

CHAPTER 1

Introduction

Natural hazards have the potential to inflict large amounts of damage on society, the effects of which are highly visible and now widely reported around the world. This makes natural disaster losses an ideal justification for action on greenhouse gas emissions if research could show that anthropogenic climate change – described by former Australian Prime Minister Kevin Rudd as “the great moral challenge of our generation” – has increased losses.

By the end of 2005 extreme events had become politically contentious in discussions on climate change. The dramatic increase in global natural disaster losses, driven mainly by an upswing in US hurricane loss activity including the devastating 2004 season and Hurricane Katrina in 2005, had led to concerns that anthropogenic climate change was contributing to this trend. In an attempt to form a consensus on this issue in the lead up to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, an international workshop¹ on climate change and disaster losses was held in May 2006 in Hohenkammer, Germany. The purpose of the workshop co-organised by Professors Roger Pielke Jr. from the University of Colorado and Peter Höpfe from Munich Reinsurance Company was to identify the factors responsible for the rise in costs of weather-related disasters over recent decades and what implications the findings had for research and policy.

¹ The author attended this workshop. Final report and other details can be found at http://cstpr.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/index.html

The 20 Hohenkammer workshop consensus statements about the attribution of disaster losses and the policy implications are contained in Table 1.1. The following four statements taken from Table 1.1 provide the platform for research and are examined in this thesis:

- (1.1) *Analyses of long-term records of disaster losses indicate that societal change and economic development are the principal factors responsible for the documented increasing losses to date.*
- (1.2) *High-quality long-term disaster loss records exist, some of which are suitable for research purposes, such as to identify the effects of climate and/or climate change on the loss records.*
- (1.3) *Because of issues related to data quality, the stochastic nature of extreme event impacts, length of time series, and various societal factors present in the disaster loss record, it is still not possible to determine the portion of the increase in damages that might be attributed to climate change due to GHG emissions.*
- (1.4) *In the near future the quantitative link (attribution) of trends in storm and flood losses to climate changes related to GHG emissions is unlikely to be answered unequivocally.*

Taken together the statements above say that losses have increased primarily due to societal change and economic development; that it has been possible to identify climate trends or variability in high-quality long-term loss records but for a number of reasons it was still not possible to determine the portion of the increase in losses that might be attributed to anthropogenic climate change, and that an anthropogenic climate change link to trends in storm and flood losses is unlikely to be made in the near future.

Table 1.1 Consensus (unanimous) statements of the Hohenkammer workshop. (From Bouwer, L. M., R. P. Crompton, E. Faust, P. Höppe, and R. A. Pielke Jr., 2007. Confronting disaster losses. *Science*, 318, 753. Reprinted with permission from AAAS.)

1. Climate change is real and has a significant human component related to greenhouse gases.
2. Direct economic losses of global disasters have increased in recent decades with particularly large increases since the 1980s.
3. The increases in disaster losses primarily result from weather-related events, in particular storms and floods.
4. Climate change and variability are factors that influence trends in disasters.
5. Although there are peer-reviewed papers indicating trends in storms and floods, there is still scientific debate over the attribution to anthropogenic climate change or natural climate variability. There is also concern over geophysical data quality.
6. IPCC (2001) did not achieve detection and attribution of trends in extreme events at the global level.
7. High-quality long-term disaster loss records exist, some of which are suitable for research purposes, such as to identify the effects of climate and/or climate change on the loss records.
8. Analyses of long-term records of disaster losses indicate that societal change and economic development are the principal factors responsible for the documented increasing losses to date.
9. The vulnerability of communities to natural disasters is determined by their economic development and other social characteristics.
10. There is evidence that changing patterns of extreme events are drivers for recent increases in global losses.
11. Because of issues related to data quality, the stochastic nature of extreme event impacts, length of time series, and various societal factors present in the disaster loss record, it is still not possible to determine the portion of the increase in damages that might be attributed to climate change due to GHG emissions.
12. For future decades the IPCC (2001) expects increases in the occurrence and/or intensity of some extreme events as a result of anthropogenic climate change. Such increases will further increase losses in the absence of disaster reduction measures.
13. In the near future the quantitative link (attribution) of trends in storm and flood losses to climate changes related to GHG emissions is unlikely to be answered unequivocally.

Policy implications identified by the workshop participants

14. Adaptation to extreme weather events should play a central role in reducing societal vulnerabilities to climate and climate change.
15. Mitigation of GHG emissions should also play a central role in response to anthropogenic climate change, though it does not have an effect for several decades on the hazard risk.
16. We recommend further research on different combinations of adaptation and mitigation policies.
17. We recommend the creation of an open-source disaster database according to agreed-upon standards.
18. In addition to fundamental research on climate, research priorities should consider needs of decision-makers in areas related to both adaptation and mitigation.
19. For improved understanding of loss trends, there is a need to continue to collect and improve long-term and homogenous data sets related to both climate parameters and disaster losses.
20. The community needs to agree on peer-reviewed procedures for normalizing economic loss data.

1.1 Research Goal and Questions

The overall goal of this thesis is to explore current and projected relationships between weather-related natural disaster losses and climate change (natural variability and anthropogenic) and the implications these have for policy aimed at minimising future losses. This is achieved by addressing the following questions:

- 1) What factors are responsible for the increase in Australian weather-related insured losses and to what extent has anthropogenic climate change influenced this trend?
- 2) How has climate change influenced Australian bushfire building damage and fatalities?
- 3) Has societal vulnerability to bushfires in Australia changed and could this be masking an upward trend in building damage that would otherwise exist due to any increases in the frequency or intensity of bushfires?
- 4) Can climate change signals be detected in tropical cyclone loss databases and what role do various factors have in shaping tropical cyclone losses in the future?
- 5) When will anthropogenic climate change signals be detected in US tropical cyclone loss data and what implications does this have for global weather-related natural disaster losses?

The answers to these research questions contribute to the science of natural disaster losses and climate change. They are also very policy relevant. Policy must be designed around the answers for it to be successful in minimising future natural disaster losses. In the absence of effective policy, future losses will rise rapidly due to expected societal changes and economic development. This is particularly the case in developing countries where some of the largest growth rates are projected to occur (Bouwer et al., 2007).

1.2 Research Methodology

Research in this thesis focuses on a number of natural disaster loss databases. These vary by type of loss e.g. insured, economic, etc, and by the number of weather-related hazards included e.g. single or multiple.

The loss normalisation process is central to this thesis. It is applied to a historical record of disaster losses to estimate losses had events occurred under the societal conditions of a common base year. When losses are normalised the time series of recorded disaster losses are adjusted for changes in population, wealth and inflation (e.g. Pielke and Landsea, 1998) and, in some cases, improved construction standards (Crompton and McAneney, 2008). Loss normalisation must be carried out to sensibly compare losses over time.

Loss normalisation studies examine long term trends in normalised losses and often explore what portion of any residual trend might be attributed to other factors including anthropogenic climate change.

1.3 Thesis Structure

The main text of this thesis comprises eight chapters including an introductory chapter (Chapter 1) and a closing chapter containing discussion, conclusions and suggestions for future work (Chapter 8). Chapters 2-7 explore current and projected relationships between weather-related natural disaster losses and climate change, and the implications these have for policy.

Chapters 2, 4, 5 and 7 contain scientific papers that have been published in international peer-reviewed journals. Chapter 2 has been published in the journal *Environmental Science and Policy*; Chapters 4 and 5 in *Weather, Climate, and Society*, and Chapter 7 in *Environmental Research Letters*. Chapter 3 updates the Crompton and McAneney (2008) loss normalisation presented in Chapter 2 and Chapter 6 is a rapporteur report prepared for the Seventh World Meteorological Organization (WMO) International Workshop on Tropical Cyclones (IWTC-VII).

The methodologies, applications and results described in the chapters are direct outcomes of my research. My contribution to co-authored research is detailed at the beginning of relevant chapters.

Chapter 2

Australia is at risk from many weather-related hazards with losses from tropical cyclones, floods, thunderstorms, hailstorms and bushfires all featuring strongly in the Insurance Council of Australia Natural Disaster Event List (hereafter “Disaster List”). The Disaster List is a record of natural hazard events in Australia that have caused significant insured losses dating back to 1967. The weather-related insured losses are normalised to year 2006 societal conditions and the long term trend in normalised losses is examined. A point of departure from previous loss normalisation methodologies is an additional adjustment applied to tropical cyclone losses to account for the influence of enhanced building standards in tropical cyclone-prone areas that have markedly reduced the vulnerability of new construction since the early 1980s.

Chapter 3

This chapter revisits the Disaster List normalisation detailed in Chapter 2. The previous normalisation ended at the 2005/06 season and the low loss activity in the five-year period up to then was noted. Since that point in time there has been heightened weather-related loss activity including large losses from severe thunderstorms in 2007; the 2009 Black Saturday bushfires; large hailstorms in 2010; the Queensland floods during summer 2010/11, and Tropical Cyclone Yasi (2011). The methodology used to normalise losses has been further refined and the loss data from seasons 2006/07 - 2010/11 have been included and normalised to season 2011/12 values.

Chapter 4

The data in the Disaster List is limited making it difficult to determine the influence of climate change on the losses from any one particular hazard. An alternative database maintained by Risk Frontiers (www.riskfrontiers.com) at Macquarie University and called ‘PerilAUS’ was drawn upon to analyse the time series of building damage and fatalities due to Australian bushfire from 1925-2009. Bushfires regained prominence in Australia following the 2009 Black Saturday fires in Victoria in which 173 people lost their lives and 2298 homes were destroyed along with many other structures.

Historical records are normalised to the societal conditions of 2008/09 and long term trends are analysed. Relationships between normalised building damage and the El Niño-Southern Oscillation and Indian Ocean Dipole are explored and the pattern of building damage from the 2009 Black Saturday fires is presented.

Chapter 5

The question of whether societal vulnerability to bushfires in Australia had changed and was masking an upward trend in building damage that would otherwise exist due to any increases in the frequency or intensity of bushfires was raised in comments on the paper in Chapter 4. This chapter contains the reply to those published comments which can be found in Appendix 1. The reply deals with each of the issues raised including a possible bias in the loss normalisation methodology and possible reductions in vulnerability due to improved building construction and/or regulation; emergency preparations and response, and skill of weather forecasting.

Chapter 6

Tropical cyclones losses are a major component of global natural disaster losses and this chapter is dedicated to them. It reviews recent tropical cyclone loss normalisation studies from around the world; the future and current US loss sensitivity to societal changes and climate change, and the financial management of extreme events.

Chapter 7

Chapter 6 shows that recent research is still not able to determine the portion of the increase in tropical cyclone losses that might be attributed to anthropogenic climate change. If the attribution of trends in storm and flood losses to anthropogenic climate change is unlikely to be made in the near future as indicated in Hohenkammer consensus statement 1.4, then the question that arises and is addressed in this chapter is when will an anthropogenic climate change signal be detected in tropical cyclone loss data should changes in tropical cyclone characteristics occur as projected?

US tropical cyclones are the focus of the analysis as the loss data is extensive and strongly influences global natural disaster losses and state-of-the-art projections of future tropical cyclone activity in the Atlantic are available. This also allows the results to be extended more generally to global weather-related natural disaster losses.

1.4 References

Bouwer, L. M., R. P. Crompton, E. Faust, P. H  ppe, and R. A. Pielke Jr., 2007. Confronting disaster losses. *Science*, 318, 753.

Crompton, R. P., and K. J. McAneney, 2008. Normalised Australian insured losses from meteorological hazards: 1967-2006. *Environ. Sci. Policy*, 11, 371-378.

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CHAPTER 2

Crompton, R. P., and K. J. McAneney, 2008. **Normalised Australian insured losses from meteorological hazards: 1967-2006.** *Environ. Sci. Policy*, 11, 371-378.

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Contribution

The initial idea for this paper came from related research and a presentation by my adjunct supervisor Professor Roger Pielke Jr. All of the data required to undertake the research was sourced and accessed by me and I researched the history of the insured loss data. I performed all of the calculations and analysis. I wrote this paper with reviews of early drafts by my principal supervisor Professor John McAneney. My contribution is estimated at 90%.

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Normalised Australian insured losses from meteorological hazards: 1967–2006

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ABSTRACT

Since 1967, the Insurance Council of Australia has maintained a database of significant insured losses. Apart from five geological events, all others (156) are the result of meteorological hazards—tropical cyclones, floods, thunderstorms, hailstorms and bushfires. In this study, we normalise the weather-related losses to estimate the insured loss that would be sustained if these events were to recur under year 2006 societal conditions. Conceptually equivalent to the population, inflation and wealth adjustments used in previous studies, we use two surrogate factors to normalise losses—changes in both the number and average nominal value of dwellings over time, where nominal dwelling values exclude land value. An additional factor is included for tropical cyclone losses: this factor adjusts for the influence of enhanced building standards in tropical cyclone-prone areas that have markedly reduced the vulnerability of construction since the early 1980s.

Once the weather-related insured losses are normalised, they exhibit no obvious trend over time that might be attributed to other factors, including human-induced climate change. Given this result, we echo previous studies in suggesting that practical steps taken to reduce the vulnerability of communities to today's weather would alleviate the impact under any future climate; the success of improved building standards in reducing tropical cyclone wind-induced losses is evidence that important gains can be made through disaster risk reduction.

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1. Introduction

Worldwide, increases in insured losses from natural hazards have risen dramatically (Swiss Reinsurance Company, 2006; Munich Re Group, 2005) leading to concerns that human-induced climate change is contributing to this trend. A critical step before drawing this conclusion is to first filter out other influences known to contribute to increased disaster losses. And so as others have done for a variety of natural disaster losses in other locations, here we normalise Australian insured disaster losses, in this case to year 2006 values. In other words, we are interested in the loss if these historical events were to impact society in 2006. Related normalisation

studies include those of Changnon and Changnon (1992a,b): U.S. storm (hurricane, winter storm, thunderstorm and windstorm); Pielke and Landsea (1998), Pielke et al. (2008) and Collins and Lowe (2001): U.S. hurricane; Pielke and Downton (2000) and Downton et al. (2005): U.S. flood; Brooks and Doswell (2001): U.S. tornado; Vranes and Pielke (under review): U.S. earthquake; Pielke et al. (2003): Caribbean and Latin American hurricane, and Raghavan and Rajesh (2003): Indian tropical cyclones.

Our starting point is the Insurance Council of Australia's Natural Disaster Event List (hereafter "Disaster List"). This comprises a catalogue of natural hazard events in Australia that have caused significant insured losses. Our focus here is

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on insured losses for the simple reason that no credible equivalent economic loss database exists for Australia. The Disaster List contains details of each event including date, area(s) affected and the industry-wide insured loss in “original” dollars. The Hobart Bushfires of 1967 were chosen as a starting point because this event was the first significant natural disaster for which credible insured industry loss figures were available. Whereas the threshold for inclusion may have changed over time, most events exceed a nominal (dollars of the day) value of AUD\$10 million. Spanning 40 years, it is one of the more comprehensive disaster loss records in the world. It is widely used by the insurance industry for scenario loss estimation and to benchmark against the output of catastrophe loss models. These applications require normalised losses and this study proposes a relatively simple methodology for achieving these.

A defensible normalisation process must adjust for changes in population, wealth, as well as inflation (Pielke and Landsea, 1998). An additional factor that cannot be neglected under Australian conditions is the influence of building regulations that stipulate more wind-resistant construction in tropical cyclone (hurricane)-prone areas (Walker, 1999). These enhancements were introduced in the wake of devastating losses caused by Tropical Cyclones Althea in 1971 and Tracy, which in 1974 almost completely destroyed Darwin, the capital city of the Northern Territory. As a result of these construction changes, specified in SAA (1989), now superseded by SASNZ (2002) (hereafter referred to as the “Wind Code”), newer buildings are generally much less vulnerable to wind damage. Given that roughly one-third of the total number of building losses over the last century caused by natural hazards in Australia have occurred as a result of tropical cyclones (Blong, 2004; Crompton et al., in press), failure to properly account for changes brought about by regulation of the Wind Code would lead to unrealistic normalised values. No other natural hazard in Australia has invoked comparable responses in terms of building standards.

The paper is constructed as follows: we begin by describing our normalisation methodology followed by a brief discussion of the key results. We then further analyse normalised losses and loss frequency by peril and seek out trends in the normalised losses over time. In particular, we shall look for any evidence that might suggest the increasing trend in original losses is due to factors such as human-induced climate change. Section 4 follows listing limitations common to most normalisation methodologies, including our own, and the paper concludes with implications for policy.

2. Normalisation methodologies

In the normalisation methodology described by Changnon and Changnon (1992a,b), insured losses to crops and property in past storms were adjusted to 1991 economic and insurance exposure conditions using three factors. The first allowed for annual changes in property values and costs of repairs; the second used census, property and insurance records to address the relative growth in the size of the property market in the area(s) impacted while the third factor used insurance company sales records to adjust for changes in insurance penetration. Pielke and Landsea (1998) employed a different

approach to normalise direct economic losses due to U.S. hurricanes to 1995 values using changes in coastal population, inflation and real (inflation-adjusted) per capita wealth. Population changes were determined from U.S. Census data, inflation was accounted for using the implicit price deflator for gross national product and real wealth using a statistic called fixed reproducible tangible wealth that was converted to a per capita value.

Our approach outlined below is conceptually equivalent to Pielke and Landsea (1998) but follows Changnon and Changnon (1992a,b) in so far as it is based on dwellings rather than population. However, in the absence of insurance company records or credible estimates of economic losses, we have been unable to adjust for changes in insurance penetration that may have occurred since 1967 (cf. Changnon and Changnon (1992a,b) and Collins and Lowe (2001)). Under Australian conditions this factor is expected to be of minor importance since adoption of insurance has been traditionally high and policies typically offer multi-peril coverage except for limitations placed on riverine flood following the 1974 Brisbane flood (Walker, 2003). Since 1974 there has been little riverine flood activity and the restricted cover has been gradually eroded over the last 10 years. We were also unable to apply the Pielke and Landsea (1998) methodology directly as no credible measure of wealth exists for Australia going back to 1967.

A more marked point of departure from previous studies is our treatment of changing building regulations that at least under Australian conditions are of manifest importance in the case of tropical cyclones. We adopt 1981 as a threshold year for the regulation of the Wind Code in order to discriminate between new and improved construction; this year also coincides with the reporting of Australian Census information. Failure to allow for the Wind Code being regulated would be to assume that the ratio of pre- to post-1981 buildings is the same in 2006 as what it was when the event occurred.

Our normalisation methodology is applied to the insured losses from all meteorological hazards including tropical cyclones, floods, thunderstorms, hailstorms and bushfires (wildfires). It converts original losses in year i (L_i) to 2006 values (L_{06}) according to the following equation:

$$L_{06} = L_i \times N_{i,j} \times D_{i,k} \times B_{tc} \quad (1)$$

where j is the Urban Centre/Locality (UCL) impacted by the event; $N_{i,j}$ is the dwelling number factor defined as the ratio of the number of occupied dwellings in 2006 in UCL j to the number in year i ; k is the State or Territory that contains the impacted UCL; $D_{i,k}$ the dwelling value factor, defined by the ratio of the State/Territory average nominal value of new dwellings in 2006 to that of year i and B_{tc} is the tropical cyclone Wind Code adjustment, which defaults to unity for all perils other than tropical cyclone.

The UCL structure is one of the seven interrelated classification structures of the Australian Standard Geographical Classification that groups Census Collection Districts together to form areas defined according to population size (Australian Bureau of Statistics (ABS)—<http://www.abs.gov.au>). In broad terms, an Urban Centre is a population cluster

of 1000 or more people while a Locality comprises a cluster of between 200 and 999 people. The number of occupied dwellings in each UCL is reported in the Census of Population and Housing (ABS—<http://www.abs.gov.au>) and an exponential or linear curve was fit to these numbers (Fig. 1(a)). Only one UCL was used for each event and when more than one was impacted, the UCL expected to have experienced most damage was used where possible.

The dwelling value factor ($D_{i,k}$) was calculated for the State or Territory containing the impacted UCL. Average nominal values of new dwelling units increase over time in an exponential fashion as shown by way of example in Fig. 1(b) for Western Australia. State/Territory values are calculated by dividing the value of building work completed within a year by the number of completions within the same year with relevant values taken from Building Activity reports (ABS—<http://www.abs.gov.au>). The increase in values is in part due to increasing average dwelling size as well as improvements in the quality of the housing stock. The dwelling values exclude the price of land and as the nominal value is by definition in dollars of the day, no further inflationary adjustment is required.

The tropical cyclone Wind Code adjustment (B_{tc}) is unique to each tropical cyclone event loss and incorporates the proportion of the loss attributable to wind damage (as opposed to flooding or storm surge); the proportion of pre- and post-1981 residential buildings in the impacted UCL both in the year the event occurred and in 2006; and pre- and post-1981 residential building loss ratios (ratios of insured losses to

Table 1 – Tropical Cyclone Tracy loss normalisation

Wind damage	100%
Pre-1981 residential building distribution	
1974	100%
2006	44%
Notional maximum gust speed at landfall	61 m/s
Residential building loss ratio	
Pre-1981	78%
Post-1981	10%
Original loss (1974)	AUD\$200 million
Normalised loss (2006, excluding B_{tc})	AUD\$7140 million
Normalised loss (2006)	AUD\$3650 million

insured value) that are a function of peak gust speed. This loss ratio also includes damage due to wind-driven rain following wind damage to the envelope of the dwelling. The adjustment assumes the post-1981 buildings were built in line with the Wind Code, i.e. no more or less vulnerable than the Wind Code prescribes. Details for this adjustment are described in Appendix 1.

An illustrative normalisation example for Tropical Cyclone Tracy (1974) is shown in Table 1. The importance of accounting for the growth in the less vulnerable post-1981 construction is evident.

3. Results

Fig. 2(a) and (b) show annual aggregated original and normalised losses for the weather-related events in the Disaster List. Annual losses have been calculated for years beginning 1 July to take account of the southern hemisphere seasonality of the meteorological hazards. The most salient observation is that the time series of normalised losses exhibits no obvious trend over time. We conclude that the increasing trend in original losses is largely attributable to changes in dwelling numbers and average nominal dwelling values and that there is no discernable evidence that human-induced climate change is significantly impacting insured losses, at least in Australia and to the present time.

Determining the influence of human-induced climate change on the losses from any one particular hazard is more difficult due to limited data and further work is required to identify patterns of behaviour characteristic of meteorological cycles such as the El Niño–Southern Oscillation (ENSO), which may be contributing to the periodic loss fluctuations evident in Fig. 2(b). Pielke and Landsea (1999) found a significant relationship between the ENSO cycle and U.S. hurricane losses.

The 10 highest ranked weather-related normalised losses are presented in Table 2 with Tropical Cyclone Tracy heading the list. There is a wide spread of natural disasters with four different hazard types represented in the top 10. This number rises to five if geological hazards were to be included as the normalised loss from the 1989 Newcastle earthquake (AUD\$4300 million) exceeds that of Tropical Cyclone Tracy.

Fig. 3 classifies the weather-related losses by hazard-type showing their contribution to relative event frequency and the total normalised loss. Tropical cyclone and hailstorm together

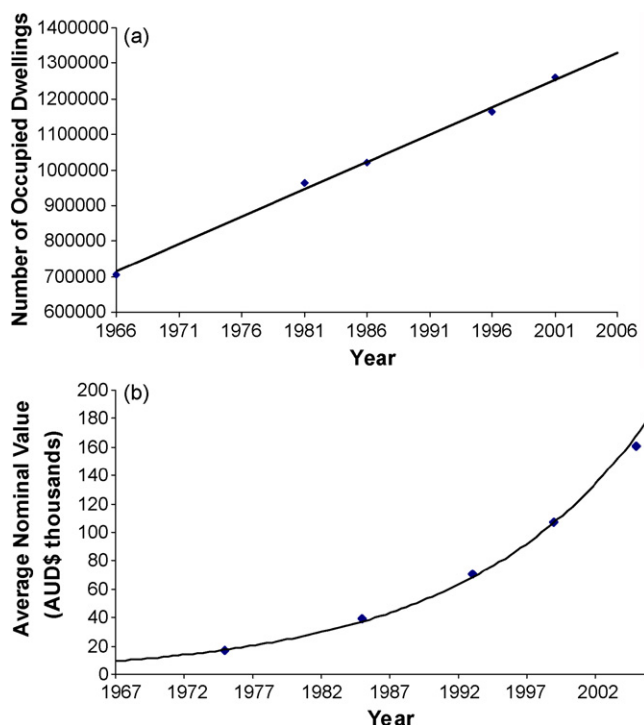


Fig. 1 – (a) Time changes in the number of occupied dwellings in the Sydney UCL. Similar curves were developed for other UCLs and (b) time changes in the average nominal new dwelling value (AUD\$ thousands) in Western Australia. Similar curves were developed for all States and Territories.

