Bushfire History in Victoria

Influence of bushfire weather severity and effectiveness of mitigation strategies on the bushfire damage toll

Part 1 Indicators of historical bushfire weather severity, 1855 to Present

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Abstract
Three objective indicators of bushfire weather are derived from available Weather Bureau data from 1855 to 2017. Rainfall data analysis calculates Monthly and Seasonal Dryness Index and maximum daily temperature analysis yields Heat Index (very hot days per month and per season) and Wind Change Days Index per month and per season. They are hypothesised to be reasonably correlated with bushfire behaviour influencers in dead fine fuel beds of grass and forest floor and consequently damage toll potential. As independent variables, they are combined to calculate an objective measure of Seasonal Severity Level for each year between 1855 and present. Seasonal Severity Level for Melbourne area and surrounds is tested against Total Fire Ban day records for Central Victoria from 1945 and found to be reasonably consistent with a correlation coefficient of 0.5. The indicators appear to be a reasonable basis for objectively assessing relative severity of bushfire seasons for a long historical period. The will be applied in Part 2 to explain and compare bushfire damage potential in years of similar seasonal severity levels with records of actual damage, year by year over three centuries.

Introduction

The aim of Part 1 is to describe a standardised way of assessing and quantifying monthly or seasonal bushfire weather using Victoria's historical weather records so that the severity of each fire season can be identified in a repeatable, objective way. Part 2 uses the objective bushfire-related weather indices to assess the influence or relevance of seasonal weather severity on the bushfire damage toll over a very long term.

Bureau of Meteorology (BOM) data for daily and monthly rainfall and maximum temperature is available back to 1855. Because there is causal linkage between this data and bushfire behaviour influencers, indicators of daily and seasonal bushfire severity can be deduced back to 1855.

This paper explains how these two data records are analysed and correlated to develop objective indicators of weather severity. BOM data does not include long term records of wind speed, but the study shows that temperature patterns can be useful predictors of wind danger days.

Theory

Indicator weather data are deduced using the causal chain between weather, bushfire behaviour and damage toll as follows:

- The driest fuel bed occurs when relative humidity (RH) is lowest, which is typically on the hottest days
- When the fuel bed of grass or forest floor is driest and wind speed is highest, flame and embers are most severe
- Damage toll potential is highest when flame and embers are most severe

Explanation**:
The core influencers on bushfire flame behaviour in a specific vegetation patch (ignitability of a fuel bed and spread potential of the flame) and its spotting potential are correlated to dryness of fine fuel bed on the ground (eg, dry grass and litter bed of a forest), amount of vertical fuel (shrubs and flammable bark) and wind speed at fuel bed level.
The two surface fuel beds that carry the bushfire flame are grass and the fine fuels in the litter bed of a forest. On average, grass cures in late spring and stays dry, whereas litter bed is already dead. Dryness of the bushfire's carrier fuel varies daily with temperature, relative humidity, wind, exposure to sun and days since rain. The damping effect of rain on fine fuel flammability in summer months is short-lived, eg, light rain lasts one day heavy rain might last 2 - 3 days.
Damage toll potential is due to the two pre-eminent threats in a severe bushfire - the fire front and the ember throw or spotting activity. The worst-case fire front runs as an inferno pushed by a strong dry wind. Ember throw derives from upwind flames, their highest density being within a few hundred metres of their vigorous mother flame flame, but capable of throwing low density live embers several kilometres downwind.
The additional ingredient is wind. Severe fires occur when the wind is strongest but, although no long-term wind records exist, most serious wind and wind change events can be deduced from temperature patterns and verified by historical media reports and other contemporary records.

The following indices are derived from available BOM data – rainfall data analysis calculates monthly and seasonal Dryness Index and maximum daily temperature analysis yields Heat Index (very hot days per month and per season) and wind change days index per month and per season. They are hypothesised to be reasonably correlated with bushfire behaviour influencers. They will then be combined to calculate an objective measure of fire season severity for each year between 1855 and present.

Dryness Index (rainfall deficit): Historical BOM rainfall data reveals the months of above and below average rainfall and the lengths of rainless periods. A useful indicator of monthly dryness is the variation from average monthly rainfall. Divergence of rainfall from average will be combined with **pan evaporation rate** to develop a **monthly dryness index** and then a **seasonal dryness index**. Therefore, the monthly and seasonal dryness indices can be derived back to 1855.

** Explanation about bushfire behaviour matters derive from O'Bryan DJ (2007), The Science of Bushfire Behaviour, Papyrus Press, Australia, which is an intensive integration and analysis of relevant worldwide bushfire behaviour research, historic and recent.

It is assumed that a season of average rainfall generates an average number of fires and average area burnt. Thus, a month of very low rain has more drying days and a higher chance of a severe bushfire event and potential damage because a fire that ignites during these conditions has a higher chance of ignition and spread.

Conversely, a month of above average rainfall suggests fewer days are dry enough to let a fire ignite or run, therefore, there is less chance of damage occurring.

Heat Index The first index derived from daily maximum temperatures is the Heat Index, measured as the number of very hot days (>35^{0}C). Thus, the potential dates of the high severity days can be traced back to 1855.

Very hot days correspond with lowest relative humidity and therefore highest fuel bed dryness, meaning a higher chance of increased ignition probability and spread potential in dead grass and forest litter bed. The more very hot days in a month or a season indicates a higher chance of ignition occurring and fire spreading.

The number of very hot days is a crude indicator of number of severe weather days. But hot days per se do not indicate damage potential. Some very hot days are calm and some have high wind speeds, but the most severe bushfire damage is correlated with highest wind speeds.

Wind Change Days Index The second index derived from daily maximum temperatures is the Wind Change Days Index. A wind change day can be predicted from Melbourne's records with reasonable probability when a very hot day (>35^{0}C maximum) or a succession of very hot days is followed by a cool day (< 25^{0}C maximum). Thus, the most potentially destructive dates can be traced back to 1855.

The most potentially damaging period in Victorian bushfire history is on a wind change day, when several hours of hot strong NW wind changes to a cooler but strong SW wind. Many such days in a month indicate higher potential for bushfires running out of control with large perimeters, meaning that more settlements and towns are in the path of runaway fires and therefore a higher chance of bushfire damage occurring.

Most wind change days affect the whole of the State, but a few (classified as weak cold fronts) do not cross north of the Dividing Range. This may tend to overestimate the wind change day count, but it may be counteracted by the undetectable windy days during a heat wave, which tends to underestimate the heat index. Subject to these limitations, the wind change days index is a useful indicator of the frequency of highest severity bushfire weather per month or per season, and therefore the probability of highest damage toll potential.

Seasonal Severity Level Assuming that Seasonal Dryness Index and the derived Heat indices are independent variables, they are combined to develop an objective Seasonal Severity Level. Seasonal severity can then be calculated from 1855 to present. This will enable objective comparison with years of bushfire damage tolls.

Method

BOM data for monthly rainfall and evaporation rate is used to develop a robust and reproducible indicator of relative monthly dryness based on divergence from average rainfall.

Bureau of Meteorology Central District records (BOM) are selected as the most representative for Victoria bushfire weather. BOM has data for Melbourne's daily and monthly rainfall and daily maximum temperature back to 1855. Being an inland region in the centre of Victoria, Melbourne weather is a reasonable indicator of southern Victoria's bushfire weather, and is a good indicator of the strong bushfire weather systems that sweep the whole of Victoria, ie, the characteristic strong hot N to NW winds followed by the cooler W to SW wind change.

Derivation of Dryness Indices

Dryness Index is relative variation from average rainfall between September and April. The residual influence of monthly rainfall on dead fine fuel varies due to evapotranspiration per month. This dryness tendency is accounted for by adjusting the Monthly Dryness Index by the respective monthly pan evaporation rate data provided by BOM.

Monthly Dryness Index = MDI =
Monthly average rainfall / monthly actual rainfall X evaporation dryness factor

To avoid exorbitant MDI numbers, monthly rainfall below 5mm is defined as 5mm.

Evaporation dryness factor for month A
= pan rate for September ^ relative pan rate for month A

The use of an exponential magnifies the drying effect for summer months beyond simple multiplication and thereby exaggerates the dryness index during the danger months to ensure the index heightens the potential risk of damage. For example, 10mm of rain in September is evaporated with a drying power of 10, and 10mm in February is evaporated with a drying power of 158 (= 10^2.2) (See next section)

Seasonal Dryness Index is sum of monthly indices.

Seasonal Dryness Index = SDI = SUM of MDI's from Sept to April

Derivation of Heat Indices

BOM records of daily maximum temperatures allows a monthly and seasonal count of hot days in the months of December to March, the number of consecutive hot days (regarded as heat waves), the number of days within these heat waves, and the number of wind change days where the maximum temperature drops from high thirties to low twenties.

(1) Seasonal Heat Index = Days > 35^{0}C

Seasonal heat index is a simple count of the number of hot days (defined as > 35^{0}C) in the months of December, January, February and March.

(2) Wind Change Days Index

Wind Change Days Index is a simple count of the number of wind change days over four months (Dec to Mar), identifiable when the maximum temperature drops from high thirties to low twenties over the next day or two. Where the drop in daily maximum temperature occurs the next day, the change came during the afternoon / evening of the first day. Where the drop occurs over two days, the change came during the morning of the second day.

Derivation of composite index - Seasonal Severity Level

Trial combinations of Seasonal dryness index and Seasonal heat indices in various algorithms led to the following simple function that deliberately confers a much greater influence of daily temperature (due to its influence on RH and therefore daily dryness of bushfire fuel) compared to Dryness Index. To better match SSL with number of TFB days, low SDI prevents TFB's so its influence can be exaggerated by a power function.

There are two varieties of SSL. Method 1 uses the input "Seasonal Heat Index (Days > 35C)" and Method 2 uses the input "Wind Change Days Index".

Method 1, hottest days

Seasonal severity level

= 5 X Seasonal Heat Index X (Seasonal dryness index / 100) ^ 0.3

Method 2, wind change days

Seasonal severity level

= 5 X Wind Change Days Index X (Seasonal dryness index / 100) ^ 0.3

Neither wind change days index nor seasonal heat index are correlated with TFB days, however they are corelated to each other because wind change days occur after single very high temperature days or after a heat wave of very high temperature days. Wind change days are typically severe weather days, but may not always reach TFB status.

