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The climatological association of strong wind changes and periods of enhanced fire weather over Victoria.

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Introduction

Wind changes dramatically affect fire behaviour and therefore impact on community and fire fighter safety. The classic paradigm in Victoria of wind changes influencing fire behaviour is the shift from a long flank fire to a wide head fire following the backing of the wind from northwesterly to southwesterly with the passage of a dry cold front, such as occurred on Ash Wednesday in 1983 (Oliver et al 1984) and on Black Saturday in 2009 (Cruz et al 2012. Cheney et al (2001) highlighted several events when dry cold frontal wind changes led to the flank of a fire becoming the head fire following a wind change, with injury or death to firefighters. However, there are other drivers of wind change such as sea-breezes, mountain waves, other topographically-induced circulations, and inversion breaking and all would likely impact fire behaviour. The questions addressed in this paper are:

- What is the climatology of strong wind changes over Victoria?
- How frequently are strong wind changes associated with days of elevated Forest Fire Danger Index?
- Are there regional variations in the climatology of combined strong wind changes and elevated high fire danger across the Victorian landscape?

Method

The primary data set used as the basis for this analysis is the latest version of a high spatial (4km grid) and temporal (1-hour) resolution fire weather climatology data set over Victoria for the period 1972-2017. The data set includes screen level wind speed and direction, temperature, relative humidity, and Forest Fire Danger Index (FFDI). The grids are generated using the WRF numerical weather prediction model, with bias correction across the full range of the weather parameters using quantile mapping, and is described in Brown et al (2016). While the gridded data has been bias-corrected, it will be termed the WRF data in this paper. Automatic Weather Station (AWS) observations (OBS), available for a lesser period and at a distributed number of stations are also used.

Based on the WRF hourly data set a wind change strength from one hour to the next can be calculated for each grid point. The metric of wind change used in this study is the magnitude of the vector difference between two successive hourly values of wind speed and direction. This will be termed hereafter the Vector Wind Change (VWC, km hr^{-2}). The VWC can have a large value if speed change is large but with small direction change, or with large direction and moderate speed change. However, large values will not occur if speed is low, irrespective of the degree of direction change. This is a different approach to the Wind Change Danger Index (WCDI) described by Huang and Mills (2006), but comparisons between the two indicate a close correspondence on most occasions, albeit with the WCDI being a little more sensitive to speed changes. The VWC is used for its simplicity and close correspondence with subjective assessments of "wind change" from inspection of wind speed and direction hourly time series both from the WRF data set and from the AWS data.

This paper first compares the WRF and the OBS climatologies of VWC and FFDI to confirm that the WRF data well represent the observed climatology. The diurnal and annual frequency distributions of VWC and FFDI are then diagnosed over the full period of the data set (1972-2017) to determine a threshold "strong" VWC value. Finally, seasonal analyses display the variation of 95th percentiles of VWC and FFDI across Victoria, and the spatial variation of numbers of days when these thresholds are jointly exceeded.

WRF compared to AWS climatology 2000-2017.

The WRF VWC and FFDI climatology are first compared with the equivalent climatology at a number of AWS locations (see Fig. 1) for the period 2000-2017. Longer time periods are not consistently available at all AWS locations, but in this analysis locations with 18 years of records are used. Metrics chosen are the 95th percentiles of highest daily VWC (VWC95) and the 95th percentiles of highest daily FFDI (FFDI95). These are chosen in that they are sufficiently high as to be unusual, but not so high that they do not allow a sample of sufficient size for robust analysis.

Figure 1. The study area: the labelled location of each AWS station is identified by a solid circle and the Department of Environment, Land, Water and Planning (DELWP)-defined Bushfire Risk Landscapes are shown in different colours and labelled in bold, italicised text.

Figure 2 shows the mean seasonal and diurnal frequency distributions of VWC95 and FFDI95 calculated individually at each location using all months from 2000-2017, and the monthly and hourly frequencies averaged over all 22 AWS locations for the WRF and the OBS data sets. Both annual cycles and diurnal cycles are well matched between WRF and OBS distributions. Interestingly, while it is not unexpected that the FFDI distribution peaks in summer and in the mid-late afternoon, the VWC distribution also shows a late afternoon/early evening maximum, and also a maximum in the warmer months, although both diurnal and seasonal peaks are broader than for the FFDI.

