was the worst of the series by a considerable margin in terms of the number (14) of days of VH FFDI (recalling that these are days when VH FFDI was observed at 1500 LCT), yet the peak seasonal FFDI was a relatively modest 42. On the other hand, the peak FFDI for the 1966-67 season and for the series as a whole was 128. This occurred on 7 February 1967, 'Black Tuesday', when 62 people were killed and 1446 major buildings were destroyed (Bond et al. 1967). The number of VH FFDI days that season was seven, in the top quartile of seasons but not reflective of the extremity of the FFDI on 7 February 1967.

These differences are certainly at least partly a consequence of the fact that only 1500 LCT observations were used to construct this graph. As will be demonstrated later, significant fire danger peaks may occur at other times during the day. There are occasions when a sharp peak of fire danger occurs between synoptic observations, evident from an examination of more frequent observations (which are, however, only readily available since AWS have been introduced during the last 10-15 years).

The second most extreme outlier in the series of peak FFDI occurred during the 1933-34 season, with a value of 92. On 9 February 1934, 'Black Friday', fires in the Florentine and Derwent Valleys caused some life and property losses.

Of the top eight seasons by number of VH FFDI days, when eight or more days of VH FFDI were recorded, five have occurred since 1997. On the other hand, of the 26 per cent of seasons with peak FFDI > 50, only four, or 17 per cent, have occurred since 1997.

As noted above, observation times stabilised at three hourly intervals between 0600 and 2100 LCT by 19 April 1947. Observations at 0000 and 0300 were added from 1 January 1970 although, as might be expected, these latter times do not figure prominently in the record of VH FFDI observations. The additional observations permit at least a degree of resolution of the time of day at which peak FFDI occurs. A decomposition of VH FFDI occurrence by month and hour of the day is displayed in Table 2(a). Also displayed, in bold, are the number of occasions when the FFDI reached or exceeded 40, close to the level at which a Total Fire Ban is usually declared in Tasmania.

Table 2(a) indicates that VH FFDI has occurred in Hobart at all synoptic times, and during every month. It is, however, rare for Very High fire danger to occur between May and August, inclusive, and unusual in September and April. Similarly it is rare between 0000 and 0600, and unusual at 0900 or 2100. Considering the smaller number of 0000 and 0300 observations compared to those at 0600, there is a suggestion that there is a higher frequency of VH FFDI at the earlier times than at 0600, although the numbers in each case are quite low. There is a rapid increase in the number of VH observations in October, a plateau in November then a further increase to a January peak. The number of observations falls to October-November levels in March, before a very substantial decline in April.

Peak time of the day for VH FFDI is 1500, as might be expected, but almost as many observations occur when 1200 and 1800 are combined. A separate database query indicates that there were 89 days in the 1947-2007 record where VH FFDI was recorded, but not at 1500, compared with 223 days during that period where VH FFDI was recorded at 1500. Thus, examination of

Table 2. Cross-tabulations (month by hour) of the number of occurrences of Very High forest fire danger index for the stations studied. Because Swansea reported only at 0900 and 1500 LCT, its FFDI distribution is plotted separately. Data are presented July-June in order to group peak months together in the centre of the table. Figures in bold text are the number of occasions when the FFDI reached or exceeded 40.

(a) Hobart City VH FFDI month by hour 1947-2007.

							Month						
Hour	*7*	*8*	*9*	*10*	*11*	*12*	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
0000			1	1		2		1	1				6
0300			1	1				2	1				5
0600			1	2			2	1					6
0900				3		6	5	1			2		17
				1		**1**							**2**
1200	1		8	11	13	28	30	18	8	2			119
				4	**4**	**10**	**4**	**5**					**27**
1500		1	9	26	27	33	45	40	33	9			223
				3	**5**	**10**	**12**	**11**	**7**				**48**
1800				9	12	11	19	26	9	1		2	89
				2	**3**	**2**	**4**	**5**					**16**
2100		1		1	1	3	2	3	3			1	15
Total	1	2	20	54	53	83	103	92	55	12	2	3	
				10	**12**	**23**	**20**	**21**	**7**				

(b) Hobart Airport VH FFDI month by hour 1960-2007.