Similarly, very hot days within a heat wave can also have high speed winds that are declared TFB

On the other hand, days with temps below 35^0C with strong winds can also be TFB's

High rainfall years can have very hot days and wind change days that do not reach TFB status

Results

Seasonal Dryness Index

The following Table illustrates how average rainfall, pan evaporation data and average rainfall are combined to generate average Monthly Dryness Indices for Melbourne between September and April, and the Seasonal Dryness Index. It also shows examples of MDI for a fire season with above average rain (1992 / 93) with a total SDI score of 328 and MDI for two of the driest fire seasons, 1892/93 with SDI 2532 and 2008/09 with SDI 2789.

Month	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Relative pan evaporation rate	1.0	1.4	1.7	2.0	2.2	2.0	1.5	1.0
Evaporation dryness factor	10	25	50	100	158	100	32	10
Average rainfall	58	66	60.3	59.1	46.8	48	50.1	57.3
Monthly Dryness Index for average rainfall	10	25	50	100	158	100	32	10
SDI = 485								485
1892/93 rainfall (mm)	58.6	88	63.6	42.7	4.9	6.4	36.9	52.9
1892/93 MDI	10	19	48	138	1513	750	43	11
SDI = 2532								2532
1992 / 93 rainfall (mm)	125.2	106	139.8	108.6	92.8	58.8	37.6	20.2
1992 / 93 MDI	5	16	22	54	80	82	42	28
SDI = 328								328
2008 / 09 rainfall (mm)	12	14.2	54.2	76.8	5	5	47.6	39.2
2008 / 09 MDI	48	116	55	77	1483	960	33	14
SDI = 2789								2782

Monthly Dryness Index is calculated for BOM data from 1855 to 2017. Data is then consolidated into Seasonal Dryness Index for each fire season and the chart is presented in Figure 1.

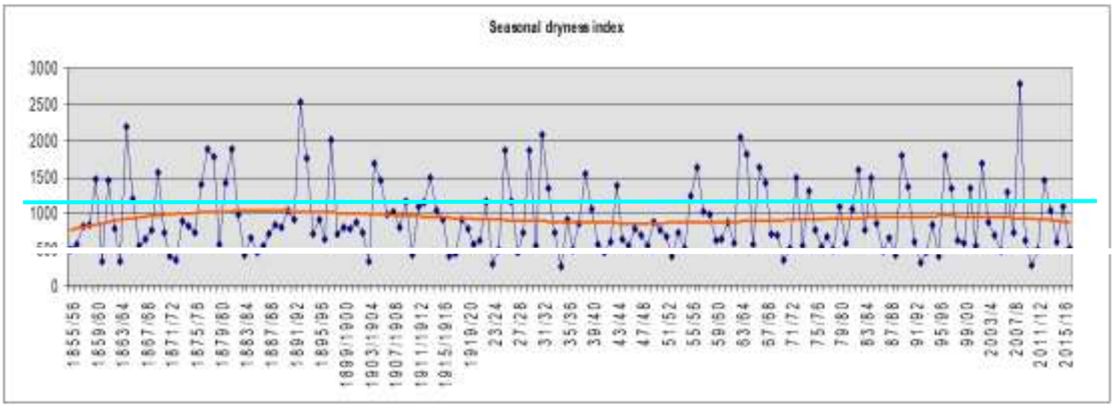


Figure 1 Seasonal Dryness Index for BOM Central District
White horizontal line is dryness index when average rainfall occurs in each month.
Blue horizontal line is dryness index when half average rainfall occurs in each month.

Figure 1 shows the variation of Seasonal Dryness Index over three centuries. The white reference line is the theoretical average rainfall SDI of 485 where every measured month has average rainfall. The blue reference line is theoretical SDI 1200, where every measured month has half average rainfall. Later comparisons in Part 2 reveal that almost all the major bushfire events in Victoria's history occurred when the Seasonal Dryness Index exceeds 1200.

The highest Seasonal Dryness Index occurred in years when both January and February had less than 10mm rain. This has only occurred five times - 1881/82, 1892/93, 1897/98 1905/06, 2008/9, and each fire season generated a major damage toll. The only two other years with consecutive extremely dry months were in February - March in 1869/70, and March - April in 1922/23.

Has seasonal dryness index changed in frequency or intensity over the years?
Figure 2 plots a fourth order polynomial trend line. This moving average shows a relatively small range of movement between 900 and 1000, slightly higher average dryness from the 1880's to 1910's, a slight dip from the 1920's to the 1980's, and a slight rise thereafter. The range of most years is 400 to 1500, with several spikes to 2000 or more.

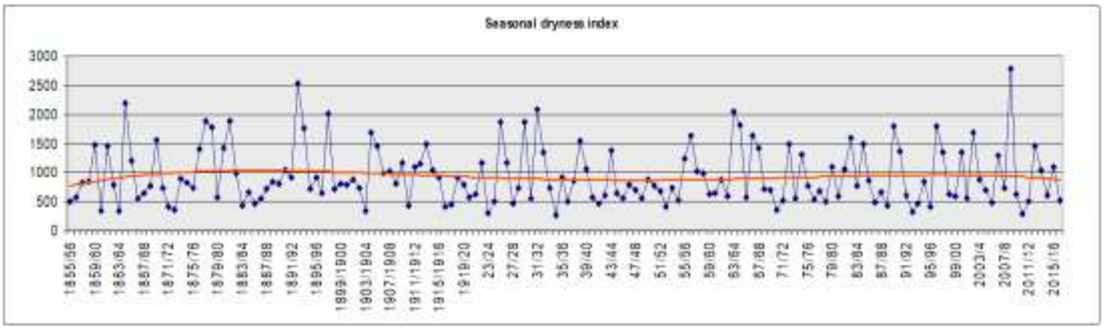


Figure 2 Seasonal Dryness Index for BOM Central District
Red line is fourth order average polynomial trend line

If we define a very dry season as a Seasonal Dryness Index > 1200, the following Table shows the variability over 150 years.

	No. of very dry seasons per 20-year period SDI > 1200	Average Seasonal Dryness Index of the driest seasons
1855/56 – 1874/75	5	1576
1875/76 – 1894/95	7	1805
1895/96 – 1914/15	4	1664
1915/16 – 1934/35	4	1787
1935/36 – 1954/55	2	1458
1955/56 – 1974/75	8	1575
1975/76 – 1994/95	4	1567
1995/96 – 2014/15	7	1674

The first thing to note is the large variability in frequency (eg, 2 to 8 very dry seasons per 20 year periods), the narrow range of dryness index (1450 to 1800), their randomness, and the absence of any trend upward or downward.
Other observations:

- SDI is a targeted measure of dryness over spring to autumn, meaning it is not necessarily comparable with general or annual droughts.
- The SDI for each fire season is very closely correlated with seasonal dryness at end of February, meaning the SDI is a reliable indicator of the most dangerous months of each bushfire season.
- Cumulative MDI data can be interrogated for totals at end of December, January or February. For example, a seriously high MDI total at end of December might be useful as a predictive measure of serious bushfire

problems in January. On the other hand, many a January throughout history has ended the fire season with huge dumps of rain.

Seasonal Heat Index

Seasonal Heat Index is a simple count of the number of hot days (defined as > 35^{0}C) in the months of December, January, February and March. Figure 3 shows the long-term chart from 1855 to 2017.

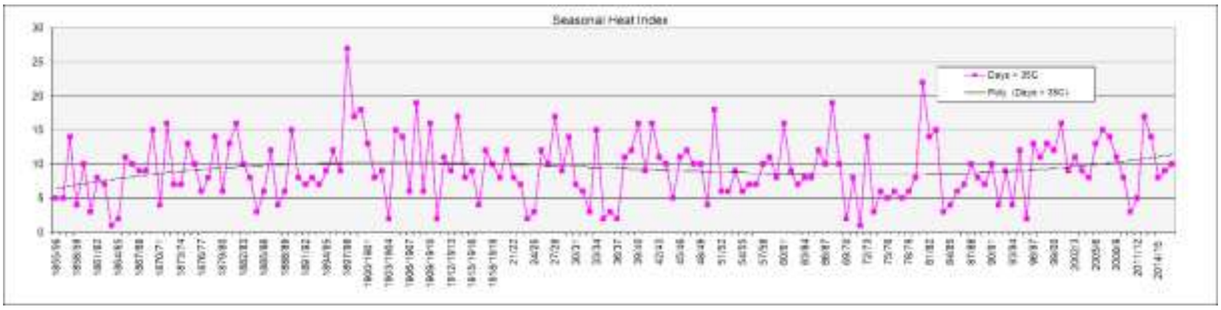


Figure 3 Seasonal Heat Index, 1855 to 2017
Black line is third order average polynomial trend line

Monthly or Seasonal Heat Index can also be regarded as a relative indicator of the number of windy days because most very hot days in Melbourne are caused by hot winds from inland, but some very hot days have no wind. Therefore, this index tends to overestimate bushfire danger potential.

Nevertheless, the value of this indicator is not in its accuracy, but in its relative size. For example, a high number of very hot days per month has a greater chance of more severe fire behaviour days than a low count of very hot days.

Has Seasonal Heat Index changed in frequency or intensity over the years?
The long-term polynomial trend line in Figure 3 shows a slight fluctuation between 8 and 10 very hot days per season. Generally, the range is from two to high teens with approx six peaks to 20 and more, the highest in 1897/98, and highly variable from year to year. There is no upward or downward trend long term.

Wind Change Days Index

Wind change days index is a simple count of the number of wind change days over four months (Dec to Mar), identifiable when the maximum temperature drops from high thirties to low twenties over the next day or two. Figure 4 shows the chart from 1855 to 2017.

The wind change index is useful as a proxy for the worst severity bushfire weather provided the following limitations are understood. Firstly, a low proportion of wind change events do not bring very strong winds, whether N – NW or W - SW winds, or both. Secondly, hot and very hot days can have very strong winds that cannot be detected by temperature differential alone. Therefore, the wind change days index tends to underestimate bushfire danger potential.

