Bushfire weather climatology of the Haines Index in southwestern Australia

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The climatology of bushfire weather as measured by the Haines Index (HI) was examined at four locations in southwestern Australia. The HI is determined by the stability and moisture content of the air in the lower atmosphere and is provided as a routine component of fire weather forecasts in the United States. High values of the HI (6) were found to be most frequent during the summer months of December and January, and were more frequent at Perth and Kalgoorlie than at Albany or Esperance. Days of moderate (5) or high (6) HI were associated with higher median values of the McArthur Grassland Fire Danger Index (GFDI) and were more likely to have a fire danger rating of extreme (GFDI ≥ 50). Days of very high fire danger (32 ≤ GFDI < 50) occurred at all values of the HI. The fact that extreme values of GFDI are strongly associated with high HI suggests that the current fire danger rating system based on surface-level weather conditions already identifies the majority of days with significant fire growth potential. Case studies of fires that burnt strongly when the GFDI was high or very high could assist in establishing whether the HI has a discernable effect on fire size or severity under these conditions.

Introduction

Weather conditions in southwestern Australia are conducive to the ignition and spread of bushfires for a period of four to nine months each year. The region has a Mediterranean-type climate characterised by mild winters, a pronounced winter rainfall maximum and regular occurrence of summer or autumn drought. Important synoptic features that determine fire weather in southwestern Australia include the location and strength of the west coast trough, the subtropical high, mid-latitude fronts and the periodic incursion of ex-tropical cyclones south of latitude 30°S. These features combine to exert a significant influence on the fire environment by determining the strength of coastal sea-breezes bringing cooler maritime air, the easterly winds bringing hot dry air from the interior of the continent, and abrupt wind changes associated with trough movements (McCaw and Hanstrum 2003). Forest, woodland and shrubland ecosystems cover much of southwestern Australia in extensive tracts of State forest, conservation reserve and unallocated crown land. Large areas of native vegetation have also been converted to cereal crops and annual pastures that cure completely by the onset of summer in December.

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The Australian Bureau of Meteorology provides forecasts of fire weather conditions daily to the Fire and Emergency Services Authority and the Department of Environment and Conservation (DEC) during the fire season. Fire danger ratings based on the Grassland Fire Danger Meter Mk IV (McArthur 1966; Cheney and Sullivan 1997) are provided for geographically defined forecast districts to regulate the lighting of fires and to inform the community of the prevailing level of fire danger. The meter provides a numerical Grassland Fire Danger Index (GFDI) and a descriptive rating representing the difficulty of suppressing fire in a standard, average pasture at a given level of curing. Weather variables used to calculate the GFDI are air temperature, relative humidity and mean wind speed measured at 10 m height in the open. The Forest Fire Behaviour Tables for Western Australia (Sneeuwjagt and Peet 1998) are used to predict fire behaviour in forest fuels but not for public warnings of forest fire danger.

Atmospheric instability is recognised as an important factor in the development of large, convectively dominated bushfires (Brotak and Reifsnyder 1977; Luke and McArthur 1978; Werth and Ochoa 1993; Bally 1995). Instability promotes the spread and intensity of fires by increasing the height and strength of the convective plume, by lofting firebrands downwind of the fire, and by inducing the mixing down of very dry, gusty winds to ground level (Werth and Ochoa 1993; Ellis 2003). Haines (1988) developed a fire weather index based on the stability and moisture content of the lower atmosphere, and provided three alternative formulations of the index to account for variation in the prevailing height of the terrain. Fire activity has been shown to correlate most strongly with an index calculated using data representative of conditions in the boundary layer above the general level of terrain, avoiding the effect of surface inversions and diurnal variability in surface temperature (Haines 1988; Bally 1995). The Haines Index (HI) is routinely provided as a component of fire weather forecasts in the United States, and Werth and Werth (1998) have compiled a regional climatology of the HI for the western United States from radiosonde data collected using a miniature radio transmitter and sensors carried aloft by balloon. Werth and Ochoa (1993) considered the HI to be a valuable indicator of the potential for rapid growth of plume-dominated fires in the western United States. In Australia, climatologies of the HI have been developed for Tasmania (Bally 1995) and Victoria (Long 2006). Bally (1995) proposed that the HI was useful as a measure of potential bushfire activity in Tasmania and provided complementary information to surface-level weather observations used to calculate the McArthur Forest Fire Danger Index (FFDI) (McArthur 1967).