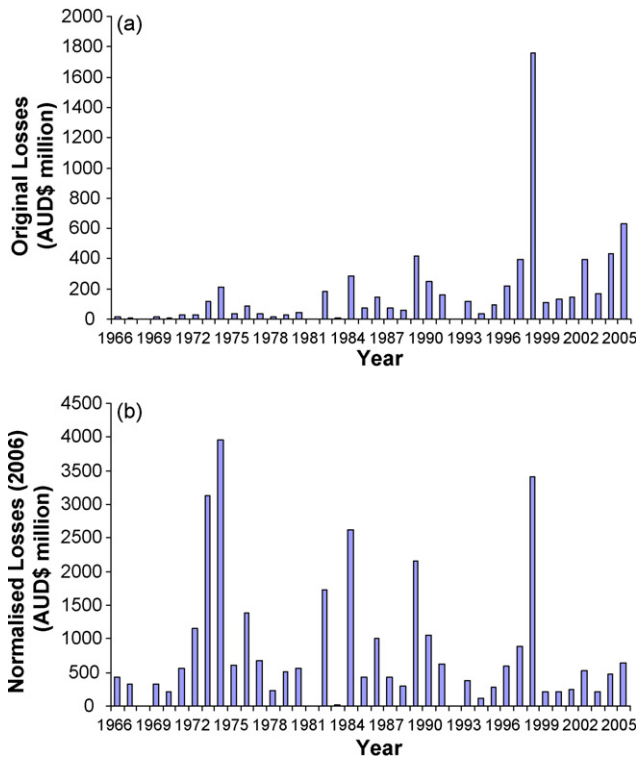


Fig. 2 – (a) Original annual aggregate insured losses (AUD\$ million) for weather-related events in the Disaster List for years beginning 1 July and (b) as for (a) but with losses normalised to 2006 values.

represent 37% of the total number of events but over 60% of the total normalised loss. Conversely, thunderstorms account for almost the same number of events, but only 11% of the total loss. Floods are potentially under-represented in this analysis because, as has already been mentioned, this peril has not been uniformly insured.

The average annual weather-related normalised damage over the 40-year period is AUD\$820 million with a standard deviation of AUD\$960 million. The recent past has been relatively benign in terms of loss activity, with annual damage

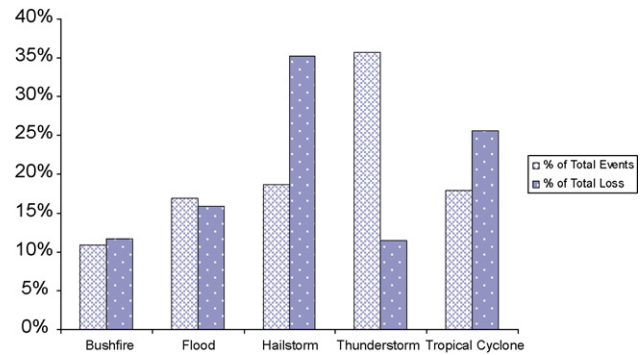


Fig. 3 – Percentage of the number of, and total normalised loss from, all weather-related events in the Disaster List by hazard-type.

over the most recent 5 years averaging AUD\$420 million, close to half the average annual loss over the entire period of the Disaster List. The most recent of the 10 highest ranked event losses (Table 2) – the April 1999 Sydney hailstorm – occurred almost 10 years ago.

In normalised values, tropical cyclone losses average AUD\$210 million per year, a figure that would rise to AUD\$340 million if the Wind Code adjustment was not included in Eq. (1). Moreover, the tropical cyclone average annual normalised loss would be even more than AUD\$340 million if the Wind Code had never been regulated. This result highlights just how effective disaster risk reduction measures can be in terms of reducing losses from natural disasters, a point that we will return to in later discussion.

4. Discussion

While our normalisation methodology quantifies the most important contributory factors, it is important to recognise that our approach, like all normalisation methods, has limitations. Most importantly, we have accepted the veracity of the original data in the Disaster List. Reporting thresholds may have changed over time, Walker (2003) identifies the fact

Table 2 – Ten highest ranked weather-related normalised losses (AUD\$ million)

Rank	Event	Year	Location	State	Original loss (AUD\$ million)	Normalised loss (2006) (AUD\$ million)
1	Tropical Cyclone Tracy	1974	Darwin	NT	200	3650
2	Hailstorm	1999	Sydney	NSW	1700	3300
3	Flood ^a	1974	Brisbane	QLD	68	2090
4	Hailstorm	1985	Brisbane	QLD	180	1710
5	Ash Wednesday Bushfires ^b	1983	Multiple	VIC/SA	176	1630
6	Hailstorm	1990	Sydney	NSW	319	1470
7	Tropical Cyclone Madge	1973	Multiple	QLD/NT/WA	30	1150
8	Hailstorm	1976	Sydney	NSW	40	730
9	Hailstorm	1986	Sydney	NSW	104	710
10	Flood	1984	Sydney	NSW	80	660

^a The 1974 Brisbane flood resulted from the degeneration of Tropical Cyclone Wanda.

^b The two separate loss entries in the Disaster List for this event have been combined into a single loss.

that minor events have been reported with a higher frequency post-1995 and that the data seems sparser prior to 1973 than beyond that year. In the absence of independent measures for accessing and correcting for these possible deficiencies, we have taken the database entries as valid; our results and conclusions are materially unchanged if only post-1973 data is analysed.

The change in the number of dwellings has been used as a proxy for population change and change in the average nominal value of new dwellings for inflation and real per capita wealth. *A priori* there is no one absolutely correct way of adjusting for these variables. An assumption made is that each line of insurance business (residential, commercial, motor, etc.) contributing to the disaster loss behaves proportionally and can be normalised using the same factors. Over the period for which contemporaneous wealth data is available (1989–2006) the increase in the total nominal value of dwellings (excluding land value) closely approximates both the increase in the total nominal household wealth, and particularly the increase in the total nominal national wealth (ABS—<http://www.abs.gov.au>) (factors of 3.3, 3.7 and 3.1, respectively). Factors calculated for the interim years also closely mirror each other. This result gives us some confidence in normalising the losses using a dwelling-based methodology.

In approximately two-third of entries in the Disaster List only one location is listed as being impacted. For the others, no spatial breakdown of losses is given and we have no means of correctly weighting the growth in dwelling numbers by the relative damage in each impacted location. Thus in the absence of better information, we have used only one UCL for the dwelling number adjustment.

Potentially more serious issues relate to changing demographics whereby it is now possible for a loss to be registered in an area where there may not have been people living in the past. Pielke and Landsea (1998) consider this possibility in their normalisation of U.S. hurricane losses and conclude that their omission did not materially alter their findings. It is less clear that this is the case for Australia particularly for hailstorms where there is no record of an event unless it impacted a populated area. This will result in an increase in frequency of small losses in the Disaster List over time. Offsetting this to some degree is the fact that a repeat of some historical bushfire loss events may now be physically impossible where original bushlands have been converted to suburbs. Nonetheless it would be naive to think that similarly large bushfire losses will not recur (McAneney, 2005).

Adjusting for demographic changes is also problematic if damage resulting from the natural hazard was confined to a small area. For example, the April 1999 Sydney hailstorm impacted an already highly developed part of Sydney, yet the dwelling number factor still adjusts for growth characteristic of the entire Sydney UCL. The reverse is also possible had the hailstorm impacted a less developed part of Sydney. This influence on the normalised values is constrained, however, as it is the average nominal value of dwellings that has been largely responsible for the escalation in Australian disaster losses. In the case of Tropical Cyclone Tracy, for example, the number of dwellings in

Darwin almost tripled between 1974 and 2006 whereas the average nominal value of new dwellings in Northern Territory increased by a factor of 13 from AUD\$18 500 to around AUD\$240 000.

Notwithstanding these and other cautions, the methodology presented here provides a relatively simple and effective way of normalising original natural hazard event losses to year 2006 values. The focus on dwelling values alone (i.e. land value excluded) ensures reasonable alignment to insured losses.

5. Policy implications

The collective evidence reviewed above suggests that societal factors – dwelling numbers and values – are the predominant reasons for increasing insured losses due to natural hazards in Australia. The impact of human-induced climate change on insured losses is not detectable at this time. This being the case, it seems logical that in addition to efforts undertaken to reduce global greenhouse gas emissions, significant investments be made to reduce society's vulnerability to current and future climate and the associated variability. Employing both mitigation and adaptation contemporaneously will benefit society now and into the future.

We are aware of few disaster risk reduction policies explicitly developed to help Australian communities adapt to a changing climate, yet disaster risk reduction should be core to climate adaptation policies (Bouwer et al., 2007). Policies such as those to improve building standards have effectively reduced risk with dramatic reductions in wind-induced losses observed following Tropical Cyclones Winifred (1986) and Aivu (1989) (Walker, 1999) and most recently, Larry (2006) (Guy Carpenter, 2006; Henderson et al., 2006). While the Wind Code was not regulated with adaptation in mind, it underlines the important gains that can be made and why there is a need to expand the role of disaster risk reduction in adaptation.

An increased threat from bushfires under human-induced climate change is often assumed. Indeed Pitman et al. (2006) and others anticipate an increase in conditions favouring bushfires. However, analyses by McAneney (2005) and Crompton et al. (in press) suggest that the main bushfire menace to building losses will continue to be extreme fires and that the threat to the most at-risk homes on the bushland–urban interface can only be diminished by improved planning regulations that restrict where and how people build with respect to distance from the forest. Disaster risk reduction of this kind would immediately reduce current and future society's vulnerability to natural hazards.

Acknowledgements

The authors acknowledge the help of Chris Henri, who, through communication with John Staveley, provided an invaluable account of the history of the Disaster List. Thanks also to Roy Leigh, Russell Blong and George Walker for helpful comments. The research was supported by the Insurance Council of Australia.

Table A1 – Five highest tropical cyclone original losses

Tropical cyclone	Year	Australian (Saffir-Simpson) category scale at landfall	Original loss (AUD\$ million)	Proportion of wind damage (%)	Proportion of pre-1981 residential construction (%)	
					Original	2006
Larry	2006	4 (3)	540	100	51	51
Tracy	1974	4 (4)	200	100	100	44
Winifred	1986	3 (2)	40	100	84	51
Vance	1999	5 (4)	35	66	50	42
Nancy	1990	2 (1)	33	33	55	31

Appendix 1. Tropical cyclone Wind Code adjustment components

A.1. Proportion of the loss attributable to wind damage

For each tropical cyclone loss in the Disaster List, we must first estimate the proportion of the loss attributable to wind damage, as opposed to flooding or storm surge. Wind damage includes water ingress due to wind-driven rainwater entering the structure in a myriad of ways including following partial or complete loss of roofing or damage to the envelope of the dwelling. The proportion was estimated using broad category bounds: 0%, 33%, 50%, 66%, or 100% (see Table A1 for examples). These estimates were made on the basis of a range of newspaper reports and official records. We assume that all of the estimated wind damage is affected by the improved building standards.

A.2. Proportion of pre- and post-1981 residential buildings

A breakdown of pre- and post-1981 residential buildings both in the year the event occurred and 2006 is also needed. These proportions were derived from 1981 and 2001 Australian Census data (ABS—<http://www.abs.gov.au>) and calculated for the same UCL used to determine the dwelling number factor (see Table A1 for examples). We assume that the average value of pre- and post-1981 residential buildings is the same.

A.3. Pre- and post-1981 residential building loss ratios

In the absence of a comprehensive set of recorded wind speeds, we estimate a characteristic wind speed for each event. Although in reality the actual wind speed responsible for damage to a structure will vary widely due to a range of factors such as the wind profile shape, translation velocity, distance from the shoreline and local surface roughness and topography, for this exercise we adopt a single metric, the maximum gust wind speed at landfall at a height of 6 m. The height is chosen to be compatible with the Walker (1995) damage functions discussed below.

With few exceptions, the characteristic wind speed was calculated in the following way. The Australian Tropical Cyclone Category Scale (Table A2) contains threshold 3 s maximum gust speeds at a height of 10 m above flat open terrain for each tropical cyclone category. These thresholds are converted to an equivalent gust at 6 m by applying a terrain/height multiplier (0.96) derived from the Wind Code.

Fig. A1 shows the resulting regression relationship between the 6 m gust values and the corresponding threshold central pressure values in Table A2. This is used to estimate each tropical cyclone's maximum gust from its landfall central pressure as reported in the Australian Bureau of Meteorology's (BoM) tropical cyclone database (BoM—<http://www.bom.gov.au/>).

Pre-defined damage functions are then used to determine pre- and post-1981 residential building loss ratios. Damage or vulnerability functions, as they are sometimes known, relate

Table A2 – Australian Tropical Cyclone (TC) Category Scale (Australian Bureau of Meteorology—<http://www.bom.gov.au/>)

Category	Strongest gust (km/h)	Strongest gust (m/s)	Approximate central pressure (hPa)	Typical effects
1	<125	<35	>985	Negligible house damage. Damage to some crops, trees and caravans. Craft may drag moorings
2	125–169	35–47	985–970	Minor house damage. Significant damage to signs, trees and caravans. Heavy damage to some crops. Risk of power failure. Small craft may break moorings
3	170–224	48–62	970–955	Some roof and structural damage. Some caravans destroyed. Power failures likely (e.g. TC Winifred)
4	225–279	63–78	955–930	Significant roofing loss and structural damage. Many caravans destroyed and blown away. Dangerous airborne debris. Widespread power failures (e.g. TCs Tracy and Olivia)
5	>279	>78	<930	Extremely dangerous with widespread destruction (e.g. TC Vance)

Gust speeds refer to 3 s gusts at a height of 10 m above flat open terrain.

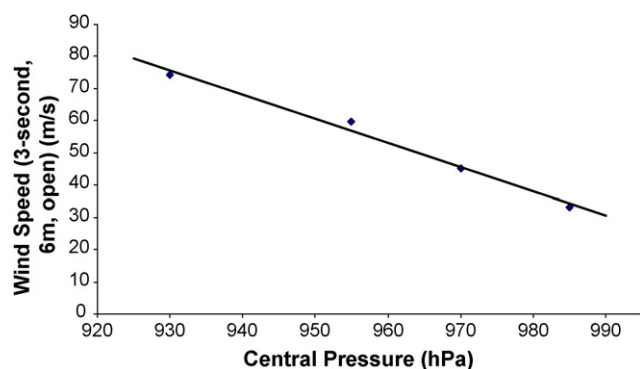


Fig. A1 – Relationship between threshold central pressure values and gust speed values (adjusted to a height of 6 m) taken from the Australian Tropical Cyclone Category Scale.

gust speeds to the fractional loss of building insured value and, in our case, vary for pre- and post-1981 construction and the Wind Region where the event made landfall. The Wind Code divides Australia into different Wind Regions and dictates more stringent construction requirements in areas more exposed to the impact of tropical cyclones. For example, the wind risk is considered the greatest along a section of coastline in Western Australia and this region is classified as Wind Region D.

Walker (1995) (also cited in Holmes (2001)) published damage functions for pre- and post-1981 residential buildings in Wind Region C; these curves are based on insurance industry experience and personal observations. Walker's pre-1981 curve is taken here to apply uniformly across Wind Regions B, C and D and we extrapolate the post-1981 curve to B and D using the Wind Code assuming that the same level of damage is tolerated for gust speeds at a given return period. Gust speeds at a given return period vary geographically according to the different Wind Regions. Our approach produced a post-1981 Wind Region B damage function that

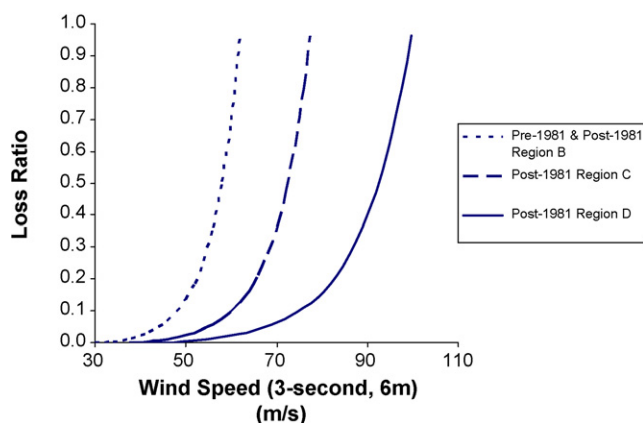


Fig. A2 – Damage functions for pre-1981 and post-1981 Wind Regions B, C and D residential buildings. Gust speeds are at a height of 6 m allowing for terrain and topographic effects. The pre- and post-1981 Wind Region C functions are from Walker (1995).

almost exactly mirrored the Walker (1995) pre-1981 curve and so for simplicity it is assumed to be the same. Fig. A2 shows all the damage functions.

The normalised tropical cyclone losses are not materially affected by the use of open terrain and unshielded gust speeds. The use of suburban terrain and fully shielded gust speeds produce similar values, with 23 of the 28 tropical cyclone normalised losses falling within 10% of each other.

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CHAPTER 3

Normalising the Insurance Council of Australia Natural Disaster Event List: 1967-2011.

3.1 Introduction

This chapter builds upon the Crompton and McAneney (2008) loss normalisation (Chapter 2). Here we normalise all insured losses in the Insurance Council of Australia (ICA) Natural Disaster Event List¹ between 1 July 1966 and 30 June 2011 to season 2011 values (where ‘season’ 2011 is defined as the 12-month period beginning 1 July 2011).

3.2 Loss Normalisation Methodology

The normalisation methodology applied to the insured losses in the ICA Natural Disaster Event List (hereafter ‘Disaster List’) is an updated version of that employed by Crompton and McAneney (2008). It converts losses recorded in season i (L_i) to season 2011 values (L_{11}) according to the following equation:

$$L_{11} = L_i \times N_{i,j} \times (D_{i,k} \times S_{i,\text{total}} / S_{i,\text{new}}) \times B_{tc} \quad (3.1)$$

where j is the Urban Centre/Locality (UCL) impacted by the event²; $N_{i,j}$ is the dwelling number factor defined as the ratio of the number of dwellings in season 2011 in UCL j to the number in season i ; k is the State or Territory that contains the impacted UCL³; $D_{i,k}$ is the dwelling value factor, defined by the ratio of the State/Territory average nominal value of new dwellings in season 2011 to that of season i ; $S_{i,\text{total}} / S_{i,\text{new}}$ is the dwelling size adjustment, defined as the ratio of the factor increase in the average floor area of total residential dwellings to the factor increase in the average floor area of new residential dwellings between season i and 2011 and B_{tc} is the building code adjustment applied to tropical cyclone losses, which defaults to unity for all perils other than tropical cyclone.

¹ Data current as at 5/3/12 (<http://www.insurancecouncil.com.au/industry-statistics-data/disaster-statistics>).

² Multiple UCLs are used where applicable.

³ Multiple States and/or Territories are used where applicable.

The UCL structure is one of the seven interrelated classification structures of the Australian Standard Geographical Classification that groups Census Collection Districts together to form areas defined according to population size (Australian Bureau of Statistics (ABS) – <http://www.abs.gov.au>). In broad terms, an Urban Centre is a population cluster of 1000 or more people while a Locality comprises a cluster of between 200 and 999 people. The number of dwellings in each UCL is reported in census years since 1966 (at 5-year intervals thereafter) in the Census of Population and Housing (ABS – <http://www.abs.gov.au>).

The dwelling value factor ($D_{i,k}$) was calculated for the State or Territory containing the impacted UCL. State/Territory average nominal values of new dwellings are calculated by dividing the value of residential building work completed within a season by the number of completions within the same season with relevant values taken from Building Activity reports (ABS – <http://www.abs.gov.au>). The dwelling values exclude the price of land and increases are in part due to increasing average dwelling size as well as improvements in the quality of the housing stock.

The dwelling size adjustment was calculated at the national level. Available average floor area of new residential dwellings data for various seasons between 1984 and 2006 was obtained from Building Activity reports (ABS – <http://www.abs.gov.au>) and an average growth rate was calculated. This growth rate was used to determine the average floor area of new residential dwellings in each of the seasons from 1966 to 2011. The average floor area of total residential dwellings in season i ($A_{i, \text{total}}$) was then calculated as follows:

$$[(A_{i, \text{new}} \times (C_i - C_{i-1} + F_i) + A_{i-1, \text{total}} \times (C_{i-1} - F_i)] / C_i \quad (3.2)$$

where $A_{i, \text{new}}$ is the average floor area of new residential dwellings in season i ; C_i is the number of dwellings in Australia in season i ; F_i is the number of demolitions in season i and $A_{i-1, \text{total}}$ is the average floor area of total residential dwellings in season $i-1$. An average demolition rate was estimated from differences between the number of residential dwellings completed and the change in the number of dwellings in a given season. For the purpose of Equation 3.2 a value of approximately 20m^2 less than $A_{1966, \text{new}}$ was assumed for $A_{1966, \text{total}}$. $S_{i, \text{total}}$ ($S_{i, \text{new}}$) is then the ratio of $A_{2011, \text{total}}$ ($A_{2011, \text{new}}$) to $A_{i, \text{total}}$ ($A_{i, \text{new}}$).

The additional factor applied to tropical cyclone losses adjusts for the influence of building code changes in tropical cyclone-prone areas that have markedly reduced the vulnerability of new construction from around the early 1980s. We adopt 1975 for Darwin, 1976 for Townsville and 1981 elsewhere as threshold years for the building code regulation of the wind standard and they are used to discriminate between new and improved construction. Failure to allow for the wind standard being regulated would be to assume that the ratio of pre- to post-19XX buildings is the same in season 2011 as what it was when the event occurred.

The tropical cyclone building code adjustment (B_{tc}) is unique to each tropical cyclone event loss and incorporates the proportion of the loss attributable to wind damaged buildings and contents (as opposed to flooding or storm surge, wind damage to cars, etc); the proportion of pre- and post-19XX dwellings in the impacted UCL both in the season the event occurred and in season 2011; and pre- and post-19XX residential building loss ratios (ratios of insured losses to insured value) that are a function of peak gust speed. This loss ratio also includes damage due to wind-driven rain following wind damage to the envelope of the dwelling. The adjustment assumes the post-19XX buildings were built in line with the wind standard, i.e. no more or less vulnerable than the wind standard prescribes.

3.3 Methodological Refinements

We have refined the Crompton and McAneney (2008) loss normalisation methodology by including the dwelling size adjustment in Equation 3.1 and we have made other less obvious refinements in the development of the other normalisation factors. Some of the refinements were made possible due to the increased availability of data and others, including the dwelling size adjustment, are enhancements. The most important refinements are discussed below.

3.3.1 Dwelling number factor

In their calculation of the dwelling number factor Crompton and McAneney (2008) used the number of ‘occupied’ dwellings and did not have data for the 1971, 1976 and 1991 census years. They estimated occupied dwelling numbers using an exponential or linear curve fit to the remaining census data between census years 1966 and 2001. In our updated approach we use the total number of dwellings (i.e. including ‘unoccupied’ dwellings) and all census data from 1966⁴. We use linear interpolation to determine the number of dwellings for seasons between census years and estimate the 2006-2011 season dwelling numbers by extrapolating from the 2001 and 2006 census data.

Crompton and McAneney (2008) used a single UCL for each event in the calculation of the dwelling number factor whereas our current approach is to use multiple UCLs when necessary with up to eight UCLs used to represent each event. The main source of additional information accessed to determine the affected locations was Risk Frontiers’ PerilAUS natural disaster database and other information sources include Bureau of Meteorology significant weather summaries and State Emergency Service event reports.

