Variability in Severe Coastal Flooding, Associated Storms, and Death Tolls in Southeastern Australia since the Mid–Nineteenth Century

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ABSTRACT

The variability in the number of severe floods that occurred in coastal catchments in southeastern Australia since the mid–nineteenth century, along with the variability in both the frequency of the weather types that triggered the floods and the associated death tolls, is analyzed. Previous research has shown that all of the severe floods identified were associated with one of two major weather types: east coast lows (ECLs) and tropical interactions (TIs). El Niño–Southern Oscillation (ENSO) is shown to strongly modulate the frequency of severe coastal flooding, weather types, and the number of associated deaths. The analysis presented herein, which examines links over more than a century, provides one of very few known statistically significant links between ENSO and death tolls anywhere in the world. Over the period 1876/77–2013/14 the average numbers of coastal floods, ECLs, TIs, and deaths associated with freshwater drowning in La Niña years are 92%, 55%, 150%, and 220% higher than the corresponding averages in El Niño years. The average number of deaths per flood in La Niña years is 3.2, which is 66% higher than the average in El Niño years. Death tolls of 10 or more occurred in only 5% of El Niño years, but in 27% of La Niña years. The interdecadal Pacific oscillation also modulates the frequency of severe floods, weather types, and death tolls. The results of this study are consistent with earlier research over shorter periods and broader regions, using less-complete datasets.

1. Introduction

Severe floods in southeastern Australia frequently isolate towns, often causing death, major disruptions to road and rail links, the evacuation of many houses and business premises, and the widespread flooding of farmland. Severe flooding can cause death. For example, there were at least 90 known deaths caused by floods in and around Gundagai in June 1852, and 25 deaths during the Brisbane River catchment floods in January 2011 (Callaghan and Power 2014).

Callaghan and Power (2014) recently developed a record of the frequency of severe floods that have occurred in coastal catchments in eastern Australia during 1860–2012, from Brisbane (Queensland) in the north, through Sydney and to Eden in New South Wales (NSW), 1500 km farther south. Their study region, which we adopt, is depicted in Fig. 1.

Callaghan and Power (2014) considered a flood to be major, which we refer to as severe in this paper to better describe their nature, if (i) it caused inundation of a river within approximately 50 km of the coast or (ii) there was nonriverine flooding overland near the coast, from the active part of a weather system, that extends at least 20 km along the coast. If severe flooding was caused in more than one catchment, it is regarded as a single severe flooding event.

In an attempt to produce reliable (or homogeneous) records of the frequency of severe flooding and weather types, Callaghan and Power (2014) restricted attention to the period from 1860, when the region (i) is extensively

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FIG. 1. Study region is shown on the left side enclosed by the dotted white line.

populated, (ii) has extensive coverage of meteorological stations, (iii) is extensively connected by telecommunication, and (iv) has busy coastal shipping traffic offshore. They concluded that all of the floods were linked to either an east coast low (ECL) or a tropical interaction (TI). Examples of a TI included a tropical cyclone (TC) that moves into the study region retaining its TC characteristics and extratropical transitions, whereby a TC or tropical low is reorganized or transformed into a more ECL-like structure (while interacting with a deep layered trough) as it moves into the study region. The importance of ECLs and other east coast low pressure systems to heavy rainfall or flooding is discussed by, for example, Pepler et al. (2014), Hopkins and Holland (1997), and G. McKay (2011, unpublished conference paper titled ''The life blood of floods: Flood producing weather systems'').

