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FIRE CLIMATES OF AUSTRALIA: PAST, PRESENT AND FUTURE

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1. INTRODUCTION

Fire is a major influence on the Australian landscape, and the continent, particularly the southeast corner, is one of the most fire-prone regions of the world. The ecosystems found in Australia have evolved with fire, and some plant species, such as eucalyptus, actively promote it. Human use and management of fire, in both historical and recent times, has shaped the land and the biodiversity. Very little of Australia remains unaffected by fire, either those deliberately lit or uncontrolled bushfires.

Australia covers a vast geographic area, with a wide variety of climates observed. These climates range from the monsoonal tropics of the north to mid-latitude Mediterranean climates in the south. Vegetation is similarly wide-ranging, with grassland and open woodland in the north, while forests and shrubland are more common in the south. Eucalyptus is the dominant species in most areas. Given this combination of climate and fuel, it is fire season somewhere in Australia throughout the year. In the north, the fire season occurs in the winter and spring months. Further south, the fire season moves into summer and autumn.

Despite the natural propensity for fire, not all years are the same in terms of fire risk and activity. Some years, major events like the Ash Wednesday fires (February 1983) or the Canberra fires (January 2003) wreak havoc on the landscape. In other years, large bushfires are rare. Understanding this variability and its relation to climate is crucial to our understanding of how fires will behave in a given area and to strategic planning for land and bushfire management agencies.

The long-term goal of this project is to develop an Australia-wide seasonal prediction scheme for fire weather risk. The current project is a precursor to accomplishing the larger goal. The goals of this project are to:

- Determine the fire weather history in Australia.
- Understand the factors that determine the interannual variability of fire climate in Australia.
- Investigate the possible impacts of climate change on fire climate.

At this time, the project is still under way. What follows is an outline on the progress thus far.

2. DATA

Creating historical records of fire weather necessitates the compilation of high-quality homogeneous climate data sets free from the effects of factors such as site moves and instrument changes. These data sets have been created by the National Climate Centre for daily rainfall and temperature in Australia. A similar data set is under development by the author for humidity. A preliminary version is used for this study. Unfortunately, no such data base exists for wind at this time. For the wind data, ordinary station data are used. The data used for this study extend from 1957-2003

In this study, the McArthur Forest Fire Danger Index (FFDI) is used (McArthur 1967). The index is an Australia-specific fire weather index, specifically geared toward dry sclerophyll (e.g. eucalyptus) forests with afuel load of 12 t/ha. It is used by fire authorities through much of Australia. It is computed daily from daily maximum temperature (T; ^{o}C), daily minimum relative humidity (RH; %), daily maximum wind speed (V; km/h) and 24-h rainfall (mm) ending at 9am of the day in question, using the following formula:

$$FFDI = 1.2753 \times DF^{0.987} \times \exp(0.0338T + 0.234V - 0.345RH)$$

The ‘DF’ refers to the so-called drought factor, a term which is intended to encapsulate the fuel state and its availability for combustion. The drought factor ranges from 1 to 10 (unitless). The low end of the scale represents unburnable fuel and the top end indicates extremely dry, highly flammable fuel. The drought factor depends on the Keetch-Byram Drought Index (KBDI, Keetch and Byram, 1968), which estimates the long-term soil moisture deficit, and the ‘most significant’ rain event in the last 20 days, accounting for short term drying. Its development is highly empirical and several methods to calculate it exist. Here, the Griffiths (1999) method is used, keeping in line with operational procedures at the Bureau of Meteorology

Values of FFDI thus computed nominally range from 0 to 100, although values above 100 are regularly observed in extreme fire weather situations. For example, the FFDI at Canberra on the day of the 2003 bushfires (18 Jan) is estimated to be 111, the highest in the record at the station. To simplify the interpretation of FFDI, fire agencies generally give a fire danger rating (FDR) as shown in Table 1 below.

Fire Danger Rating	FFDI range
low	0-5
moderate	5-12
high	12-25
very high	25-50
extreme	50+

Table 1. McArthur FFDI values for each Fire Danger rating class

While the fuel types and loads assumed in the calculation of FFDI are not generally met across most of Australia, the calculation gives a good proxy for fire weather in general and provides a sound basis for comparison across the broad region of Australia.