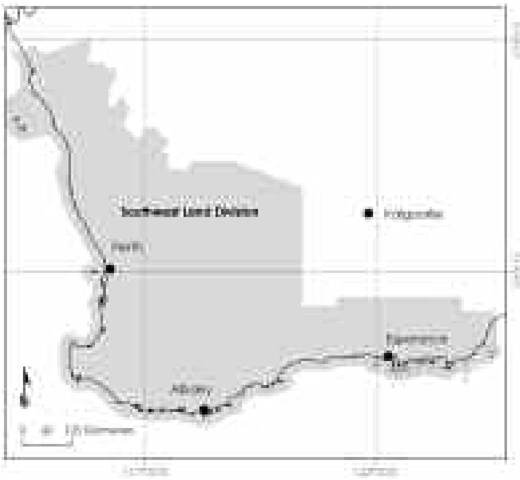
Bannister and Hanstrum (1995) developed a fire weather climatology for southwestern Australia that identified distinctive weather patterns associated with extreme fire weather days. This climatology was based on surface conditions and did not take account of atmospheric instability. On occasions, fire growth and spread exceed expectations based on the GFDI. This may be due to the influence of burning conditions at surface level, including low fuel moisture content and terrain-induced winds, or to atmospheric conditions such as instability (Luke and McArthur 1978) and mixing down of dry air from aloft (Mills 2005). The HI is one of several simple indices that could be provided to fire managers as a guide to the potential for atmospheric conditions to influence fire behaviour. We undertook this study to provide baseline information about the climatology of the HI in southwestern Australia, and to examine the relationship between the HI and fire danger ratings derived from surface-level observations using the GFDI.

Methods

Surface-level and upper air observations were available at four representative locations in southwestern Australia, where upper air observations are routinely obtained from radiosonde data (Fig. 1): Perth (15 m above sea level (asl)), Kalgoorlie (365 m asl), Albany (68 m asl) and Esperance (25 m asl). Surface data were obtained from automatic weather stations that form part of the Australian Bureau of Meteorology observation network and upper air data were recorded during routine radiosonde flights at 0000 UTC (0800 Western Standard Time). Trends in the occurrence of the HI over five years (1999-2004) were examined for the period August to April which spans the fire season when dead fine-fuels in forest, woodland and shrubland are potentially dry enough to ignite and sustain a bushfire.

The HI comprises a stability term and a moisture term. Stability is represented by the temperature difference between two levels in the atmosphere. For this study we calculated values for the mid-level index using data from the 850 and 700 hPa levels (approximately 1500 and 3000 m asl respectively). Although three of the four observation sites used in the study are close to sea level, we selected the mid-level index because much of southern Western Australia is an elevated peneplain at 250 to 400 m asl with occasional high points above 1000 m. The moisture term represents the difference between temperature and dew-point at the 850 h Pa level. Stability and moisture terms are allocated a score of 1 to 3 (Table

Fig. 1 Map of southwestern Australia showing place names mentioned in the text.



1) and then summed to provide a single index with a value between 2 and 6. An index value of 2 or 3 indicates moist stable air with very low risk of large fire development, while values of 4, 5 and 6 indicate respectively low, moderate and high risk of large fire development.

The GFDI was calculated for the months from December to March using hourly weather data input into the equations of Noble et al. (1980). Grass was assumed to be 100 per cent cured and the fuel load was constant at 4.75 tonne/hectare. The maximum GFDI for the day was used to determine the fire danger rating class according to the following thresholds: low (<2.5), moderate (2.5–7.5), high (7.5–32), very high (32–49) and extreme (50+). In Western Australia, the transition from the high to very high classes is set at 32 which is higher than specified on the standard Grassland Fire Danger meter and higher than the criterion applied to public warnings in other Australian States (Cheney and Sullivan 1997).

Results

Values of the Haines Index

The HI exhibited a clear seasonal trend at all four locations (Table 2). Values of HI 5 and 6 were most frequent during the months of December and January at Perth, Kalgoorlie and Esperance. At Albany, days of HI 6 were slightly more common in November but the combined total of days of HI 5 or 6 was greatest in December. Kalgoorlie had the highest frequency of HI 6 followed by Perth, Esperance and Albany. Low HI values were most frequent at the start (August–September) and end (April) of the season.

Relationship between Haines Index and GFDI

At all four locations median GFDI values were lowest for HI 2 or 3 and highest for HI 6 (Table 3). Median GFDI values at each locality were within the moderate fire danger class. Perth's median GFDI was highest, followed in order by Kalgoorlie, Esperance and Albany. The range of GFDI associated with each class of HI is illustrated in Fig. 2 using notched box plots (McGill et al. 1978). For clarity of presentation vertical axes in Fig. 2 have a maximum value of 100 and a small number of days with a greater GFDI are not shown. Days of extreme fire danger (GFDI > 50) at Perth and Albany were very strongly associated with HI 5 or 6. Kalgoorlie and Esperance experienced a few extreme fire danger days when the HI was only 3 or 4, but extreme days were still most common when HI was 5 or 6. Days of very high fire danger (32 ≤ GFDI < 50) occurred at all values of the HI.