3.3.2 Dwelling value factor

The most obvious refinement in Equation 3.1 is the dwelling size adjustment which was not included in the Crompton and McAneney (2008) normalisation methodology. Both our current approach and Crompton and McAneney (2008) used the average nominal value of new dwellings to represent the change in replacement value over time. However, part of the increase in new dwelling values is due to the increase in the average floor area of new dwellings. The dwelling size adjustment is required as the size of new dwellings increases faster than the size of total dwellings and it is the increase in the size of total dwellings that needs to be included in our normalisation.

⁴ The 2011 census data is yet to be released.

Our updated way of calculating the dwelling value factor for each State and Territory is to use our derived average nominal value of new dwellings for seasons 1974-2010 (1973-2010 for Tasmania). We extrapolate to season 2011 using the average growth rate over the seasons 2005-2010 and to season 1966 using the average growth rate over the seasons 1974-1984 (1973-1983 for Tasmania). Crompton and McAneney (2008) determined new dwelling values for each State and Territory by fitting an exponential curve to 5 of the derived data points.

3.3.3 Building code adjustment

Refinements to the building code adjustment include the use of multiple UCLs in line with the updated dwelling number factor approach. We also make an allowance for demolitions (consistent with the approach used in the dwelling size adjustment) when calculating the proportion of pre- and post-19XX dwellings in the impacted UCL.

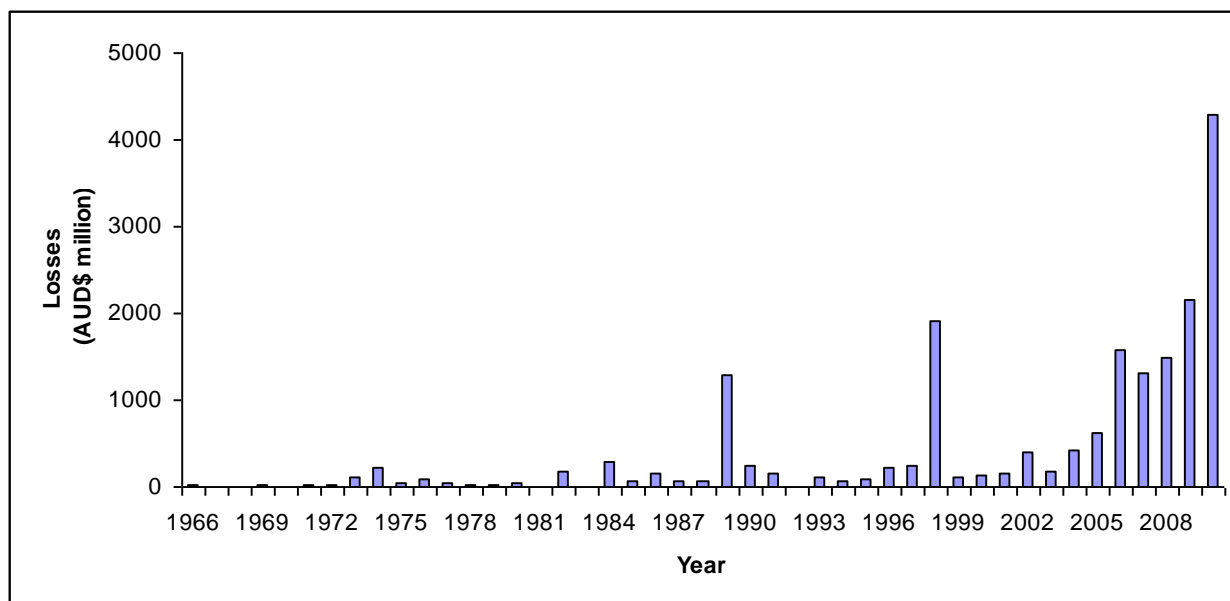
Crompton and McAneney (2008) adopted 1981 as a threshold year throughout tropical cyclone-prone areas of Australia for the building code regulation of the wind standard whereas our updated approach varies the threshold year in Darwin and Townsville. We have also updated our estimated proportion of the insured loss attributable to wind damaged buildings and contents.

While our normalisation methodology (Equation 3.1) quantifies the most important contributory factors, it is by design, an approach that can be applied to a large number of events. It is important to recognise that our methodology has limitations and does not encompass all of the factors unique to each event. Taking Tropical Cyclone Tracy as an example, since Tracy made landfall in 1974 the extent of government owned housing in Darwin has fallen and this affects insurance penetration as the government owned homes and flats were not insured through private insurance (Mason and Haynes, 2010). On the other hand the proportion of pre-1975 dwellings in Darwin in season 2011 will be less than estimated due to the occurrence of Tracy.

3.4 Results

Figure 3.1 presents the annual aggregate insured losses and the annual aggregate normalised insured losses for all events in the Disaster List. Figure 3.2 presents the same data for weather-related events only. The losses have been normalised and aggregated by season (years beginning 1 July) to take account of the southern hemisphere seasonality of the meteorological hazards.

(a)



(b)

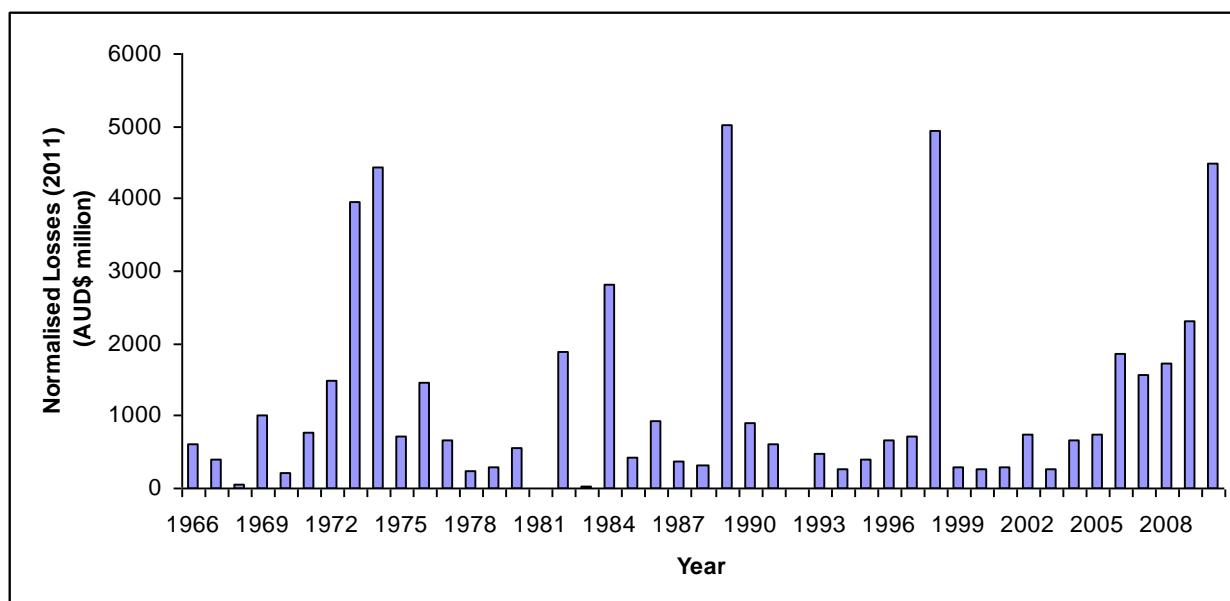
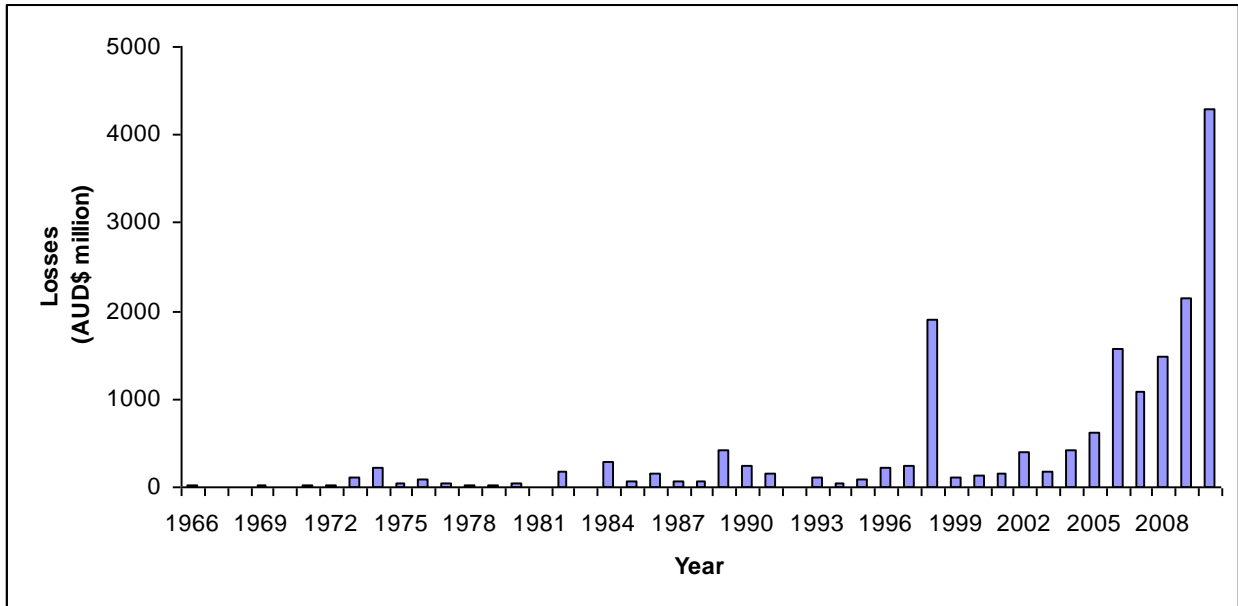


Figure 3.1 (a) Annual aggregate insured losses (AUD\$ million) for all events in the Disaster List for years beginning 1 July; (b) as in (a) but with losses normalised to season 2011 values.

(a)



(b)

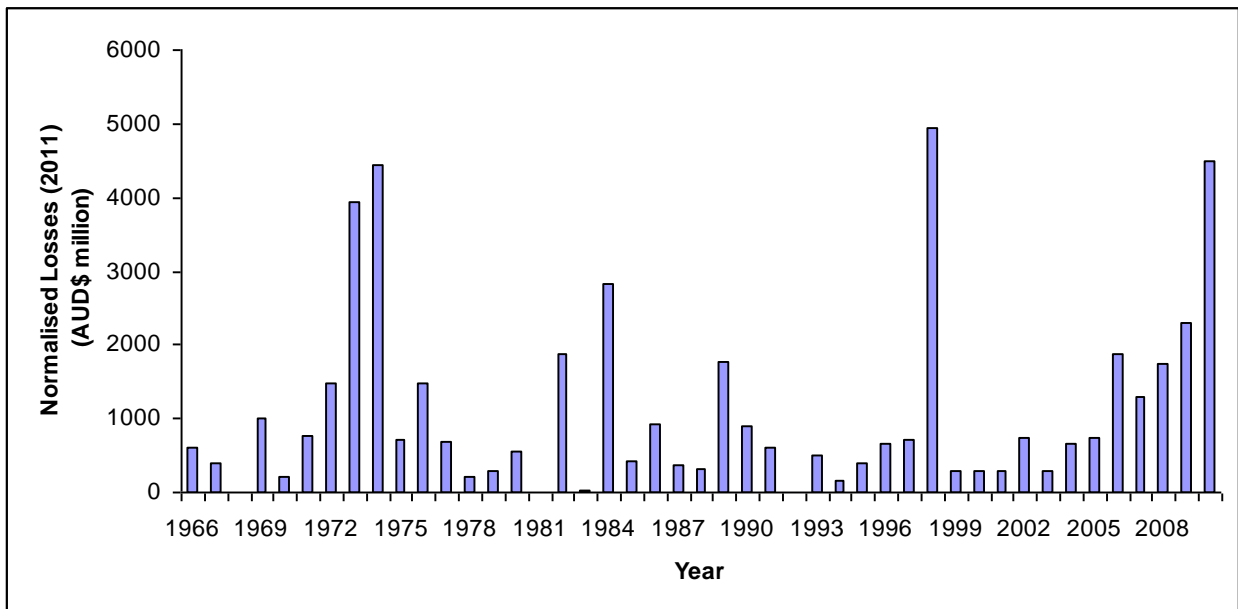


Figure 3.2 (a) Annual aggregate insured losses (AUD\$ million) for weather-related events in the Disaster List for years beginning 1 July; (b) as in (a) but with losses normalised to season 2011 values.

The top 10 normalised insured losses are given in Table 3.1. The highest ranked normalised insured loss is the 1999 Sydney hailstorm and the average annual normalised insured loss over the 45-year period is AUD\$1175 million. The equivalent weather-related average is AUD\$1092 million.

In their normalisation of the Disaster List ending at the 2005 season Crompton and McAneney (2008) noted the low loss activity in the most recent 5 seasons. Since that time there has been heightened weather-related loss activity with the most recent 5 seasons to 2010 averaging slightly more than double the 45-year average of AUD\$1092 million. However the annual weather-related insured loss over the most recent 10 seasons (2001 – 2010) averaged AUD\$1439 million which is within approximately 30 % of the average annual loss over the full 45-year period of the Disaster List.

The loss activity in recent seasons does not alter the Crompton and McAneney (2008) conclusion that there is no discernable evidence to date that anthropogenic climate change is significantly impacting Australian insured losses. The trend in the updated time series of normalised annually aggregated weather-related insured losses (Figure 3.2b) is not statistically significant at the 10% level.

Table 3.1 Ten highest ranked normalised insured losses (AUD\$ million).

Rank	Event	Year	Location	State	Loss (AUD\$ million)	Normalised loss (2011) (AUD\$ million)
1	Hailstorm	1999	Sydney	NSW	1700	4296
2	Tropical Cyclone Tracy	1974	Darwin	NT	200	4090
3	Earthquake	1989	Newcastle	NSW	862	3240
4	Flood ^a	1974	Brisbane	QLD	68	2645
5	Flood	2010/11	Multiple	QLD	2380	2508
6	Hailstorm	1985	Brisbane	QLD	180	2063
7	Ash Wednesday Bushfires ^b	1983	Multiple	VIC/SA	176	1796
8	Severe Storm	2007	Multiple	NSW	1480	1742
9	Tropical Cyclone Madge	1973	Multiple	QLD/NT/WA	30	1492
10	Tropical Cyclone Yasi	2011	Multiple	QLD	1330	1384

^aThe 1974 Brisbane flood resulted from the degeneration of Tropical Cyclone Wanda.

^bThe two separate loss entries in the Disaster List for this event have been combined into a single loss.

3.5 Acknowledgments

The author acknowledges the help of Acacia Pepler who assisted with the collection of data and event specific information.

3.6 References

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CHAPTER 4

Crompton, R. P., K. J. McAneney, K. Chen, R. A. Pielke Jr., and K. Haynes, 2010.

Influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925–2009. *Wea. Climate Soc.*, 2, 300-310.

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Contribution

This paper was conceived from discussions with Professors John McAneney and Roger Pielke Jr. about research I undertook as part of my employment at Risk Frontiers. I performed all of the calculations and analysis except that underpinning Figure 4 which was produced by Dr Keping Chen. Dr Keping Chen contributed sections 2f and 3d and I wrote the remainder of this paper. Professor McAneney reviewed early drafts and all co-authors read later versions and gave suggestions prior to submission. My contribution is estimated at 80%.

Media highlights: [The Economist](#)

Influence of Location, Population, and Climate on Building Damage and Fatalities due to Australian Bushfire: 1925–2009

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ABSTRACT

This study reevaluates the history of building damage and loss of life due to bushfire (wildfire) in Australia since 1925 in light of the 2009 Black Saturday fires in Victoria in which 173 people lost their lives and 2298 homes were destroyed along with many other structures. Historical records are normalized to estimate building damage and fatalities had events occurred under the societal conditions of 2008/09. There are relationships between normalized building damage and the El Niño–Southern Oscillation and Indian Ocean dipole phenomena, but there is no discernable evidence that the normalized data are being influenced by climatic change due to the emission of greenhouse gases. The 2009 Black Saturday fires rank second in terms of normalized fatalities and fourth in terms of normalized building damage. The public safety concern is that, of the 10 years with the highest normalized building damage, the 2008/09 bushfire season ranks third, behind the 1925/26 and 1938/39 seasons, in terms of the ratio of normalized fatalities to building damage. A feature of the building damage in the 2009 Black Saturday fires in some of the most affected towns—Marysville and Kinglake—is the large proportion of buildings destroyed either within bushland or at very small distances from it (<10 m). Land use planning policies in bushfire-prone parts of this country that allow such development increase the risk that bushfires pose to the public and the built environment.

1. Introduction

Widely heralded in the media as Australia's worst natural disaster (e.g., Rule 2009), the 7 February 2009 Black Saturday bushfires (wildfires) in Victoria were but the most recent reminder of the potential for natural hazards to impact Australian communities (Crompton and McAneney 2008). Fueled by record high temperatures and high winds in the midst of a protracted drought, the Black Saturday fires claimed 173 lives and 2298 houses (Victorian Bushfires Royal Commission 2009) as well as numerous other structures, including schools and police stations. This paper attempts to place these most recent bushfire impacts into a historical context.

Following a method analogous to Crompton and McAneney (2008) and other recent work (Bouwer 2010), this paper asks: What would have been the impact of past bushfires if they were to recur under current societal conditions? Without accounting for the known influence societal factors have on disaster records, it is impossible to know whether the devastation inflicted by the Black Saturday fires was truly anomalous, whether this provides a glimpse of the future under expected changes in climate, and what policy changes might prove effective in reducing the impact of future disasters. In examining such questions, we shall also reevaluate work undertaken before the Black Saturday fires (e.g., McAneney et al. 2009) and present some patterns of building destruction in these particular bushfires.

Despite claims that the Black Saturday fires were Australia's greatest natural disaster (e.g., Rule 2009), several previous events have been more destructive in

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terms of loss of life and property damage, even before the societal influence has been accounted for: in 1974, Cyclone Tracy laid waste the city of Darwin, demolishing about 3700 dwellings and damaging another 3300 to the point that only 6% of the building stock was left habitable (Walker 1975); in 1899, Cyclone Mahina, a category-5 tropical cyclone, claimed about 410 lives; and the heat wave that preceded the 1939 Black Friday bushfires in Victoria is blamed for 438 deaths (from the research organization Risk Frontiers's "PerilAUS" natural disaster database, described below in section 2a; Blong 2004; McAneney et al. 2009; Haynes et al. 2010). Of the more extreme bushfires, 1694 houses were lost in the 1983 Ash Wednesday fires in Victoria and South Australia (PerilAUS; Blong 2004; McAneney et al. 2009; Haynes et al. 2010), and, although we have been unable to verify this independently, 2000 buildings were reportedly destroyed in the 1898 Red Tuesday fires in Victoria (State Government of Victoria 2003, p. 10). Regardless of its ranking in terms of numbers of fatalities and property damage, the extreme impacts in the Black Saturday fires warrant critical examination. This same sentiment led the Victorian state government to form a royal commission with wide executive powers to scrutinize all aspects of bushfire management leading up to and during the bushfires (Victorian Bushfires Royal Commission 2009).

The process of adjusting time series of disaster losses for changes in population, wealth and inflation and, in some cases, improved construction standards is known as normalization and has been applied in a wide range of locales for a range of phenomena (e.g., Pielke and Landsea 1998; Pielke et al. 2008; Crompton and McAneney 2008; Zhang et al. 2009; Barredo 2009, 2010; Vranes and Pielke 2009). Accounting for inflation/deflation is necessary because the value of a currency changes over time while increases in population and wealth mean more people and property are located in exposed areas.

In respect to Australian bushfire, McAneney et al. (2009) argued that the stability over the last century of exceedance loss statistics for building damage suggested that it was premature to conclude that a signal of greenhouse-gas emissions was present. The authors contend that, given that these loss statistics had proved so stable in the face of the vast societal changes that took place over the twentieth century, any greenhouse-gas signal cannot be large or significant. This study revisits this question using a different approach by explicitly accounting for these societal changes.

Whereas a greenhouse gas-driven climatic-change signal has thus far not been detected in normalized disaster loss records for a wide range of perils in locations around the world [see review by Bouwer (2010) and references therein], and is unlikely to be detected in at least storm

and flood losses in the near future (Höppe and Pielke 2006), patterns of behavior characteristic of meteorological cycles such as El Niño–Southern Oscillation (ENSO) have been identified in normalized Atlantic Ocean hurricane damages (Pielke and Landsea 1999). ENSO and another coupled ocean–atmosphere oscillation, the Indian Ocean dipole (IOD), are also known to influence the weather and climate of eastern Australia (McBride and Nicholls 1983; Power et al. 2006; Ashok et al. 2003; Cai et al. 2009b); the former oscillation is in the equatorial Pacific Ocean and the latter in the Indian Ocean.

An El Niño (La Niña) phase of the ENSO cycle refers to the situation in which sea surface temperatures in the central to eastern Pacific Ocean are significantly warmer (cooler) than the long-term average, whereas a positive IOD (pIOD) event is when the eastern Indian Ocean is cooler than normal and the western Indian Ocean is anomalously warmer (Saji et al. 1999). El Niño events increase the chance of drought along eastern Australia (Kiem and Franks 2004) and bushfire (Williams and Karoly 1999), whereas La Niña events often presage widespread increases in rainfall (Power et al. 2006) and chance of flooding (Kiem et al. 2003). Ummenhofer et al. (2009) showed that a lack of negative IOD (nIOD) events was strongly related to drought in southeastern Australia, and Cai et al. (2009a) report a link between pIOD events and enhanced bushfire risk over Victoria. Moreover, Cai et al. (2009a) found that pIOD events were more effective than El Niño events in preconditioning Victorian bushfires, a robust result that was not conditional on the definitions adopted for each. This paper will examine the relationships between ENSO and the IOD and normalized bushfire building damage in Australia.

The remainder of this paper is structured as follows: we begin with a description of Risk Frontiers' PerilAUS inventory of Australian bushfire building damage and the bushfire fatality database of Haynes et al. (2010). The normalization methods, ENSO and IOD definitions, and the method used to examine patterns of building damage in the Black Saturday fires for two of the most severely impacted towns, Marysville and Kinglake, are then detailed. We then present key results, including those from two historic case studies (the 1967 Hobart fires and the 1983 Ash Wednesday fires) used to "ground truth" the normalization method. The paper concludes with a discussion of results and some implications for public policy with regard to bushfire in Australia.

2. Data and methods

a. Bushfire building damage and fatality data

The current study draws upon Risk Frontiers' databases of natural disasters in Australia (hereinafter referred to as

PerilAUS). Data entries were derived mainly from archival searches of the *Sydney Gazette* and *Sydney Morning Herald* (dating from 1803 and 1831, respectively) and were cross referenced against other local newspapers and official documents in other states or territories where necessary and other reference material where available (Coates 1996; Blong 2004; Haynes et al. 2010). In the case of bushfire and except for some years prior to 1926 for which data are incomplete, it provides a comprehensive national record of Australia's loss events. Although it is expected that any bushfire that resulted in significant building damage and numbers of fatalities has already been cataloged, the database is constantly being improved and revalidated. In the course of this study, further events, including a bushfire that destroyed 454 houses in Victoria in 1962 (State Government of Victoria 2003, p. 10), were identified and added to the record. These additional events and those from more recent bushfire seasons were not included in the McAneney et al. (2009) analysis.

For almost 1200 events listed in PerilAUS, it is possible to estimate the number of buildings destroyed, with damaged buildings (residential, public, commercial and industrial, etc.) converted to house equivalents HE using relative building costs and floor areas for different types of buildings (Blong 2003). One HE can correspond to the complete destruction of one median-sized house, two such houses each 50% destroyed or, for example, a suburban police station experiencing damage amounting to 47% of its replacement value. McAneney et al. (2009) note that most outcomes from bushfires tend to be binary in nature, with buildings either being completely destroyed or surviving relatively unscathed. Damage to building contents, cars, machinery, aircraft, crops, and so on is not included in the HE estimates.