							Month						
Hour	*7*	*8*	*9*	*10*	*11*	*12*	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
0000			1	1		1		3					6
0300					1			1					2
0600			1					1					2
0900				4	1	3	1	2	1	1	1		14
								1					
1200	1	1	6	14	21	34	38	18	13	6	1		153
			1	**3**	**3**	**6**	**11**	**6**	**1**				**31**
1500		1	6	28	31	39	51	46	31	7	1		241
			2	**3**	**10**	**10**	**9**	**13**	**7**				**54**
1800			1	8	16	21	29	30	9				114
				3	**3**	**4**	**5**	**8**					**23**
2100				1	3	1	2	1	1				9
Total	1	2	15	56	73	99	121	102	55	14	3		
			3	**9**	**16**	**20**	**25**	**28**	**8**				

Table 2. Continued.

(c) Launceston Airport VH FFDI month by hour 1960-2007.

	Month						
Hour	*10*	*11*	*12*	*1*	*2*	*3*	*Total*
1200		2	9	11	7	4	33
1500	1	4	25	52	36	11	129
		1	**1**	**3**	**5**	**1**	**11**
1800		1	10	27	13	4	55
Total	1	7	44	90	56	19	
		1	**1**	**3**	**5**	**1**	

(d) Strahan Airport VH FFDI month by hour 1987-2007.

	Month					
Hour	*11*	*12*	*1*	*2*	*3*	*Total*
0000				1		1
0300				1		1
				1		**1**
0600				1		1
0900		1		1	1	3
1200	1	4	1	4	1	11
				1	**1**	**2**
1500	1	2	2	3	1	9
				1		**1**
1800		1	2			3
Total	2	8	5	11	3	
				3	**1**	

(e) Mt Wellington VH FFDI month by hour 1995-2007.

	Month									
Hour	*8*	*9*	*10*	*11*	*12*	*1*	*2*	*3*	*4*	*5*	*Total*
0000			1								1
0300	1		1			1	1			1	5
0600			1	2	1	2	4	1		1	12
							1				**1**
0900		1	1	1	2	1	2	2			10
			1				**1**				**2**
1200			1			1					2
			1								**1**
1500			1	3							4
			1								**1**
1800				1	1	1					3
2100	1		1								2
Total	2	1	7	7	4	6	7	3		2	
			3				**2**				

the 1500 LCT record alone is likely to miss a substantial fraction (29 per cent, in the Hobart data above) of the occurrences of VH FFDI in a three-hourly time series, and it is highly likely some events would occur between the three-hourly synoptic observations.

An illustrative example of such a day, and the one with the highest non-1500 FFDI, is 24 January 1990, which recorded a peak FFDI (based on synoptic observations) at Hobart of 60 at 1200. By 1500 a cool southeasterly change had pushed through the observation site, and the FFDI had fallen to three.

Examination of the events where FFDI reached the more significantly dangerous level of 40 reveals that this has only occurred between October–March and, with two exceptions at 0900, between 1200 and 1800 LCT. It is perhaps noteworthy that there are as many 1200 LCT occurrences of VH40+ as 1500 occurrences during October-December, but significantly fewer during January-February.

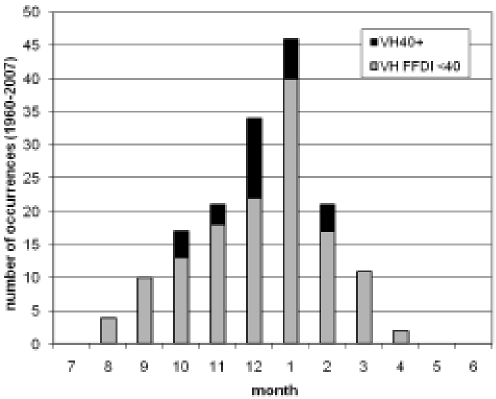
Data for Hobart Airport are both more uniformly available (digitised observations at all synoptic hours from 1 January 1960) and less prone to the effects of changes in the local environment than is the case with the Hobart City record. The record does not, of course, extend back as far as that of Hobart City. While the two sites are quite close (approximately 20 km apart), it is useful to examine Hobart Airport data as a check on that of Hobart City, particularly in respect of trends in the data.