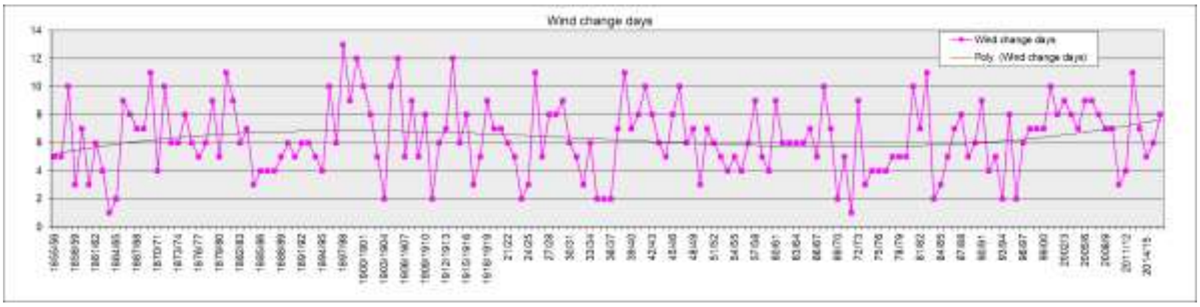


Figure 4 Wind Change Days Index from 1855 to 2017
Black line is third order average polynomial trend line

Has the Wind Change Days Index changed in frequency or intensity over the years?

The long-term polynomial average trend line in Figure three shows a slight fluctuation between 5 and 7 wind change days per season. Generally, the range is 2 to 12 and highly variable from one year to the next. There is no upward or downward trend long term.

Comparison of Seasonal Heat Index (= "Days > 35C") and "wind change days"

The following chart shows a significant correlation between frequency of wind change days and hot days (>35^{0}C). For example, if there are less than 10 hot days per season, 70 to 80% have wind change events. If there are more than 10 hot days, 55 to 70% have wind change events.

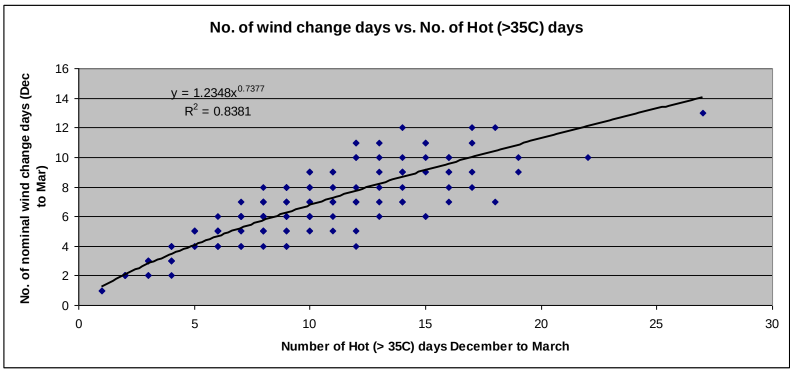


Figure 12 Wind Change Days Index against Seasonal Heat Index, 1855 to 2017

The parabolic shape reflects less wind change days as more hot days occur. This is explained as follows. More hot days means more days are locked within heat waves, and because the wind change day occurs at the end of each heat wave, more heat waves mean less wind change days.

Ratio of wind change days / very hot days varies between ½ and 1. When half, it means long heat waves. Meaning more TFB days if dryness index is high. When 1. it means standalone very hot days, meaning less TFB days if dryness index is low

Seasonal Severity Level, Method 1, hottest days

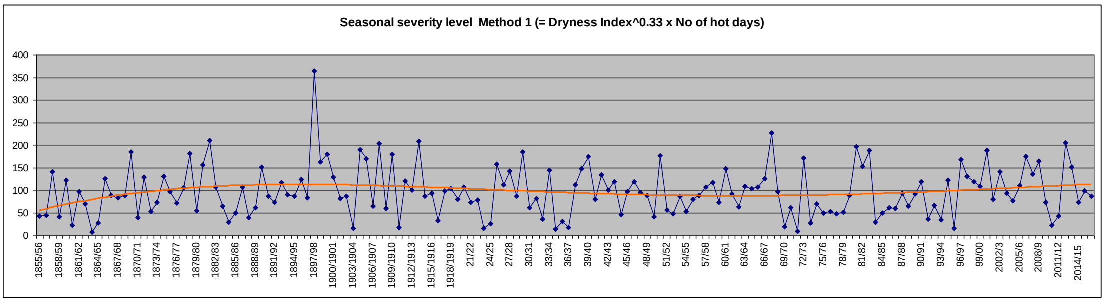


Figure 5 Seasonal Severity Index, Method 1 (hottest days)
Red line is fourth order polynomial trend line

The fourth order polynomial trend line in Figure 5 indicates a more or less static average level for over 150 years, showing neither an increasing nor decreasing trend. Apart from the spike in 1897/98, highest peaks are around the 200 mark. The range in most years is between 50 and 150, but there are several spikes above and below that range. There is no upward or downward trend long term.

Seasonal Severity Level, Method 2, wind change days

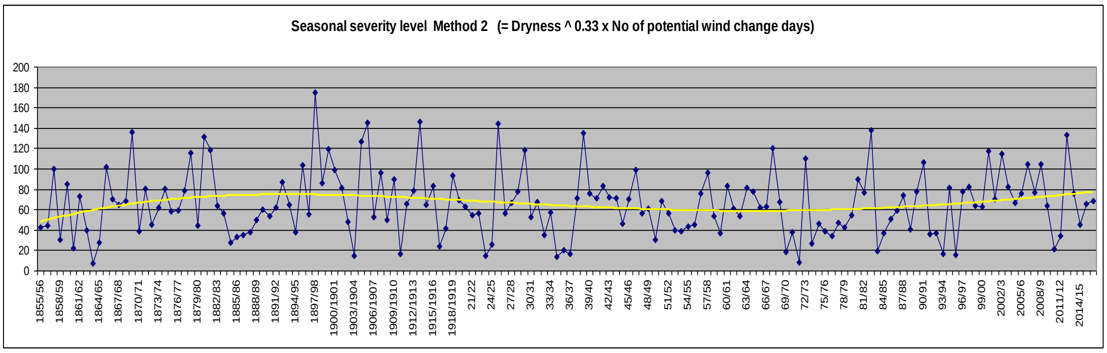


Figure 6 Seasonal Severity Index, Method 2 (wind change days)
Trend line is fourth order polynomial.

The fourth order polynomial trend line in Figure 6 indicates a slightly fluctuating average level for over 150 years, but showing neither an increasing nor decreasing trend. Apart from the spike in 1897/98, most other peaks are around the 140 mark. The range in most years is between 30 and 100, but there are several spikes above and below that range. There is no upward or downward trend long term.

Both Methods are compared in the next section.

Discussion

Comparison of Seasonal Severity Index Methods to Total Fire Ban frequency

A Total Fire Ban (TFB) day can be interpreted as the confluence of the hottest, driest and windiest day. These are the days when the severest fires are expected. Therefore, number of TFB days per year can be regarded as a reasonable indicator of relative seasonal severity and hence relative damage potential. Thus a season with 15 TFB days has more chance of developing damaging runaway infernos that a season with 5 TFB’s.

The Total Fire Ban (TFB) Day concept commenced as a state-wide measure in 1945/46 (then called ACUTE FIRE DANGER days) and in 1985/86, TFB’s were declared by separate regions. This study uses TFB days for BOM’s Central District because it matches the weather records of Melbourne.

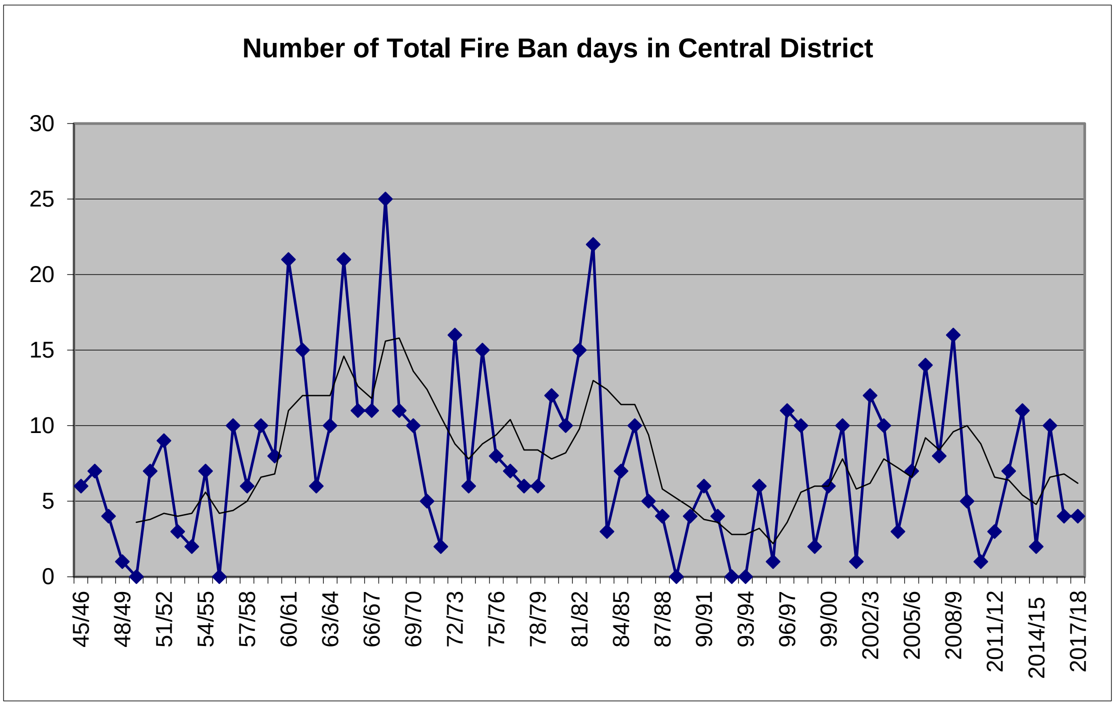


Figure 7 Total Fire Ban Days in Central District of BOM (sourced from CFA website). This sketch line is the 5-year moving average, to highlighting peaks and troughs in TFB frequency over the decades.

The above TFB Chart shows a fluctuating trend line over the period 1945 to present, from higher numbers in the 1960’s (range 10 to 20) and 1970’s to lower numbers in the late 1980’s to mid-1990’s (range 0 – 6), and variable numbers thereafter.

Figure 8 compares Seasonal Severity Level Method 1 (“Days > 35C”) with TFB frequency.

