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Climate variability in the land of fire and flooding rain

Kiem, Franks and Verdon examine the relationship between multi-temporal climate variability and the risk of floods and bushfires

Abstract

Traditionally, the chance of climate related emergencies (e.g. floods, bushfires) occurring has been considered the same from one year to the next. However, recent research has highlighted the fact that this is definitely not the case. Analysis has revealed strong relationships between the El Niño/Southern Oscillation (ENSO) and the occurrence of climate related emergencies, especially in eastern Australia. In addition, climatological studies have also revealed multi-decadal epochs of distinct climate states across eastern Australia. Within these multi-decadal epochs significant variability exists in the magnitude and frequency of ENSO impacts resulting in elevated (or reduced depending on the climate state) risk of extreme events such as floods, bushfires and droughts. Given that ENSO events can now be detected several months prior to their peak impact period, the opportunity exists to use climate variability insights to more accurately predict the chance of climate related emergencies occurring in the forthcoming season or year. Understanding of climate mechanisms that deliver high risk periods allows optimisation of emergency responses and effective management and mitigation of the disasters that occur as a result of the naturally occurring climate extremes for which Australia is renowned.

Introduction

It is well known that Australia displays marked climate variability ranging from long and destructive droughts to sudden and pervading flooding, interspersed with severe life and property threatening bushfires. Therefore, in order to minimise the impacts on the social and economic security and well-being of Australians, the quantification and understanding of climatological and hydrological variability is of considerable importance for properly estimating the risk of climate related emergencies (e.g. floods, bushfires) occurring in an upcoming season or year. At present, risk estimation methods are largely empirical in that observed histories of climate extremes are analysed under the assumption that the chance of an extreme event occurring is the same from one year to the next (Franks and Kuczera, 2002). Traditionally, physical climatological mechanisms that actually deliver climate extremes have not been taken into account.

Despite the development of rigorous frameworks to assess the uncertainty of risk estimates, these techniques have not previously acknowledged the possibility of distinct periods of elevated or reduced risk. However, recent research has highlighted the existence of multi-decadal epochs of enhanced/reduced flood risk across NSW (Franks, 2002a, b; Franks and Kuczera, 2002; Kiem et al., 2003). In particular, Franks and Kuczera (2002) demonstrated that a major shift in flood frequency (from low to high) occurred around 1945. Previous authors have noted that the mid-1940's also corresponded to a change in both sea surface temperature anomalies as well as atmospheric circulation patterns (Allan et al., 1995), suggesting large-scale ocean-atmospheric circulation patterns are linked to the Australian climate.

In addition to hydrological observations of changing climate risk, climatological insights into the mechanisms of climate variability point to the invalidity of purely empirical approaches to risk estimation. Indeed, numerous previous studies have shown that strong relationships exist between rainfall and streamflow and the global-scale ocean-atmospheric circulation process known as the El Niño/Southern Oscillation (ENSO). ENSO refers to the anomalous warming (El Niño) and cooling (La Niña) that periodically occurs in the central and eastern tropical Pacific Ocean as a result of the Southern Oscillation. For a comprehensive description of ENSO and a review of research into its causes and effects refer to Philander (1990) or Diaz and Markgraf (2000).

In terms of eastern Australian climate, the warm El Niño events are associated with below average rainfall and higher than average temperatures and evaporation, whereas the cool La Niña events typically deliver enhanced rainfall totals and cooler than normal conditions (e.g. Allan, 1988; Nicholls et al., 1996; Power et al., 1999; Verdon et al. 2004b). It is well known that the Australian climate varies markedly from year to year and these studies demonstrate that this variability is strongly related to ENSO, especially in eastern Australia. Kiem et al. (2003) demonstrate that year-to-year flood (and drought) risk also varies significantly and that this variability is also closely related to ENSO (Figure 1).

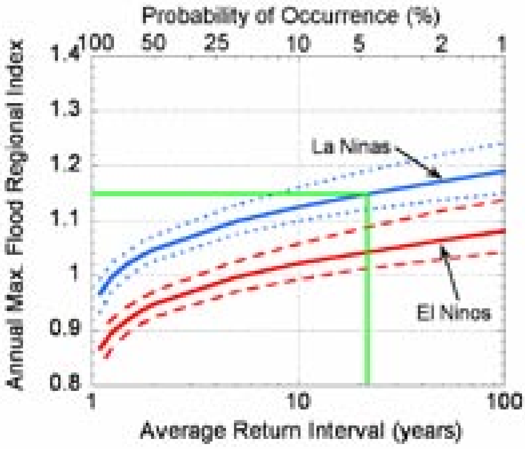
The other major climate related emergency affecting Australia is bushfires. The weather variables that generally increase the risk of bushfires are low precipitation and relative humidity combined with high temperature and wind speed. Since the high variability of rainfall and temperature in eastern Australia is strongly associated with the regional influences of ENSO (e.g. Allan, 1988; Nicholls et al., 1996; Power et al., 1999), it follows, and is demonstrated by Verdon et al. (2004a), that the ENSO also has a significant influence on eastern Australian bushfire risk (Figure 2).