Previous research indicates that there is a great deal of variability in eastern Australian rainfall, streamflow, flooding and flood risk on interannual (e.g., McBride and Nicholls 1983; Chiew et al. 1998; Power et al. 1998, 1999a; Kiem and Franks 2001; Kiem et al. 2003; Verdon et al. 2004; Speer 2008; Speer et al. 2009, 2011; King et al. 2014), and decadal–multidecadal time scales (Power et al. 1999a,b; McKeon et al. 2004; Kiem et al. 2003). Much of the interannual variability is due to El Niño–Southern Oscillation (ENSO; McBride and Nicholls 1983; Chiew et al. 1998; Power et al. 1998, 1999a; Kiem and Franks 2001; Kiem et al. 2003; Verdon et al. 2004; Pui et al. 2011; Speer 2008; Speer et al. 2011). Much of the decadal/multidecadal variability is due to the interdecadal Pacific oscillation (IPO; Power et al. 1999a; Folland et al. 1999; Parker et al. 2007; Christensen et al. 2013; Henley et al. 2015; Power et al. 1999a,b; McKeon et al. 2004; Verdon et al. 2004; Cai and van Rensch 2012). These links also extend to variability in heavy and extreme rainfall, and flood frequency in eastern Australia (Franks and Kuczera 2002; Braganza et al. 2015, chapter 4; Micevski et al. 2006; Kiem et al. 2003; Kiem and Verdon-Kidd 2013; King et al. 2013).

Here, we determine if ENSO and the IPO modulate the frequency of the severe coastal floods, and the frequency of the associated weather types and death tolls, in our much longer record. We will also quantify the magnitude of any modulation evident. An investigation of this kind, in which we examine variability in storm types, major flooding, and death tolls, has not been conducted previously for this region.

The data and methods used in this investigation are described in section 2. Variability in severe floods, ECLs, TIs, and their associated death tolls, as well as the roles of ENSO and the IPO in causing the variability, are described in section 3. Results are summarized and briefly discussed in section 4.

2. Data and methods

Callaghan and Power (2014) included a description of severe coastal floods in the same study region from January 1860 to December 2012. An extension of this list to include the severe floods that occurred during the period January 2013–December 2014 is given in appendix A. The date of occurrence, the type of weather system that triggered the flood, and the death toll are provided.

In this paper, we use the term ENSO years, defined here as the period from May in one year to April in the following calendar year. This choice reflects the typical life cycle of ENSO events (i.e., both El Niño and La Niña events), which tend to grow, mature, erode, and end within this period (see, e.g., Power and Smith 2007). We use the first year in the period to refer to that period, so that 1860, for example, is used to refer to the period April 1860–May 1861. The analysis described covers the period 1860–2013. The Southern Oscillation index (SOI) averaged over the period June–December is used as the ENSO index. This index is also consistent with the life cycle of ENSO and has been used successfully in previous studies (e.g., Power et al. 1995; Power and Smith 2007; Callaghan and Power 2011; Power and Kociuba 2011; Chung et al. 2014; Salinger et al. 2014). Note that the SOI becomes available from 1876, and so correlations are performed on data from this year.

Correlation coefficients between time series of severe floods, ECLs, TIs, and associated death tolls, as well as either the SOI or an index for the IPO, are calculated. The statistical significance of correlation coefficients is tested using the method described by Power et al. (1998), a method that takes temporal persistence in the time series into account. We will refer to this as the P98 method (see appendix B). Monte Carlo methods involving randomly generated simulated data (also described in appendix B) are then used as a double check on the statistical significance of correlations involving the SOI. We will find that the Monte Carlo method gives similar results to the P98 method.

The significance of the results is expressed either as a *p* value, or as a percentage value for the corresponding statistical significance level. The *p* value is equal to the estimated probability that the magnitude of the observed correlation coefficient can be exceeded in magnitude by chance, under the assumption that the data can be approximated as a red-noise process (Power et al. 1998).

3. Variability and its links to ENSO and the IPO

a. Variability

The time series of the number of severe floods (F), ECLs, TIs, and total deaths from freshwater flooding per year are presented in Fig. 2. Time series of ECLs and TIs are exhibited in Fig. 2a, and their sum equates to the number of floods. Deaths associated with ECLs and TIs are given in Fig. 2b, and their sum equates to the number of deaths. Substantial variability is evident, ranging between 0 and 6 floods per year, 0 and 5 ECLs per year, 0 and 6 TIs per year, and 0 and 46 deaths per year, about long-term averages of 1.6 floods per year, 0.92 ECLs per year, 0.73 TIs per year, and 4.0 deaths per year. These, and other basic statistics, are presented in Table 1.