As with Hobart City, VH FFDI at Hobart Airport (Table 2(b)) has occurred at all synoptic times and every month (except, here, in June). The peak month, by the number of VH observations, is January, and there is a steady increase over the previous months, without any evidence of the plateau seen in the Hobart City data. There is a rapid decline from March into April. A 1500 LCT peak is clear in the time of most frequent VH FFDI observation, but it is less marked relative to the times either side than is the case at Hobart City (representing slightly less than half of the 1200-1800 VH FFDI occurrences).

At the VH40+ level, there is a very slightly broader set of months and times than at Hobart City. Also, 1200 LCT VH40+ FFDI is as frequent as 1500 only during October. November and December have a clear 1500 LCT peak.

Data are available for Swansea from 1 January 1960, but include only 0900 and 1500 LCT observations. Nonetheless, it is possible to examine seasonal features and indications of any possible trends over the period of available record. This is done in the form of a graph of seasonal variation, rather than in tabular format as is the case with the other stations, because most VH observations at this station occurred at 1500. Figure 3 displays this monthly distribution of VH FFDI for Swansea. Grey bars indicate occurrences of Very High 24-39 and the black indicates those reaching or exceeding 40. No discrimination is made of the time of day of the observations, however only 13 occurred at 0900. Interestingly, seven of these occurred during

Fig. 3 Monthly distribution of Very High FFDI at Swansea. Grey represents occurrences of fire danger index values between 24-39, while black indicates occurrences of index values of 40 or more.



spring, a disproportionately high number. The highest FFDI value, Extreme 58, was recorded at 0900 on 12 October 2006 during an event which, as noted elsewhere, will be the subject of further study.

Figure 3 indicates a steady increase in the number of VH FFDI events at Swansea into a strong January peak, then a more rapid decline into April. No events have occurred in May-July (inclusive) during the period of available observations. The distribution of VH 40+ events is limited to October-February, peaking in December. There is the suggestion of a plateau early in the season, with approximately the same number of observations in November as October. However, this represents at best a weak signal.

Launceston Airport and Strahan

The distribution of VH FFDI at Launceston Airport by month and synoptic hour is substantially different to the eastern and southeastern stations, as indicated in Table 2(c). VH FFDI is confined to the months of October-March (although only one October event has occurred in the record) and the afternoon hours of 1200-1800. There is a very steep increase from November to a pronounced January peak, with values falling away less abruptly through February-March. Only observations at 1500 LCT between November-March have recorded VH 40+ FFDI, with a small February peak of only five occurrences.

The monthly distribution of FFDI for Strahan, on Tasmania's west coast, is similar to that for Launceston Airport, as evident in Table 2(d). Data for Strahan are available only from October 1987, less than half the period of record of Hobart and Launceston Airports. VH FFDI occurs only during the period November-March with a peak in February. The total number of such observations is very substantially lower than is the case for Launceston, even allowing for the longer record of that station. Peak time of day for VH FFDI is 1200. The observations of VH FFDI (including one of VH 40) between 0000 and 0600 LCT all occurred during one event, on 21 February 2001, ahead of the passage of a trough associated with a cool change. The majority of VH FFDI observations occur either at 1200 or 1500. Only four VH 40+ events occurred in the record, three in February and one in March. Two of the VH 40+ events occurred at 1200, suggesting that a mid-afternoon fire danger peak is not as strongly favoured on the west coast as at other low-lying areas.