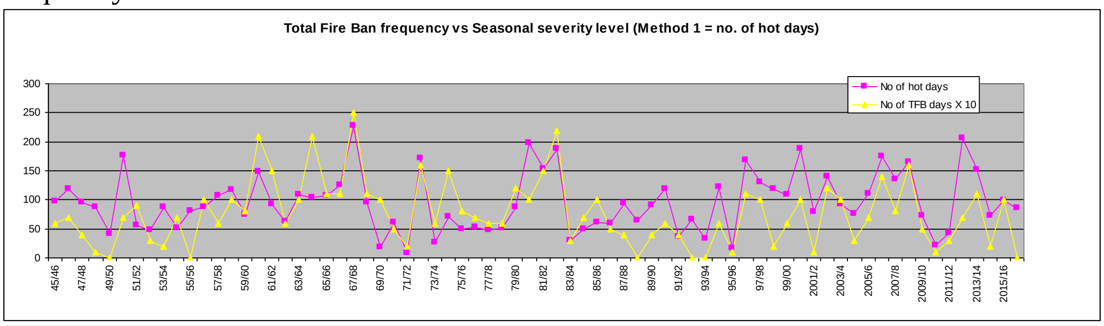


Figure 8 TFB Day frequency compared to Seasonal Severity Index, Method 1 (hottest days)
Note – TFB day frequency is multiplied by 10 to match the scale of the Seasonal severity level.

The match is generally good, with peaks, troughs and slopes in reasonable agreement. The discrepancy occurs because the "Days > 35C" overestimates number of windy days, ie, some hot days have light winds and would not qualify as TFB days. The statistical correlation for all years since mid-1940's is moderate at $R^2 = 0.38$, but for years since 1985/86, when TFB's became regional, is higher at $R^2 = 0.51$.

Figure 9 compares Seasonal Severity Level Method 2 (wind change days) with TFB frequency.

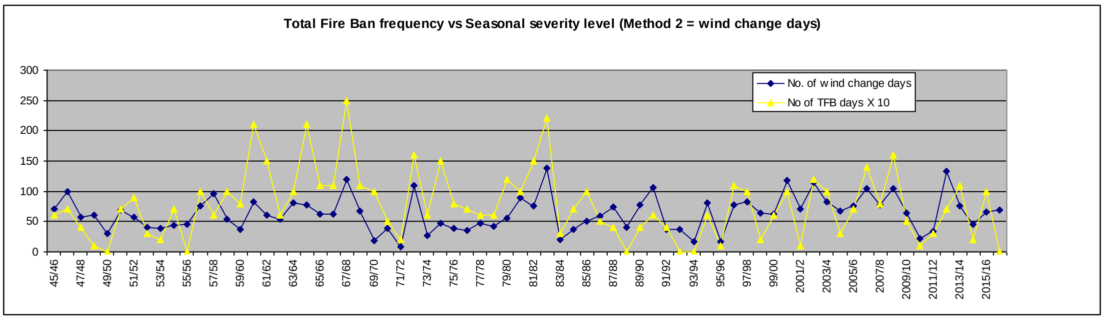


Figure 9 TFB Day frequency compared to Seasonal Severity Index, Method 2 (wind change days)
Note – TFB day frequency is multiplied by 10 to match the scale of the Seasonal severity level.

The match is visually not as good as Figure 8, but most peaks, troughs and slopes are in reasonable agreement. The discrepancy occurs because the Wind Change Index underestimates windy days. The statistical correlation for all years since mid-1940's is moderate at $R^2 = 0.35$, but since 1985/86, when TFB's became regional, is higher at $R^2 = 0.45$.

Note 1 Because Method 1 is expected to overestimate bushfire danger potential and Method 2 is expected to underestimate it, an average of the two was compared to TFB frequency. Interestingly, it did not add significant accuracy to the correlation for all seasons from mid-1940's ($R^2 = 0.38$), or from 1985/86 ($R^2 = 0.50$).

Note 2 When calculating these correlation coefficients (R^2), the statistical analysis is comparing the numerical values of SSL (which is calculated from derived **seasonal data**) and TFB frequency (which is calculated from actual **daily data**). Whilst an R^2 of 0.5 implies indicative rather than accurate correlation, it is adequate for the purposes of this paper.

The purpose of the SSL is not to match actual numbers of TFB days. Instead it is seeking to confirm if a year with a high SSL has a relatively high number of TFB's, or a low SSL year has a lower number of TFB days. In this regard, the better match is Method 1 ("Days > 35C") because the peaks, troughs and slopes are in more consistent agreement.

Conclusion A high R^2 quantitative match is not expected because TFB's are determined from weather data on individual days, whereas the SSL applies to the weather patterns of the whole season. Nevertheless, the moderate and consistent correlation levels of both SSL methods with TFB frequency are adequate confirmation of their usefulness and robustness as reasonably objective indicators of the relative damage potential of each bushfire season from 1855 to present. By identifying potential damage years, they allow comparison with actual damage, and allow analysis to explain the differences.

Comparison of Seasonal Dryness Index with el Nino and drought years

Because Seasonal Dryness Index is designed to detect summer dryness, it does not necessarily match with notorious drought years and climatic indices like el Nino and the Indian Ocean Dipole.

(1) El Nino Its impact diminishes before summer months. The BOM web site lists the 12 strongest El Niño events as 1905, 1914, 1940, 1941, 1946, 1965, 1972, 1977, 1982, 1991, 1994 and 1997. Only the five years marked in red had elevated SDI by end of February.

Technical Note The shift in rainfall away from the western Pacific, associated with *El Niño*, means that Australian rainfall is usually reduced through winter–spring, particularly across the eastern and northern parts of the continent. Generally speaking, El Niño's impact on Australian rainfall diminishes from November onwards, so that by summer the El Niño-induced tendency towards drier than average conditions has almost entirely broken down across the east and south of the country.
www.bom.gov.au/climate/updates/articles/a008-el-nino-and-australia.shtml
http://www.bom.gov.au/climate/enso/ninocomp.shtml

(2) Indian Ocean Dipole
References are not specific enough to assess its impact on dryness in summer months. Wikipedia quotes:
"A 2009 study by Ummenhofer et al. at the University of New South Wales (UNSW) Climate Change Research Centre has demonstrated a significant correlation between the IOD and drought in the southern half of Australia, in particular the south-east. Every major southern drought since 1889 has coincided with positive-neutral IOD fluctuations including the 1895–1902, 1937–1945 and the 1995–2009 droughts.
The research shows that when the IOD is in its negative phase, with cool Indian Ocean water west of Australia and warm Timor Sea water to the north, winds are generated that pick up moisture from the ocean and then sweep down towards southern Australia to deliver higher rainfall. In the IOD-positive phase, the pattern of ocean temperatures is reversed, weakening the winds and reducing the amount of moisture picked up and transported across Australia. The consequence is that rainfall in the south-east is well below average during periods of a positive IOD.
The study also shows that the IOD has a much more significant effect on the rainfall patterns in south-east Australia than the El Niño-Southern Oscillation (ENSO) in the Pacific Ocean as already shown in several recent studies"

(3) The Federation drought is known as the worst drought of eastern Australia, 1895-1903, but only one of those years (1897/98) had a Seasonal Dryness Index above 1000.
The "noughties" (2000 to 2009) are often quoted as a drought decade, but Figure 2 shows only four of those years had a Seasonal Dryness Index above 1200.
Notorious drought events can include winter or spring dry spells, which is not a relevant indicator of fire behaviour in summer months.

Comparison of Seasonal Heat Index (Days > 35C) and Seasonal Dryness Index

Figure 10 plots Seasonal Heat Index against Seasonal Dryness Index.

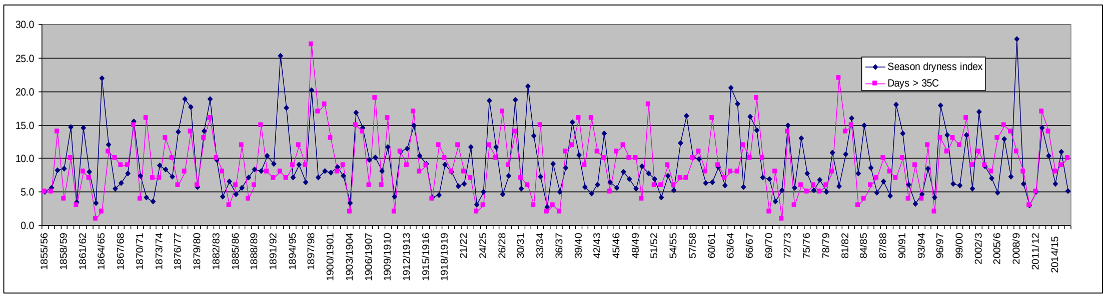


Figure 10 Seasonal Heat Index against Seasonal Dryness Index, 1855 to 2017

The first thing to note is that there is no visual or statistical correlation between seasonal dryness and number of very hot days, which suggests they are independent variables. There are some years of very high Seasonal Dryness Index and low number of hot days, and conversely, a few years of high Seasonal Dryness Index and a large number of hot days.

The 1897/98 season has the highest number of very hot days (27) and also a very high seasonal Dryness Index (2000). The coincidence of these two indicators nominates it as the most severe bushfire season in our history.

Inspection of the Figure 10 charts shows that very hot days are not correlated with SDI. The following table shows that in years of highest SDI, the number of very hot days is variable, but typically low. Likewise in those years with highest number of very hot days, SDI is variable. To date, only one season was severely dry AND had the highest ever number of hot days – 1897 / 98. Theoretically, this year had the ingredients of the worst ever bushfire season in Victoria's history. Part 2 comparisons reveal the damage toll in that season was correspondingly catastrophic.

Year	Highest Seasonal Dryness Index	Days > 35C	Highest number of Days > 35C	Seasonal Dryness Index
1864/65	2,200	2		
1871/72			16	420
1881/82			16	1,880
1892/93	2,532	8		
1897/98	**2,016**	**27**		
1897/98			**27**	**2,016**
1907/08			19	1,020
1931/32	2,080	6		
1950/51			18	775
1963/64	2,055	8		
1967/68			19	1,420
1980/81			22	580
2008/09	2,790	11		

Closer inspection of shorter periods reveals unexpected and variable correlations between seasonal dryness and seasonal heat index. The study found it varied from linear proportionate to zero to inverse in a random pattern: For example, the following groupings coincided with noticeable changes in correlation.

- 1855/56 to 1863/64, "Days > 35C" was directly linear with seasonal heat index, meaning that the dryer the season, the more hot days occurred. R^2 = 0.57.