In addition to building damage information, PerilAUS also contains details of bushfire-related fatalities, including names of the deceased. This information was used by Haynes et al. (2010) as the entry point to forensic, witness, and police statements contained in coroners' inquest reports for each known death from 1901 to 2007/08. An outcome of that study was a database of civilian bushfire fatalities; our study will analyze those entries over a common time horizon with building damage for bushfire years 1925–2008. The definition of *bushfire years*, in which 1925 represents the 12-month period beginning 1 July 1925, reflects the Southern Hemisphere bushfire season.

b. Normalizing house equivalents

To normalize bushfire building damage (HE) records to current societal conditions we simply convert the HE in bushfire year i (HE_i) to bushfire year 2008 numbers (HE_{08}) as follows:

$$HE_{08} = HE_i \times N_{i,j}, \quad (1)$$

where $N_{i,j}$ is the dwelling number factor defined as the ratio of the number of dwellings in bushfire year 2008 in state or territory j to those present in bushfire year i . The number of dwellings in each state or territory is reported in the census of population and housing and/or year books [available from the Australian Bureau of Statistics (ABS) online at <http://www.abs.gov.au>]. A dwelling is defined as a structure intended for human habitation—normally a house, flat, caravan, and so on—but also includes hotels, prisons, hospitals, and so on that were occupied on census night. National censuses were undertaken irregularly until 1961 and at 5-yearly intervals since. Linear interpolation was used to determine the number of dwellings for years between census years, and the 2007 and 2008 bushfire year numbers were estimated by extrapolating from the 2001 and 2006 figures. Growth in the number of dwellings is assumed as a proxy for growth in HE.

Equation (1) ignores any explicit correction for inflation and wealth as measured in economic terms. The HE representation avoids the need for an inflation adjustment; whether an adjustment for increasing economic wealth is required is less obvious. An argument for its inclusion stems from the manifest increase in the average size of Australian dwellings over time: for example, the average increase in the average number of bedrooms per dwelling between 1976 and 2006 was 0.3% per year (from the ABS data). If this rate of increase had held constant over the entire analysis period, then the average dwelling size would have increased by 28% between 1925 and 2008. On the other hand, we expect most of that increase has been implicitly accounted for in the manner by which the HE data were derived: if, by way of example, we imagine a hypothetical bushfire event in which 100 houses were destroyed, then we assume that this equates to 100 HE whether the event occurred in 1930 or 1990. Although Blong (2003) differentiates between small, median, and large houses based on floor area, this level of detail is not often included in the source documents and so, for most building types, numbers of HE were based on a single (median) size of each building type. This being the case, we have chosen not to further adjust the HE data for changes in wealth; however, any adjustment of economic losses would also require both an inflation and economic wealth adjustment.

c. Normalizing fatalities

Bushfire-related fatalities F are normalized in a similar manner to HE under the assumption that fatalities change in proportion to population (Pielke et al. 2003; Vranes and Pielke 2009):

$$F_{08} = F_i \times P_{i,j}, \quad (2)$$

where $P_{i,j}$ is the population factor defined as the ratio of the population in bushfire year 2008 in state or territory j to the population in bushfire year i . The population in each state or territory is reported annually in the Australian Historical Population Statistics (from the ABS). The 2008 bushfire year state and territory populations were extrapolated from 2007 values using the average population growth rate over the previous 5 years. Where a bushfire event impacted more than one state or territory, the database provides a geographical breakdown of fatalities so that the data can be normalized separately and added together to determine the F_{08} numbers. This was similarly the case for the HE data and normalization of them.

d. Validation of normalization methods

Equations (1) and (2) assume that growth in the exposure—number of bushfire-prone dwellings and population in the areas impacted—occurred at the same rate as the growth in total number of dwellings and population for each state or territory. Except for a few particular bushfires, data are not available to allow a more precise estimate of growth in exposed areas over time.

We can get some sense of the relative accuracy of this assumption by comparing state/territory-based dwelling number and population event factors with those derived by weighting equivalent local-level factors by each local area's proportional contribution to event building damage and fatalities. Urban center/locality (UCL)-based factors were calculated for two of the most damaging historical bushfires: the 1967 Hobart fires and 1983 Ash Wednesday fires. Although UCL-level growth may not necessarily mirror bushfire-prone dwelling and population growth, we expect this to be a more accurate representation than the state/territory-level figures.

The UCL structure is one of the seven interrelated classification structures of the Australian standard geographical classification that groups census collection districts together to form areas defined according to population size (from the ABS). In broad terms, an urban center is a population cluster of 1000 or more people, and a locality comprises a cluster of between 200 and 999 people. The number of dwellings and population in each UCL is reported in census years in the census of population and housing (available from the ABS).

e. ENSO and IOD

There exist multiple definitions for the El Niño and La Niña phases of ENSO, based upon either the Southern Oscillation index (SOI) or various sea surface temperature

(SST)-based metrics, but these generally concur for the major El Niño and La Niña events. Here we adopt the Japan Meteorological Agency (JMA) index of 5-month running mean of spatially averaged SST anomalies over a region of the tropical Pacific (4°S–4°N, 150°–90°W). An ENSO year from October through to the following September is then categorized as El Niño (La Niña) if JMA index values are 0.5°C (−0.5°C) or greater (less) for at least 6 consecutive months (including October, November, and December). All other years are classified as neutral. The JMA index for the post-1949 period is based on observed data and, for the years 1925–48, upon reconstructed monthly mean SST fields (Meyers et al. 1999).

In a similar way, IOD events are definition dependent, and we adopt that of Cai et al. (2009a). They define an event using an index of the IOD called the dipole mode index (Saji et al. 1999) in spring (September, October, and November), referenced to the climatological mean over the period 1880–2008. A pIOD (nIOD) event occurs when the index is greater (less) than 0.75 of its long-term standard deviation. Cai et al. (2009a) focused on the spring season as this is when pIOD events peak, and they relate the classification to the following summer season (December, January, and February). All other years are classified as neutral.

The above ENSO and IOD definitions correspond for the worst months for Australian bushfire impacts—December, January, and February—with bushfire years defined earlier as 12-month periods starting 1 July. Classifications according to the above definitions are given in Table 1 (see <http://coaps.fsu.edu/jma.shtml>). Cai et al. (2009c) noted the recent high frequency of pIOD events, with five occurring during 2002–08.

f. Post-Black Saturday observations

After the Black Saturday fires, Risk Frontiers undertook an aerial reconnaissance for the Kinglake area and Melbourne's northeastern suburbs, which are interfaced with extensive bushland. On-the-ground surveys were not possible at the time (11 February 2009), with access to many of the impacted areas prohibited while police conducted crime-scene investigations.

Quantitative damage analysis focused on Marysville and Kinglake, the two towns most severely damaged. The main aim was to reveal the spatial pattern of destroyed properties in relation to distance from surrounding bushland boundaries. A Melbourne-based company, Airtech (<http://www.airtechaustr.com/>), provided 15-cm-resolution, georeferenced postfire imagery captured on 22 and 24 March 2009. These images were manually interpreted, and locations of a total of 1156 destroyed buildings and other surviving structures were digitized. For the distribution

TABLE 1. Years 1925–2008 (each beginning 1 Jul) identified as either El Niño or La Niña (ENSO), and pIOD or nIOD (IOD). Other years are classified as neutral for each oscillation.

Years		
ENSO	El Niño	1925, 1929, 1930, 1940, 1951, 1957, 1963, 1965, 1969, 1972, 1976, 1982, 1986, 1987, 1991, 1997, 2002, 2006
	La Niña	1938, 1942, 1944, 1949, 1954, 1955, 1956, 1964, 1967, 1970, 1971, 1973, 1974, 1975, 1988, 1998, 1999, 2007
IOD	pIOD	1925, 1941, 1946, 1951, 1961, 1963, 1967, 1972, 1977, 1982, 1987, 1991, 1994, 1997, 2002, 2004, 2006, 2007, 2008
	nIOD	1933, 1942, 1947, 1954, 1956, 1958, 1959, 1960, 1964, 1974, 1975, 1996

and extent of prefire bushland, we performed various supervised image classifications with the 2.5-m-resolution, orthorectified imagery in the 2009 SPOTMaps series (<http://access.spot.com/>). It was possible to reliably evaluate the best classification results given the fine resolution of imagery employed and the relative small size of the study area. Once the locations of buildings and bushland boundaries were known, we then calculated distance-based statistics relevant to land use planning and insurance pricing.

3. Results

a. Case studies

We first test the legitimacy of our assumptions that HE and fatalities have increased in proportion to the state/territory-level increase in the total numbers of dwellings and population. Table 2 shows state-based dwelling and population factors (as defined previously) for the 1967 Hobart and 1983 Ash Wednesday bushfires as well as UCL-weighted event factors, calculated by weighting UCL dwelling and population factors by their relative contribution to the total event HE and fatality numbers.

For the Hobart fires, state dwelling and population factors closely mimic their UCL-weighted equivalents (Table 2). Seven UCLs were used to calculate the weighted dwelling factor, with a 60% weight given to the Hobart UCL factor. Only the Hobart UCL was used for the weighted population factor as all 64 fatalities

occurred there. The closeness of the state and UCL-weighted factors is not surprising given the size of Hobart as compared with the rest of Tasmania—in 2008 the population in the Hobart UCL stood at approximately one-quarter of the total for the entire state (from the ABS). In other words, the state-based figures are also highly weighted toward Hobart.

In contrast to the Hobart fires, 12 UCLs were used to calculate the weighted dwelling factor for the Ash Wednesday fires, with no one contributing more than 22% of the total building damage. Similar treatment was used for the weighted population factor, where nine UCLs were used with a weighting of not more than 19% applied to each of the contributing UCL factors. All of the UCLs impacted by this event were small relative to the state in which they are located, and the differences are greater than was the case for Hobart, with both state-level factors underestimating growth in dwellings and population at the local level (Table 2).

Table 2 gives some confidence that, while it is possible for state- and local-level normalization factors to diverge, the variation does not appear to be systematic; if anything, it provides some indication that our assumption may be conservative as state-level data may underestimate dwelling growth in exposed areas. It was not possible to derive UCL-weighted factors for the entire analysis period as the UCL structure did not exist prior to the 1966 census (from the ABS).

Table 3 compares the Hobart and Ash Wednesday UCL-weighted normalized HE and fatalities with the data recorded for these events together with those experienced on Black Saturday. The key observation is that the Black Saturday death toll appears to be an aberration: after normalizing the data, the ratio of fatalities to building damage in the Black Saturday fires is more than double that for Hobart and Ash Wednesday. We note that the normalization factors are different for HE and fatalities and so the values shown in the final column in Table 3 are not just a simple arithmetic ratio of the recorded data.

b. Time series of building damage and fatalities

Figures 1a and 2a show time series of the annual aggregated bushfire HE and fatalities recorded in Peril-AUS and the Haynes et al. (2010) database for bushfire years 1925–2008; Figs. 1b and 2b present the corresponding

TABLE 2. State and UCL-weighted dwelling and population normalization factors for the 2008 bushfire year.

Bushfire	State dwelling factor	UCL-weighted dwelling factor	State population factor	UCL-weighted population factor
Hobart 1967	2.0	2.1	1.3	1.1
Ash Wednesday 1983	1.5	1.8	1.3	1.9

TABLE 3. Recorded and UCL-weighted normalized HE and fatalities in the 1967 Hobart, 1983 Ash Wednesday, and 2009 Black Saturday fires.

Bushfire	HE	Fatalities	Normalized HE	Normalized fatalities	Ratio of normalized fatalities to normalized HE
Hobart 1967	1557	64	3196	70	2.2%
Ash Wednesday 1983	2253	58*	3958	110	2.8%
Black Saturday 2009	2852	173	2852	173	6.1%

* Corrected from Haynes et al. (2010).

normalized values. Regression analysis on the recorded data reveals increasing trends (Figs. 1a and 2a), more pronounced in the case of Fig. 1a—trends that are reversed in the normalized data (Figs. 1b and 2b). None of these trends are statistically significant at the 10% level, and the overriding impression is of a time series that is dominated by occasional extreme excursions from the mean.

The average annual normalized HE over all years is 301 (Table 4), and the equivalent figure for fatalities

is 14. The former is some 3.6 times that determined by McAneney et al. (2009), a difference that arises primarily from normalizing the data. Other factors that influence this difference are 1) the inclusion of other events that had not been previously identified, 2) extending the analysis period to include Black Saturday, and 3) beginning the analysis in 1925 rather than in 1900—the years between 1900 and 1926 for which data exist being characterized by low levels of building damage.

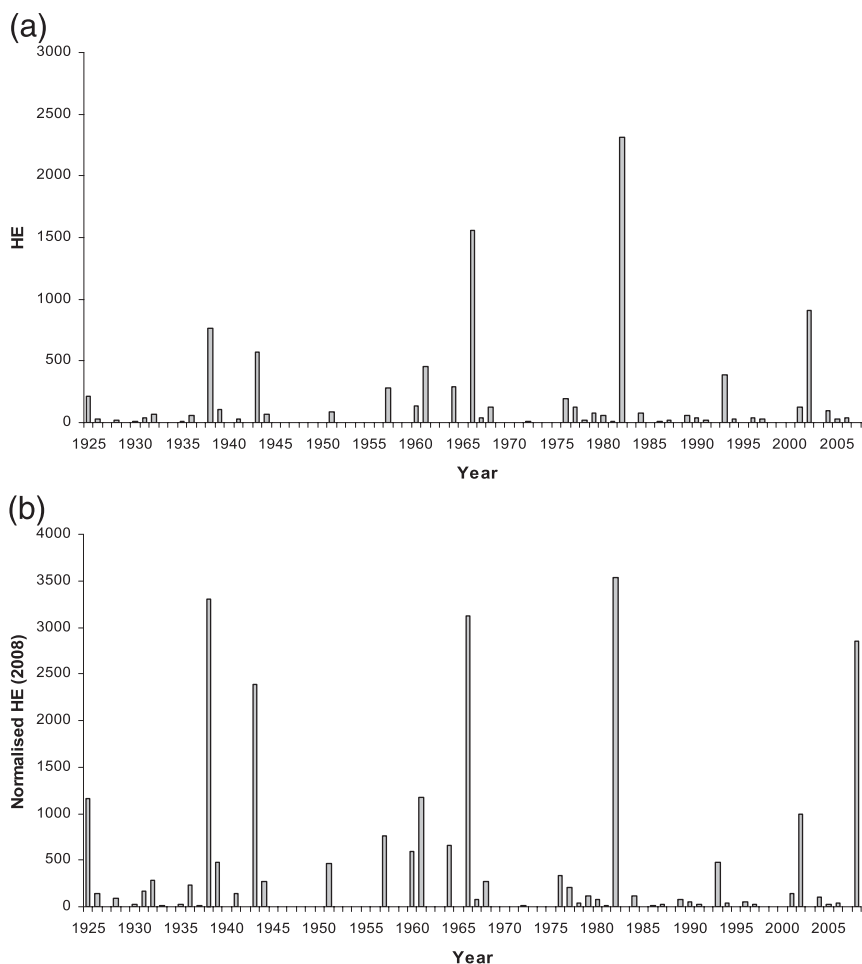


FIG. 1. (a) Annual aggregate HE for bushfire events in PerilAUS for years beginning 1 Jul; (b) as in (a) but with HE normalized to 2008 bushfire year values.

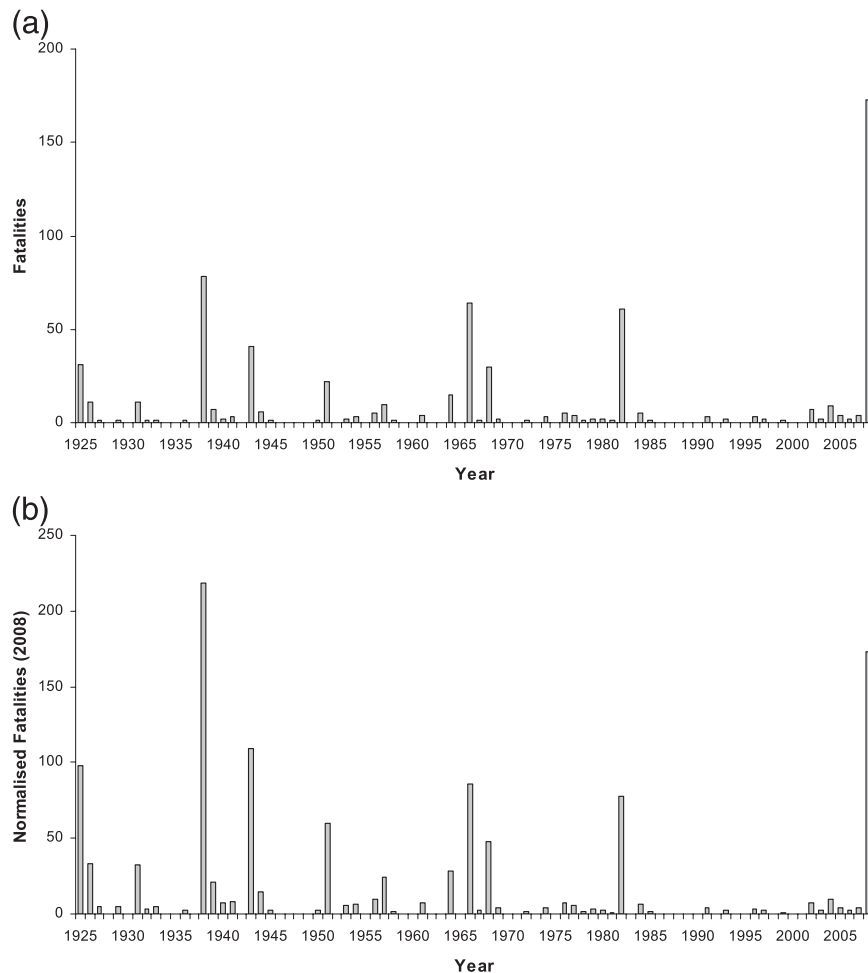


FIG. 2. (a) Annual aggregate fatalities for bushfire events in the Haynes et al. (2010) database for years beginning 1 Jul; (b) as in (a) but with fatalities normalized to 2008 bushfire year values.

The seemingly anomalous loss of life in the Black Saturday fires and 2008 bushfire year is subject to further scrutiny in Fig. 3, which shows the ratio of annual aggregate normalized fatalities [Eq. (2)] to normalized HE [Eq. (1)] for those bushfire years for which the normalized HE is greater than 600. Adoption of a 600-HE threshold, which conveniently reduces the data to the 10 most damaging years, was done simply to eliminate those years with little or no building damage and/or few or no fatalities. The generally decreasing pattern in Fig. 3 over time is broadly insensitive to the threshold of building damage adopted: a very similar pattern is revealed if a threshold of 100 HE is applied. Of the 10 most damaging years, not since close to the beginning of the analysis period, the 1938 bushfire year, has there been a higher ratio of normalized fatalities to building damage (Fig. 3) than in the 2008 bushfire year. The ratio of total normalized fatalities to HE over the entire analysis period is 4.7%.

c. ENSO and IOD relationship with normalized bushfire building damage

Table 4 shows the median, average, and standard deviation (of normalized HE) over the 84-yr study

TABLE 4. Summary statistics by ENSO and IOD phase for annual aggregate normalized building damage for years 1925–2008 (each beginning 1 Jul). Numbers in parentheses were derived using the SOI definition of ENSO.

		Median annual normalized HE	Avg annual normalized HE	Std dev of annual normalized HE
ENSO	El Niño	29 (37)	414 (378)	864 (823)
	Neutral	38 (33)	282 (252)	690 (606)
	La Niña	0 (0)	240 (328)	783 (929)
IOD	pIOD	77	574	1012
	Neutral	10	247	690
	nIOD	0	110	244
	All years	20	301	743

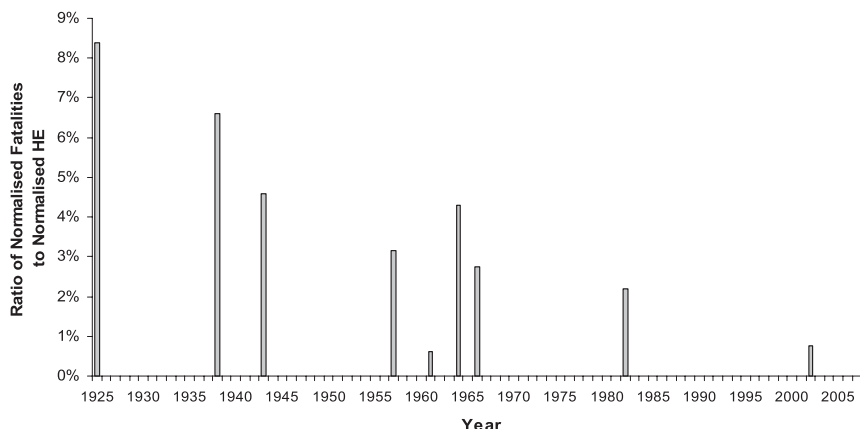


FIG. 3. Ratio of annual aggregate normalized fatalities [Eq. (2)] to HE [Eq. (1)] for years (beginning 1 Jul) in which normalized building damage exceeded 600 HE.

period for ENSO and IOD classified years. There are distinct differences in the median annual and average annual normalized HE for El Niño and La Niña years as there are for pIOD and nIOD years. As expected, the average building damage is highest in El Niño and pIOD years and the median damage in La Niña and nIOD years is zero. The distribution of damage over all years is highly skewed.

The relationship between ENSO and bushfire building damage is reasonably robust, although the strength of the relationship is weakened if an alternative SOI-based definition is applied (Table 4). Under the SOI definition, an El Niño (La Niña) year occurs when the average of June–December monthly SOI values is less (greater) than -5 (5) (S. Power 2009, personal communication). The difference between the average building damage in El Niño and La Niña years is substantially reduced under the SOI definition but the median in La Niña years is still zero.

It is important to note the statistics in Tables 4 and 5 are sensitive to building damage in the most destructive of bushfire years. The 10 most damaging years in terms of normalized HE account for almost 80% of total normalized damage, and the ENSO classification of only one of these bushfire years (2008—the fourth largest) differs between the two ENSO definitions: using the SST definition, the 2008 bushfire year is classified as neutral (Table 1) whereas under the SOI definition, it is categorized as La Niña.

Tables 4 and 5 suggest that the IOD is more discriminating than ENSO in relation to normalized bushfire building damage in Australia (the SST definition of ENSO was used in Table 5). The two most damaging combined phases are pIOD/neutral and pIOD/El Niño, which together make up 17 of the 84 bushfire years in the study period (Table 5). The 1938 bushfire year (La Niña

year, neutral IOD year) is the only example in which extreme building damage (normalized HE > 1000) occurred in either a La Niña or nIOD year.

As pointed out earlier, bushfire years (beginning 1 July), ENSO years (beginning 1 October), and IOD years (relating to the summer season) do not completely overlap. The effect of this difference is negligible as less than 0.2% of the total normalized HE occurred in the months from 1 July to 30 September inclusive and almost 95% of the total normalized building damage occurred during summer (December, January, February).

d. Post-Black Saturday analysis: Kinglake and Marysville

Destroyed buildings in Kinglake and Marysville were categorized as a function of distance from bushland boundaries, and these data are presented in Fig. 4. A key feature is that about 25% of destroyed buildings were located physically within the bushland boundary, and 60% and 90% were within 10 and 100 m of bushland (Fig. 4). Most buildings in Marysville lay within 200 m of the bushland boundary and, given the wind change that occurred early in the evening on 7 February 2009, would have been subject to ember attack from multiple directions (Victorian Bushfires Royal Commission 2009).

TABLE 5. Average annual normalized HE by ENSO (SST definition) and IOD phase for years 1925–2008 (each beginning 1 Jul). Numbers in parentheses are the number of years on which the average is based.

		IOD		
		pIOD	Neutral	nIOD
ENSO	El Niño	631 (10)	142 (8)	— (0)
	Neutral	645 (7)	239 (35)	110 (6)
	La Niña	39 (2)	358 (10)	110 (6)

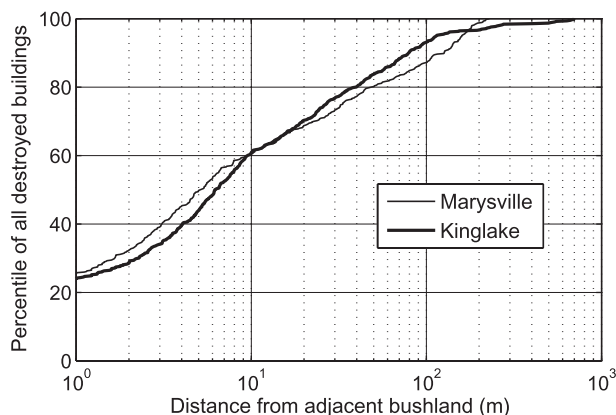


FIG. 4. Cumulative distribution of buildings destroyed in relation to distance from nearby bushland. The number of samples for Marysville and Kinglake is 540 and 616, respectively.