Relationship between ENSO and climate related emergencies in eastern Australia

To illustrate the relationship between floods in eastern Australia and individual El Niño and La Niña events, Figure 1 shows the historic flood frequency curves associated with both El Niño and La Niña extremes. The annual maximum regional flood index (RI) shows the ratio of each annual maximum flood to the long-term mean annual maximum flood averaged across the NSW study region (Franks, 2002b). Therefore an RI greater than one indicates a maximum flood event that is worse than the historical average.

Figure 1 clearly shows that the Probability of Occurrence (PO), which is equal to the inverse of the Average Return Interval (ARI), for an annual maximum flood during a La Niña year is much higher than the PO for a flood of the same magnitude in El Niño events. For example, the PO for an annual maximum flood with RI equal to 1.0 (i.e. the average annual maximum flood) is approximately 17 per cent (ARI between five and six years) if it is an El Niño year compared with greater than 76 per cent if it is La Niña (ARI approximately 1.3 years). This implies that nearly all La Niña events will be associated with an above average annual maximum flood event. Also strikingly apparent from Figure 1 (illustrated by the green lines) is the inadequacy of the traditional '1 in 100 year flood' estimate. If the risk of flooding is assumed to be the same from year to year (i.e. the traditional and current assumption) then the chance of flood occurring during La Niña events is severely underestimated—with the PO for annual maximum flooding equivalent to the traditionally estimated '1 in 100 year flood' more than four times greater than traditionally estimated during La Niña events (ARI of 100 compared with ARI of ~23 years for the equivalent flood during La Niña years).

Figure 1. Regional flood frequency curves under El Niño (red) and La Niña (blue) conditions.



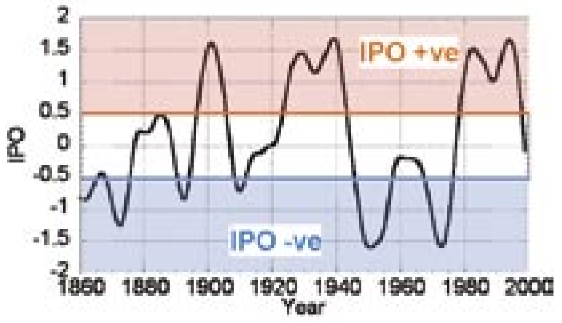
Dashed lines indicate 90 per cent confidence intervals. Horizontal green line indicates the magnitude of the '1 in 100 year flood' calculated using ALL years (i.e. under the traditional assumption that flood risk is the same from year to year). Vertical green line indicates that the probability (~4.3%) of the '1 in 100 year flood' occurring during a La Niña event is more than four times greater than traditionally estimated (see Kiem et al. (2003) for further details).

To illustrate the role of El Niño events in elevating bushfire risk, and the potential for predicting future high fire danger seasons, Figure 2 shows the percentage increase in the number of days with high (or greater than high) bushfire risk when El Niño years are compared to non-El Niño years. Daily bushfire risk is based on the Forest Fire Danger Index (FFDI; McArthur, 1967), with FFDI greater than 12 indicating a high (or greater than high) bushfire risk (Verdon et al.. 2004a). As can be seen, every station shows increases in bushfire risk with the south-east of NSW particularly elevated. This is significant given the devastating bushfires that occurred in this area in the summer of 2002/2003 and the fact that this period was also associated with El Niño conditions. While this does not mean that every El Niño will be associated with bushfires similar to those experienced in 2002/2003 (or vice versa), Figure 2 does suggest that the risk of bushfires occurring is significantly increased during El Niño events.

The results presented in Figures 1 and 2 clearly demonstrate that ENSO processes (El Niño and La Niña events) play a major role in determining flood and bushfire risk in eastern Australia. The fact that individual ENSO events can be detected at least six months prior to their consequent peak impact periods means that significant insight can be gained into the

Figure 2. Percentage increases in NSW bushfire risk under El Niño conditions compared to non-El Niño conditions.

Figure 3. Inter-decadal Pacific Oscillation index (1860-2000) – data supplied by the UK Meteorological Office.



forthcoming season or year. This enables adaptive management decisions to be made and damage minimisation procedures to be put in place before the period of elevated flood or bushfire risk. Such climate risk management strategies, based on insights gained through extensive research into ENSO and other climate processes, are now routinely applied in various domains (e.g. agriculture) in Australia and many other regions (see Meinke et al. (2005) for a useful overview).