- 1864/65 to 1879/80, “Days > 35C” was inversely related to seasonal dryness index to the power 0.25, but with a wide scatter $R^2 = 0.04$, meaning the dryer the season, the less hot days occurred.
- 1880/81 to 1896/97 “Days > 35C” was weakly positive with SDI, power 0.25, but with a wide scatter, $R^2 = 0.1$, meaning that there was virtually no correlation between seasonal dryness and number of hot days.
- 1897/98 to 1926/27 “Days > 35C” was directly linear, meaning that the dryer the season, the more hot days occurred, $R^2 = 0.54$
- 1927/28 to 1992/93 “Days > 35C” was weakly positive with SDI, power 0.25, but with a wide scatter, meaning that there was virtually no correlation between seasonal dryness and number of hot days. $R^2 = 0.04$
- 1993/94 to 2016/17, “Days > 35C” was more positive with SDI, power 0.6, with substantially less scatter, $R^2 = 0.4$, meaning the dryer the season, the more hot days occurred.

Correlations change with length of sample period, but their significance or their predictive capacity has not been pursued.

Comparison of “Wind Change Days” and SDI

Figure 11 plots number of wind change days against Seasonal Dryness Index.

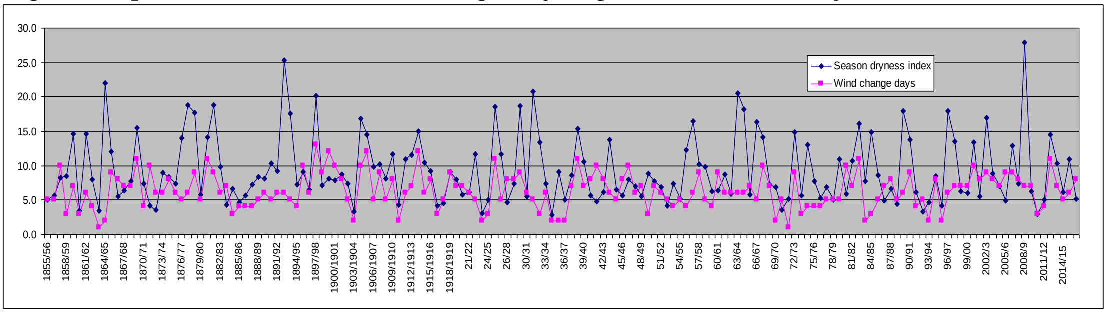


Figure 11 Wind Change Days Index against Seasonal Dryness Index, 1855 to 2017

Similar to Figure 10, the key thing to note is there is no visual or statistical correlation between seasonal dryness and number of wind change days, which again supports their usefulness as independent variables. The 1997/98 season has the highest number of wind change days (13) and also a very high seasonal Dryness Index (2000). The coincidence of these two precursors reinforces its previous nomination as the most severe bushfire season in our history.

Conclusion

Three objective indicators of bushfire weather are derived from available Weather Bureau data from 1855 to present. Rainfall data analysis calculates Monthly and Seasonal Dryness Index and maximum daily temperature analysis yields Heat Index (very hot days per month and per season) and Wind Change Days Index per month and per season. They are hypothesised to be reasonably correlated with bushfire behaviour influencers in grass and forest fuel beds and damage toll potential. They are combined to calculate an objective measure of Seasonal Severity Level for each year between 1855 and present. Seasonal Severity Level is tested against Total Fire Ban day records for BOM’s Central District from 1945 to present and found to be reasonably well correlated, particularly since 1985, when TFB declarations became regionalised, yielding a correlation coefficient of 0.5. They form a reasonable basis for predicting relative severity of bushfire behaviour and potential bushfire damage by year over three centuries, and comparing them in Part 2 to records of bushfire damage, allowing inquiry of reasons why and why not.

Addendum

Comparison of Seasonal Severity Level Analysis with climate change postulations, assertions and declarations regarding bushfire threat

This Addendum can confirm at the outset that climate change has been occurring at Melbourne Weather Station since 1960. The INSET in 3A below shows that if we measure Melbourne's average temperature as half the difference between average maximum and average minimum, our average has risen by 1.5 C over the past 60 years – our monthly minima have risen by 3 C but our monthly maxima have remained unchanged. Before 1960, our average minimum and maximum temperatures had been static for 105 years. It appears however that this climate change has not influenced any factors that determine bushfire risk.

This Part 1 (historical weather severity) analysis shows the weather factors that influence bushfire behaviour are unchanged and well within their long-term fluctuations. The Part 2 analysis shows that whilst seasonal weather has some influence on the potential annual damage toll, the actual toll is strongly influenced by other factors, namely state-wide policies and local mitigation measures. Appropriate government policies have lessened the bushfire threat and reduced the damage toll in similar severe seasons, and local mitigation measures can reduce or even eliminate flame and ember threat by application of four protection options – managing separation distance between house and ignition source, flame location around the house and its height, ember vulnerability on the house and applying suppression intervention. I suggest that further state wide policy improvements can eliminate the bushfire threat in targeted areas independently of real or imagined weather trends.

The assertion by climate change spokespeople that the bushfire threat is worsening is based on their assumptions that weather severity is deteriorating and that the severe bushfire is not defendable. Both assumptions are incorrect.

Assertions by climate change people that bushfires will be more severe are now listed and examined in the light of the Part 1 and Part 2 analyses.

1 McArthur Forest Fire Danger Index is increasing, meaning that extreme fire weather days have become more frequent.

Source: http://www.climatechangeinaustralia.gov.au/

"Fire weather is monitored using a McArthur Forest Fire Danger Index (FFDI), which is calculated from daily temperature, wind speed, humidity and a drought factor, at sites with consistent data across Australia.

An increase in the annual (July-June) cumulative FFDI is observed across all 38 sites analysed in Australia from 1973 to 2010, and is statistically significant at 16 of those sites, particularly in the south-eastern part of the country.

This increase across southeast Australia is characterised by an extension of the fire season further into spring and autumn.

There has also been an increase in high FFDI values (90th percentile) from 1973–2010 at all 38 sites, with a statistically significant increase at 24 sites, indicating that extreme fire weather days have become more frequent over time.

The FFDI increases are partly driven by temperature increases that are attributable to climate change.

Comments

A The use of cumulative FFDI by the quoted study has no scientific credibility because FFDI has been applied well beyond its design criteria. Therefore, its findings are flawed:

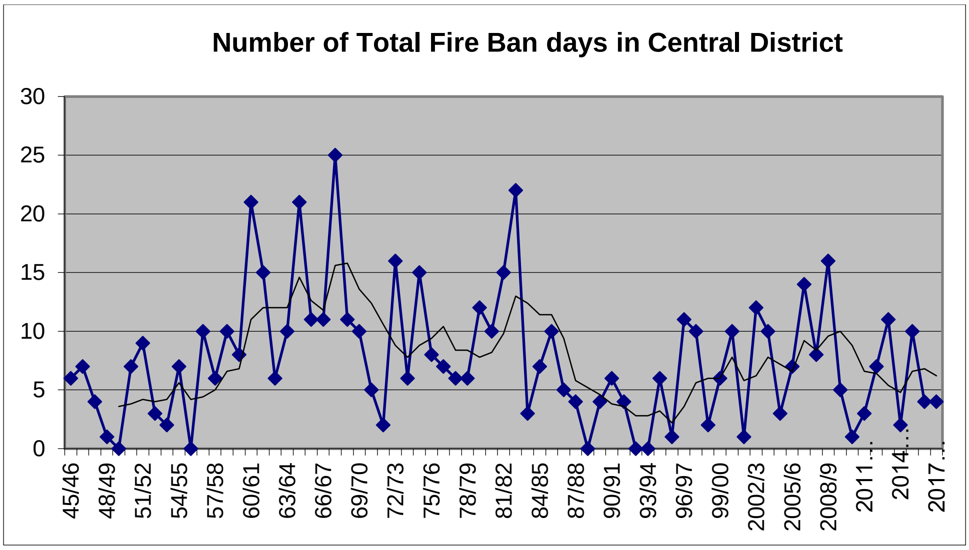
- It is meaningless to use cumulative FFDI as an indicator of seasonal bushfire behaviour.
- It is invalid to use cumulative FFDI as an indicator of potential daily bushfire behaviour severity.

Explanation: McArthur designed FFDI to assess potential bushfire behaviour of dry fine fuel on a given day with real time weather – temperature and relative humidity (RH%) to estimate the moisture content of dead, dry fine fuel on the ground that feeds the flash flame and wind speed to estimate the fire's spread rate through the fuel bed.
FFDI varies throughout the day, but often peaks mid to late afternoon.
Daily peak FFDI can last for one hour or several hours.
When FFDI exceeds 30 to 50, severe bushfire behaviour can be expected.
Severe fire behaviour is explained by peaks in FFDI, not average FFDI.
Cumulative FFDI is an average.
Cumulative 3pm FFDI over a defined period, eg, one week, indicates an average FFDI for the period and masks peak FFDI on a given day, eg, 4 days of FFDI 10 and two of 50 totals 140 and computes to an average FFDI 20 per day. Thus, two potentially severe weather days in that week are masked by cumulative FFDI.
Cumulative 3pm FFDI over a variable period is effectively a measure of average daily FFDI for the period.

Note 1: The best use of daily FFDI data to measure fire season severity is to count the number of days that peak FFDI exceeds say FFDI 50, which is the typical level for a TFB Day declaration.
Note 2 :This SSL paper did not use FFDI as an input variable due to absence of historic 3pm wind speed. However, it verified SSL validity with number of TFB days per season.