4. Discussion

In assuming bushfire-related building damage and fatalities change in proportion to dwelling numbers and population, Eqs. (1) and (2) estimate the number of HE and fatalities in a given event had it occurred under 2008 bushfire year societal conditions. There are other factors not accounted for in the normalization methods, although we expect their influence, particularly on the building damage record, to be minimal relative to societal change. For example, it is likely that some historical bushfires occurred in what were formerly unpopulated areas and thus would have registered no building damage, whereas in these same areas large losses may now be possible. The opposite is also true where original bushlands have been converted to suburbs so that some historical bushfire impacts may now be physically impossible.

Haynes et al. (2010) suggest that a reduction, over time, in the number of people living and working in isolated rural locations would have influenced the fatality data. The effect of this shift was evident in the decreased number of fatalities due to late evacuation, the most common activity at time of death (Haynes et al. 2010). More specifically, Haynes et al. (2010) found a marked decline in those who died while evacuating from working outside and they concluded that this in part explained the absence of a trend in the fatality data (prior to the Black Saturday fires) despite considerable population growth. Notwithstanding these and other qualifications, Figs. 1b and 2b show our best estimates of normalized bushfire building damage and fatalities.

Is the normalized building damage realistic? The average nominal value of a new house (excluding land) in Australia in the 2008 bushfire year was approximately AU\$260,000 (from the ABS) so that, in dollar loss terms, the average annual building damage of 301 HE (Table 4)

equates to AU\$78 million. As noted earlier, this amount excludes building contents, cars, and so on and so will underestimate the property loss, but it does include both insured and uninsured building damage. From an independent dataset, but using a conceptually similar normalization method, Crompton and McAneney (2008) found the average annual insured property loss from weather-related natural disasters between 1967 and 2006 to be around AU\$820 million (in 2006 dollars), of which about 12%, or AU\$98 million, can be attributed to bushfire. Despite the stated differences, the closeness of these two independent estimates provides some confidence in the method and results. The relationship between normalized building damage and ENSO and the IOD provides additional confidence.

Similar to the result of Cai et al. (2009a) we found normalized Australian bushfire building damage to be more strongly related to the IOD than to ENSO. This is unsurprising as Cai et al. (2009a) follow the Ellis et al. (2004) definition of a significant bushfire, and this incorporates historical impacts (fatalities, property, and livestock losses) rather than meteorological variables or indices. The significant Victorian summer bushfire seasons that the Cai et al. (2009a) study is based upon are therefore correlated with years of high normalized Australian building damage (61% of the total normalized HE occurred in Victoria), at least over the common time period since 1950.

The Black Saturday fires rank fourth in terms of normalized building damage. There were 173 fatalities, more than double the recorded number in any other bushfire event over the analysis period. After normalization, the Black Saturday death toll ranks second to the 1939 Black Friday fires with 214 normalized fatalities. In other words, history suggests that even larger impacts are possible under the climate of past decades. However, this ranking should not detract from the extreme impacts and high ratio of normalized fatalities to building damage in the Black Saturday fires and the need for policy changes to reduce the likelihood of this happening again.

One unequivocal result from our analyses is the absence of any significant trend in normalized HE over time (Fig. 1b). This being the case, a reasonable conclusion at this time, consistent with similar studies summarized by Bouwer (2010), is that it is not possible to detect a greenhouse-gas climatic-change signal in the time series of Australian bushfire building damage once it has been normalized. Such an influence is not ruled out by our analysis, but, if it does exist, it is clearly dwarfed by the magnitude of the societal change and the large year-to-year variation in impacts. Moreover it seems highly implausible that the net effect of other factors such as changes

in bushfire risk management is being exactly balanced by a greenhouse gas-driven climatic-change influence.

5. Policy implications

This study has shown that increasing building damage due to bushfire in Australia is largely being driven by increasing dwelling numbers and that the impact of greenhouse gas-driven climatic change is not detectable at this time. With this in mind, to reduce the impact of future bushfire events, investments to reduce societal vulnerability need to be made and are likely to bring immediate benefit. Adaptation should be undertaken concurrently with mitigation so that success in addressing bushfire risk in Australia in the short term at least is not misunderstood in terms of obtaining global agreement on reduction of greenhouse-gas emissions.

The Black Saturday tragedy occurred in the face of significant investments (Ashe et al. 2009) and improvements in bushfire risk management and suppression. We take the view that the extreme property losses were in part related to the close proximity of many dwellings to bushland. Chen and McAneney (2004) showed that, although distance to bushland is not the only variable determining bushfire vulnerability, it is demonstrably the most important, with the probability of home destruction decreasing strongly as a function of this distance, a result interpreted as being indicative of ember density and flammability. In the towns of Kinglake and Marysville, where the majority of building damage occurred in the Black Saturday fires, we have shown that 25% of destroyed buildings were literally located within bushland and that 60% were within 10 m of the bushland boundary. Under the extreme conditions prevailing on that day, it is difficult to imagine that homes in the flame zone could have been successfully defended against the combined threats of flames, radiant and convective heating, and embers.

The “prepare, stay, and defend or leave early” bushfire policy, adopted by all Australian fire authorities at the time of the Black Saturday fires, arose on the basis of concerns about the likelihood of large losses of life occasioned by late evacuation (Handmer and Tibbits 2005; Haynes et al. 2010) and the perceived impracticability of evacuating large numbers of people every time severe bushfire conditions exist, circumstances that might arise in some years and some parts of the country for much of the summer. The policy put the actions of residents as central in the protection of lives and property and has the commendable attribute of discouraging an unwarranted dependence upon emergency services. On the other hand, an incorrect interpretation of this policy during Black Saturday may also have contributed to a mistaken belief that homes constructed within or in

close proximity to the bushland could be successfully defended against bushfires in extreme conditions.

Our results raise serious questions about land use planning in Australia in relation to bushfire risk. The comparison of state- and UCL-level normalization factors (Table 2) is cause for further concern as it suggests dwelling growth in areas of high bushfire risk may be occurring faster than state averages. We echo the sentiments of McAneney et al. (2009) that, without changes in policy, particularly in land use planning, further bushfire catastrophes are inevitable.

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CHAPTER 5

Crompton, R. P., K. J. McAneney, K. Chen, R. A. Pielke, Jr., and K. Haynes, 2011. [Reply](#). *Wea. Climate Soc.*, 3, 63-66.

Crompton, R. P., K. J. McAneney, K. Chen, R. A. Pielke, Jr., and K. Haynes, 2011. [Corrigendum](#). *Wea. Climate Soc.*, 3, 141.

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Contribution

This paper is a reply to the published comments (see Appendix 1) on the paper contained in Chapter 4. I performed all of the calculations and wrote this paper with contributions from Dr Katharine Haynes. Professor John McAneney reviewed early drafts and all co-authors read later versions and gave suggestions prior to submission. My contribution is estimated at 70%.

Reply

RYAN P. CROMPTON, K. JOHN MCANENEY, KEPING CHEN, ROGER A. PIELKE JR.,
AND KATHARINE HAYNES

(Manuscript received and in final form on 22 December 2010)

In our article (Crompton et al. 2010) we normalized bushfire building damage to current societal conditions by multiplying historical loss records by the factor change in total dwelling numbers from when the event occurred to 2008/09. The dwelling number factor was calculated at the state level and we tested the validity of this resolution using two historic case studies: the 1967 Hobart and 1983 Ash Wednesday bushfires. No trend in building damage was found after normalization.

Nicholls (2011) speculates that the absence of an upward trend in normalized building damage may reflect a bias introduced through our use of state level normalization factors and presumed reductions in vulnerability over the time period examined: 1925–2009. Here we explain why the factors that Nicholls states as being unaccounted for either miss the most important points, are uncertain and unquantifiable, or are negligible in extreme impact events such as the 7 February 2009 Black Saturday bushfires. The extreme impact events are critical as these dictate the pattern in normalized building damage.

The first issue raised by Nicholls (2011) is that state level normalization factors do not account for the increasing urbanization of Australia and that this is important because capital city populations are generally far less vulnerable to bushfires than those living in small towns or isolated communities. Our estimate of population distribution change is not as dramatic as that reported by Nicholls: according to the Australian Historical Population Statistics [available from the Australian Bureau of Statistics (ABS) online at <http://www.abs.gov.au>], the proportions of the population *outside* each of the capital cities of Victoria, New South Wales, and Tasmania in 1958 were 37%, 45%, and 68% and

equivalent figures for 2007 (the latest year for which data were available) were 27%, 37%, and 58%. If we adopt the ABS classification on urban and rural dwellings (the ABS defines urban areas to be those with 1000 or more people), the change of rate is even less pronounced over a similar timeframe: the proportions of rural dwellings in Victoria, New South Wales, and Tasmania in 1961 were 16%, 15%, and 33%, only slightly decreasing to 11%, 11%, and 29% in 2006 (dwelling data are contained in the census of population and housing and are available from the ABS). Note that these three states of southeast Australia account for over 90% of total normalized building damage.

In focusing on urbanization and the relative vulnerability of cities and areas outside of cities, Nicholls (2011) misses the point—what matters most to our normalization is how the rate of growth of bushfire-prone dwellings compares to that of state level total dwellings. In particular, he overlooks urban encroachment into bushlands on the fringes of many Australian cities (e.g., Fig. 1). Rapid urban encroachment has resulted in an increase in the absolute number of bushfire-prone dwellings in Melbourne (Victoria), Sydney (New South Wales), and Hobart (Tasmania). It also has produced a likely increase in the proportion of bushfire-prone dwellings in some capital cities (e.g., Sydney and Hobart); that is, the rate of growth of bushfire-prone dwellings exceeds that of total dwellings in some capital cities. While it is not possible to quantify this or the number of bushfire-prone dwellings at any resolution throughout our period of study, if this has occurred, then the rate of growth of bushfire-prone dwellings in some capital cities must have also exceeded that of respective state level total dwellings.

We should also note that there is evidence to suggest that for some areas outside of capital cities, the rate of growth of bushfire-prone dwellings has been similar to and, if anything, larger than the contemporaneous

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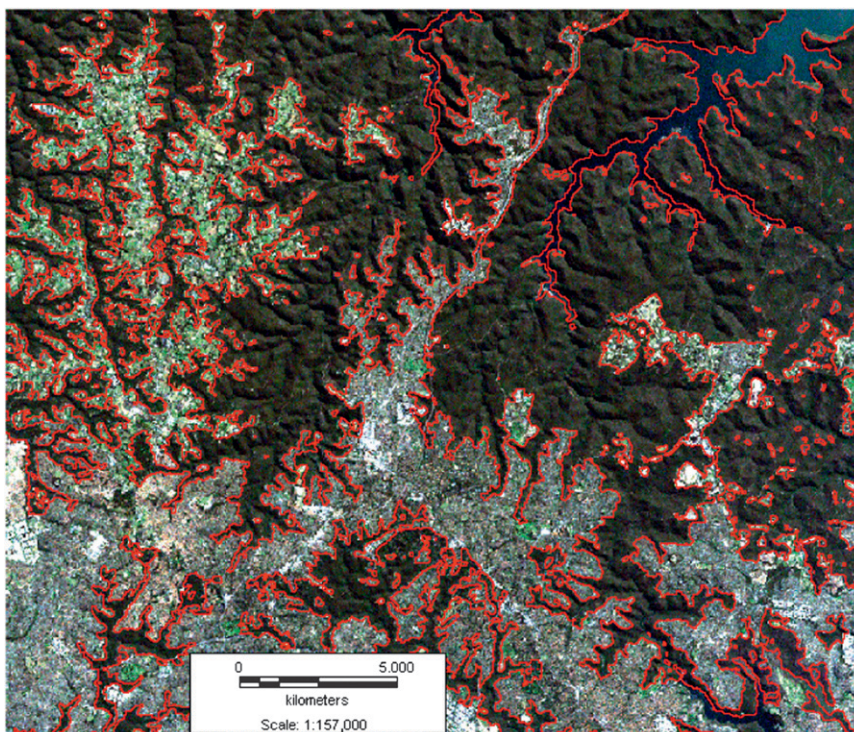


FIG. 1. Aerial view of northern Sydney showing the highly dissected and complex interface (red line) between bushland (dark green) and urban areas.

growth in statewide total dwellings. This evidence includes the 1983 Ash Wednesday fires case study shown in Table 2 of our original article and two of the most severely affected locations (Kingslake and Marysville) in the 2009 Black Saturday fires (Table 1). There is further evidence in those areas impacted by the 1967 Hobart fires outside of Hobart.

So what is the significance of this discussion?

Where rates of bushfire-prone dwelling growth exceed that of total dwellings across the state, then this will have the opposite effect to that suggested by Nicholls (2011): historic events should have a larger normalization factor applied to them, which would in turn tend to make the trend in normalized damage negative. In other words, if anything, our normalization using state total dwellings is likely conservative.

Nicholls (2011) refers to several factors that may have led to a reduction in building vulnerability to bushfire over time. He also suggests bushfire risk reduction measures undertaken by property owners to be a recent phenomenon. However, preparing a property and active defense to save lives and livelihoods has been a necessity for generations of rural Australians. The “stay and defend, or leave early” policy may have become official Australian Fire Authority Commission policy in 2005, but it has been implemented as a survival strategy in

rural areas and country towns since European settlement (Handmer and Tibbits 2005). An examination of many eyewitness accounts of Australian bushfire preparation and survival demonstrates that little has changed over 100 years (Haynes et al. 2010).

Nicholls (2011) further argues that changes in building or planning regulations and autonomous actions by householders (in response to official enquiries into past major bushfire disasters or otherwise) would have led to a decline in damage. While many lessons have been learned from past experience, it is unlikely that any changes implemented would have prevented the impacts of the most extremely damaging bushfires. The most important lesson that should have been learned

TABLE 1. The factor change in dwellings at 10-yr intervals relative to the 2008 bushfire year. The underlying data are from the census of population and housing in the stated years (available from the ABS).

Year	Dwelling factor		
	Victoria	Kingslake UCL	Marysville UCL
1966	2.3	Not available	2.1
1976	1.7	Not available	2.3
1986	1.4	3.5	1.4
1996	1.2	2.6	1.1

from past experience is simply to avoid development in high risk areas. In their analysis of bushfire risk at Melbourne's urban fringe, Buxton et al. (2011) argue that vulnerability has increased because of the failure of land use planning regulations. We agree with this assessment.

An analysis of each of the major bushfires over the past five decades (including the 1967 Hobart fires, the 1983 Ash Wednesday fires, the 1994 Sydney fires, and the 2009 Black Saturday fires) shows that Australia has a history of development in high risk areas. About 80%–90% of destroyed buildings in major bushfires have been *consistently* located within 100 m of nearby bushland (Chen and McAneney 2004; Crompton et al. 2010). In our analysis of the Black Saturday fires (Crompton et al. 2010), we reported the large proportion of buildings destroyed in Kinglake and Marysville that were located either within bushland or at very small distances from it (<10 m). Our observations suggest that in the early part of last century, lives were lost and homes destroyed where people were living and working in the bush, often in logging camps; more recently, people have chosen to live in bushland for lifestyle reasons (Haynes et al. 2010).

In his mention of changing regulations, Nicholls (2011) does not consider factors that may have *increased* vulnerability over time. A number of lay witnesses who appeared at the 2009 Victorian Bushfires Royal Commission cited stringent and complicated regulations, which *inter alia* restricted the clearing of vegetation around properties, as key factors that increased the vulnerability of their homes to bushfires. Since vulnerability is largely a function of distance from the bushland interface (Chen and McAneney 2004; Crompton et al. 2010), the large proportion of buildings destroyed within bushlands in the Black Saturday fires suggests that building vulnerability has not decreased.

Another possible source of reduced vulnerability cited by Nicholls (2011) was improved emergency preparations and response, such as better firefighting equipment and management. As stated already, the urban fringe in Australia is growing rapidly. While there is a danger in generalizing and we acknowledge that communities are far from homogeneous, many of those residing on the urban–bushland interface have very limited experience and knowledge of bushfires. As demonstrated in 2003 in Canberra and again in 2009 in Bendigo, Horsham, and Narre Warren (Whittaker et al. 2009), many whose homes were destroyed were unaware that they were at *any* risk from bushfires.

What has become clear over the last decade or two is that many bushfires cannot be fully controlled through prescribed burning, clearing, or suppression. Fire

services have become increasingly overwhelmed, resulting in a shift of responsibility back onto individuals to prepare their homes and protect themselves. Communities in Victoria are regularly and explicitly told by the Country Fire Authority not to expect an official warning or assistance during a bushfire. While there has been significant emphasis on community self-reliance over the last decade, getting individuals to actually prepare properties, make a bushfire plan, and stick to it has proved challenging (Tibbits and Whittaker 2007; Haynes et al. 2010).

We do not question that improved emergency management has led to a reduction in the lives and property lost in numerous smaller bushfires, as we believe this to be the case. However, in large catastrophic fires such as Black Saturday, firefighting and emergency services have limited capacity to reduce fatalities and property losses. Under the extreme weather conditions prevailing during most of the major loss events that dominate the time history of building damage (see Fig. 1 of our original article), there is little fire services can do to control the spread of fire and protect individual properties.

The final issue raised by Nicholls (2011) is that improvements in weather forecasts over several decades may have reduced vulnerability. This is highly speculative and there is little evidence from anywhere that weather forecasts materially influence property damage from extreme events, even if they do save lives. The weather conditions on Black Saturday were very well forecast and accurate warnings were issued to emergency responders, politicians, and the public prior to February 7. What Black Saturday clearly demonstrated is the reverse: that despite accurate weather forecasts and significant emergency/bushfire planning and response, there is always the potential for large-scale life and property loss.

Providing warnings is only one step in a very complicated chain. The difficulty is achieving adequate preparedness and risk reduction among the community so that people can respond effectively when warnings are given. Survivors of the Black Saturday fires (Whittaker et al. 2009) had a high level of awareness that this was a day of Total Fire Ban (99% of survey respondents). However, the events of Black Saturday suggest little connection between such awareness and individuals taking appropriate actions.

We would like to make it explicitly clear that neither in our original article nor in our discussion here do we dispute that anthropogenic climate change is occurring; rather, we show, as others have also done for other perils in other jurisdictions (Bouwer 2011), that societal changes can explain the increasing trend in Australian bushfire damage.

Our result—that there is no discernable evidence that normalized building damage is being influenced by climate change due to the emission of greenhouse gases—is not surprising, when you consider that bushfire damage is not solely a function of bushfire weather; far from it, in fact. Even given a gradual aggravation of bushfire weather due to anthropogenic climate change or other factors, a bushfire still has to be ignited. Once ignited, a bushfire then has to traverse the landscape and impact a populated area, where outcomes in terms of damage will be a function of the spatial disposition of dwellings with respect to the fire front, and especially distance of properties from the bushland boundary (McAneney et al. 2009). These factors all contribute a large degree of stochasticity to eventual event loss outcomes.

The Nicholls (2011) speculations are worthy of discussion but no evidence is presented to support these contentions. Moreover, the evidence that we are aware of and have presented here in relation to a potential bias in our normalization methodology and to the possible sources of reduced vulnerability does not undermine our findings in any way. Our conclusion holds up well without Nicholls' proposed caveat. Generally speaking, if others are able to improve upon our normalization methodology, then we encourage them to do so.

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CORRIGENDUM

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In Crompton et al. (2011), there was a mistake in an in-text citation and a missing reference. The second Whittaker et al. (2009) in-text citation on page 65 (second column, fourth paragraph) should have been Whittaker et al. (2010).

The staff of *Weather, Climate, and Society* regrets any inconvenience this may have caused.

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CHAPTER 6

Crompton, R. P., S. Schmidt, L. Wu, R. Pielke Jr., R. Musulin, and E. Michel-Kerjan, 2010. **Economic impacts of tropical cyclones**. *Rapporteur report prepared for the Seventh World Meteorological Organization (WMO) International Workshop on Tropical Cyclones (IWTC-VII), La Réunion, France. 15-20 November 2010.*

Contribution

Part of my responsibilities as an invited rapporteur for the Seventh World Meteorological Organization (WMO) International Workshop on Tropical Cyclones (IWTC-VII) were to prepare a report summarising progress on the economic impacts of tropical cyclones since the last IWTC (i.e. approximately 4 years). I planned, structured, put together and wrote the report with contributions to sections from members of the working group as follows: Silvio Schmidt – 4.5.2.2b and 4.5.3; Dr Liguang Wu – 4.5.2.2a; Professor Roger Pielke Jr. – 4.5.2.2b; Rade Musulin – 4.5.4, and Professor Erwann Michel-Kerjan – 4.5.4. Members of the working group reviewed drafts of the report. My contribution is estimated at 60%.

SEVENTH INTERNATIONAL WORKSHOP ON TROPICAL CYCLONES

4.5: Economic Impacts of Tropical Cyclones

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4.5.1. Introduction

Global natural disaster losses have risen dramatically in recent decades and tropical cyclones have contributed significantly to this trend. Tropical cyclones account for nine of the ten most costly inflation-adjusted insurance natural disaster losses (2009 dollars) between 1970 and 2009 (Swiss Re, 2010). Of these nine, eight impacted the US and surrounding areas and one impacted Japan. In original loss values, tropical cyclones account for two of the five most costly economic losses and four of the five most costly insurance losses from natural disasters over the period 1950 to 2009 (Munich Re, 2010). All hurricanes in the top five of both original loss lists impacted the US and Hurricane Katrina tops the original and inflation-adjusted loss lists.

The increase in tropical cyclone losses has led to concern that anthropogenic climate change is contributing to this trend. In response to this, numerous studies of databases¹ from around the world have been undertaken to examine the factors responsible for this increase. Research has also focused on what role various factors may have in shaping tropical cyclones losses in the future. This report summarises those efforts.

The significant increase in losses has also made the question of how to better manage tropical cyclones, and natural hazards more generally, even more salient. An important component of catastrophe risk management is the development of adequate and sustainable financial protection for potential victims of future disasters and our report discusses this financial management aspect.

4.5.2. Loss normalization

4.5.2.1 Introduction

Before comparisons between the impacts of past and recent tropical cyclones can be made, various societal factors known to influence the magnitude of losses over time must be

¹ Data quality can be affected by, for example, changes in access to and in the assessment of natural catastrophe losses.

accounted for. This adjustment process has become commonly known as *loss normalization* (Pielke and Landsea, 1998).

Normalizing losses to a common base year is undertaken primarily for two reasons: first, to estimate the losses sustained if events were to recur under current societal conditions and secondly, to examine long term trends in disaster loss records. In particular, to explore what portion of any trend remaining after taking societal factors into account may be attributed to other factors including climate change (natural variability or anthropogenic).

Climate-related influences stem from changes in the frequency and/or intensity of tropical cyclones whereas socio-economic factors comprise changes in the vulnerability and in the exposure – value of assets at risk – to the natural hazard. Socio-economic adjustments have largely been limited to accounting for changes in exposure, although Crompton and McAneney (2008) adjusted Australian tropical cyclone losses for the influence of improved building standards introduced since the early 1980s.

Bouwer (2010) provides a recent comprehensive summary of loss normalization studies. Table 1 has been adapted from that study to include only those relating to tropical cyclones. In what follows we focus on the more recent tropical cyclone loss normalization studies.

Table 1: Tropical cyclone loss normalization studies (adapted from Bouwer (2010)).