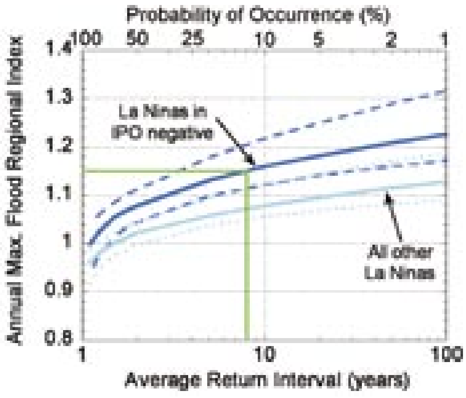
Multi-decadal variability of climate impacts in Eastern Australia

Recent climatological studies have also revealed multi-decadal variability in the modulation of the magnitude and frequency of ENSO impacts (Power et al., 1999; Kiem et al., 2003). In particular, Power et al. (1999) investigated marked temporal changes in ENSO correlations to Australian climate (i.e. rainfall and temperature) records. The temporal stratification of the climate sequences was achieved according to what has been termed the Inter-decadal Pacific Oscillation (IPO). The IPO is defined by low frequency (15 to 30 years) anomalous warming and cooling of Pacific-wide sea surface temperatures (Power et al., 1999; Folland et al., 1999; Allan, 2000), and is similar to the Pacific Decadal Oscillation (PDO; Mantua et al., 1997; Franks, 2002a). Power et al. (1999) showed how ENSO correlations with Australian rainfall and temperature changed with the observed changes in persistent large-scale Pacific Ocean sea surface temperature anomalies. Importantly, Power et al. (1999) and Verdon et al. (2004b) demonstrated that individual ENSO events (i.e. El Niño, La Niña) have stronger impact across Australia during the negative phase of the IPO, implying that there exists a multi-decadal modulation of the magnitude of ENSO impacts. Figure 3 shows the IPO index over the period 1860 to 1999.

Following Power et al. (1999) and Verdon et al. (2004b), Figure 3 indicates that persistent periods of enhanced ENSO impacts may exist at decadal and longer timescales, though it should be noted that part of this persistence is due to the smoothing algorithm chosen to produce the IPO index (see Power et al. (1999) for details). Anecdotal evidence also supports the idea of 'changes in climate' occurring during the mid 1940's and again in the mid-1970's over eastern Australia. To test the idea that El Niño and La Niña induced variability is enhanced under the IPO negative states, regional flood (Figure 4) and bushfire risk (Figure 5) data were stratified according to both the IPO and ENSO indices (Kiem et al., 2003; Verdon, et al. 2004a).

Figure 4 shows regional flood frequency curves for La Niña events under IPO negative and IPO non-negative conditions. It can be clearly seen that the PO for an annual maximum flood in an IPO negative La Niña event is even higher than the PO for a flood of the same magnitude in non-IPO negative La Niña events. As mentioned previously nearly all La Niña events are associated with above average annual maximum floods implying that flood risk in IPO negative La Niña events is *extremely* high. The PO for an annual maximum flood with RI equal to 1.1 (i.e. 10 per cent greater than the average annual maximum flood) is approximately four per cent (ARI ~25 years) during non-negative IPO La Niña compared with greater than 33 per vent during IPO negative La Niña. During El Niño events the PO for an annual maximum flood with RI equal to 1.1 is less than 0.3 per cent. Figure 4 further illustrates the inadequacy of the traditional '1 in 100 year flood' estimate. The PO for annual maximum flooding equivalent to the traditionally estimated '1 in 100 year flood' (illustrated by the horizontal green line) is more than twelve times greater than traditionally estimated during IPO negative La Niña events (ARI of 100 compared with ARI of ~8 years for the equivalent flood during IPO negative La Niña years) implying a significant underestimation of risk.

Figure 4. Regional flood frequency curves for La Nina events under IPO negative (dark blue) and IPO non-negative (light blue) conditions.