The highest number of deaths occurred during the 12 months from May 1892. Most of these deaths

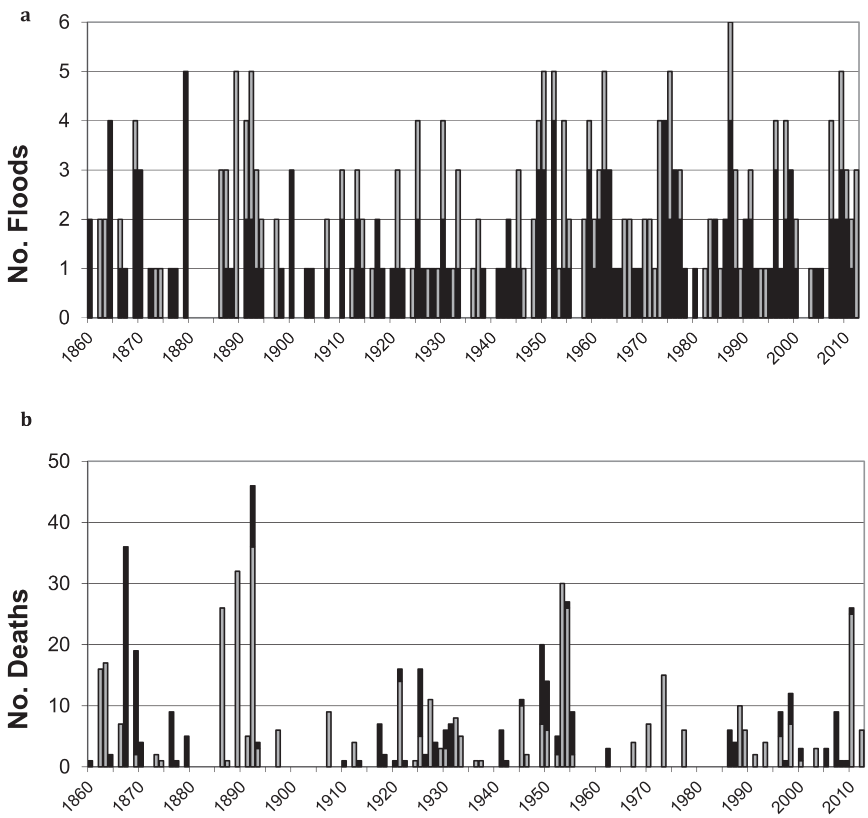

FIG. 2. Number of (a) severe floods and (b) deaths, 1860–2013. The floods triggered by ECLs are represented with black bars and the floods triggered by TIs are represented with by gray bars in (a). The death tolls during ECL-triggered floods are represented with black bars and the death tolls during TI-triggered floods are represented by gray bars in (b). Statistics for the data presented are summarized in Table 1.

occurred when a TI triggered flooding in the Brisbane–Ipswich region. This remains the highest flood reliably recorded on the Brisbane River.

In the last 50 yr, the single event causing the highest death toll (25) was the TI that caused major flooding in southeast Queensland. This event was dominated by extreme flash flooding in the Lockyer valley and on the Toowoomba Range.

b. Links to ENSO

Some of this variability in severe floods, ECLs, TIs, and total deaths from freshwater flooding per year in the

TABLE 1. Basic statistics include averages in all years, El Niño years, and La Niña years, as well as the differences (%) between the averages in La Niña and El Niño years.

Event	Avg (per year)			Change between La Niña and El Niño years (%)
	All years	El Niño years	La Niña years	
Major flood	1.6	1.2	2.3	92
ECL	0.92	0.77	1.2	55
TI	0.73	0.48	1.2	150
Deaths per year	4	2.28	7.3	220
Deaths per flood	2.5	1.93	3.2	66
Percentage of years with major floods	74	63	82	30
Percentage of years with ECLs	53	46	64	39
Percentage of years with TIs	45	37	56	51
Percentage of years with deaths	47	37	59	59
Years with >10 deaths (%)	12	5	27	440

TABLE 2. Correlation coefficients between the number of floods, ECLs, TIs, and deaths with the SOI and IPO index. The p values are given in parentheses.