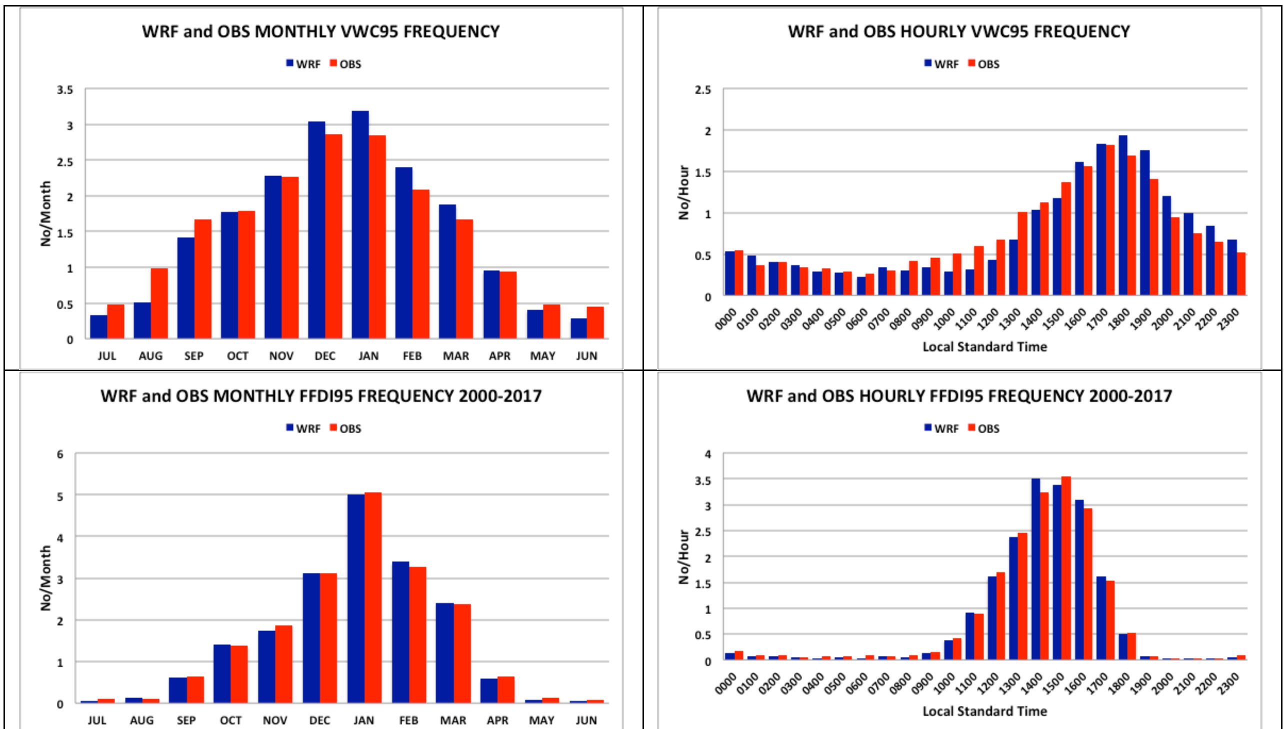

Figure 2. Average frequency distributions by month and by hour of 95th percentile highest daily VWC and FFDI events for all 22 locations from the WRF and from AWS observations for the period 2000-2017. NB Times are Local Standard Time.

Figure 3 shows the scatterplots of 95th percentile VWC and FFDI for each individual station. The agreements are remarkably good given likely issues of representivity of, in particular, the wind observations versus the model values in terms of anemometer exposure, observation reporting practice, and WRF model characteristics. Again, while it is not unexpected to see a considerable range in values of FFDI across the state with stations ranging from the far northwest to the alpine and coastal East Gippsland, the large range in the VWC95 values is perhaps less expected a priore.

Figures 2 and 3 indicate that the gridded values of VWC95 and FFDI95, and their seasonal, diurnal, and geographic variations, are well represented in the gridded fire weather data set.