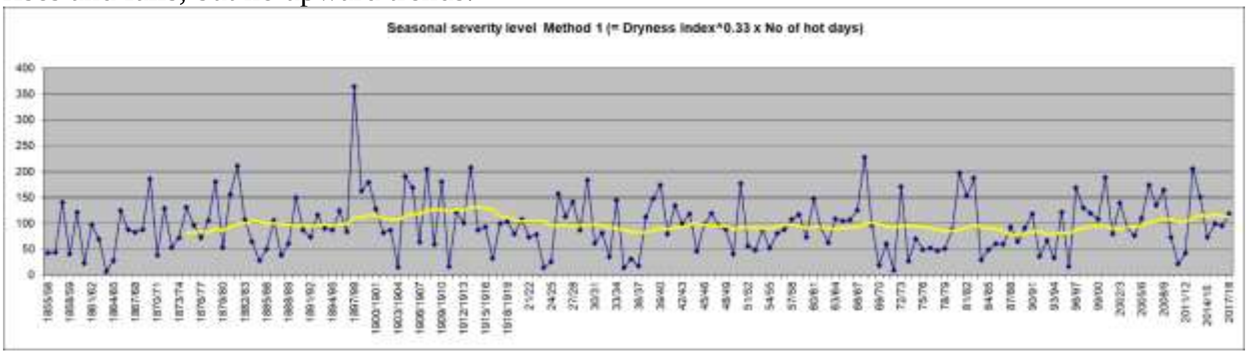
B Extreme fire weather days have become more frequent

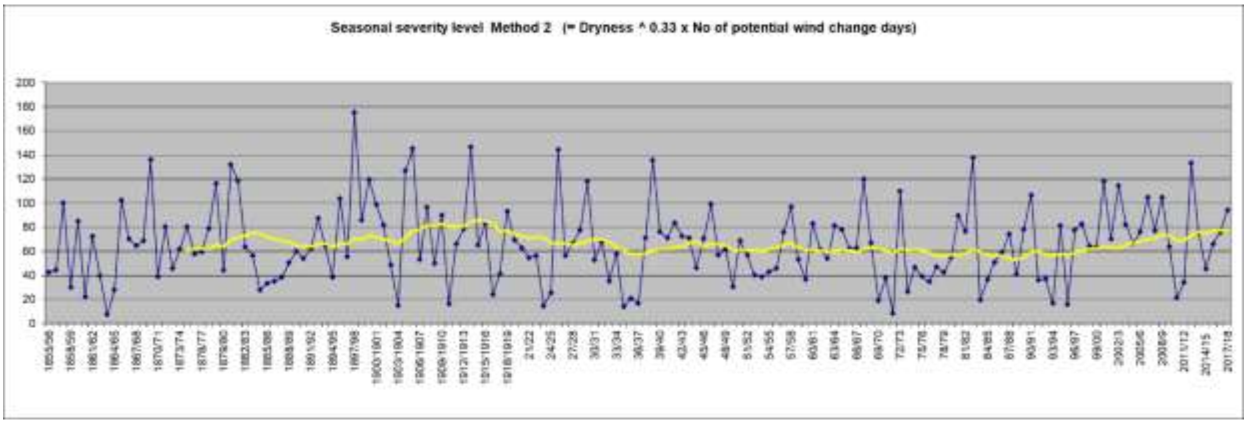
B1 The best and most direct measure of extreme fire weather days is number of TFB Days per year for a specific area. The following chart shows total Fire Ban Days per year in Central District of BOM.



The trend line shows the 5-year moving average to highlight identifiable peaks and troughs in TFB frequency over the decades. The chart also shows a net falling trend in TFB days per year since the late 1960's.

B2 The SSL analysis has developed two independent measures of seasonal severity level to analyse BOM data from 1855 to present. Both were verified against TFB data with a plausible correlation coefficient of R^2=50. To the extent that SSL predicts numbers of TFB Days, the 20-year moving average trend line shows slight rises and falls, but no upward trends.



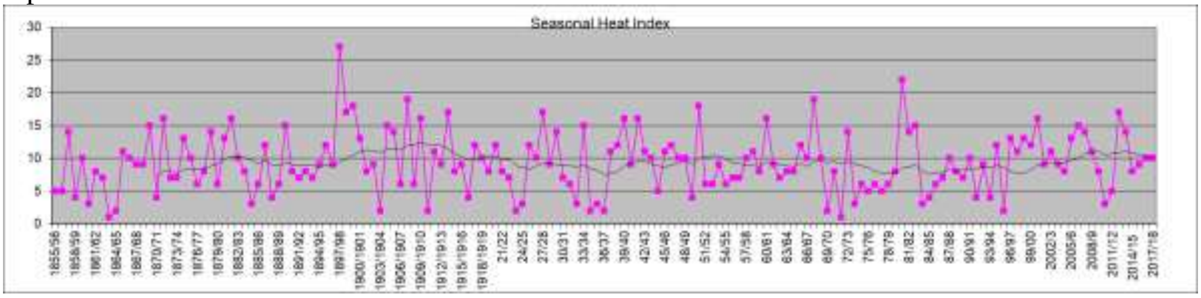


Conclusion: Available evidence does not support the assertion that extreme fire weather days have become more frequent.

2 Melbourne will swelter through more very hot days

Source https://www.theguardian.com/environment/2015/jan/26/climate-change-will-hit-australia-harder-than-rest-of-world-study-shows
"The national science agency CSIRO and the Bureau of Meteorology have released the projections based on 40 global climate models, producing what they said was the most robust picture yet of how Australia's climate would change. Melbourne will swelter through an average of 24 days above 35^0C by 2090, up from 11 in 1995."

Comment
The evidence from Melbourne weather station data does not support this finding. Here is the long-term chart of days above 35^0C for Melbourne between Sept and April:



The 20-year rolling average in 2016 is 10.5 days above 35^0C, in 1995 is 8, in the 1950's it is 9.5, and in 1900 to 1914 it is 11 - 12.

Conclusion: There is no evidence of an upward trend in number of very hot days per year, whether recent or long term.

3 Assertions by Climate Change Council

Source https://www.climatecouncil.org.au/resources/vicbushfires/

- "Climate change is increasing the risk of bushfires in Victoria and lengthening fire seasons.
- Extreme fire weather has increased since the 1970s in the east and south of Australia, including Victoria, with the fire season length extending from October to March.
- Climate change is now making hot days hotter, and heatwaves longer and more frequent.
- Drought conditions have been increasing in Australia's southeast.
- Climate change is driving an increase in dangerous fire weather, which in turn is increasing the frequency and severity of bushfires."

3A Risk of bushfires is increasing in Victoria due to climate change and fire seasons are becoming longer

Risk of bushfire occurrence depends on fuel factors and human influence factors as well as weather factors. If the fuel and human factors are held constant, risk of bushfire occurrence and spread increases with daily temperature, air dryness and wind speed.
To link climate change to bushfire risk, we therefore need evidence that climate change measured as increase in average annual temperature for Melbourne and surrounds can be linked to increases daily temperature, air dryness and wind speed.

Alas, fire season severity is driven by peaks of daily temperature, air dryness and wind speed, not annual averages.

Length of fire season is generally linked to spring or autumn rainfall deficiencies. We therefore need evidence that climate change measured as increase in average annual temperature for Melbourne and surrounds can be linked to spring or autumn rainfall deficiencies. The SSL analysis examined rainfall data for September to April each year from 1855 to present. There is no evidence of recent or persistent spring or autumn rainfall deficiencies.

Conclusion There is no evidence to support the assertion that the risk of bushfires is increasing in Victoria or that fire seasons are becoming longer due to spring or autumn rainfall deficiencies.

3B Extreme fire weather has increased since the 1970s in Victoria

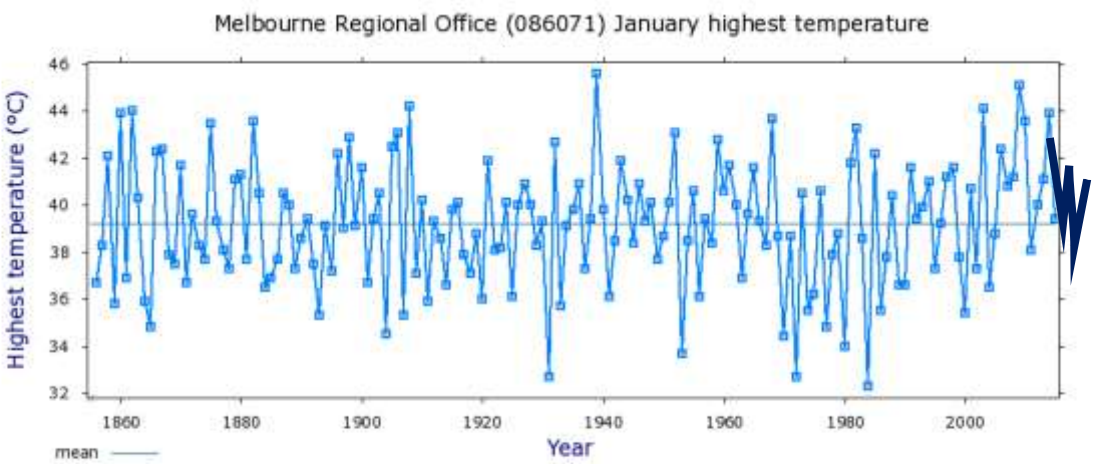
The Charts in 1B show that bushfire influencing weather factors have not increased since the 1970's.

3C Hot days are becoming hotter, heatwaves are becoming longer and more frequent.

Comment

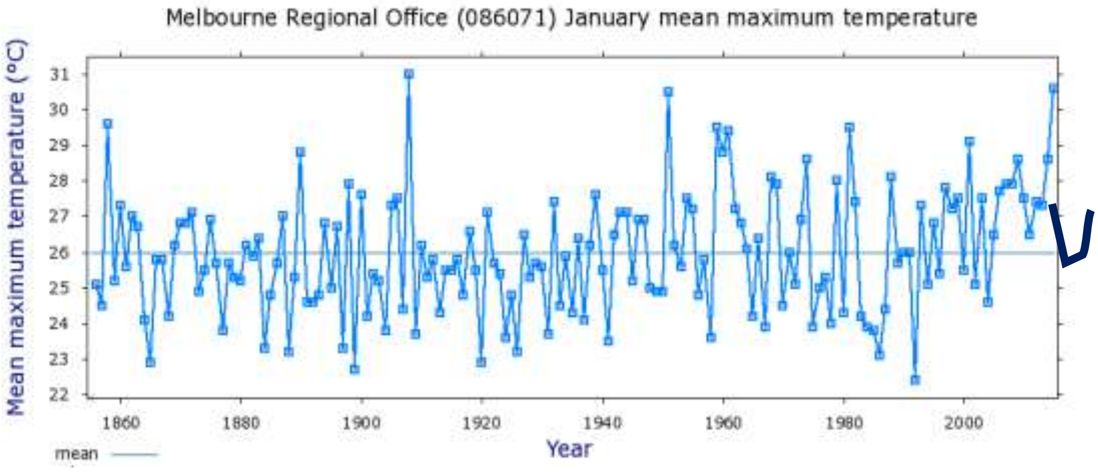
C1 Hot days are becoming hotter

Chart 1 shows there is no long term upward trend in the highest temperature in January, but there is perhaps the hint of a short term rise after 2000. Similar findings for February highest temperature. The cooler reading at Olympic Park tends to cancel out the rise (see INSET below)



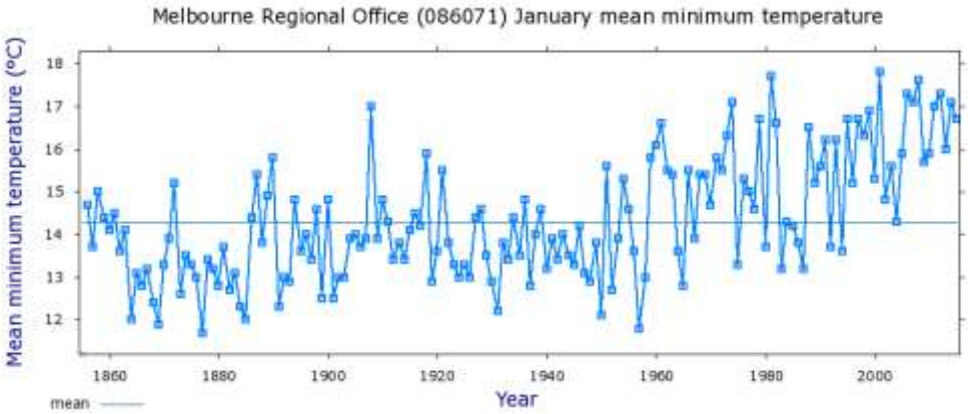
Dark blue line is the reading from replacement BOM weather station at Olympic Park.