Variable	Correlation coefficient between variable and the SOI (with p values)	Correlation coefficient between variable and the IPO index (with p value)
Major flood frequency	0.3 (<0.01, 0.0)	−0.5 (0.15)
ECL frequency	0.2 (0.04, 0.05)	−0.4 (0.2)
TI frequency	0.3 (0.001, 0.001)	−0.5 (0.2)
Death toll	0.3 (0.001, 0.001)	−0.4 (0.27)

study region of coastal southeastern Australia is also linked to ENSO. This can be illustrated in several ways. For example, the correlation coefficient between the variables and the SOI (over the period 1876–2013, the period when SOI data are available) are all statistically significant (see Table 2).

The long-term average number of events experienced in the study region differs between El Niño and La Niña years. This is illustrated in Fig. 3, which shows that the average number of floods, ECLs, TIs, and deaths in La Niña years are all much higher than their corresponding averages in El Niño years. The percentage increase is especially marked for death tolls (220%). This large increase occurs because the frequency of both ECLs and TIs increases, and the increase in the deadliest systems—the TIs (Callaghan and Power 2014)—is also large (150%). Death tolls of 10 or more occurred in 27% of La Niña years, but only 5% of El Niño years. The average number of deaths per flood in La Niña years is 3.2, which is 66% higher than the average in El Niño years. See Table 1 for further details.

Approximately 75% of all years have at least one flooding event. Approximately 63% of El Niño years and 82% of La Niña years have at least one flooding event.

Further illustration of the impact of ENSO on the frequency of the events is evident in the proportion of years (%) in which floods, ECLs, TIs, and deaths occur. In every case, the events occurred more frequently during La Niña years than they did during El Niño years. The proportion of La Niña years that witnessed each event type is greater than the proportion of El Niño years in all cases. See Table 1 for further details.

This analysis clearly indicates that ENSO has an impact on the number of events. This occurs despite the fact that the impact of ENSO on seasonal rainfall in coastal southeastern Australia at certain times of the year is weak (Pepler et al. 2014). This earlier result should therefore not be interpreted as meaning that ENSO's impact on coastal southeastern Australia is unimportant.

c. Decadal variability and its links to the IPO

Ten-year running sums of the number of floods, ECLs, TIs (all in Fig. 4a), deaths (Fig. 4b), and deaths per flood

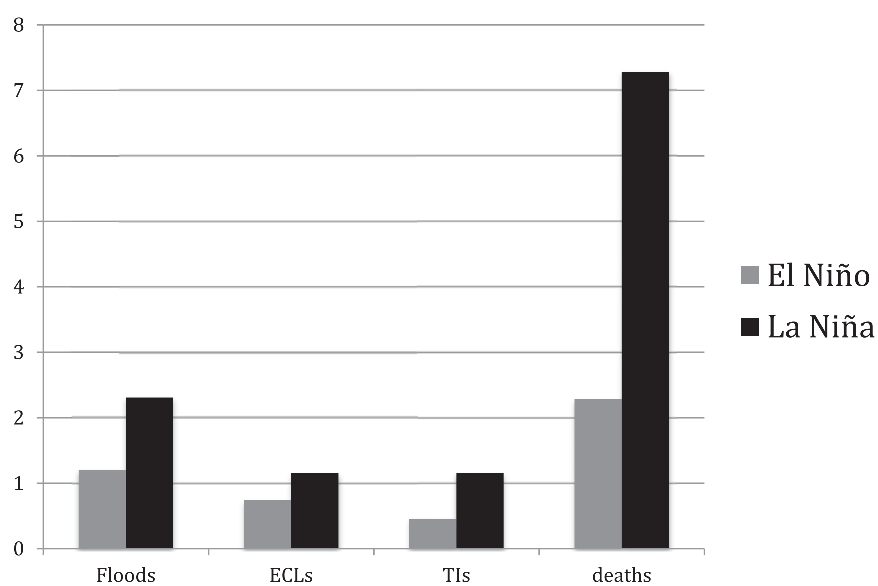

FIG. 3. Average number of severe floods, ECLs, TIs, and deaths for both El Niño (gray bars) and La Niña (black bars) years.