Mt Wellington

As indicated in Fig. 1, Mt Wellington lies in southeast Tasmania. The AWS is located near the summit, at an elevation of 1261 m above sea level, and represents a very different environment to any of the other stations examined.

Table 2(e) lists occurrences of VH FFDI and VH 40+ FFDI in the same format as earlier tables. VH FFDI has occurred during most months in spring through autumn, but only rarely in March through May and in September. While the length of record is only 12 years, there is the suggestion of peaks of VH FFDI in October-November and January-February.

VH FFDI has occurred at every synoptic hour, but with a peak at 0600 and 0900. This peak, in particular, is substantially different to that observed at lower level stations. It is likely that the diurnal peak of fire danger occurs as an inversion develops or descends overnight to below the level of the AWS, allowing upper level dry air to reach the summit and upper slopes of Mt Wellington (but not low elevations, in general). Wind speed above the inversion increases ahead of a cool change later in the day, and the FFDI increases also. As the inversion begins to erode as a result of the approaching change and thermal mixing during the day, the dew-point temperature at the AWS increases (via mixing from lower levels) and the FFDI falls.

Five instances of VH 40+ FFDI are indicated in Table 2(e). These occurred in only two events: 21 February 2001 and 12 October 2006. It is worth noting also that all but one of the October instances of VH FFDI occurred between 2100 on 11 October and 0600 on 12 October 2006.

Springtime fire danger

As noted above, there is a perception of a 'spring bump' or peak in the fire danger during springtime within the fire management community in Tasmania. The above data do not seem to support this perception other than the plateau in the number of occurrences of

VH FFDI in the statistics for October and November at Hobart. A closer examination of springtime FFDI data is useful to clarify the origin of this idea.

A springtime fire danger peak is defined here as a period in which the October peak monthly FFDI exceeded that of November by at least (arbitrarily) 10, or the November peak exceeded that of December by the same amount. Identification of months satisfying either of these criteria is relatively simply automated, and the criteria quantify the intuitive idea of a springtime 'bump' as a period in which the FFDI is enhanced, followed by a quieter interval prior to the 'main' fire season peak. Only observations after April 1947 are used. Examination of Table 3(a) reveals that of the 25 local peak values recorded, 10 occurred at either 1200 or 1800 LCT (and this excludes instances in 1993 and 1997 where the same peak value occurred at 1800 LCT, in addition to the documented 1500 LCT value). It was for this reason that data earlier than 1947 were excluded from the analysis, as the lack of non-1500 data was felt likely to distort the actual number of springtime season peaks recorded.

Of the 60 seasons' data, 25 display an October or November peak monthly FFDI that exceeds (by at least 10) that of the following month. It can reasonably be said, then, that a 'springtime bump' has occurred slightly less frequently than one in every two years at Hobart in the last 60 years. There is no obvious trend in the frequency, except that springtime peaks were relatively less frequent in the 1950s, 1970s and 1980s, and more frequent in the 1960s (every season between 1961-68) and since 2000. Seasonal peak FFDI values that occurred during spring are noted in Table 3 highlighted in bold (i.e. in addition to being local maxima, exceeding the peak FFDI of the following month, the highlighted observations are peak values for the entire season in which they occurred). There are twelve fire seasons in which the seasonal peak FFDI occurred during springtime, 20 per cent of the total.

A similar analysis was conducted to test the occurrence of a springtime FFDI peak at Hobart Airport. Table 3(b) displays data in the same fashion as Table 3(a), but for Hobart Airport. Some 21 of the last 47 seasons (45 per cent) show a springtime local VH FFDI peak (with a peak defined as before). Of the 21 occurrences listed, 10 represent the peak FFDI recorded during the corresponding season. Thus, 21 per cent of seasons had a springtime FFDI peak as the season overall peak. These are very similar statistics to those noted at Hobart City, and increase confidence in the validity of the observations.