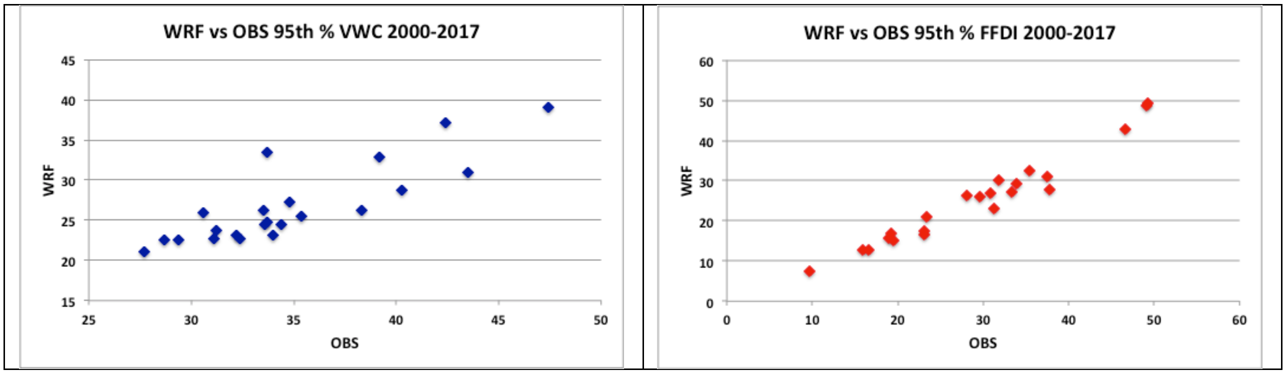

Figure 3. Scatterplots of WRF vs OBS VWC95 and FFDI95 for the 22 individual stations.

1972-2017 Climatology

The climatology of the full 1972-2017 data set is now addressed. Figure 3 showed considerable geographic variation across Victoria in the magnitude of the annual VWC95 for the 2000-2017 period. Figure 4 shows the magnitude of VWC95 and FFDI95 by location, with the locations ranked by magnitude, for the full period. The highest VWC95 are generally in the South West and West Central regions, and near the coast, while lower values are seen in the north, northwest, and in East Gippsland. The FFDI95 values are highest in the northwest, north and South West through West Central, with lower values over elevated terrain and in Gippsland. There is not a strong relation between the locations in the two time series. Thus, a more careful analysis of the occurrences of these two independent events, and how this varies across the landscape, may be instructive.

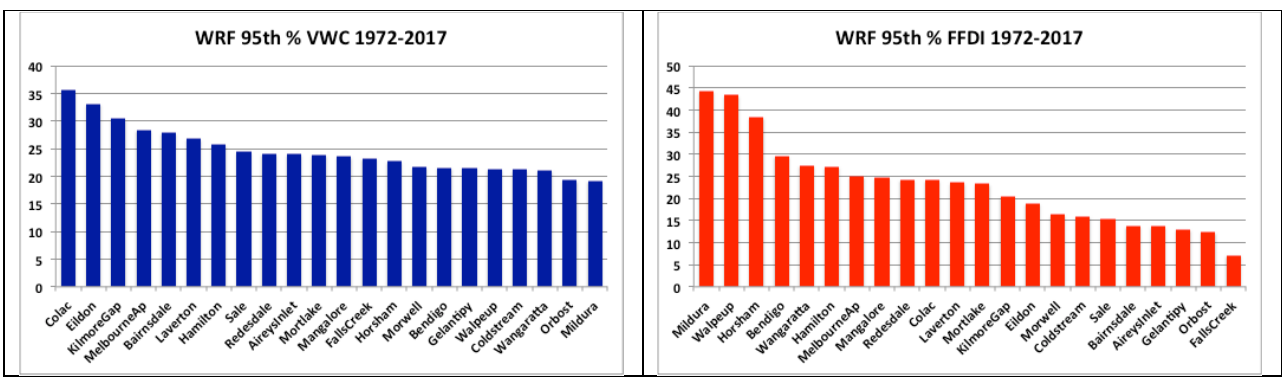

Figure 4. Annual VWC95 (left) and FFDI95 (right) magnitudes for the period 1972-2017, at each of the station locations shown in Fig. 1, with locations ranked by magnitude.

Climatology of Joint Events

It might be postulated that a day on which there is significant wind change that is also a day of elevated FFDI is one that will be of greater importance to fire managers than a day on which only one of these events occurs. Counting the number of days per year or per season at each location when specified thresholds are each exceeded provides a means of assessing this. The question then becomes what constitutes a suitable threshold for each variable, given their climatologies vary across Victoria. In this section we focus only on the December-January-February season when most elevated fire danger days occur, and somewhat arbitrarily choose two sets of thresholds as a first test of this analysis.