Hazard	Location	Period	Normalization	Normalized Loss	Reference
Tropical cyclone	Latin America	1944-1999	GDP ¹ per capita, population	No trend	Pielke et al. 2003
Tropical cyclone	India	1977-1998	Income per capita, population	No trend	Raghavan and Rajesh 2003
Tropical cyclone	USA	1900-2005	Wealth per capita, population	No trend since 1900	Pielke et al. 2008
Tropical cyclone	USA	1950-2005	Capital stock	Increase since 1971; No trend since 1950	Schmidt et al. 2009a
Tropical cyclone	China	1983-2006	GDP	No trend	Zhang et al. 2009
Tropical cyclone	China	1984-2008	GDP	No trend	Zhang et al. 2010
Tropical cyclone	USA	1900-2008	GDP	Increase since 1900	Nordhaus 2010
Weather (incl. tropical cyclone)	Australia	1967-2006	Dwellings, dwelling values	No trend	Crompton and McAneney 2008
Weather (incl. tropical cyclone)	USA	1951-1997	Wealth per capita, population	No trend	Choi and Fisher 2003
Weather (incl. tropical cyclone)	World	1950-2005	GDP per capita, population	Increase since 1970; No trend since 1950	Miller et al. 2008

¹Gross domestic product (GDP) is a measure of a country's overall official economic output. It is the market value of all final goods and services produced in a country in a given year.

4.5.2.2 Case studies

a) China

Zhang et al. (2009) examined the direct economic losses and casualties caused by landfalling tropical cyclones in China during 1983-2006 using the data released by the Department of

Civil Affairs of China. The economic loss data was estimated by the governments usually at town and county levels and collected by provincial governments and reported to the Department of Civil Affairs. Zhang et al. (2009) show that in an average year, seven tropical cyclones made landfall over the Chinese mainland and Hainan Island, leading to 28.7 billion yuans (2006 RMB) in direct economic losses and killing 472 people. A significant upward trend in the direct economic losses was found over the 24-year period. This trend disappeared after the rapid increase in the annual total Gross Domestic Product (GDP) of China was taken into consideration, a result that suggested that the upward trend in direct economic losses was a result of Chinese economic development.

More recently, Zhang et al. (2010) updated the earlier analysis to 2008 and also included a consumer price index (CPI) inflation-adjusted time series of direct economic losses (Fig. 1). Over the period 1984-2008, tropical cyclones led to 505 deaths and 37 billion yuan in direct economic loss per year accounting for about 0.4% of annual GDP. The annual total direct economic losses increased significantly due to the rapid economic development over the 25-year period, while the percentage of direct economic losses to GDP (the ‘normalization’) and deaths caused by landfalling tropical cyclones decreased over this period. Both studies concur that economic development is the primary factor responsible for the increasing tropical cyclone damage in China.

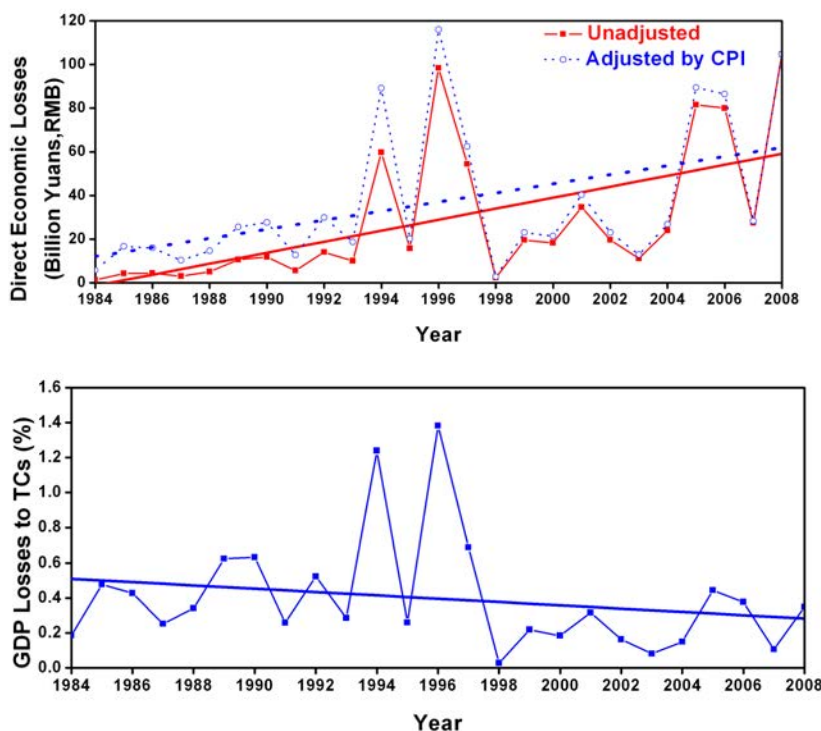


Figure 1: The economic losses released by the Department of Civil Affairs of China and the corresponding CPI-adjusted losses each year in billion yuans (top); the GDP-normalized losses in percentage (%) (bottom). Corresponding linear trends from 1984 to 2008 are also shown (source: Zhang et al. (2010)).

Over the past 25 years, tropical cyclones made landfall on the Chinese mainland and Hainan Island with an average landfall intensity of 29.9 m/s and they retained their tropical cyclone intensity for 15.6 hours over land (Zhang et al., 2010). No significant trends in landfalling frequency and intensity have been found. Rainfall associated with landfalling tropical

cyclones is a major contributor to damage in China. A recent study (Chen et al., in prep.) shows a significant increase in the time landfalling tropical cyclones spend over land with tropical storm intensity. By separating the tropical cyclone rainfall from other weather systems, Chen et al. (in prep.) find that the overall rainfall associated with landfalling tropical cyclones was dominated by significant downward trends over the past 25 years (Fig. 2). In the extreme rainfall days (Fig. 3), Chen et al. (in prep.) also do not find an overall increasing trend. These results suggest that the significant upward trend in typhoon damage cannot be explained by changes in tropical cyclone activity.

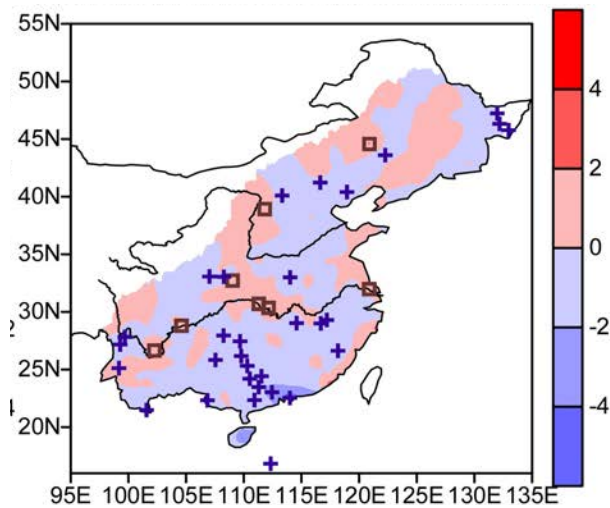


Figure 2: Trends (mm/year) in annual rainfall associated with landfalling tropical cyclones in China. The symbols indicate that the trends are statistically significant at the 95% level (source: Chen et al. (in prep.)).

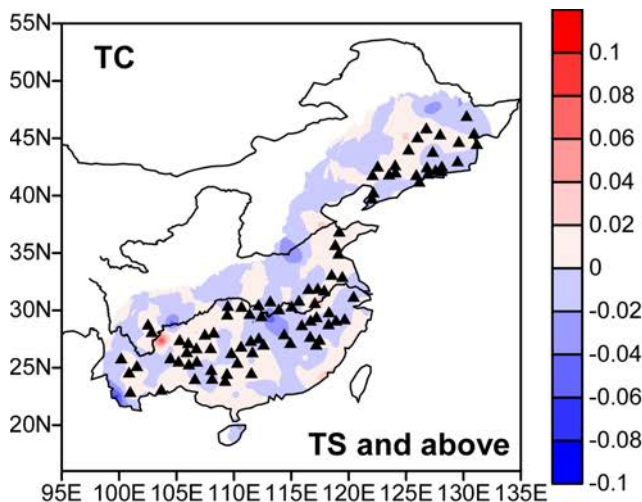


Figure 3: Trends (day/year) in extreme rainfall days associated with landfalling tropical cyclones in China. The symbols indicate that the trends are statistically significant at the 95% level (source: Chen et al. (in prep.)).

b) US

Given the major contribution of US tropical cyclone losses to global natural catastrophe losses, it is not surprising that US loss data has been studied rigorously. Here we discuss results of three recent studies: Pielke et al. (2008), Schmidt et al. (2009a) and Nordhaus (2010), as well as an unpublished update to Pielke et al. (2008) (prepared by R. Crompton and R. Pielke Jr.).

Pielke et al. (2008) normalized mainland US hurricane damage from 1900-2005 to 2005 values. The study utilized historical economic damage from the *Monthly Weather Review* annual hurricane summaries supplemented by the storm summary data archived on the National Hurricane Center (NHC) Web site.

Two normalization methodologies were presented with broadly consistent results. The 'PL05' methodology (as used by Pielke and Landsea (1998)) adjusted for changes in population (in affected coastal counties), inflation (national level) and wealth (national real per capita wealth). The 'CL05' methodology (as used by Collins and Lowe (2001)) differed from PL05 in its use of coastal county housing units rather than population. The wealth multiplier was therefore different, as it corrected for national changes in housing units – rather than population – to determine a change in wealth per housing unit. The calculation of CL05 involved the same inflation multiplier as PL05.

Figs. 4 (a) and (b) from Pielke et al. (2008) show that the results for the two different approaches to normalization for the complete data set are generally very similar, with larger differences further back in time. Pielke et al. (2008) note the extremely low amounts of damage during the 1970s and 1980s compared to other decades. The decade 1926-1935 had the largest damage and 1996-2005 the second most damage among the past 11 decades. With \$140-157 billion of normalized damage, the 1926 Great Miami storm was the single largest storm loss and the most damaging years were 1926 and 2005. They estimate the average annual normalized damage in the continental US to be approximately \$10 billion over the 106-year period analysed. Major hurricanes (Saffir-Simpson categories 3 to 5) accounted for less than a quarter of the US landfalling tropical cyclones but the vast majority of the damage.

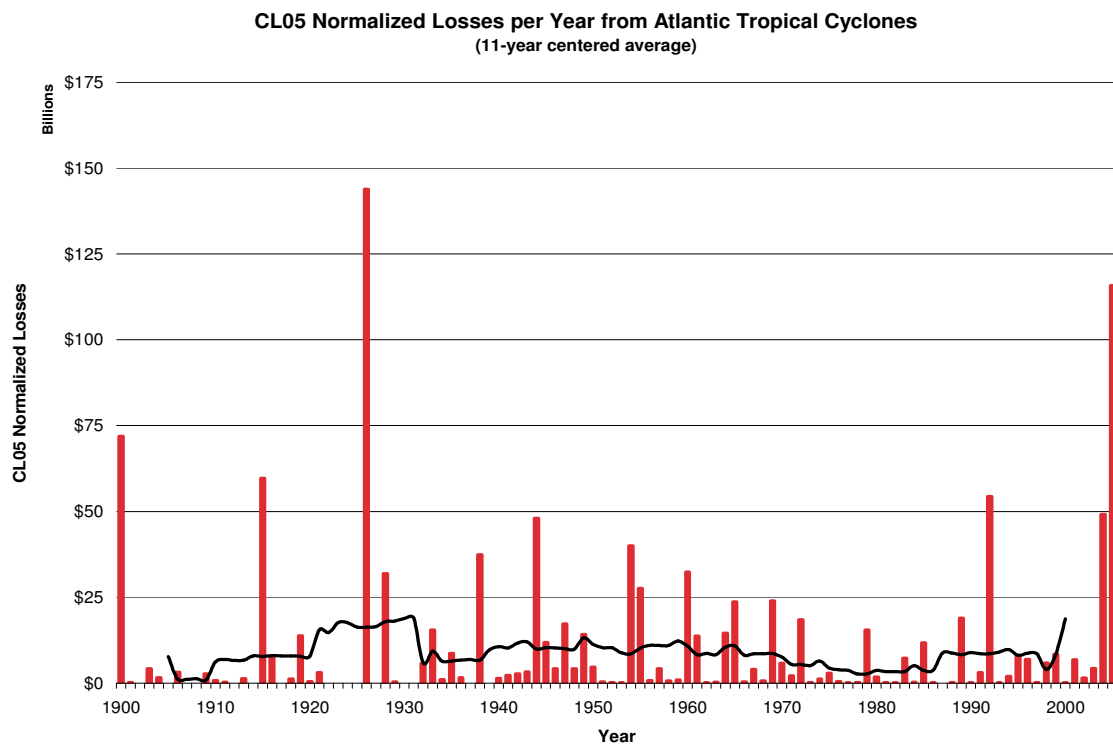
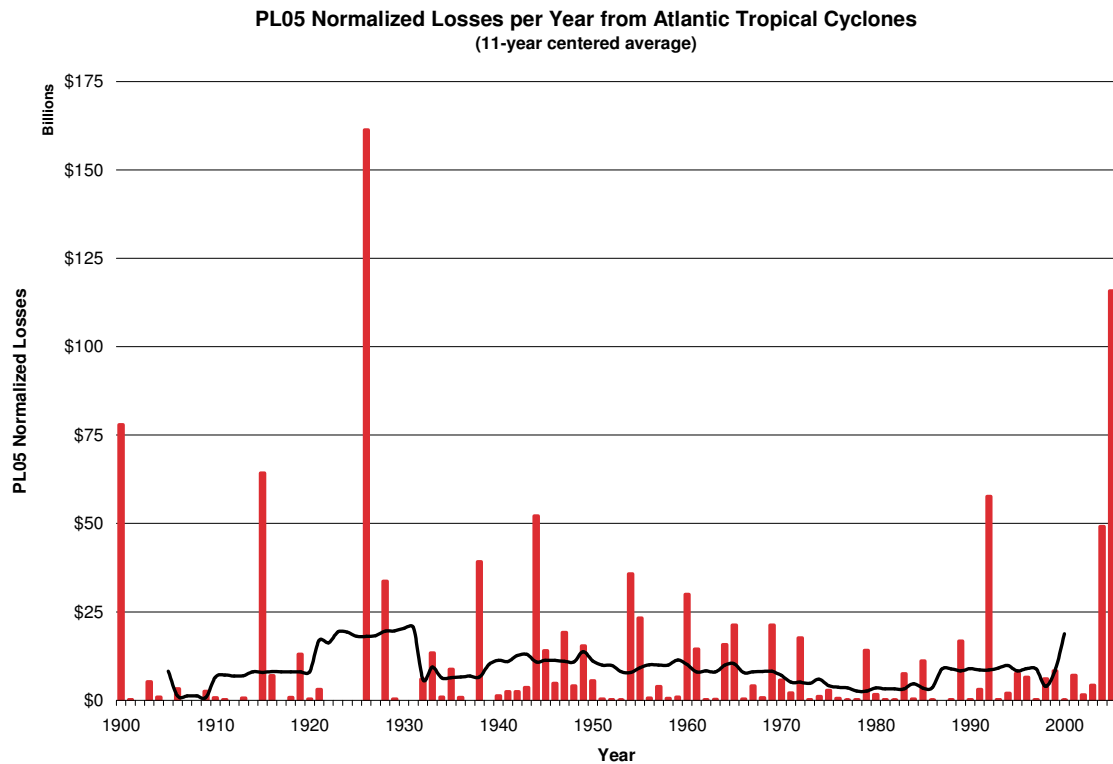


Figure 4: US Gulf and Atlantic damage, 1900-2005, normalized: PL05 methodology (top) and CL05 methodology (bottom) (source: Pielke et al. (2008)).

Pielke et al. (2008) reported no trends in the absolute data (or under a logarithmic transformation) over the period 1900 to 2005 across both normalized data sets. They point out that the lack of trend in normalized losses followed the lack of trends in landfall frequency or intensity observed over the twentieth century. Given the lack of trends in hurricane frequency or intensity at landfall, Pielke et al. (2008) conclude that any trend observed in the normalized losses would necessarily reflect some bias in the adjustment process, such as failing to recognize changes in adaptive capacity or mis-specifying wealth. That they did not find any such bias suggested that factors not included in the normalization could not have been significant. In conclusion, Pielke et al. (2008) note that unless action is taken to address the growing concentration of people and wealth in hurricane-prone coastal areas, damage will increase, and by a great deal.

Schmidt et al. (2009a) analysed US tropical cyclone economic loss data (1950-2005) from Munich Re's NatCatSERVICE® database (131 storms). They accounted for the socio-economic effects contained in the loss data and then subjected the adjusted data to a trend analysis. By doing this, any remaining trend in the adjusted (normalized) loss data would then point to a change in the risk situation that is very likely the result of climate change (both natural or anthropogenic) (Schmidt et al., 2009a). Schmidt et al. (2009a) introduce a new adjustment approach whereby loss data are adjusted to the socio-economic level of 2005 using changes in the capital stock at risk. Capital stock at risk data was obtained from the value of all housing units in all US counties affected by each storm (Schmidt et al., 2009a).

Schmidt et al. (2009a) report a non-statistically significant positive trend for the period 1950-2005, but a statistically significant positive trend in the adjusted data for the period 1971-2005. During the latter period losses increased on average by 4% per year² although this trend was no longer significant when the Hurricane Katrina loss was excluded. The authors conclude that the remaining positive trend in losses since 1971 could not be directly related to anthropogenic climate change but it could at least be interpreted as natural climate variability. They note that the period 1971-2005 begins at a phase of low storm activity in the North Atlantic and ends in the current phase of high activity, variation that results from natural climate variability in the North Atlantic. They also note that the Intergovernmental Panel on Climate Change (IPCC) states that it is more likely than not that humans have contributed to a trend in intense tropical cyclone activity since the 1970s (cf. IPCC, 2007a) and so suggest that any increase in losses could, more likely than not, be partly related to anthropogenic climate change.

Schmidt et al. (2009a) discuss two essential differences between their normalization methodology and the Pielke et al. (2008) 'PL05' methodology. The first is their use of capital stock at risk (determined from the number of housing units and mean home value) rather than the wealth at risk (determined from population and per capita wealth) employed in Pielke et al. (2008). Secondly, Schmidt et al. (2009a) apply regional figures for mean home value whereas Pielke et al. (2008) use the national average for per capita wealth. Fig. 5 shows the different rate of change in these metrics over time (Schmidt et al., 2009a). The wealth at risk factors are higher than the capital stock at risk factors and this difference generally increases back in time.

²The same results are obtained when looking at the Pielke et al. (2008) dataset of normalized losses over the same period.

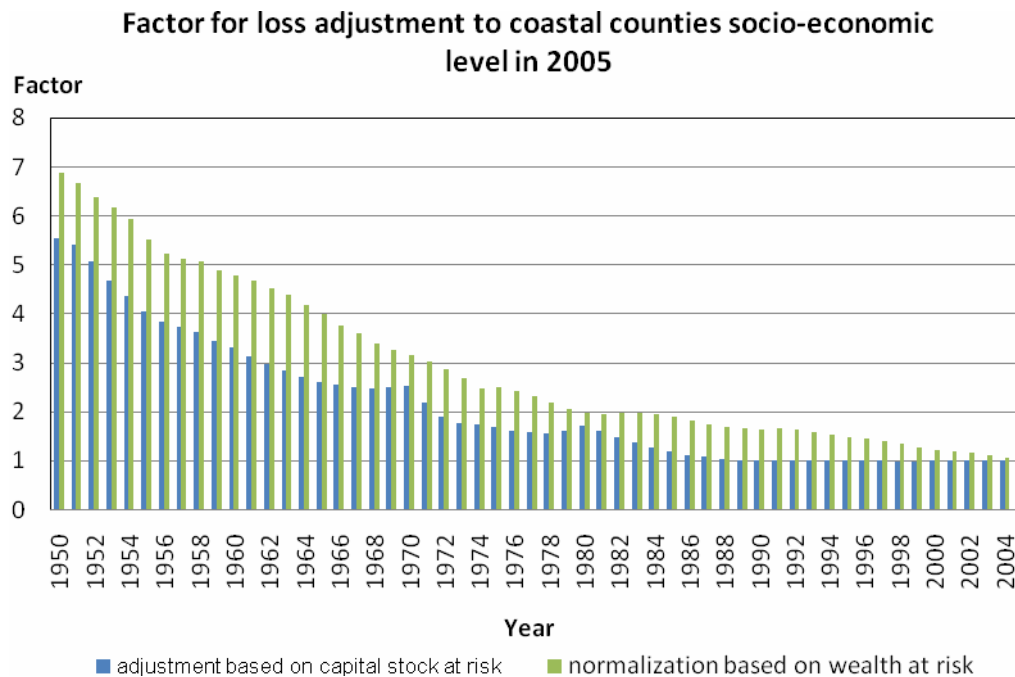


Figure 5: Blue bars show the factors applied for adjustment of losses to 2005 socio-economic level based on capital stock at risk (e.g. losses in year 1962 will be multiplied by factor 3). Green bars show the factors applied based on wealth at risk (population in 177 coastal counties and real wealth per capita). Losses adjusted by wealth at risk will be higher than adjusted by capital stock at risk (source: Schmidt et al. (2009a)).

Nordhaus (2010) normalized the economic impacts of US hurricanes over the period 1900 to 2008 by assuming damages were proportional to US nominal GDP. Data were obtained from “The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2006” (http://www.nhc.noaa.gov/Deadliest_Costliest.shtml).

Nordhaus (2010) states that the normalization approach is a reasonable way of accounting for economic growth assuming no adaptation and no variation in technology and the location and structure of economic activity. Among other factors, Nordhaus (2010) investigated the effect coastal migration had on losses and concluded that although these factors raised the ratio of hurricane damages to GDP in the last half-century, they did not entirely account for the rise in losses over that period.

Here we update the Pielke et al. (2008) analysis to include US hurricane losses from the 2006 to 2009 seasons with all losses now normalized to 2009 values. Fig. 6 shows the normalized US hurricane losses for 1900 to 2009. While it is apparent that there is no obvious trend over the entire time series, our emphasis is on the period 1971-2005 for which Schmidt et al. (2009a) report a statistically significant trend. (This trend in the log-transformed annual normalized losses was significant at the 10% level). Schmidt et al. (2009a) also show what effect a single event can have on the result as the trend was no longer significant when the Hurricane Katrina loss was excluded. In what follows, we investigate the effect that accounting for recent seasons has had on resulting trends beginning in 1971.

Similar to Schmidt et al. (2009a) we find a statistically significant (at the 10% level) trend ($P\text{-value} = 0.091$) in log-transformed annual normalized losses (2009 values) during 1971-2005. However the trend is not statistically significant (at the 10% level) when the time series is

extended to any year after 2005 (e.g. 1971-2006, etc.). This highlights the difficulty that the large volatility in the time series of tropical cyclone losses poses when estimating trends over short periods of time.

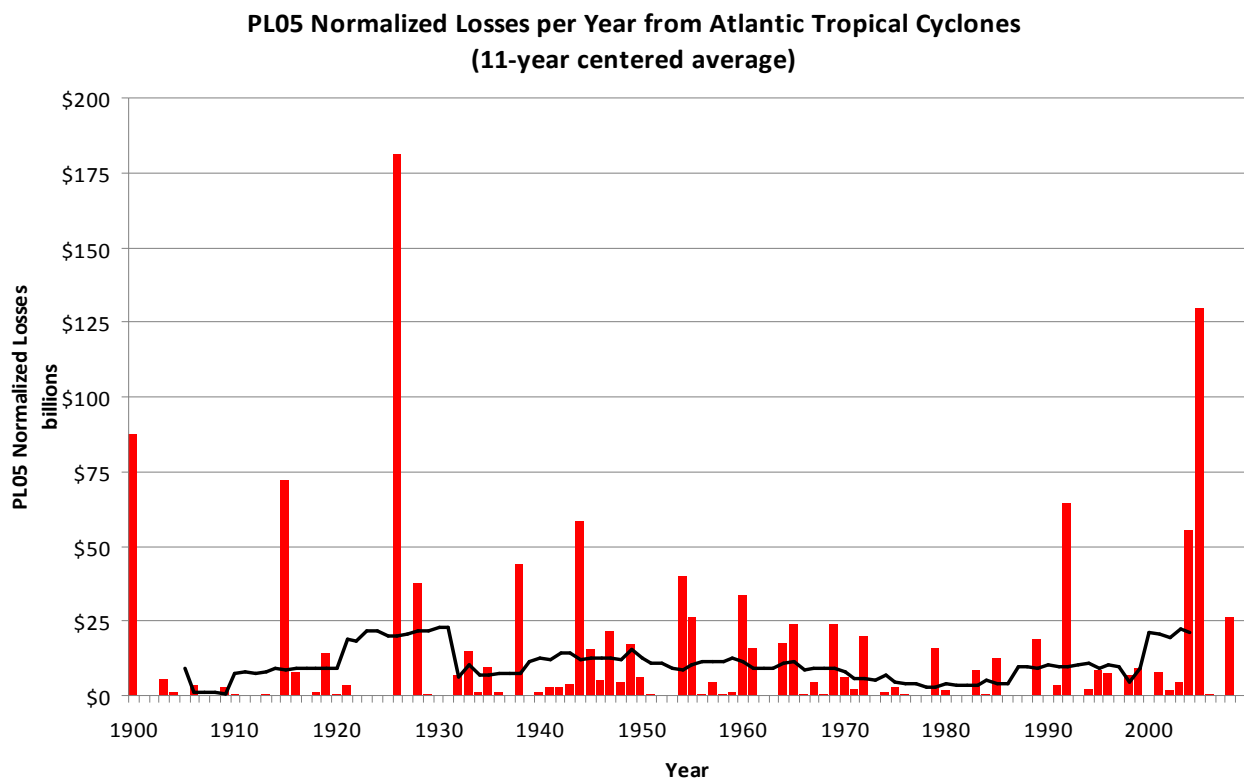


Figure 6: US Gulf and Atlantic damage, 1900-2009, normalized (2009 values) using the PL05 methodology.

c) Australia

Crompton and McAneney (2008) normalized Australian weather-related insured losses over the period 1967-2006 to 2006 values. Insured loss data were obtained from the Insurance Council of Australia (<http://www.insurancecouncil.com.au/>). The methodology adjusted for changes in dwelling numbers and nominal dwelling values (excluding land value). A more marked point of departure from previous normalization studies was an additional adjustment for tropical cyclone losses to account for improvements in construction standards mandated for new construction in tropical cyclone-prone parts of the country.