At Swansea, springtime peak VH FFDI have occurred in 10 of the 47 seasons 1960-2007. Table 3(c) indicates these, with the same derivation used as

Table 3. Occasions when a springtime peak in fire danger occurred. Rows highlighted in bold are not only springtime peaks, but peak values of FFDI for the entire fire season.

(a) Hobart City local peak FFDI in Oct.-Nov.

Season	*Peak FFDI*	*Date/time (LCT)*
1951	**25**	**2/11/1951 1800**
1959	52	21/11/1959 1200
1961	**65**	**14/11/1961 1500**
1962	**50**	**17/11/1962 1200**
1963	**43**	**18/10/1963 1200**
1964	33	30/11/1964 1500
1965	37	13/10/1965 1500
1966	45	23/11/1966 1200
1967	30	27/10/1967 1500
1968	**24**	**16/10/1968 1200**
1972	39	19/10/1972 1500
1978	**31**	**2/10/1978 1500**
1982	43	6/11/1982 1500
1986	29	4/11/1986 1500
1987	40	2/11/1987 1800
1990	35	13/11/1990 1500
1991	**37**	**25/11/1991 1500**
1993	33	26/11/1993 1500
1995	**72**	**17/10/1995 1500**
1997	46	22/11/1997 1500
2000	**35**	**5/10/2000 1500**
2002	**72**	**7/11/2002 1800**
2003	51	15/11/2003 1500
2004	**46**	**18/11/2004 1200**
2006	**74**	**12/10/2006 1200**

(b) Hobart Airport local peak FFDI in Oct.-Nov.

Season	*Peak FFDI*	*Date/time (LCT)*
1961	**49**	**14/11/1961 1500**
1964	**31**	**30/11/1964 1500**
1966	61	23/11/1966 1200
1967	38	27/10/1967 1500
1968	41	16/10/1968 1200
1972	25	19/10/1972 1500
1972	25	24/10/1972 1500
1979	36	31/10/1979 1500
1981	33	6/10/1981 1200
1982	**105**	**6/11/1982 1500**
1985	**28**	**13/11/1985 1500**
1988	**47**	**13/11/1988 1500**
1990	36	13/11/1990 1800
1991	43	25/11/1991 1500
1995	**33**	**17/10/1995 1500**
1996	80	25/11/1996 1500
2000	**48**	**5/10/2000 1500**
2002	**79**	**7/11/2002 1800**
2003	**69**	**15/11/2003 1500**
2004	39	18/11/2004 1200
2006	**126**	**12/10/2006 1200**

Table 3. Continued.

(c) Swansea local peak FFDI in Oct.-Nov.

Season	*Peak FFDI*	*Date/time (LCT)*
1964	**24**	**25/11/1964 1500**
1965	**33**	**24/10/1965 1500**
1966	35	23/11/1966 1500
1968	88	28/10/1968 1500
1972	34	24/10/1972 1500
1977	**40**	**9/11/1977 1500**
1982	**62**	**24/11/1982 1500**
1990	31	13/11/1990 1500
2004	27	19/11/2004 1500
2006	**82**	**12/10/2006 1500**

earlier. Again, seasonal peak FFDI are highlighted. Fewer seasons are listed or highlighted than was the case at either Hobart or Hobart Airport, suggesting a weaker ‘springtime bump’ effect than is the case in southeast Tasmania. Approximately the same proportion of springtime peaks, however, one in two, was a seasonal peak as in the case of both Hobart sites.

There is no evidence of a significant springtime peak in FFDI either at Launceston Airport or Strahan, as can be seen from Table 2. Interestingly, however, the November VH 40+ event at Launceston Airport in Table 2(c) was the peak FFDI recorded in the 1982 season, with FFDI of 62 (the only Extreme FFDI in the Launceston Airport synoptic record), and the only springtime peak, as defined above.

The above analysis considered springtime peaks in terms of highest FFDI recorded, whether by month or season. Other metrics are possible, of course, including the number of VH FFDI observations recorded in any given month. A springtime peak is again evident in about half the years when Hobart data are re-examined using this metric. While the details are not included here, the characteristics of the peak are very similar to those revealed using the definition applied in earlier paragraphs.