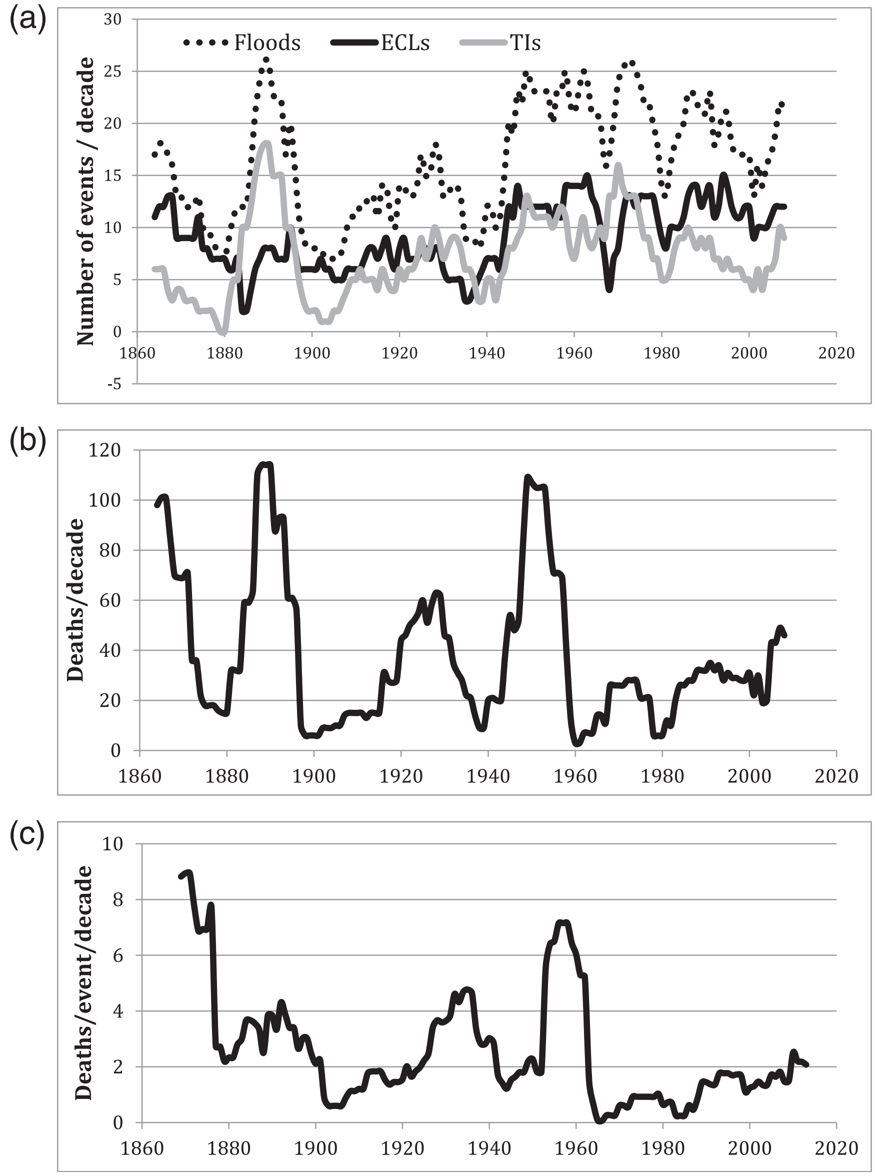

FIG. 4. Decadal variability (10-yr running averages) in the frequency of (a) severe floods (dotted line), ECLs (black line), and TIs (gray line); (b) deaths; and (c) deaths per severe flood.

(Fig. 4c) are presented. All variables show pronounced variations in the range 7–26 floods per decade, 2–15 ECLs per decade, 0–18 TIs per decade, 3–114 deaths per decade, and 0–9 deaths per flood per decade. Death tolls have been relatively low since 1960, despite an increase in the number of floods.

A time series for the IPO, using the method described by Parker et al. (2007), is made available by the Met Office. The correlation coefficients between 10-yr running averages in the IPO time series and 10-yr running averages of the time series of the frequency of severe floods, ECLs, TIs, and deaths are −0.53, −0.38, −0.46, and −0.38, respectively. None of the correlation coefficients are statistically significant (see Table 2). This occurs despite the larger correlation coefficients because the number of degrees of freedom is markedly reduced when taking decadal averages (see, e.g., Power et al. 1998).