Average maximum temperature January - no long term upward trend, but there is perhaps the hint of a short term rise after 2000. February's chart shows similar pattern. The cooler reading at Olympic Park tends to cancel out the rise (see INSET below).



Dark blue line is the reading from replacement BOM weather station at Olympic Park.

Whereas the monthly average maximum temperature show no upward trend, Melbourne's average minimum temperature has risen sharply by 3^0C since 1960. The cooler reading at Olympic Park removes only 0.4^0C from this rise (see INSET below).



Thus if we measure Melbourne's average temperature as half the difference between average maximum and average minimum, our average has risen by 1.5^0C over 60 years, yet our maxima remain unchanged.

Why then is minimum temperature rising?

INSET
The Melbourne way of reducing global warming
Reduce average maximum temperatures by one whole degree by changing location of weather station.

Melbourne Regional Office Weather Station closed mid January 2015.
Duplicate recordings at the Olympic Park site began in June 2013.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Melbourne Regional Office … is closing													
2013	27.3	29.2	27.6	21.3	18.1	15.4	15.9	16.5	20.1	19.8	22	24.7	21.5
2014	28.6	28.4	25.4	21.1	19.3	15.8	14.7	16.2	19.3	22.6	23.9	25	21.7
2015	30.6												
Olympic Park is new weather station													
2013						14.9	15.7	16.3	19.5	19.1	20.8	23.7	
2014	27.3	27.1	24.4	20.6	19	15.4	14.5	15.4	18.5	21.7	22.7	23.9	20.9
2015	25.9	26.4	22.7										
Difference													
2013						-0.5	-0.2	-0.2	-0.6	-0.7	-1.2	-1	
2014	-1.3	-1.3	-1	-0.5	-0.3	-0.4	-0.2	-0.8	-0.8	-0.9	-1.2	-1.1	-0.8
2015	-4.7												

This Table shows:
** Average annual maximum temperature fell by 0.8^0 C.
** Average maximum temperature for each fire season month (Nov to Mar) fell by 1 – 1.3^0 C
** The 4.7^{0}C fall in Jan 2015 is an anomaly. The station closed in mid Jan after a heat wave.
Melbourne Regional Office weather station is within the CBD, Olympic Park is just outside the CBD.
The big city is obviously a heat trap.
For how long has the heat of the big city inflated the temperatures?
Should January's mean max temp chart be now be reduced retrospectively by 1.3 degrees for the past few decades?

What about average Monthly Minimum Temperatures?

average monthly Minimum temp													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Melb Regional Office													
2013	16	17.6	16.7	12.3	9.8	7.4	8.4	9.3	11.2	11.1	12.4	14.3	12.2
2014	17.1	16.8	15.3	13.3	11.1	9.8	8.4	7.9	10	11.4	13.2	15.2	12.5
2015	16.7												
Olympic Faverage minimum temp													
2013						6.9	8.2	9.2	10.9	10.9	12	13.9	
2014	16.5	16.3	14.8	12.9	11	9.6	8.4	7.6	9.8	11	12.7	14.8	12.1
2015	15.9												
Difference													
2013						-0.5	-0.2	-0.1	-0.3	-0.2	-0.4	-0.4	
2014	-0.6	-0.5	-0.5	-0.4	-0.1	-0.2	0	-0.3	-0.2	-0.4	-0.5	-0.4	-0.4
2015	-0.8												

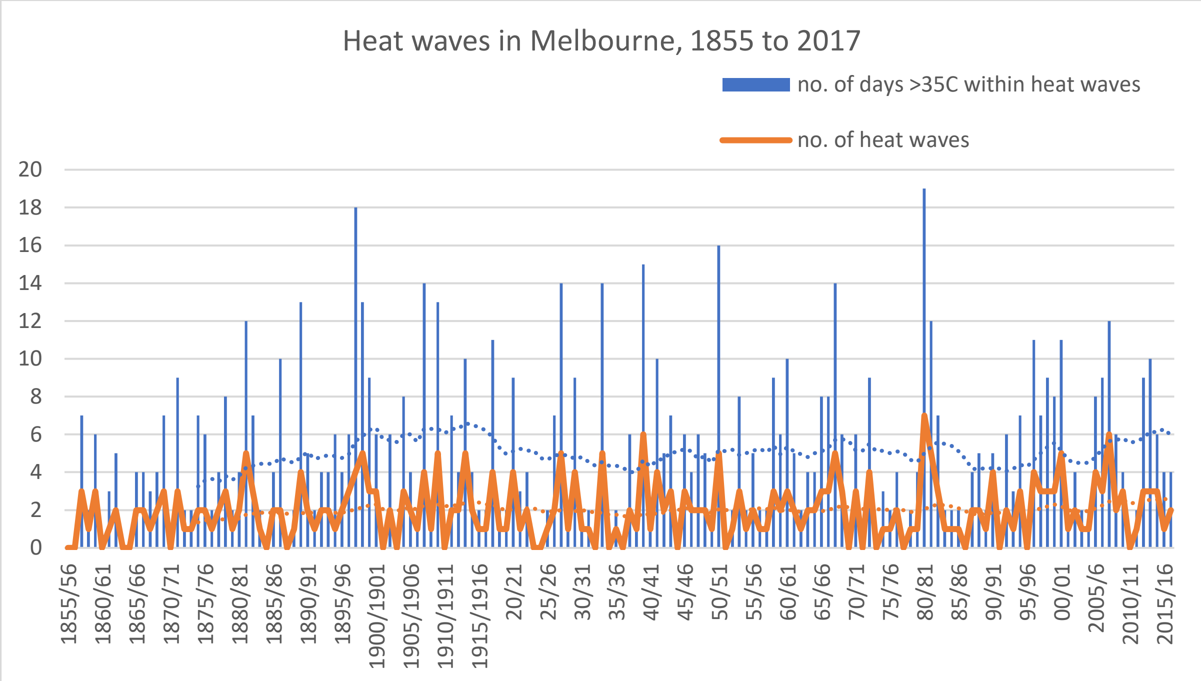
The Table shows
** Average annual minimum temperature fell by 0.4^0 C.
** Average minimum temperature for each fire season month (Nov to Mar) fell by 0.4 to 0.6^0 C
** The 0.8^0 C fall in Jan 2015 is an anomaly. The station closed in mid Jan after a heat wave.

Conclusion Hot days are not becoming hotter

C2 Heatwaves are becoming longer and more frequent

The SSL Analysis examined the number, frequency and length of heat waves at Melbourne weather station from 1855 to present.
A heat wave is defined as two or more consecutive days at or above 35^{0}C.
The following Chart shows:

- no upward trend in number of heat waves
- no upward trend in frequency of heat waves
- no upward trend in length of heat waves

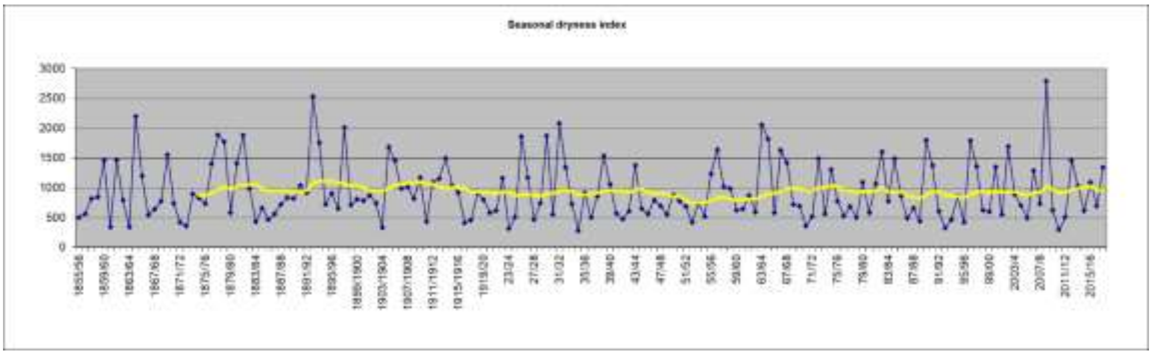


Conclusion: there is no evidence that heatwaves are becoming longer and more frequent at Melbourne weather station.

3D Drought conditions are increasing in Australia's southeast.

The SSL Analysis examined the seasonal rainfall from 1855 to present in a way that over-emphasised the influence of rainfall deficiency in the hottest months on potential for fine fuel dryness. It is therefore a useful indicator of drought conditions during the fire season, as compared to drought during winter or other months when bushfire danger is not expected.

The chart shows no upward or downward trend in fire season drought conditions.



Conclusion: There is no evidence that fire season drought conditions are increasing at Melbourne weather station.