3. 1957-2003 FIRE WEATHER HISTORY

To date, fire weather histories have been completed for 18 stations in southeast Australia. Similar computations across the remainder of Australia, about 55 stations in total, are planned. Figure 1 shows the probability of obtaining a given FDR in a given October through March fire season for Canberra, the nation's capital. For example, during the first year of the record (1957-8), the FFDI exceeds the 'moderate' rating on about 90% of the 182 days in the fire season, the 'high' rating on about 55%, the 'very high' rating on about 30%, and the 'extreme' rating on less than 5% of days. However, the time series shows that there is considerable interannual variability, with several years having a large number of days in the 'very high' and 'extreme' ratings (e.g. 1982-3) and some years having very few days in these categories (e.g. 1974-5).

Figure 2 shows a spatial view of plots as in Fig. 1 for 10 stations in SE Australia. From this, it can be seen that the amount of interannual variability at Canberra (centre) is typical of inland stations in SE Australia. Careful examination of these plots shows that the many of the station's probabilities exhibit some degree of spatial correlation, although the absolute values of the probabilities does vary. Relatively high and low risk years are the same across wide regions. In contrast, coastal stations such as Adelaide (top left) and Coffs Harbour (upper right) show considerably less interannual variability, and probabilities are reasonably constant from year to year. Stations in the Murray River Basin (Mildura and Bendigo; centre and bottom left), the plots show a distinct upward trend in the FDR probabilities beginning in the late 1970s. In the next section, possible sources of this variability are examined.

4. CONTROLS ON FIRE CLIMATE VARIABILITY

As noted in the introduction, one of the goals of this research is to identify climate factors which influence fire weather across Australia. It is well-known that one of the most important controls on climate in Australia is the El Nino-Southern Oscillation (ENSO) phenomenon. Indeed, Williams and Karoly (1999) documented a strong link between fire weather and ENSO at 6 of their 8 (widely spaced) stations across Australia. The data here allows for more regional aspects of this relationship to be examined.

Figure 3 depicts a spatial view of the simultaneous correlation between Oct-Mar average Southern Oscillation Index and the daily-averaged FFDI at the various stations in SE Australia. Over the interior of New South Wales (NSW), the correlations are quite strong (red numbers). Over much of the rest of the region weak to moderate (but still significant) correlations are seen (green, blue numbers). In South Australia and northern NSW, the correlations are insignificant (black numbers). The region of the strong relationship in interior NSW corresponds to the regions of strong ENSO-rainfall relationships reported in other studies (e.g. McBride and Nicholls 1983, Nicholls 1989).

Figure 4 demonstrates the effect of ENSO on the observed fire climate. The plot shows the difference in the relative frequency of the FDR for Canberra during El Nino and La Nina years. Similar to Williams and Karoly (1999), a strong relationship is seen between the FDR and the phase of ENSO. The frequency of 'very high' and 'extreme' days more than doubles during the warm phase of ENSO (El Nino). Similar variations are seen at many of these stations.

From these figures, it follows that ENSO plays a large role in modulating the fire climate in SE Australia. Statistical tests indicate that significant differences between El Nino and La Nina years exist in seasonal means of maximum temperature, rainfall and relative humidity at many of these stations. Given the strong correlations between rainfall and humidity and rainfall and temperature, it is reasonable to suggest that the FDR differences are largely determined by the ENSO-rainfall relation.

Despite the significant correlations, ENSO only explains 15-35% of the variance. A closer look indicates that much of the difference between El-Nino and La Nina years is due to the very strong El Ninos observed in 1982-3 and 1997-8. For weaker El Nino conditions, the relationships are not as strongly defined. Different ENSO events evolve differently, and are likely to have different climatic effects.

In short, ENSO is not the entire answer to fire climate variability. For a more complete understanding, other potential influences must be examined. The following is speculation on some possible influences on the observed record. Any actual effects on Australian fire climate remain to be determined.