The signs of the correlation coefficients are nevertheless consistent with previous research (Power et al. 1999b; Verdon et al. 2004; Kiem et al. 2003), the relationships evident on interannual time scales described in the previous subsection, and what is seen in climate models (Walland et al. 2000; Arblaster et al. 2002; Power et al. 1995). The statistical relationships therefore very likely reflect genuine physical relationships.

The average numbers of severe floods, ECLs, TIs, and deaths in years when the IPO time series was negative are 2.0, 1.0, 1.0, and 5.4, respectively. These figures are 67%, 39%, 110%, and 225% larger than the corresponding figures during years in which the IPO time series was positive. If we instead use decadal variability in the IPO time series to stratify the data rather than the annual IPO data, the last set of figures above become 54%, 33%, 85%, and 93%. Death tolls were 10 or more in 14 yr when the IPO time series was negative, but in only 1 yr when the IPO time series was positive. Similarly, death tolls of 10 or more occurred in 12% of years during negative decadal phases of the IPO, but in only 6% of years during positive decadal phases. Key statistics are summarized in Table 2.

There is also pronounced interdecadal variability (Fig. 4), which is partly due to the modulating effect of the IPO discussed above. The number of floods is generally greater after 1945 than before, consistent with the findings of Franks and Kuczera (2002) and Kiem et al. (2003), who examined flood frequencies over NSW more broadly. After 1960, 90% of years experienced at least one major flood, which represents a 50% increase in the same statistic calculated over the early part of the record (1860–1935).

There are two decadal peaks in the number of floods: one from the mid-1880s to the mid-1890s and another from the late 1960s to the late 1970s. Both periods experienced decades with 26 major floods. Every year during 1887–95 witnessed at least one major flood. There were 18 TIs, and 6 of these were TCs. There have not been this many tropical cyclones affecting the study region in any decade either before or since this time. This high level of storm activity caused the splitting of Stradbroke Island (Callaghan and Helman 2008). The highest death toll on record (46) discussed above also occurred during this period.

The later period experiencing an equal record high level of major flooding, triggered by larger than average numbers of both ECLs and TIs. In fact nearly the entire period between the early 1940s and the mid-1970s experienced a high frequency of major flooding. During 1967, for example, there were three major floods, two of which were triggered by tropical cyclones. Tropical cyclones also occurred offshore during 1967 that did not trigger major flooding. Together these offshore systems and the systems that did trigger major flooding caused the worst beach erosion on record at the Gold Coast and in northeastern NSW (e.g., Callaghan and Helman 2008). This record erosion event marked the beginning of persistent erosion issues in this region during the following decade.

Deaths have been relatively few since the late 1950s (Fig. 4b), and the number of deaths per event has been relatively low since the early 1960s (Fig. 4c). This reduction occurred even though the number of floods increases toward the end of the record (Fig. 2). Deaths per event were greatest during the early part of the record when warning services were largely unavailable, many settlers lived on fertile areas on the flood plains of rivers, and an awareness of the risks posed by flooding was not as wide (Callaghan and Power 2014).

4. Summary and discussion

We examined interannual and decadal variability in the frequency of severe floods, the storms that triggered them, and the resulting death tolls from freshwater flooding in an important coastal region in southeastern Australia. The region contains two of Australia's largest cities (Sydney and Brisbane) as well as some of most densely populated coastal zones in Australia, and the population is growing rapidly. Variability in this region is therefore of major interest. The new dataset also allows us to examine variability in this region over a longer period than has been possible previously.

ENSO is shown to strongly modulate the frequency of severe flooding, associated storms, and death tolls. Over the period 1876–2013 the average numbers of floods, ECLs, TIs, and deaths in La Niña years are 2.3, 1.2, 1.2, and 3.7 per year, respectively, which are all much higher than their El Niño year counterparts (Table 1). Elevated risk during La Niña years is also evident in related quantities. For example, while death tolls of 10 or more occurred in 27% of La Niña years, such tolls only occurred in 5% of El Niño years. The average number of deaths per flood in La Niña years (3.2) is also higher (by 66%) than the average in El Niño years.