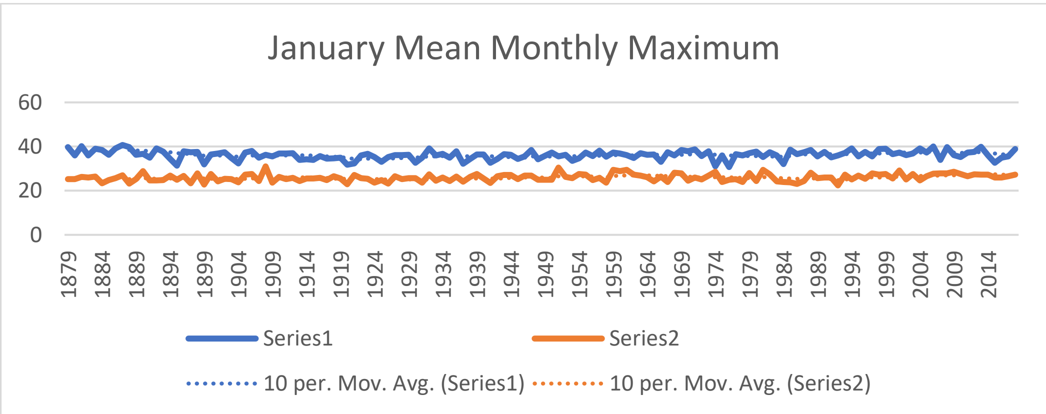
3E Dangerous fire weather is increasing, which in turn is increasing the frequency and severity of bushfires.

The SSL analysis shows that severe weather has not increased, and has remained within the expected long-term range.
The following Table summarises data for higher severity fire seasons from the Part 2 analysis by historic policy eras. It shows the proportion of higher severity fire seasons has remained consistent at 31 to 33% of summers. It raises the possibility that fire season severity is independent of the rise in average temperature that has occurred at Melbourne’s weather station since the 1960’s.

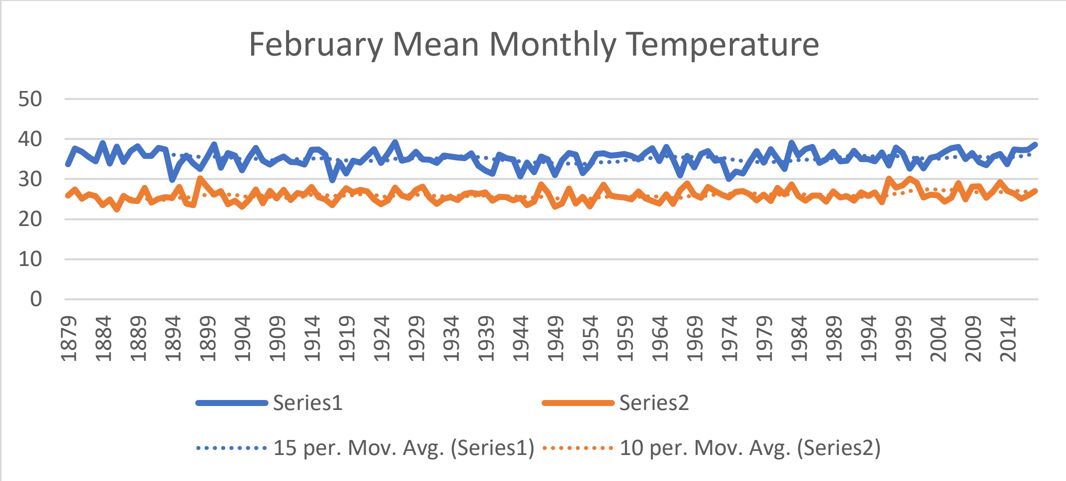
Policy Era	**No. of years with higher severity fire seasons SSL > 115**	
1855/56 to 1900/01	15 / 45	33%
1900/01 to 1944/45	14 / 45	31%
1945/46 to 2017/18	22 / 70	31%

The Part 2 analysis suggests that the bushfire frequency and severity is not becoming worse due to weather factors. On the contrary, it shows that the bushfire threat responds to good bushfire protection policies, independent of weather severity. Appropriate policies have lessened the bushfire damage toll and we suggest that further policy improvements can eliminate the bushfire threat in targeted areas. The recent increase in bushfire damage during severest weather is due to policy failure, not the weather.

Finally, if we explore the theory that Melbourne’s severest weather, ie, hottest and driest, blows down to us from our inland deserts to the NW, our maxima cannot be higher than inland weather stations. The inland station with the longest data sequence is Alice Springs. Both months show Melbourne data running parallel and below Alice Springs. Both stations have a flat trajectory. Neither station has an upward trend.



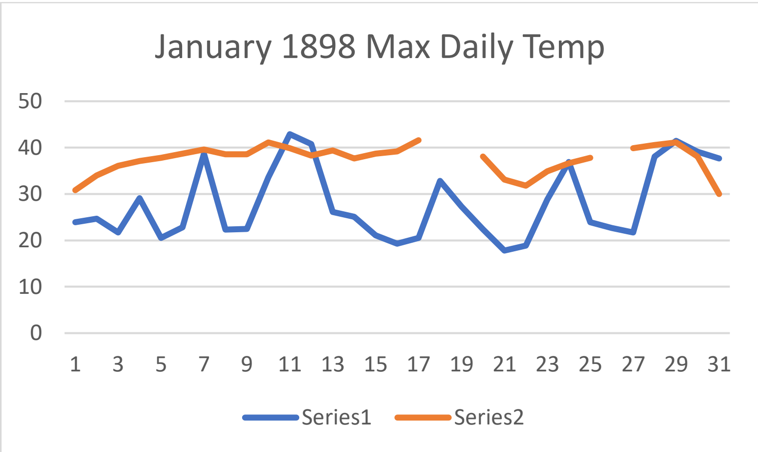
Series 1 is Alice Springs, Series 2 is Melbourne.



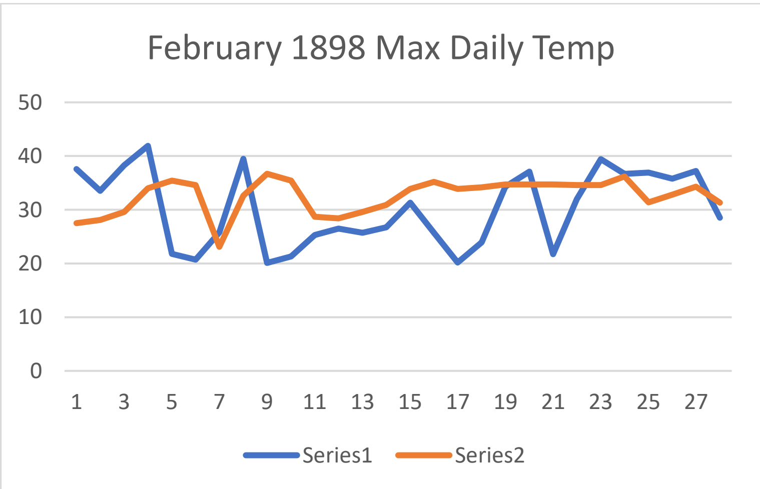
Series 1 is Alice Springs, Series 2 is Melbourne.

We now look at temperature comparisons for three notorious bushfire days.

1 Red Tuesday occurred on 1 Feb 1898, in the middle of an eight-day heatwave, from Jan 28 to Feb 4.

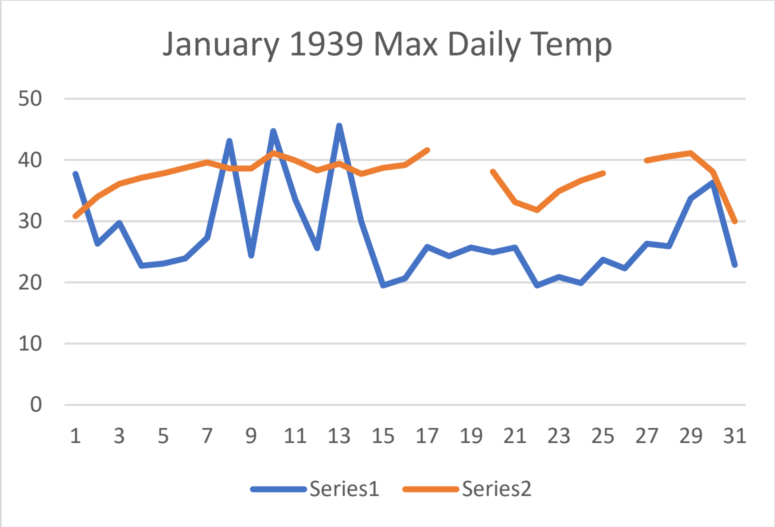


Series 1 is Melbourne, Series 2 is Alice Springs.



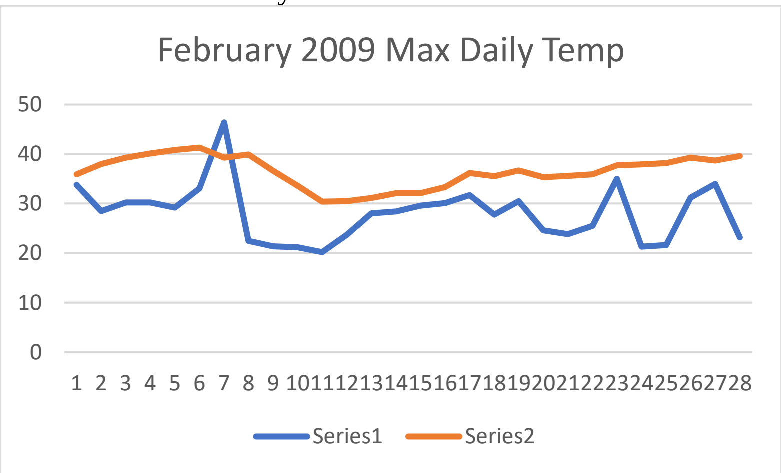
Series 1 is Melbourne, Series 2 is Alice Springs.

2 Black Friday, 13 Jan 1939



Series 1 is Melbourne, Series 2 is Alice Springs.

3 Black Saturday 7 Feb 2009



Series 1 is Melbourne, Series 2 is Alice Springs.

We can regard Alice Springs maxima as an indicator of average inland temperature. Many of Melbourne's hottest days equalled Alice Springs temperature.
Some Alice Springs days were well below expected inland temperatures, probably due to localised cloud cover over the Alice. Nevertheless, Melbourne reached expected inland temperatures from other inland areas.
Surprisingly some Melbourne days reached temperatures well above very hot inland temperatures. Why? Is there a Fohn-like effect that causes very hot inland air to become hotter in Victoria?