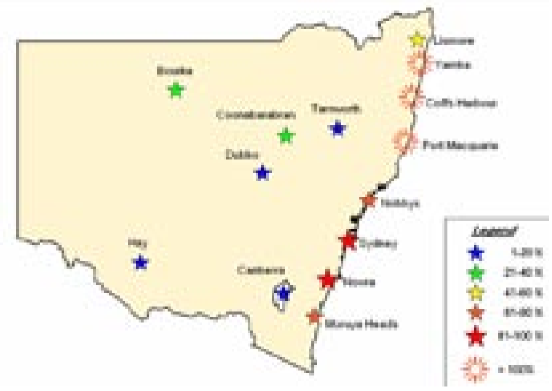


Dashed lines indicate 90 per cent confidence intervals. Horizontal green line indicates the magnitude of the '1 in 100 year flood' calculated using ALL years (i.e. under the traditional assumption that flood risk is the same from year to year). Vertical green line indicates that the probability (~12.5%) of the '1 in 100 year flood' occurring during a La Niña event is more than twelve times greater than traditionally estimated (see Kiem et al. (2003) for further details).

These results support the notion that the IPO enhances ENSO impacts. Importantly for flood management, it has been shown that in addition to modulating the magnitude of ENSO impacts there also tends to be a higher frequency of La Niña events during the IPO negative phase (Kiem et al., 2003). Therefore, contrary to the traditional assumption that flood risk is the same from one year to the next the results summarised here indicate that La Niña years are associated with enhanced flood risk (Figure 1) and that this risk is further elevated when the IPO is negative (Figure 4). Compounding the impact of the enhanced IPO negative La Niña type floods is the fact that La Niña events are much more likely to occur during the decadal/multi-decadal periods when the IPO is negative. This is supported by historical observation data where multi-year periods are associated with clusters of high magnitude floods (e.g. 1950s) for many regions of eastern Australia. Such non-stationarity of flood risk is statistically anomalous under traditional assumptions and therefore is not adequately accounted for in current flood risk management strategies. Nor are the links between climate variability and flooding currently used to predict and prepare for periods when emergency flood events are likely to occur despite the fact that such concepts are now routinely used to manage climate risk in agriculture and other domains (see Meinke et al. (2005) for an overview).

Figure 5 shows the percentage increase in bushfire risk when IPO negative El Niño events are compared with all other El Niño years. In comparison to Figure 3 (where all El Niño events were compared with non-El Niño events and it was shown that bushfire risk is elevated during El Niño events) it can be seen that IPO negative El Niño events are associated with an even greater risk of bushfire than the non-IPO negative El Niño events. This supports the notion that the magnitude of ENSO impacts is enhanced during periods when the IPO is negative and implying that bushfire risk is extremely high during IPO negative El Niño events when compared to all other years.

Figure 5. Percentage increases in NSW bushfire risk for El Niño events under IPO negative conditions compared to El Niño events occurring in non-negative IPO phases (see Verdon et al. (2004a) for further details).



Implications for emergency management

In this paper, the relationship between multi-temporal climate variability (e.g. ENSO and IPO) and the risk of floods and bushfires across NSW has been demonstrated. These results also confirm the observation that IPO negative conditions tend to be associated with enhanced impacts of individual ENSO events (Power et al., 1999; Verdon et al., 2004b) and increased frequency of La Niña events (Kiem et al., 2003), resulting in the risk of climate related emergencies occurring being distinctly non-stationary. This is at odds with current assumptions that each year is associated with the same risk of flood or bushfire. Accordingly, there are a number of implications for optimal management of emergency services.

Year to year variability of extreme climate impacts is marked in eastern Australia and is primarily the result of individual ENSO events. While individual flood and bushfire events are impossible to predict the good news is that simple detection methodologies based on indices of ENSO activity provide at least six months lead time prior to the annual period of peak ENSO impacts (i.e. the time when bushfires and floods are most likely), usually September to April for eastern Australia (e.g. Stone et al., 1996). Furthermore, understanding of other non-ENSO processes, such as the IPO, that alter the magnitude and frequency of ENSO impacts (e.g. Power et al., 1999; Kiem et al., 2003; Verdon et al., 2004a, 2004b), has the potential to greatly improve our ability to forecast climate anomalies, and therefore high risk periods with respect to flood and bushfires. However, whether or not low frequency oscillations like the IPO (and other non-ENSO processes) can be measured in real time, or forecast months in advance, to enable improved seasonal and annual forecasts is the subject of current research. In any case, it is currently possible to use at least the ENSO related insights presented in this study to more accurately determine the chance of climate related emergencies occurring in the forthcoming season or year. The lead time provided via insights into climate processes enables adaptive planning for emergency management services in anticipation of elevated climate risk periods—a concept that is already routinely being applied to manage climate risk in other domains (e.g. agriculture).

Floods and bushfires are, and always will be, part of the Australian climate and it is impossible to prevent these natural disasters from occurring. Therefore, adequate understanding of the mechanisms that cause enhanced risk periods, and the recognition that enhanced risk periods exist but are predictable, is essential to effectively manage and minimise the damage associated with floods and bushfires when they do occur.

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