We also identified a statistically significant link between death tolls from freshwater drowning in our coastal study region, and a widely used ENSO index (the SOI). This adds to what seems to be a very limited list of known statistically significant links between ENSO and deaths, anywhere in the world. For example, a review of the impact of ENSO on human health (Kovats et al. 2003) identified only two studies in which statistically significant links had been established between ENSO and human mortality rates. The first study (Bouma and van der Kaay 1996) described statistically significant increases in malarial deaths in the Punjab in India and in Sri Lanka, arising from La Niña–driven increases in monsoonal rainfall. The second study (Kuhnel and Coates 2000) examined the impact of ENSO on the total number of deaths linked to natural hazards, over a much broader region of eastern Australia than we examine. Their study region encompasses all of the eastern mainland states (i.e., Queensland, New South Wales, and Victoria), of which our study region is a small but important subset. They found that La Niña elevated the risk of death from flooding over this much broader region, consistent with our results for the coastal zone alone. Interestingly, Kuhnel and Coates (2000) found that most deaths in eastern Australia linked to ENSO actually tend to occur during El Niño years, in association with heat waves. Whether or not this is true in our (coastal) study region is unclear.

It is well established that ENSO variability can be predicted to an extent on seasonal time scales (e.g., Latif et al. 1994). This, together with the strong links we have identified between ENSO and severe flooding, and associated death tolls, highlights the possibility that flood risk and death tolls might also be partially predictable. Whether or not this is the case, we can infer from the data presented in this study that there may be benefits in raising awareness of the risks posed to life and safety from flooding and from the severe storms identified, as part of seasonal prediction and weather warning services. Thus, for example, the increased risk from severe flooding might also be part of the seasonal outlook leading in to La Niña years, or when a severe storm of the type identified is forecast. The risks seem to be widely recognized in the broader community in association with tropical cyclones. There might also be an increasing awareness in the risks linked to east coast lows, but this does not seem to be the case for the other weather systems identified.

Marked decadal (and interdecadal) variability is evident in all variables, within ranges of 7–26 floods per decade, 2–15 ECLs per decade, 0–18 TIs per decade, 3–114 deaths per decade, and 0.0–8.9 deaths per flood per decade. It is reassuring to note that both death tolls and deaths per flood have been relatively low since 1960. Factors that have contributed to this trend include very substantial improvements in the quality of severe weather forecasts and emergency services, as well as greater access to forecasts. During the nineteenth and early twentieth centuries forecasts were largely unavailable, many settlers lived on fertile areas on the flood plains of rivers, and an awareness of the risks posed by flooding was not as widely appreciated (Callaghan and Power 2014). The reduction in deaths per event might also reflect a generally greater awareness of the risks posed by severe weather in the community. These factors have been offset by an increase in the frequency of severe floods and by a very marked increase in population density (Callaghan and Power 2014). For example, Australian Bureau of Statistics figures indicate that Sydney's population was 2953 in 1796, but thereafter grew rapidly to 629 503 in 1911, 3 204 696 in 1981, and 4 627 345 in 2011. An inadequate understanding of the risks posed by flood in some sections of the community might also have contributed to some of the recent deaths (Callaghan and Power 2014), highlighting the value of ongoing educational programs.

Evidence presented in section 3c, together with consistent information presented previously using observational data (Power et al. 1999a,b; Verdon et al. 2004; Kiem et al. 2003; Micevski et al. 2006; Kiem and Verdon-Kidd 2013) and climate model output (Walland et al. 2000; Arblaster et al. 2002; Power et al. 1995), indicates that the IPO modulates the frequency of severe coastal flooding on interdecadal time scales. The average number of severe floods, ECLs, TIs, and deaths during negative decadal phases of the IPO is higher in each case, than during positive decadal phases. Death tolls of 10 or more occurred in 12% of years during negative decadal phases, but in only 6% of years during positive decadal phases. The extent to which this decadal modulation reflects predictability beyond ENSO time scales is unclear (Power et al. 1995; Westra et al. 2015).