The first threshold choice is the number of occasions on which the 95th percentile is jointly exceeded for each event. This is both simple and allows for equal numbers of potential events for each variable. The number of events per year when this criterion is satisfied is shown in Fig. 5 (left), with the locations ordered by magnitude. Greatest frequencies, around 2 days per summer season, occur in coastal, South West and West Central locations, with lower values in Alpine, northern, and East Gippsland regions. There are two things to note here. First, a 95th percentile event will occur some 4.5 days per summer, so if the two events occur randomly, then joint 95th percentile events are likely on some 0.2 days per summer. Thus, these frequencies, even at the lowest numbers, indicate some association of the two events: ie they are not completely random. Second, for some of the locations the FFDI95 value is quite low, and on such a day a strong wind change may not be problematic for fire management.

This suggests a second option: to choose a threshold for each variable that is more associated with fire behavior. For FFDI there are established classes of fire danger, and in this case we chose an FFDI value of 25 – the lower limit of the "Very High" fire danger rating. The choice of a VWC threshold is much less well posed, as while the Ash Wednesday and Black Saturday wind changes well exceeded the 95th percentile, other relatively weak wind changes can have significant effects on fire behavior (eg Peace et al 2015). In this case we have chosen a VWC value based on the second quartile of the VWC95 values shown in Fig. 4: 24 km hr^{-2}. Each criterion will thus have a varying frequency across the chosen locations. The ordered magnitude of counts per summer season when VWC>24 and FFDI>25 on the same day is shown on the right panel of Fig. 5, and rather different ordering is seen to that in the left panel, reflecting the differing combinations of VWC and FFDI climates. The regions with the highest frequencies during the summer season are the South West, West Central, and extending into the southern parts of the Mallee and Murray- Goulburn, with the lower frequencies in both the far northwest, the north, and Alpine and East Gippsland. Again, frequencies are above those expected by random occurrence.

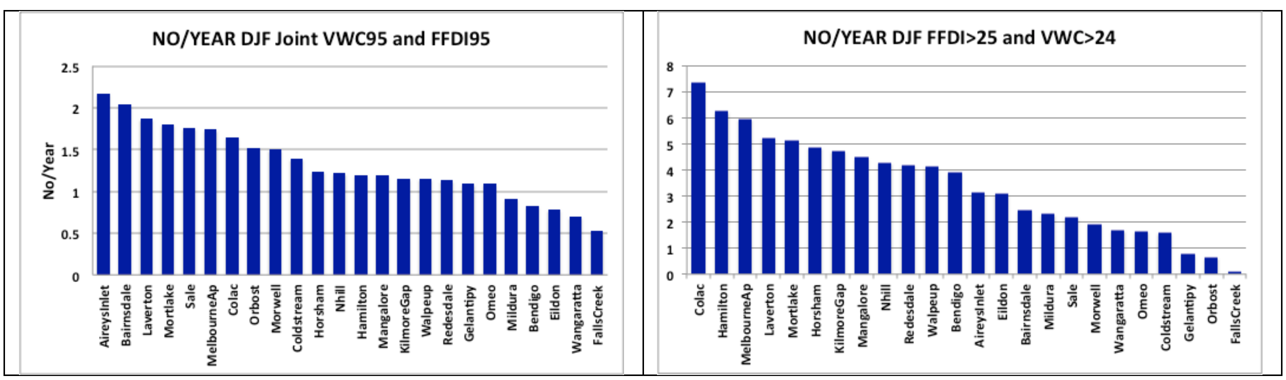

Figure 5. Numbers of joint VWC95 and FFDI95 events per summer (left), and numbers of days when FFDI>25 and VWC>24 (right), with locations ordered by magnitude.

Discussion and Concluding Remarks

This preliminary examination shows that there are clear geographic variations across Victoria in the frequency of strong wind changes, and also in the frequencies of days when both strong wind changes and elevated fire danger both occur. Understanding these regional variations and frequencies may assist fire management planning, particularly if the thresholds relevant to fire management can be refined. It was also noted that the frequencies of days in summer when both elevated fire danger and strong wind changes occur is considerably higher than that expected if the events occur randomly. Theories for this include: 1) both FFDI and VWC are positively dependent on increasing wind speed, so high values of each will tend to occur when wind speeds are higher; and 2) the well-known association of days of extreme fire danger ahead of a dry cool change (and thus a high value of VWC) in Victoria. There may be other factors as well, and these associations are a focus of ongoing investigation. Finally, the frequencies of elevated FFDI and VWC in the spring and autumn prescribed burning seasons are also subject of ongoing investigation, as are tests involving more targeted threshold values.

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