Crompton and McAneney (2008) found no statistically significant trend in weather-related insured losses once they were normalized in the manner described above. They emphasize the success improved building standards have had in reducing building vulnerability and thus tropical cyclone wind-induced losses. Due to limited data, they did not analyse the losses from any one particular hazard. In total, only 156 event losses were included in their analysis and this relatively small number results from the combined effect of a short data series and sparse population, especially in tropical cyclone-prone locations of the country.

d) World

Miller et al. (2008) compiled a global normalized weather-related catastrophe catalogue covering the principal developed and developing countries (Australia, Canada, Europe, Japan,

South Korea, United States, Caribbean, Central America, China, India, the Philippines). Various data sources were accessed and losses surveyed from 1950 to 2005, however post-1970 data were more reliable across all countries. Economic losses were normalized to 2005 values by adjusting for changes in wealth (GDP per capita in USD), inflation (national level) and population (national level).

Miller et al. (2008) discuss a number of issues in relation to their methodology including what effect applying a national level population factor has on normalized losses. They state that for those events that impacted certain high growth, coastal regions such as Florida, their national population factor will understate the true population growth rate. A regression of global normalized hurricane losses over the period 1970-2005 found a statistically significant (at the 5% level) trend.

More generally, Miller et al. (2008) found a 2% per year increasing trend in global normalized weather-related losses after 1970. However their conclusions were heavily weighted by US losses and their removal eliminated any statistically significant trend. Their results were also strongly influenced by large individual events such as Hurricane Katrina. The significance of the post-1970 global trend disappeared once national losses were further normalized relative to per capita wealth (i.e. by multiplying each region's normalized losses by the ratio of US GDP per capita to regional GDP per capita to approximate a homogenous distribution of wealth). They confirm that the principal driver of increasing global disaster losses to date was tropical cyclones in wealthy regions and that there was insufficient evidence to claim any firm link between global warming and disaster losses.

4.5.3. Future and current loss sensitivity

A number of studies have projected US tropical cyclone losses. This has been done to either quantify the effect of anthropogenic climate change (due to a projected change in tropical cyclone frequency and/or intensity) on its own, or to compare the effect of projected changes in both exposure and climate. Future losses will also be sensitive to changes in vulnerability, but this factor is usually held constant. Table 2 (from Schmidt et al. (2009b)) summarizes US tropical cyclone loss projection studies and Table 3 provides a more detailed account of some of the more recent studies as well as that of Schmidt et al. (2009b). The logic usually employed in these studies to examine the effects over a given time horizon is presented below.

Anthropogenic climate change effect

Emission scenario → tropical cyclone projection (frequency and intensity) → relationship between tropical cyclone normalized damages and intensity (wind speed) (referred to as 'loss function') → projected anthropogenic climate change influence on tropical cyclone losses

Exposure effect

e.g. projected changes in population and wealth

Total effect

Anthropogenic climate change effect + Exposure effect + Anthropogenic climate change effect × Exposure effect + 1

Table 2: Overview of studies to estimate future storm losses in the USA resulting from global warming (source: Schmidt et al. (2009b)).

Study	Loss function	Assumed change in intensity	Assumed change in frequency	Result
Cline (1992)	Increase in intensity produces a linear increase in losses	Increase of 40–50% with 2.3–4.8°C warming	-	Average loss increases by 50%
Fankhauser (1995)	Increase in intensity triggers a 1.5 increase in losses	Increase of 28% with warming of 2.5°C	-	Average loss (global) increases by 42%
Tol (1995)	Connection is in the quadratic form $f(x) = ax + bx^2$	Increase of 40–50% with warming of 2.5°C	constant	Increase in losses of 300 million US\$ (1988 values)
Nordhaus (2006) ^a	$d = \alpha \times \text{wind speed}^8$	Increase of maximum wind speeds of 8.7% with warming of 2.5°C	constant	Average loss increases by 104%
Stern et al. (2006)	$d = \alpha \times \text{wind speed}^3$	Increase of 6% with warming of 3°C	-	Average loss increases by 100%
Hallegatte (2007) ^b	Physical storm model to create synthetic storms; loss function in the form $d = \alpha \times (s) \times \text{wind speed}^3$	Increase of 10% under the expected climate conditions at the end of the 21st century	no change in absolute number	Increase in landfalls and maximum wind speed (+13%) Average loss increases by 54%
Pielke (2007)	$d = \alpha \times \text{wind speed}^3$ (further scenarios with elasticity of 6 and 9)	Increase of 18% by 2050	constant	Increase in loss of 64% ^c
Notes	^a Losses adjusted for economic development using GDP. ^b Losses adjusted for population and wealth trends, s for vulnerability index. ^c Additional loss increase of 116% from the combined effect of increase in intensity and socio-economic trend.			

Table 3: Detailed overview of recent US future loss sensitivity studies.

Study	Year	Anthropogenic climate change effect			Exposure effect			Total effect	
		Emission scenario	Tropical cyclone projections	Elasticity of damages w.r.t. wind speed ¹	Change in loss	Variable(s)	Change in loss	Change in loss	
Pielke 2007	2050	Intensity: +18% (upper end of estimates) ² Frequency: no change		3, 6, 9 (Derived value: 3.9)	Range: +64% to +344%	Population & wealth	+180%, +600% Baseline year: 2000	Range: +460% to +3105%	
Schmidt et al. 2009b	2050	IPCC A1 Intensity: +3% ³ Frequency: no change		3 (Derived value: 2.8)	+11%	Capital stock	+297% Baseline year: 2005	+317%	
Bender et al. 2010	2090	IPCC A1B	Changes in damage potential were estimated by combining the percent of historical damage ⁴ by Saffir-Simpson category with their 80-year model-based projected percent change in hurricane frequency by category.		18-model ensemble mean: +28% Range: -54% to +71%	-	-	-	
Nordhaus 2010	2100	Doubling of CO ₂	Intensity: +8.7% ⁵ , +13.7% ⁶ Frequency: no change	3, 7.27, 9 (Derived value: ≈ 9)	Central estimate: +113% Range: +29% to +219%	-	-	-	

¹ This refers to the power of wind speed that damage is proportional to, e.g. damage α (wind speed)^y.

² Estimates were based on expert elicitation.

³ Based on Bengtsson et al. (2007).

⁴ Pielke et al. (2008) normalized losses.

⁵ Calculated using the Knutson and Tuleya (2004) intensity / SST relationship assuming a 2.5°C increase in sea surface temperature (SST).

⁶ Based on Emanuel (2005) assuming a 2.5°C increase in SST.

Elasticity

- Pielke (2007), Schmidt et al. (2009b) and Nordhaus (2010) all derived loss functions using per-storm normalized US hurricane losses and maximum wind speed at landfall reported by the NHC. Pielke (2007), Schmidt et al. (2009b) and Nordhaus (2010) used normalized losses from 1900 to 2005, 1950 to 2005 and 1900 to 2008 respectively.

Despite the various assumptions made in each of the studies in Table 3, the estimated changes in future tropical cyclone losses in the US resulting from anthropogenic climate change fall into two broadly similar pairs of studies. The Pielke (2007) lower estimate extrapolated to 2100 is approximately +128%, a figure comparable to the Nordhaus (2010) central estimate of +113%. On the other hand, linearly extrapolating the Schmidt et al. (2009b) estimate to 2090 results in an approximate +20% change in loss, whereas the Bender et al. (2010) ensemble-mean estimate is +28%.

Both Pielke (2007) and Schmidt et al. (2009b) show that exposure growth will have a greater effect than anthropogenic climate change on future US tropical cyclone losses. Pielke (2007) adopted a conservative approach in deliberately selecting upper end estimates for the anthropogenic climate change effect on tropical cyclone intensity. Schmidt et al. (2009b) note that the anthropogenic climate change-induced increase in loss results in an additional loss of wealth in the sense that it increases loss over and above the proportional increase in exposure (capital stock).

Loss functions have also been used by Nordhaus (2010) and Schmidt et al. (2010) to estimate the climate-induced (i.e. resulting from natural variability and any unquantifiable anthropogenic contribution) increase in mean US tropical cyclone damage since 1950. Nordhaus (2010) estimates an 18.4% increase in mean damages since 1950 based on an elasticity of 9 and a 1.9% increase in intensity. The intensity estimate was calculated using the Knutson and Tuleya (2004) intensity / SST relationship assuming a 0.54°C increase in SST.

Schmidt et al. (2010) examined the sensitivity of storm losses to changes in socio-economic and climate-related factors over the period 1950-2005. They show losses to be much more responsive to changes in storm intensity (as estimated by changes in the basin-wide Accumulated Cyclone Energy (ACE) between successive “warm phases”) than to changes in capital stock. Nonetheless capital stock had a greater effect on losses due to its far greater increase over the study period. They determine that the increase in losses was approximately three times higher for socio-economic changes (+190%) than for climate-related changes (+75% based on the 27%³ increase in ACE between the “warm phases” 1926-70 and 1995-2005 – the authors note that the latter “warm phase” had not ended) and state that the extent to which the climate-related changes were the result of natural climate variability, or anthropogenic climate change, remains unanswered.

4.5.4. Financial management of extreme events

Previous sections have showed that the significant growth in exposure in hazard-prone areas have been the primary reasons for the increase in natural disaster losses (both insured and uninsured) in the US and other parts of the world. This result is consistent with the conclusion from Kunreuther and Michel-Kerjan (2009) that the increase in losses is due to growth in population and assets coupled with a lack of investment in risk reduction measures. Recent catastrophes have highlighted many challenges,

³ Schmidt et al. (2010) note that this increase was well above the 0.4% - 5% long-term (post-1870) average increase in storm intensity between successive “warm phases” and by applying this range to the period 1950-2005 they show that the expected increase in loss (due to the increase in storm intensity only) would have been 1.4% - 14%.

including how to best organize systems to pay for the damage caused by natural disasters and how to mitigate their effects.

4.5.4.1 Catastrophe insurance: how it is changing in the US

In most Organization for Economic Co-operation and Development (OECD) countries, insurance penetration is quite high, so a large portion of the economic damage from natural disasters is covered by public or private insurance. For truly catastrophic risks, many countries have developed some type of private sector - government partnerships for certain risks or certain exposed regions (as is the case for example in the UK, France, Spain or Japan). In the US, cover for damage due to floods and storm surge from hurricanes has been available through the federally managed National Flood Insurance Program (NFIP) since 1968 (Michel-Kerjan, 2010). State government programs supplement private sector cover in many US states; in Florida, the state has set up a reinsurer (the Florida Hurricane Catastrophe Fund) and a direct insurer (Citizens) which absorb a considerable proportion of the state's hurricane risk.

Cover against wind damage in the US has typically been offered in standard homeowners' insurance policies provided by private insurers. A number of extremely damaging hurricanes since the late 1980's (including Hugo, Andrew, and others during the intense hurricane seasons of 2004 and 2005) caused substantial instability in property insurance markets in coastal states. High loss activity prompted most insurers doing business in coastal states to seek major price increases; however, state insurance regulators failed to authorize the full amounts requested. Even with the restricted premium increases, rates doubled or even tripled in the highest risk areas in Florida between 2001 and 2007 (Kunreuther and Michel-Kerjan, 2009). Due to their inability to charge adequate premiums many insurers reduced their exposure in coastal regions and in December 2009 State Farm, for example, announced that it would discontinue 125,000 of its 810,000 property insurance policies in Florida (State Farm, 2009).

The combined effect of dramatically increased premiums for private residential wind insurance in coastal states and the decline in access to coverage for those in areas most exposed to wind damage has resulted in increased demand for government programs that provide insurance for residents in high-risk areas at highly subsidized rates. While subsidized rates have short term political benefit they do not encourage investment in risk reduction measures. Moreover, inadequate rates lead to large deficits in government pools over time and excessive growth in high risk areas and thus an even greater potential for large losses. Historically inadequate rates fuelled the dramatic exposure accumulation in the southeastern US where large losses have subsequently occurred.

4.5.4.2 The disaster mitigation challenge

Insurance (public and private) plays a critical role in providing funds for economic recovery after a catastrophe. But insurance merely transfers risks to others with a broader diversification capacity; simply purchasing insurance does not reduce the risk. The insurance system can play a critical role in providing incentives for loss mitigation by sending price signals reflecting risk. Regulatory efforts to limit

premium increases in high risk areas can diminish the insurance system's ability to perform this function.

Disaster mitigation measures can offset some of the upward pressure demographic and economic drivers (as discussed in previous sections) exert on tropical cyclone losses. Kunreuther and Michel-Kerjan (2009) shed some light on this aspect by analysing the impact that disaster mitigation would have had on reducing losses from hurricanes in four states in 2005: Florida, New York, South Carolina, and Texas. In their analysis of the impact of disaster mitigation, they considered two extreme cases: one in which no one invested in mitigation and the other in which everyone invested in predefined mitigation measures. A US hurricane loss model developed by Risk Management Solutions (RMS) was used to calculate losses assuming appropriate mitigation measures on all insured properties. The analyses revealed that mitigation has the potential to significantly reduce losses from future hurricanes with reductions ranging from 61% in Florida for a 100-year return period loss to 31% in Texas for a 500-year return period loss. In Florida alone, mitigation is estimated to reduce losses by \$51 billion for a 100-year event and \$83 billion for a 500-year event.

In a study for the Australian Building Codes Board, McAneney et al. (2007) estimated that the introduction of building code regulations requiring houses to be structurally designed to resist wind loads had reduced the average annual property losses from tropical cyclones in Australia by some two-thirds. Their estimate was based on the likely losses had the building code regulations never been implemented or had they always been in place.

Without regulations, the challenge lies in encouraging residents in hazard-prone areas to invest in mitigation measures and this has been highlighted by many recent extreme events. Even after the devastating 2004 and 2005 US hurricane seasons, a large number of residents in high-risk areas still had not invested in relatively inexpensive loss-reduction measures, nor had they undertaken emergency preparedness measures. A survey of 1,100 residents living along the Atlantic and Gulf Coasts undertaken in May 2006 revealed that 83% had taken no steps to fortify their home, 68% had no hurricane survival kit and 60% had no family disaster plan (Goodnough, 2006).

Homeowners, private businesses, and public-sector organizations often fail to voluntarily adopt cost-effective loss-reduction measures, particularly if regulatory actions inhibit the insurance system from providing sufficient economic incentives to do so. In addition, the magnitude of the destruction following a catastrophe often leads governmental agencies to provide disaster relief to victims – even if prior to the event the government claimed that it would not do so. This phenomenon has been termed the 'natural disaster syndrome' (Kunreuther, 1996). This combination of underinvestment in protection prior to a catastrophic event and taxpayer financing of part of the recovery following can be critiqued on both efficiency and equity grounds.

4.5.4.3 Global risk financing in coming decades

In coming decades, global trends in population distribution, economic development, wealth accumulation and increasing insurance penetration will place significant strain on the ability to absorb economic losses and undertake post-event reconstruction. The problems that Florida is currently experiencing may develop elsewhere. For example,

patterns of urbanization in areas of China vulnerable to typhoons resemble those of Florida in years past.

Musulini et al. (2009) analysed the financial implications of future global insurance losses. Future losses were estimated by using projected values of the variables used to normalize losses and an additional adjustment was made for changes in insurance penetration. Their analysis revealed that new peak zones (those locations that have the largest disaster potential globally) are likely to emerge in several developing nations due to the projected changes in demographics, wealth and insurance penetration. They note that the rapid projected exposure accumulation was similar to that experienced in Florida between 1950 and 1990. Musulini et al. (2009) conclude that the future loss levels will have significant ramifications for the cost of financing disasters through the insurance system, both in the new peak zone locations and in the system as a whole. Their results were independent of any anthropogenic climate change effects on future losses.

Musulini et al. (2009) identify an additional factor that must be considered to correctly assess the proper level of investment in loss mitigation. They refer to three lenses through which loss mitigation activities can be viewed: life safety, protection of individual properties, and management of overall economic impact. While building code development traditionally focuses on the first two, the authors argue that consideration also needs to be given to the current and future potential for large disaster losses in the area where the building code applies.

The management of overall economic impact means that current building code design should also reflect the current and future potential impact of large disaster losses on the overall economy (Musulini et al., 2009). The destruction of a single building can be easily absorbed into the normal building capacity of an economy but the destruction of one million homes by a major hurricane cannot – the required diversion of material and labour to post-event reconstruction from other activities would cause massive stress and disruption. The potential economic damage from tropical cyclones can become very significant at a macroeconomic level as exposure grows disproportionately in high risk areas, particularly when there is a dramatic increase in insurance penetration (Musulini et al., 2009).

Musulini et al. (2009) conclude that the economic value of loss mitigation must reflect the expected cost of risk transfer over the lifetime of the building. Since the cost of risk transfer is affected by the aggregate level of risk in an area it can change if the surrounding area is subject to significant population growth and wealth accumulation. Loss mitigation should therefore also target areas of high potential future growth (Musulini et al., 2009).

4.5.4.4 Integrating the financial management of disasters as part of a national strategy

In the aftermath of the very destructive 2004/05 US hurricane seasons, increasing the country's resiliency to natural disasters was destined to become a national priority in the US. As other crises occurred locally and abroad attention was directed away from this issue, the question of how to best organize financial protection and risk reduction against future hurricanes remains largely unanswered.

Other countries that have suffered disasters are faced with similar questions. Outside of the OECD countries, developing countries have started to think about these issues. In many cases, populations are growing fast and assets at risk have increased significantly as a result of decades of economic development. People and businesses are turning to their governments and the private sector for solutions. These solutions will come in the form of micro-insurance (well-developed in India and several African countries today), strong government participation (as is the case in China), traditional insurance, or the transfer of catastrophe exposure directly to investors on the financial markets (e.g. catastrophe bonds of which over 160 have been issued to date) (Michel-Kerjan and Morlaye, 2008).

Each country will have to define and select what solutions make the most sense given its culture, current development of its insurance market, risk appetite and other national priorities. These solutions will also evolve over time as a response to the occurrence of (or absence of) major catastrophes. Higher climate variability and increasing exposure means that the financing of disaster risks and long-term disaster mitigation planning must become a critical element of the national strategy in many countries to assure sustainable development.

4.5.5. Conclusions

Research into the economic impacts from tropical cyclones now spans many basins (Northwest Pacific, North Atlantic, North Indian, South Pacific, Southeast Indian). What is evident from studies to date is an increasing trend in tropical cyclone losses over time. The main drivers of the increasing trend are demonstrably socio-economic factors. While it has been possible to identify natural climate variability (consistent with geophysical trends) in normalized data, no study has yet been able to detect an anthropogenic climate change influence. This does not imply that such an influence has been ruled out; however it does suggest that its influence, if any, is currently minimal in the context of societal change and large year-to-year variation in impacts. This is consistent with Höppe and Pielke (2006) and with the review by Bouwer (2010) of weather-related losses more generally.

Socio-economic and climate-related trends will lead to further loss increases in the future (cf. IPCC, 2007b). Research into future US tropical cyclone losses suggests that the socio-economic factors will continue to be the principal loss drivers and that the long term effects of anthropogenic climate change are likely to exacerbate future impacts.

The collective research presented here suggests that there is much to be gained in both the short and long term from reducing societal vulnerability to tropical cyclones. Without efforts to address this, the economic impacts from tropical cyclones will continue to rise rapidly on the back of an ever increasing exposure. This is particularly the case in developing countries where some of the largest growth rates are projected to occur (Figs. 7-9 and Bouwer et al., 2007). Financial solutions that encourage vulnerability reduction can be used as an effective tool to minimize future losses.

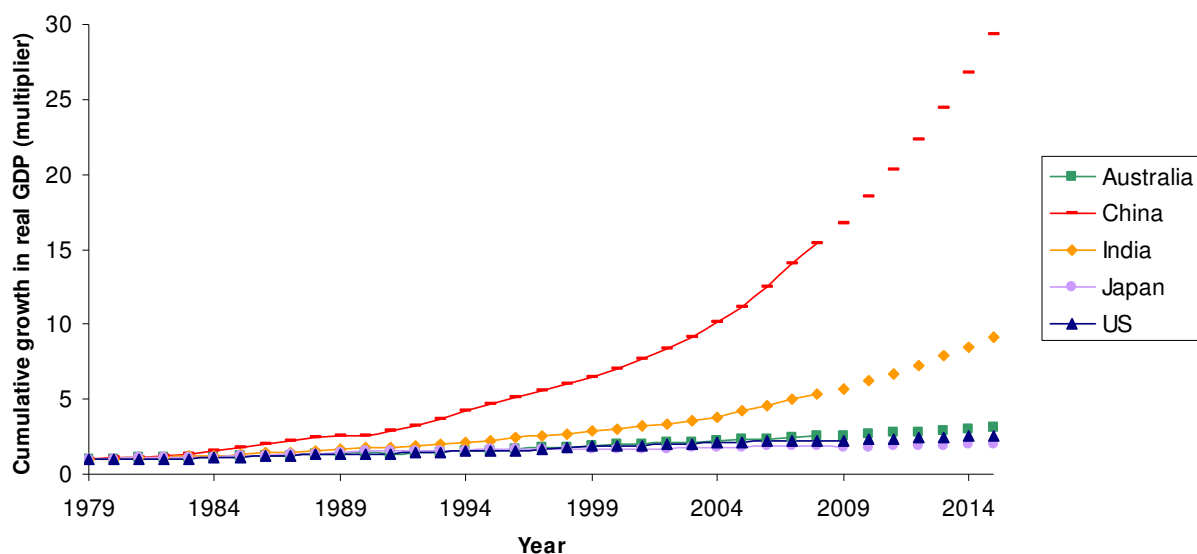


Figure 7: The cumulative effect of growth in real GDP (GDP in constant prices) relative to 1979 for selected countries. Points on each country's curve that are not connected are estimated (projected) values (data source: International Monetary Fund World Economic Outlook Database (IMFWEO) - <http://www.imf.org/external/ns/cs.aspx?id=28>).