Note that in this study, we only considered deaths associated with freshwater flooding. Deaths arose from other factors linked to the same severe weather events, including death at sea. A large number of deaths at sea associated with severe weather off southeastern Australia occurred during the nineteenth century. For example, 121 lives were lost when *The Dunbah* was wrecked on Sydney Heads on 20 August 1857, in what has become known as the Dunbah storm. A storm on 12 July 1866 caused the loss of many vessels including the 552-ton *Cawarra* on Oyster Bank near Newcastle, with 62 lives lost. The total death toll at sea from this event was approximately 100. The SS *Dandenong* lost 40 lives during a storm on 10–12 September 1876 that became known as the Dandenong gale, and the Maitland gale on 5–7 May 1898 caused more than 50 fatalities in 15 vessels in NSW coastal waters, with 24 lost from the SS *Maitland* alone. We hope to provide additional information on deaths at sea linked to severe storms in southeastern Australia in a future study.

Note that in this study we restricted our attention to examining the impact of ENSO and the IPO on the variability. Future work could examine the influence of other modes of variability that are known to influence Australia (see, e.g., Risbey et al. 2009; Braganza et al. 2015, chapter 4).

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TABLE A1. Severe floods during January 2013–December 2014.

Event reference No.	Location	Date	Type	Fatalities
254	Brisbane Creeks, Lockyer Valley, and Grafton	27–28 Jan 2013	TI3	3
255	Mid–North Coast NSW	23–24 Feb 2013	TI3	2
256	Hunter	1–3 Mar 2013	TI2	0

also thank the Met Office for the IPO time series and the National Library of Australia for making their excellent newspaper archive available online (https://trove.nla.gov.au/newspaper). Thanks are also given to Anthony Kiem, Ailie Gallant, Andrew King, and the anonymous reviewers for helpful comments on earlier drafts.

APPENDIX A

Description of Additional Severe Floods

Callaghan and Power (2014) included a description of events from January 1860 to December 2012. In this appendix we extend this list up to December 2014. The event reference number, the type of weather event that triggered the flood [see Callaghan and Power (2014) for more details], and the death toll from freshwater flooding arising from the flood are provided. Callaghan and Power (2014) identified 253 severe floods, so the first additional severe flood identified here is assigned a reference number of 254. Only three additional severe floods occurred during January 2013–December 2014. (See Table A1.)

APPENDIX B

Methods Used to Assess the Statistical Significance of the Correlation Coefficients

The statistical significance of the correlations is estimated using both the P98 method [as defined in section 2, i.e., the method described by Power et al. (1998)] and the Monte Carlo methods described below. The P98 method is ideally suited to red, normally distributed data. The Monte Carlo methods are suitable for nonnormally distributed data. Results indicate that both methods give similar results for the data used in this investigation.

a. Correlations with the SOI

The statistical significance of correlations with the SOI is determined using both the P98 method and a Monte Carlo method described below.

The statistical significance of correlation coefficients can be affected by serial correlation. This is only true, however, if there is serial correlation present in both of the time series being correlated [see, e.g., formulas given by Power et al. (1998)]. As the lag(1yr) autocorrelation of the SOI is close to zero over the periods studied, we do not need to incorporate this affect into the assessment of statistical significance of correlation coefficients involving the SOI. This simplifies the Monte Carlo experiments that are required.

The synthetic data used when assessing the statistical significance of correlation coefficients between the SOI and each of severe floods, ECLs, TIs, and death tolls result in a randomly generated number derived from the 1860–2013 relative frequency distribution of these variables. These randomly generated time series are then correlated with the actual SOI time series. Three thousand synthetic time series are generated and correlated with the observed SOI time series. The proportion of correlation coefficients (expressed as a decimal, e.g., 0.01 for 1% of the simulations) that have magnitudes greater than or equal to the magnitude of the observed correlation coefficient provides the estimate of the p value in each case.

b. Correlations between 10-yr running averages and sums

Persistence obviously needs to be taken into account when assessing the statistical significance of correlation coefficients between two 10-yr running averages. However, use of 10-yr running values gives rise to statistics that are much more closely matched by normally distributed data (consistent with the central limit theorem), and so in this case the P98 method alone is used to assess the statistical significance.

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