Springtime trends

While the frequency of springtime local peaks shows no obvious trend, there is a suggestion that springtime seasonal FFDI maxima are becoming more frequent in the case of both Hobart and Hobart Airport. Figure 4 displays the number of occasions, grouped by decade, since 1947 when VH FFDI in excess of 40 occurred during springtime at Hobart. There were two such occasions prior to 1947, both at 1500 LCT, but the lack of data at other synoptic times makes a direct comparison difficult.

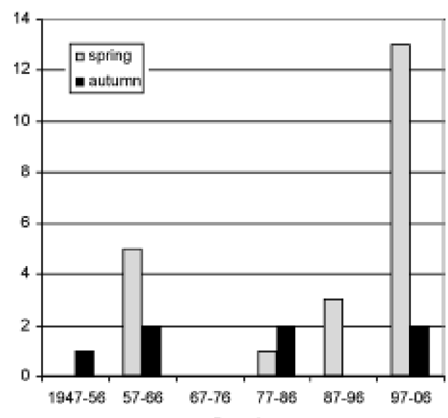
Individual synoptic observations are used as the basis of the figure, so it is possible that more than one event was counted in any one day. As is evident from Table 2(a), there are no September events. The first month with more than one occurrence (not shown) is October 1995, with others in November of 1997 and 2002. Seven events occurred in October 2006 (during 11-12 October) a period of exceptional fire weather, as noted above.

Figure 4 indicates a strong increasing trend in the number of significant springtime fire weather events. As such, it is important to ensure that the trend is real, and not an artefact of instrumental changes at the site.

There have been a number of changes to the Hobart observation site during the course of its history. In particular, the installation of an AWS occurred in 1994, close to the time of rapid increase in the frequency of springtime VH40+ events. If the observed changes are driven solely by instrumental changes, a similar summer and autumn breakdown should reveal the same trend.

The autumn analysis is also displayed in Fig. 4, and no obvious trend is evident. For the summer season (not shown), 32 of the 60 seasons since 1947 have at least one VH40+ event. Of these, 16 occur since 1980 (50 per cent in the last 45 per cent of the record), and eight occur since 1995 (25 per cent in the last 20 per cent of the record). Thus, there is no significant trend evident in the analysis of either the autumn or summer records, strongly suggesting that the observed trend on the springtime data is real, rather than being an artefact of the instrumental and environmental changes that have certainly occurred.

Fig. 4 Decadal distribution 1947-2007 of spring and autumn occurrences of FFDI greater than or equal to 40 at Hobart.



Springtime occurrences of VH40+ FFDI at Hobart Airport (not shown) reflect the trends evident at Hobart. Considering the data in terms of months during which at least one VH40+ event occurred (in order not to assign too much weight to the exceptional 11-12 October 2006 fire weather event which appears as six VH40+ occurrences at Hobart Airport), some 44 per cent of such months have occurred in the last 26 per cent (12 years) of the record, and a quarter have occurred since 2003 (last nine per cent of the record). Again, an examination of summer occurrences reveals no obvious trend in the data (not shown). There is, however, the suggestion of an increasing trend with the autumn data as all cases occur since 1991, although the small number of cases (six) limits the degree of confidence in this observation.

Station fire danger percentiles

Determination of the relative frequencies of the highest FFDI values recorded at a location are important for characterising the nature of fire danger experienced there. For fire management purposes, it is also useful to have an indication of more routinely experienced fire danger levels. For this reason, Table 4, displaying fire danger percentiles, is included. The 50th, 75th, 90th, 95th and 99th percentiles for each of the stations examined above are calculated from the 0900-1800 synoptic observations for the period October-March, representing what is for most stations the most active times of the day during the most active time of the year. (Replacing 0900-1800 with 0300-1200 in the case of Mt Wellington makes only a very slight difference to the outcome.) For Hobart City, the period over which the percentiles are calculated is April 1947 to April 2007. For the other stations, it is the entire record period as detailed in Table 1.