Discussion

There is a clear seasonal pattern in occurrence of the HI in southwestern Australia. During the summer period, from December to February, moderate to high HI values predominate on the west coast (Perth) and inland (Kalgoorlie), and to a lesser extent along the south coast (Albany and Esperance). This pattern reflects both the location of the west coast trough and

Table 1. Procedure for determining stability and moisture terms for the mid-level Haines Index.

Stability term temperature difference 850 – 700 hPa (°C)	*Stability score*	*Moisture term temperature – dew-point at 850 hPa (°C)*	*Moisture score*
< 6	1	< 6	1
6 – 10	2	6 – 12	2
> 10	3	> 12	3

Table 2. Monthly frequencies (per cent of days per month) of the Haines Index at 0000 UTC for radiosonde observation sites in southwestern Australia.

Station	*Lat./ Long.*	*Haines Index*	*August*	*September*	*October*	*November*	*December*	*January*	*February*	*March*	*April*
Perth	31.9	2/3	65	55	42	33	19	20	21	31	34
	115.9	4	21	16	23	14	21	21	23	26	14
		5	13	24	23	31	37	32	35	27	26
		6	1	5	12	22	23	27	21	16	16
Kalgoorlie	30.8	2/3	44	39	32	30	17	22	38	46	35
	121.5	4	15	19	13	24	25	23	19	20	13
		5	13	26	25	24	28	23	20	18	28
		6	8	16	20	22	30	32	23	16	14
Albany	34.9	2/3	76	66	58	49	38	37	42	52	51
	117.8	4	16	15	19	12	15	26	27	21	21
		5	7	16	19	27	36	29	23	16	21
		6	1	3	4	12	11	8	8	11	7
Esperance	33.8	2/3	62	56	50	37	32	32	40	47	48
	121.9	4	21	17	27	24	23	25	27	23	23
		5	14	21	13	26	28	27	19	21	20
		6	3	6	10	13	17	16	14	9	9

Table 3. Median GFDI for different values of the Haines Index during the period December-March.

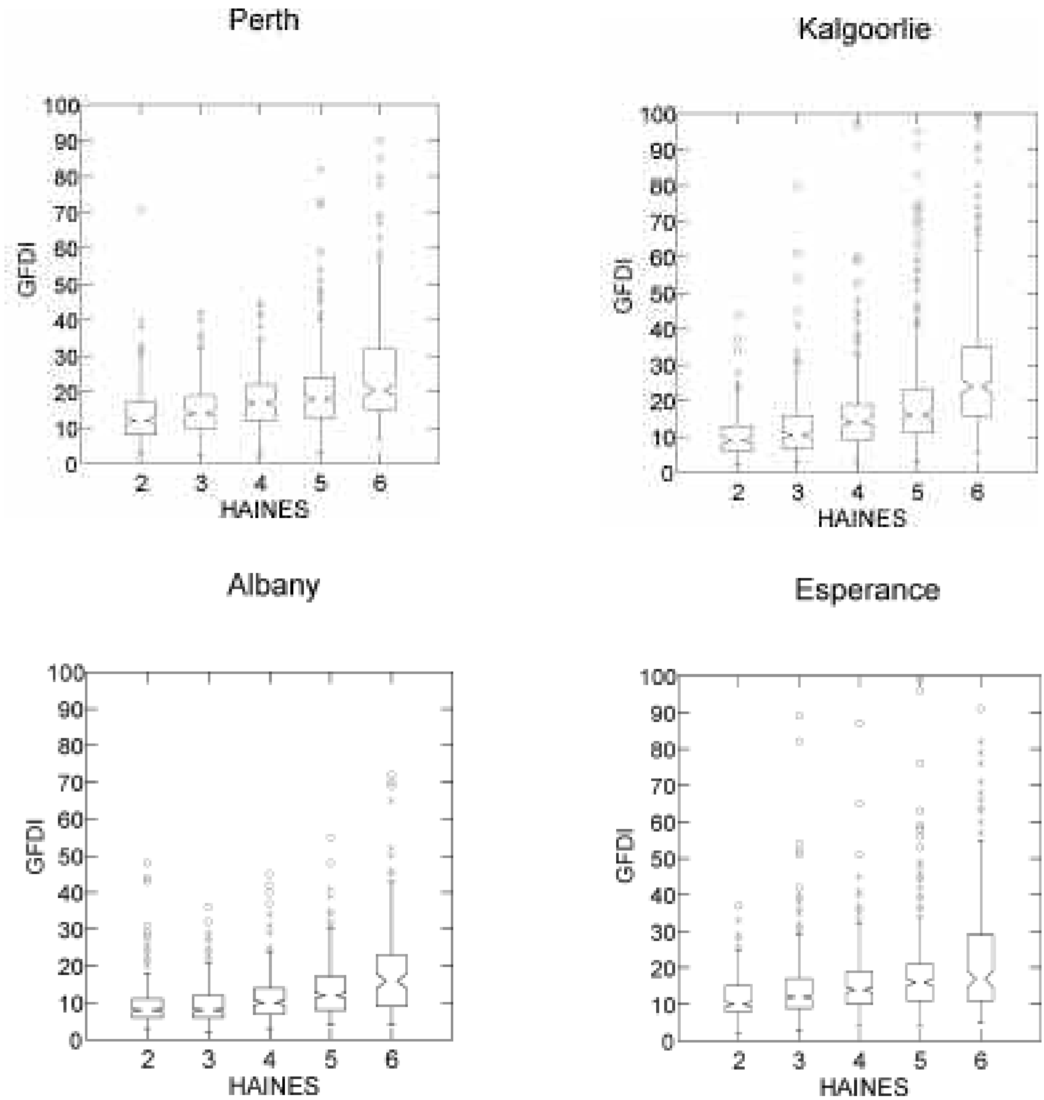
Haines Index	*Perth*	*Kalgoorlie*	*Albany*	*Esperance*
2/3	14	10	9	12
4	17	14	10	14
5	19	16	12	16
6	24	24	17	17
All classes	16	14	9	13