A likely source of fire climate variability is the Indian Ocean sea surface temperature (SST). Nicholls (1989) showed the difference in SST between Indonesia and the central Indian Ocean is positively correlated to rainfall in a broad NW-SE band across central Australia and negatively correlated to east coast rainfall. This pattern of ocean temperatures is similar to the recently identified Indian Ocean Dipole (Saji et al., 1999), which may be an extension of ENSO into the Indian Ocean (Allan et al., 2001).

Another possible source of variability is the Southern Hemisphere Annular Mode (SAM). Thompson and Wallace (2000) describe an annular mode as ‘a zonally symmetric, meridional seesaw in atmospheric mass between the [pole] and the mid-latitudes’. It is an episodic phenomenon with a lifetime of about 10 days. The effect of SAM on Australia varies with the season; the positive phase of SAM corresponds with generally higher summer rainfall in north central and southeast Australia and lower winter rainfall in southeast and southwest Australia (H. Hendon, personal communication). On longer time scales, historical records of SAM activity suggest that the strength of SAM has been increasing since the 1970s (Marshall 2003). A peak was also found in the late-1950s and early 1960s (Jones and Widmann, 2004).

The possibility of decadal scale variations also remains. It has been noted that many aspects of the southern hemisphere circulation changed in the late-1970s (e.g. van Loon et al., 1993). These changes are likely interrelated to the above mentioned trend in SAM and the observed changes in the behaviour of ENSO since the late-70s (see Fedorov and Philander, 2000).

An active area of climate research is the determination of whether the decadal scale variations in ENSO and SAM are related to ‘natural’ climate variability or a reflection of anthropogenic climate change. The changes in SAM have been linked to the increase in greenhouse gases (e.g. Kushner et al., 2001) and stratospheric ozone depletion (e.g. Thompson and Solomon 2002). The changes in ENSO are associated with long-term increase in SST in the eastern Pacific (e.g. Federov and Philander 2000). However, the resolution to these questions has not been finalized.

The direct effects of anthropogenic climate change on fire climate is another potential source of variability. Examining the 2002-3 drought, Nicholls (2004) suggests the possibility that the enhanced greenhouse effect is exacerbating droughts in SE Australia through higher temperatures and increased evaporation. At many of the stations in Fig. 3, this season is one of the worse on record (e.g. Cobar and Bendigo). The possibility that the upward trends are due to this cannot be ruled out at this time.

Work is also underway with Kevin Hennessy of the CSIRO to use the output from climate models and the observed fire histories to estimate the effects that climate change may have on future fire climate. By imposing the changes on the distributions of temperature, wind speed, humidity and rainfall indicated by the model on the observed time series, the effects of global warming can be estimated. This has been done for SE Australia. Generally, the results indicate that the number of days with an FDR of ‘very high’ or ‘extreme’ will increase, doubling at some sites. Daily-average FFDI increases, particularly in the spring and summer months, suggest a longer fire season at many locations. More details of this work will be available at the conference. While much remains to be done to fully understand the strengths and limitations of our approach and the model, our results are broadly similar to other fire danger climate change studies across Australia (e.g. WIlliams et al. 2001)

5. CONCLUDING REMARKS

Many questions and tasks remain in this research and other related projects. The fire weather history for all the stations remains to be completed. A thorough examination of all the potential sources of climate variability needs to be done. With this, a better understanding of the factors influencing fire climate variability across Australia will be the result. However, some critical issues, such as the interactions between the climate and vegetation, remain unexamined at this time. This points to the need to gain physical insight, in addition to a statistical understanding, into the processes involved. This will assist in the development of a seasonal forecasting scheme.

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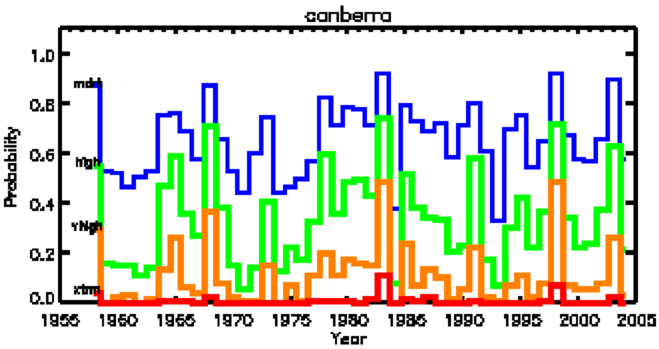

Figure 1. Time series of the probability of obtaining an FDR of moderate (blue), high (green), very high (orange) or extreme (red) during a given October-through March fire season. This example is for Canberra.