For Hobart, Hobart Airport and Launceston, the 50th percentile broadly represents the boundary between Low and Moderate FFDI, while for Swansea that occurs at the 75th percentile, and for Strahan and Mt Wellington around the 90th percentile. The 90th percentile at the first three stations is broadly the Moderate-High boundary of 11-12, which occurs at the 95th percentile for Swansea and (not shown) the 98th percentile for Strahan and Mt Wellington. The boundary between High and Very High FFDI (23-24) occurs around the 99th percentile for Hobart, Swansea and Launceston Airport, and (not shown) about the 98th percentile for Hobart Airport and at percentile 99.8 for both Strahan and Mt Wellington.

It is of interest to examine the possibility of trends in the fire danger observed at Tasmanian locations, in addition to the sharp trend in significant events evident in southeast Tasmania. Of the sites examined above, Hobart and Launceston Airports and Swansea have had relatively uniform site characteristics and observation schedules over an extended period, and their data were used to plot trends of fire danger over the periods of available record. The three plots have very similar characteristics so only Hobart Airport data are displayed in Fig. 5. The data used are the entire record of Hobart Airport, divided into fire seasons as discussed above, with percentiles of FFDI calculated for each season. Percentiles 95, 99 and 99.5 are plotted.

Table 4. Fire danger percentiles for each of the stations studied. Percentiles evaluated from 0900-1800 LCT synoptic observations for the period October-March.

	Percentile				
Site	*50*	*75*	*90*	*95*	*99*
Hobart	4	7	11	14	26
Hobart Airport	5	9	13	18	31
Launceston Apt	4	8	12	15	23
Swansea	3	5	8	11	24
Strahan	1	3	5	7	15
Mt Wellington	1	2	4	6	15

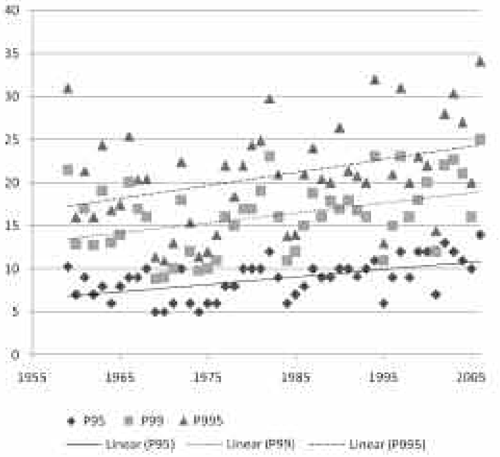
There does appear to be a slight increasing trend. Linear regression lines are superimposed on each plot to indicate the trend. The slope of the regression line increases as the percentile examined increases: the slope of the 95th percentile regression line is 0.087, that for the 99th percentile is 0.117 and for the 99.5th percentile is 0.151. As might be expected, the scatter of the plot also increases with increasing percentile. The correlation between year and 95th percentile FFDI is 0.544, while that for the 99.5th percentile decreases to 0.356. This suggests a steady slight increase in FFDI over time, and a greater increase in more extreme events. The data suggest a degree of interannual variability, increasing at the extremity of the distribution.

Discussion

The creation of a database of forest fire danger index values has enabled a useful ability to examine the variation in potential for fire activity in space and through time in Tasmania. Many of the results support anecdotal expectations, for example, the generally earlier onset during a fire season of potentially dangerous conditions in the south and east compared with the north and west of Tasmania.

The data also indicate the existence of a peak in fire danger during the spring in southeast Tasmania, and to a lesser extent on the east coast (but not in the north or west) in about one season in two. In about 20 per cent of cases, this peak is the primary fire danger period of the season.

Fig. 5 Plot of 95th, 99th and 99.5th percentile values of FFDI recorded for each fire season 1960-2006 at Hobart Airport, using all available data. The 95th percentile values are plotted with diamonds, 99th with squares and 99.5th with triangles. Linear regression lines are plotted for each series.