the more northerly latitudes of Perth and Kalgoorlie. The west coast trough marks the boundary between drier continental air to the east and moister, cooler maritime air to the west. Often during the summer the trough lies offshore at 0000 UTC. Moderate and high HI values are less frequent on the south coast because of the proximity to the ocean and a persistent synoptic regime of cooler maritime onshore winds in the lower levels of the atmosphere.

Moderate to high HI values were strongly associated with days of extreme fire danger (GFDI>50) at all locations. Bannister and Hanstrum (1995) identified several distinctive weather patterns responsible for extreme fire weather days in southwestern Australia. In south coastal areas, extreme fire danger conditions are linked to the formation of a prefrontal trough and are more frequent in early summer. Extreme fire danger on the west coast typically results from the combination of a strong high to the south of the State (Western Australia) and a trough over northern parts of the South West Land Division (see Fig. 1). This synoptic pattern is most common in January and February. The fact that extreme GFDI values are strongly associated with HI 6 suggests that the current fire danger rating system based on surface-level weather conditions already identifies a high proportion of days with significant fire growth potential. There are, however, exceptions, including days when the west coast trough traverses inland bringing cooler moister conditions at the surface, yet relatively warm and windy conditions exist aloft due to strong baroclinicity.

The climatology of the HI in southwestern Australia differs in several respects to that described for Tasmania by Bally (1995) where HI values were uniformly distributed throughout the year without an obvious summer peak. The proportion of days with HI 5 or 6 at Hobart ranged from 17 to 25 per cent, which is lower than observed at any of the sites in southwestern Australia for December to February. Bally (1995) also found that the association between HI and the McArthur FFDI was relatively weak, and proposed that the HI provided additional information about fire potential that was quasi-independent of the surface-based FFDI. Long (2006) examined

Fig. 2 Notched box plots showing the median and range of the GFDI associated with different values of the Haines Index for Perth, Kalgoorlie, Albany and Esperance. Boxes are notched at the median value and return to full width at the upper and lower confidence interval values. Notches that do not overlap indicate population medians that differ at the 95 per cent level of confidence. Outlier values are plotted individually as asterisks or open circles. Outliers exceeding a GFDI of 100 have not been plotted.



the occurrence of extreme fire weather days at Melbourne Airport between 1970 and 1999 and reported that while days of HI 6 were almost three times as frequent as days of extreme GFDI or FFDI, there was a good correlation between the number of extreme fire danger days and the number of days of HI 6 in a fire season. Long's data for Melbourne Airport are consistent with our finding that days of extreme fire danger are more common at high values of the HI.

Development of further climatologies of the HI for southern Australia would contribute to an improved understanding of relationships between fire danger and atmospheric conditions. Further work should aim to extend the climatology for southwestern Australia for longer than five years and to examine case studies of unexpectedly severe fire behaviour that occurred on days when the GFDI was not extreme, particularly in association with the passage of west coast troughs. Case studies of fires that burnt strongly when the

GFDI was high or very high could assist in establishing whether the HI has a discernable effect on fire size or severity under such conditions.

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