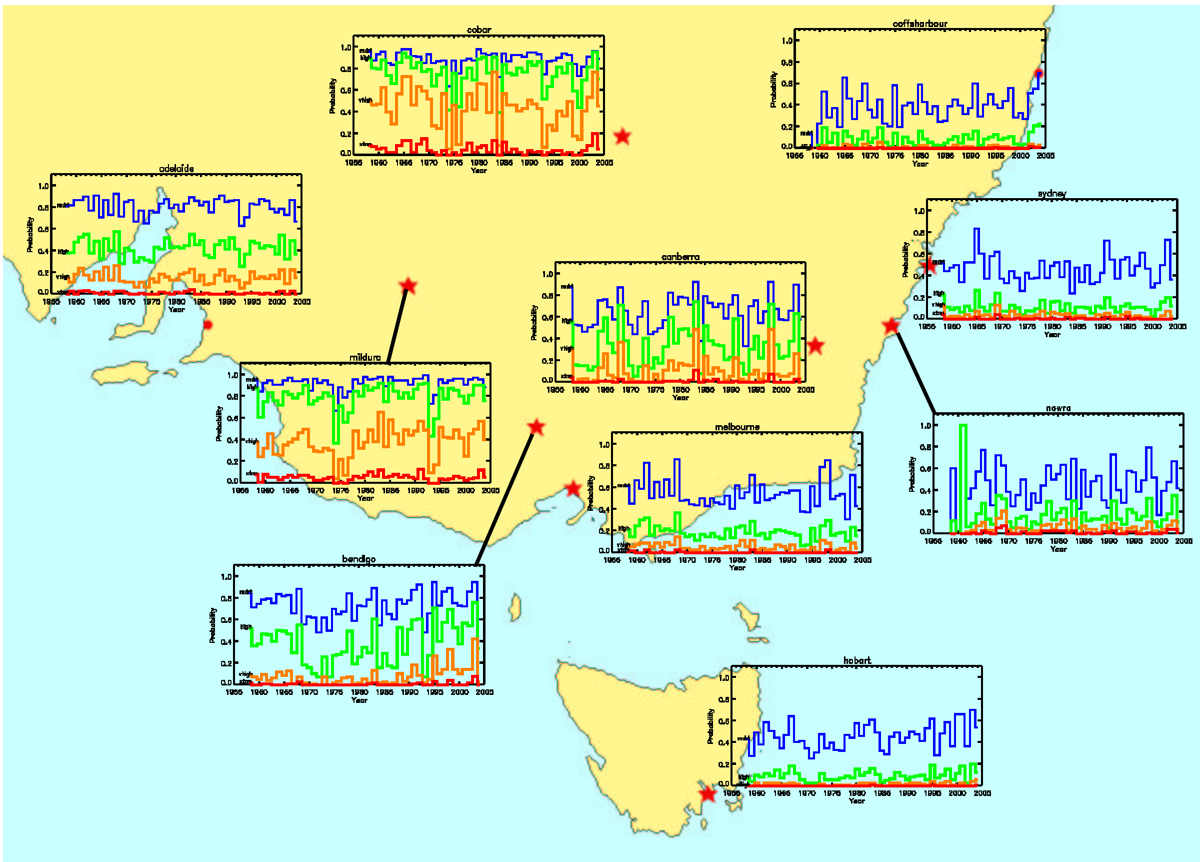

Figure 2. Map showing FDR probability time series (as in Figure 1) at 10 stations across southeast Australia.