Differences in the diurnal behaviour of fire danger at low-lying and elevated sites are also evident in the data. The observed early morning peak in fire danger at high elevation has important operational implications for fire managers, particularly in view of the relatively high proportion of Tasmania that lies in excess of 1000 metres above sea level. In such environments, the overnight and early morning period cannot necessarily be assumed to be a period of low activity, when fire crews can be stood down or rested ahead of an anticipated busier day.

It is possible that there is an element of diurnal forcing of summertime changes through southeast Tasmania, which is less strongly developed early in the fire season (see, e.g., the introduction to Mills (2002) for a discussion of models of the effect of the diurnal cycle on summertime cool changes). Thus, as noted above, there are as many 1200 LCT VH40+ peaks as 1500 LCT peaks at Hobart during the early part of the fire season. At this time, land-surface heating might be expected to play a less significant role in frontal development and movement. Conversely, there are fewer such 1200 peaks during January-February, when land-sea temperature contrast is greater. Similarly, the most common time of peak FFDI for Strahan is 1200 LCT.

The evidence for this argument is equivocal, however. There is no similar change in the peak time of FFDI for Hobart Airport during the course of a season, for example. This is an area which may repay additional study, potentially connecting historical data with recent advances in the understanding of the dynamics of summertime cool changes (e.g. Mills 2002).

Available data suggest a broad increase in the fire dangers recorded in eastern Tasmania over the last several decades. In addition, there is evidence that the southeast in particular has seen an increase over the last decade in the number of dangerous springtime fire weather episodes. The events have occurred across a range of soil (and, by implication, fuel) moisture conditions, suggesting that it is the result not just of a general recent decline in springtime rainfall in southeast Tasmania, as indicated, for example, in Alexander et al. (2007). An examination of these events shows very low dew-point temperatures to have occurred in many cases.

It is possible that changes in instrumentation and exposure over time could have some impact on these results. For example, Shepherd (1991) documented changes in the characteristics of the Hobart City observation site that would impact systematically on calculated fire dangers. Also, AWS were progressively installed in many locations over the last decade and a half. It is likely that the AWS sensors respond differently to very dry air masses than do wet and dry-bulb thermometers. Lucas et al. (2007) suggested that the inhomogeneities in measured humidity associated with the installation of an AWS are, however, relatively small. On the other hand, changes in measured wind can be significant, particularly at higher wind speeds – generally, the range within which higher fire dangers occur.

Supporting the evidence for a real increase in the number of dangerous fire weather days in springtime is the fact that both Hobart and Hobart Airport show an increase during the mid-1990s despite the fact that an AWS was installed at Hobart Airport in 1990, and at Hobart City in 1994. Also, there has been no commensurate increase in the number of dangerous summer or autumn days, which might be expected if instrumental changes were responsible for the increased observation of very dry air masses, or increased windiness. It is possible that these recent changes are the result of interdecadal variation rather than a broader climatic trend. From a fire management perspective, however, this is not as important as the fact that it represents a change from the experience of the relatively recent past, and may require a higher degree of preparedness earlier in the fire season than might otherwise be anticipated.

Again as noted in Alexander et al. (2007), the trends in percentile values are consistent with observations elsewhere, and with modelled global trends. In particular, the observed greater trend in more extreme values is consistent with those observed and modelled elsewhere.

Interestingly, Westerling et al. (2006) report a recent increase in western US forest fire activity during spring, which they attribute to meteorological factors (rather than oft-cited land use changes). In the western US, however, the increase in fire activity is strongly correlated with increasing temperatures and earlier onset of spring snowmelt, factors which are not significant in southeast Tasmania.

Future research will examine several points noted above. The fire weather on and leading up to 12 October 2006 was exceptional and will be documented separately. More generally, the recent increase in springtime extreme fire danger will be examined, to highlight common features of the underlying weather and to identify any broadscale atmospheric features that might influence the changes.

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