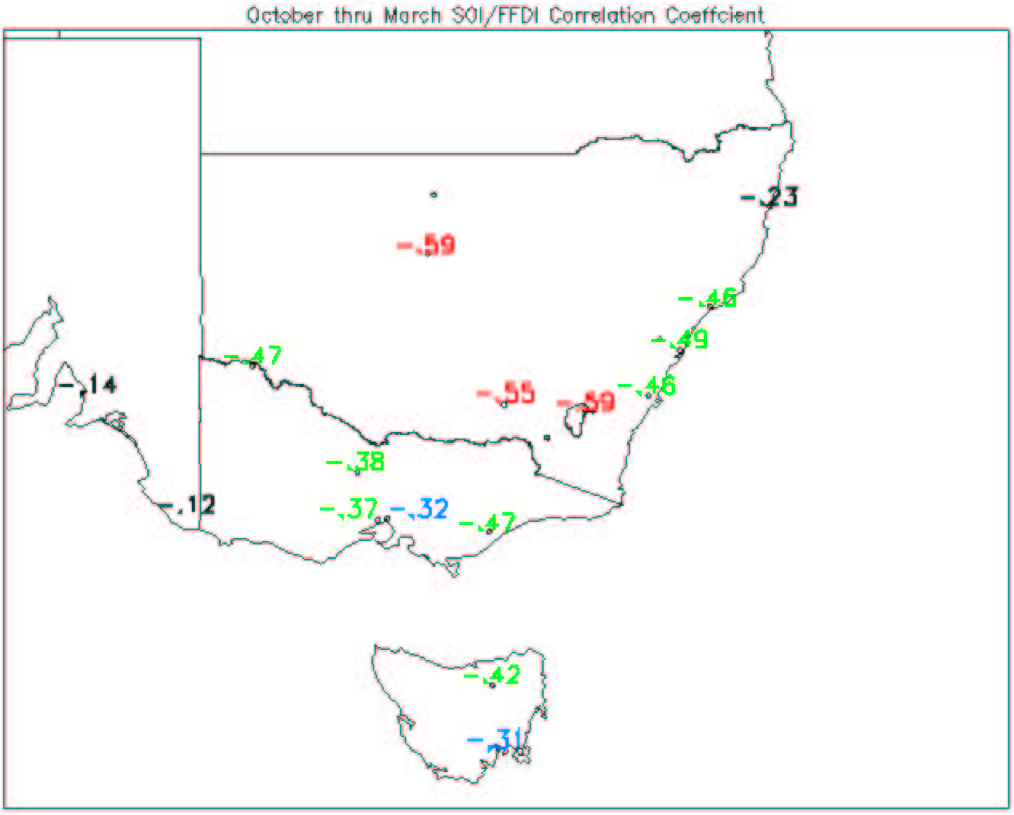

Figure 3. . Correlations of fire season FDI and fire season-averaged daily FFDI. Significance at the 95% level occurs when r~0.3.

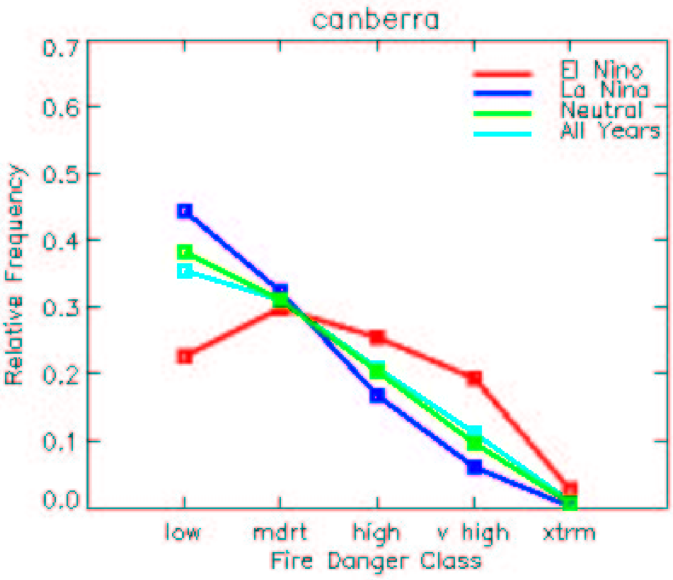

Figure 4 Relative frequency of occurrence of FDR during an October through March fire season during El Nino, La Nina, Neutral and all years.