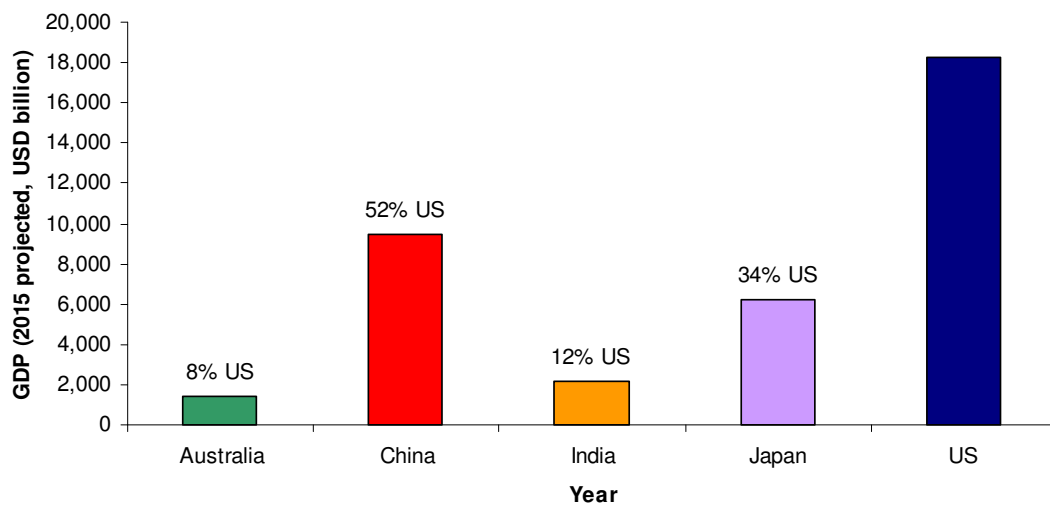
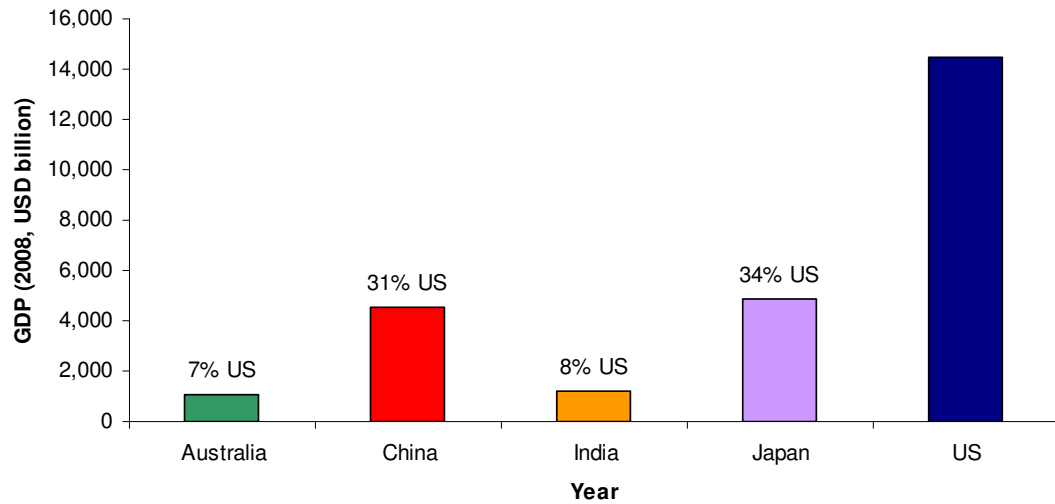


Figure 8: GDP in current prices (nominal values) as at 2008 (top) and estimated values for 2015 (bottom) for selected countries. The most recent year there is actual GDP values (as opposed to estimated values) across all selected countries is 2008. Also shown is each country's GDP relative to US GDP (data source: IMFWEO - <http://www.imf.org/external/ns/cs.aspx?id=28>).

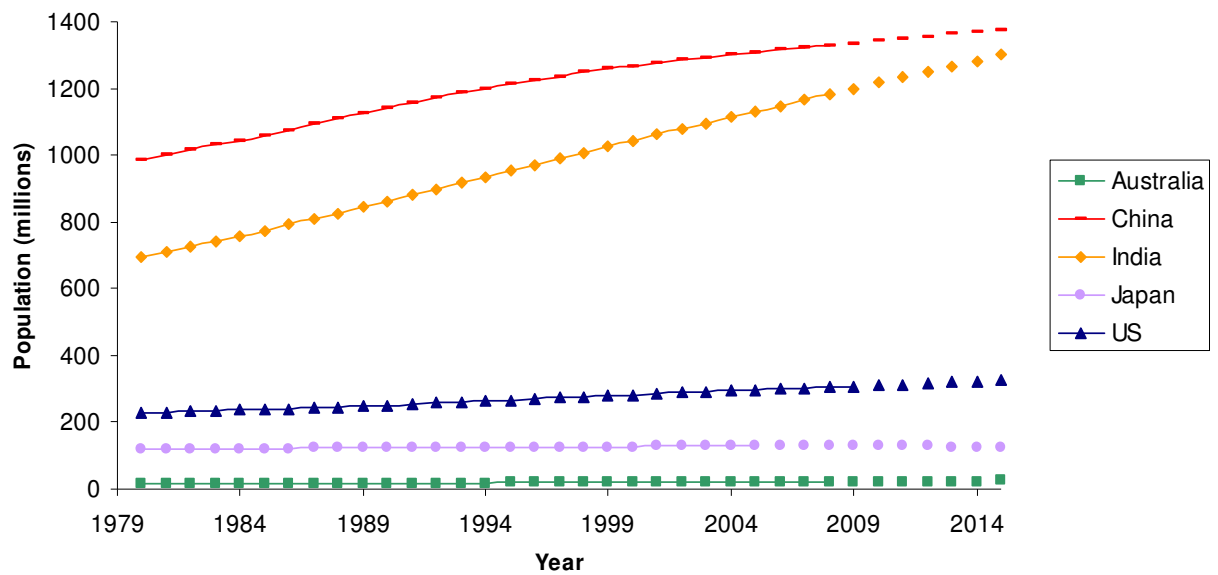


Figure 9: Population in selected countries. Points on each country’s curve that are not connected are estimated (projected) values (data source: IMFWEO - <http://www.imf.org/external/ns/cs.aspx?id=28>).

4.5.6. Recommendations

Continue efforts to enhance our understanding of past and future exposure and vulnerability to help guide policy aimed at minimizing future impacts and to help inform future financing needs:

- The Past - develop an open-source, peer-reviewed loss database that includes economic and demographic statistics. This should be accompanied by a global landfall database (currently being developed).
- The Future - continue to improve our understanding of the future risk given projected changes in climate and society. This is dependent upon further research into projected tropical cyclone activity and the elasticity of damages with respect to wind speed.

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CHAPTER 7

Crompton, R. P., R. A. Pielke Jr., and K. J. McAneney, 2011. **Emergence timescales for detection of anthropogenic climate change in US tropical cyclone loss data.** *Environ. Res. Lett.*, 6, 4pp.

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Contribution

The idea for this paper stemmed from my involvement in the 2006 Hohenkammer workshop and a presentation by Dr Tom Knutson in 2009. I conceived the study, designed and implemented the simulation model, conducted the analysis and drafted the paper. Professor Roger Pielke Jr. provided the normalised US hurricane loss data. I discussed the simulation methodology and results with Professors Pielke Jr. and John McAneney and they both reviewed drafts of the paper. My contribution is estimated at 90%.

Media highlights: [The New York Times](#); [Environmental Research Web](#); [Insurance Journal](#)

Emergence timescales for detection of anthropogenic climate change in US tropical cyclone loss data

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Abstract

Recent reviews have concluded that efforts to date have yet to detect or attribute an anthropogenic climate change influence on Atlantic tropical cyclone (of at least tropical storm strength) behaviour and concomitant damage. However, the possibility of identifying such influence in the future cannot be ruled out. Using projections of future tropical cyclone activity from a recent prominent study we estimate the time that it would take for anthropogenic signals to emerge in a time series of normalized US tropical cyclone losses. Depending on the global climate model(s) underpinning the projection, emergence timescales range between 120 and 550 years, reflecting a large uncertainty. It takes 260 years for an 18-model ensemble-based signal to emerge. Consequently, under the projections examined here, the detection or attribution of an anthropogenic signal in tropical cyclone loss data is extremely unlikely to occur over periods of several decades (and even longer). This caution extends more generally to global weather-related natural disaster losses.

Keywords: tropical cyclones, climate change, losses, disasters, United States

 Online supplementary data available from stacks.iop.org/ERL/6/014003/mmedia

1. Introduction

Increasing weather-related natural disaster losses have been well documented [1, 2]. Various changes (societal, building codes, etc) are known to influence the time series of disaster losses, and research to date has focused on determining whether an anthropogenic climate change signal is present after these changes have been accounted for by a process called loss normalization [3–5]. No insured or economic loss normalization study has yet been able to detect (much less attribute) an anthropogenic signal across a range of perils and locations around the world [5].

This study is concerned with the risk posed by US tropical cyclones (referred to as ‘tropical storms’ in the Atlantic when these tropical storm systems reach a maximum sustained wind speed of 63 kph), a peril that has significantly influenced global weather-related natural disaster losses (supplementary

discussion and table S1 available at stacks.iop.org/ERL/6/014003/mmedia). Hurricanes—tropical cyclones with winds of 119 kph or greater—account for eight of the ten most costly inflation-adjusted insurance losses (2009 dollars) caused by weather-related hazards between 1970 and 2009 [1]. Not surprisingly the time series of US tropical cyclone damage has attracted special attention [3, 6–8].

That a residual trend, due to anthropogenic climate change or otherwise, has thus far not been detected in normalized US tropical cyclone damage should not be surprising as there has been no observed increase in hurricane frequency and intensity at landfall over the period for which normalization data is available [3, 9, 10]. Moreover, it has not yet been possible to detect anthropogenic signals in Atlantic Ocean basin records [9, 10]. Despite this, Knutson *et al* [10] conclude that a detectable and perhaps substantial anthropogenic influence

Table 1. Damage and storm changes by Saffir–Simpson category. Damage statistics are derived from the Pielke *et al* [3] normalized storm losses and projections are from Bender *et al* [11]. In our analysis we relied on the PL05 analysis of Pielke *et al* [3]. For two reasons the damage statistics differ from those of Pielke *et al* [3]: (i) theirs were based on the number of landfalls (a storm may make multiple landfalls) whereas ours are based on the number of landfalling storms. Ten storms with multiple landfalls were categorized according to their most intense crossing and their losses aggregated, and; (ii) we excluded zero and non-zero subtropical storm losses to ensure direct correspondence with tropical storm projected changes. The Saffir–Simpson category is the category at landfall for the damage statistics. From Bender M A, Knutson T R, Tuleya R E, Sirutis J J, Vecchi G A, Garner S T and Held I M 2010 Modeled impact of anthropogenic warming on the frequency of intense Atlantic hurricanes *Science* **327** 454–8. Reprinted with permission from AAAS.

Saffir–Simpson Storm Category	Storm loss frequency and damage distribution			Projected per cent changes over 80 years (warm versus control)				
	Count of loss events	Count per year	Per cent of total damage	CMIP3 ensemble	GFDL	MRI	MPI	HadCM3
Tropical	57	0.54	2.0	–13	+4	–16	–14	–14
1	44	0.42	5.0	–52	–40	–45	–48	–66
2	34	0.32	7.4	–17	–15	–28	–36	–53
3	53	0.50	35.6	–45	+9	–34	–51	–64
4	14	0.13	42.5	+83	+100	+72	+17	–56
5	3	0.03	7.4	+200	+400	+800	+100	0

on Atlantic tropical cyclone activity cannot be ruled out in the future. This raises an important question: if changes in storm characteristics in fact occur as projected, then on what timescale might we expect to detect these effects of those changes in damage data? The present study addresses this question.

2. Data and methods

In a recent study, Bender *et al* [11] estimated it would take 60 years for a projected increase in frequency of category 4 and 5 Atlantic hurricanes to emerge as a signal in a time series of category 4 and 5 hurricanes. This result was derived from an ensemble mean of 18 global climate change projections—the 18 models were from the World Climate Research Programme coupled model intercomparison project 3 (CMIP3) and used the Intergovernmental Panel on Climate Change (IPCC) A1B emissions scenario. Using a regional model of the atmosphere and a high-resolution hurricane model, Bender *et al* [11] projected an 81% increase in the frequency of category 4 and 5 hurricanes in 80 years, or roughly a +1% linear trend per year. The 60-year emergence timescale for this trend was based on bootstrap re-sampling using category 4 and 5 annual hurricane counts between 1944 and 2008.

We modify the Bender *et al* [11] emergence timescale methodology and apply their model-based projections of the per cent change in the number of Atlantic storms in each Saffir–Simpson (SS) category to the annual frequency of economic losses due to each category (table 1). We use the storm loss list from Pielke *et al* [3] with two exceptions: the subtropical storm loss and an incorrectly classified tropical storm loss (actually subtropical) in 1974 were removed. The resulting list is then a catalogue of mainland US landfalling Atlantic storms (tropical storm to category 5) (see supplementary discussion for further detail, available at stacks.iop.org/ERL/6/014003/mmedia).

In addition to the 18 CMIP3 model ensemble mean, we also analyse the four projections of Bender *et al* [11] for Atlantic storm activity in the context of anthropogenic climate change from four of the individual CMIP3 global models (table 1)—Geophysical Fluid Dynamics Laboratory GFDL-CM2.1; Japanese Meteorological Research Institute MRI-CGCM; Max Planck Institute MPI-ECHAM5, and the

Hadley Centre UK Meteorological Office UKMO-HadCM3. Frequency projections from the individual models result from the same downscaling methodology as that applied to the 18-model ensemble [11]. The variability in projected storm activity between global models is due to differences in wind shear, potential intensity and other environmental factors (see Bender *et al* [11] for further detail).

To estimate the time it takes for each of the five anthropogenic signals (hereafter referred to as CMIP3, GFDL, MRI, MPI and HadCM3) to emerge in storm losses we first construct an arbitrary length synthetic loss time series. We do this by modelling the number of storm losses in each category in each year of the time series using a Poisson distribution (supplementary discussion and table S3 available at stacks.iop.org/ERL/6/014003/mmedia). (The Poisson parameter [12] is the average storm count per year for each SS category.) Our use of a Poisson distribution gives a signal emergence time in hurricane behaviour similar to that estimated in Bender *et al* [11] (see supplementary discussion available at stacks.iop.org/ERL/6/014003/mmedia).

Storm losses are sampled (with replacement) from the Pielke *et al* [3] normalized direct economic storm losses (1900–2005) and aggregated annually. In successive years the projected per cent changes in SS storm category are applied to loss frequencies on an annual basis assuming a linear trend. We then calculate the gradient of the least-squares line fitted to the synthetic loss time series and repeat this process many times (10 000 iterations) for each length tested. If there is a sufficiently small number (<5%) of positive (i.e. when testing for a negative trend) or negative (i.e. when testing for a positive trend) gradients the signal is deemed to have emerged and the earliest end year of the synthetic loss time series in which this threshold is met is referred to as the emergence timescale ($p = 0.05$) (following Bender *et al* [11], see figure 1 and table 2, plus supplementary discussion for further detail available at stacks.iop.org/ERL/6/014003/mmedia).

3. Results

Anthropogenically driven changes in damage potential over 80 years are estimated by weighting the per cent of total damage by SS category with the corresponding projected per

Table 2. Emergence timescale, change in damage potential and the simulated mean change in damage after 80 years and at the emergence timescale. Simulated values (10 000 iterations) refer to the per cent change in damage between the mean damage calculated from the least-squares lines and the average annual damage calculated over the 106 year normalized historical record. In estimating values beyond 80 years, we linearly extrapolate the projections in table 1. Emergence timescales are rounded to the nearest 10 years.

	Emergence timescale (years)	Change in damage potential (%)		Simulated mean change in damage (%)	
		After 80 years	At emergence timescale	After 80 years	At emergence timescale
CMIP3 ensemble	260	+30	+94	+30	+106
GFDL	150	+72	+135	+71	+138
MRI	150	+73	+137	+74	+138
MPI	550	−9	−62	−9	+41
HadCM3	120	−54	−81	−54	−82

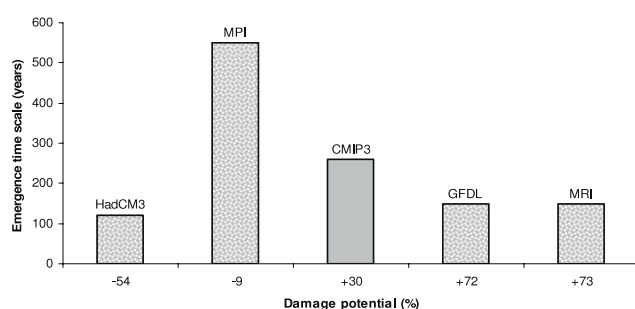


Figure 1. Emergence timescale of anthropogenic signals in normalized damage versus the per cent change in damage potential after 80 years. Damage potentials vary from those in Bender *et al* [11] due to the use of different damage statistics, as presented in table 1. Emergence timescales are rounded to the nearest 10 years.

cent changes in frequency (table 1). The results are shown in figure 1 and table 2. The CMIP3 ensemble change in damage potential is +30% with the contribution from the increase in more intense events dominating that from the decrease in less intense events. The same holds true for the GFDL and MRI models while the reverse is true for the MPI model. A negative change in damage potential for the HadCM3 model (figure 1 and table 2) is obvious as it projects a decrease or zero change in frequency across all SS categories (table 1).

The absolute change in damage potential is roughly related to the emergence timescale of anthropogenic signals in normalized losses. The MPI model has the smallest absolute change in damage potential (9%) and it takes 550 years, the largest of those tested, for a signal to emerge (figure 1 and table 2). On the other hand, the MRI signal has the equal second fastest emergence timescale at 150 years despite the model having the largest absolute change in damage potential (73%). The HadCM3 signal emerges the fastest (120 years) and we estimate the emergence timescale of the CMIP3 ensemble signal to be 260 years (figure 1 and table 2). Other factors that influence the emergence timescale beyond the absolute change in damage potential include the sign of the projections (there is less variability in simulated storm numbers as the annual frequency decreases); the consistency of the sign throughout SS categories and the magnitude of projections.

A closer examination of the MPI signal emergence demonstrates the interplay of some of these factors. The MPI model change in damage potential and simulated mean change in damage are negative (−9%) after 80 years (table 2)

as is the simulated mean gradient (least-squares estimate). At the emergence timescale, however, the simulated mean change in damage and mean gradient (least-squares estimate) are both positive. It takes approximately 280 years for the simulated mean gradient to change sign: the percentage of positive gradients does not fall below 5% at any time during the first 280 years and it is not for a number of years after the SS category 1, 2 and 3 frequencies have become zero (supplementary table S4 available at stacks.iop.org/ERL/6/014003/mmedia) that the signal emerges.

The MPI signal is the only signal that emerges earlier (540 years) if sub-periods are also examined—the number of negative gradients falling below 5% between years 80 and 543 (see supplementary discussion for further detail, available at stacks.iop.org/ERL/6/014003/mmedia). When simulating beyond the 80-year extent of frequency projections, we assume the same linear rate of change from the first 80 years. If the annual frequency in any SS category reaches zero before the emergence timescale (supplementary table S4 available at stacks.iop.org/ERL/6/014003/mmedia), it is held at zero beyond that point, regardless of physical reality. As is to be expected, there is generally good agreement between the change in damage potential and simulated mean change in damage (table 2).

4. Discussion

Our study is based upon a number of other assumptions. In using projections from Bender *et al* [11] we consider only climate projections from the IPCC Fourth Assessment Report (AR4) A1B emissions scenario and we accept the limitations of all models. Moreover we also adopt the Bender *et al* [11] assumption that the frequency and intensity of landfalling storms are representative of Atlantic basin activity. Our study ignores future rising sea-levels and related adaptation efforts, both of which will be important for damage arising from storm surge, as well as any future changes in tropical cyclone rainfall. With respect to these issues, we note that the historical damage record compiled by the US National Hurricane Center generally does not include losses associated with rainfall-induced flooding [6].

While there are inevitable uncertainties in the loss record, the fact that normalized damage reflects the El Niño–Southern Oscillation (ENSO) cycle [13] and trends in landfall frequency and intensity [3] in geophysical data gives cause for confidence

that the time series is of sufficient quality for our purposes. However our simulation approach does not preserve the ENSO influence or that of others such as the Atlantic Multi-decadal Oscillation. By modelling event loss frequency as a Poisson distribution we also ignore any of the clustering between SS categories prevalent in the annual loss records.

Our analysis assumes that any future changes in building codes, land-use planning and other risk reduction and climate adaptation strategies are addressed in future normalization such that the normalized losses remain unbiased. A bias would make signal detection more difficult but will only occur if these factors are not accounted for in future normalization. We use losses normalized to year 2005 values to estimate emergence timescales but our results are independent of values at this year. If we normalize losses to values at any year throughout the synthetic loss time series the same emergence timescales are obtained (see supplementary discussion for further detail, available at stacks.iop.org/ERL/6/014003/mmedia).

5. Conclusions

This study has investigated the impact of the Bender *et al* [11] Atlantic storm projections on US tropical cyclone economic losses. The emergence timescale of these anthropogenic climate change signals in normalized losses was found to be between 120 and 550 years. The 18-model ensemble-based signal emerges in 260 years.

This result confirms the general agreement that it is far more efficient to seek to detect anthropogenic signals in geophysical data directly rather than in loss data [14]. It also has implications for the emergence timescale of anthropogenic signals in global weather-related natural disaster losses given these losses are highly correlated with US tropical cyclone losses (supplementary discussion and table S1 available at stacks.iop.org/ERL/6/014003/mmedia). Our results suggest that the emergence timescales are likely to be even longer than those determined for US tropical cyclone losses given that different perils will have different sensitivities to future anthropogenic climate change and may even change in different directions. We note that US tropical cyclone losses may become increasingly less correlated with global weather-related records as the loss potentials of developing countries in particular continue to rise rapidly, irrespective of future changes in climate [15]. This means that the relationship between the signal emergence time in US tropical cyclone losses and global losses may weaken over time.

Based on the results from our emergence timescale analysis we urge extreme caution in attributing short term trends (i.e., over many decades and longer) in normalized US tropical cyclone losses to anthropogenic climate change. The same conclusion applies to global weather-related natural disaster losses at least in the near future. Not only is short term variability not 'climate change' (which the IPCC defines on timescales of 30–50 years or longer), but anthropogenic climate change signals are very unlikely to emerge in US tropical cyclone losses at timescales of less than a century under the projections examined here.

Our results argue very strongly against using abnormally large losses from individual Atlantic hurricanes or seasons as

either evidence of anthropogenic climate change or to justify actions on greenhouse gas emissions. There are far better justifications for action on greenhouse gases. Policy making related to climate necessarily must occur under uncertainty and ignorance. Our analysis indicates that such conditions will persist on timescales longer than those of decision making, strengthening the case for expanding disaster risk reduction in climate adaptation policy [15].

Acknowledgments

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SUPPLEMENTARY DATA

Emergence timescales for detection of anthropogenic climate change in US tropical cyclone loss data

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Supplementary Discussion

Disaster Loss Time Series & Correlation

Two frequently cited sources of global weather-related natural disaster losses are global reinsurance companies Munich Reinsurance Company (Munich Re) and Swiss Reinsurance Company (Swiss Re). The Munich Re database contains economic and insured losses with data post-1980 considered more reliable; the Swiss Re published record of insured losses begins in 1970. The original losses (recorded when an event occurred) from the Munich Re database (1980-2005) were provided by Munich Re and these losses as well as the US tropical cyclone original losses used in Pielke *et al* [S1] (including our adjustments made to this list referred to in the main text) were inflation-adjusted to year 2005 dollars (figures S1 and S2) using the US Consumer Price Index (CPI) (Bureau of Labour Statistics - <http://www.bls.gov/cpi/#tables>). The Swiss Re inflation-adjusted (year 2008 dollars) insured losses [S2] for the period 1970-2005 were converted back to original losses and to year 2005 dollars (figure S3) also using the US CPI. The losses in all databases are reported in US dollars.

The Pearson product-moment correlation coefficients for US original and inflation-adjusted tropical cyclone losses with both series of global weather-related natural disaster losses are presented in table S1. There is a high degree of correlation and all of the coefficients in table S1 are extremely significant, each having a P -value < 0.0001. The t -statistics for each of the correlation coefficients are also presented in table S1. It was not possible to correlate normalized losses due to the unavailability of normalized global records.

Emergence Timescale Methodology (using Bootstrap Re-sampling) & Analysis

The methodology is as follows (see table S2 for further detail):

Synthetic loss time series construction

- 1) Categorize the normalized Atlantic storm losses from the period 1900-2005 by Saffir-Simpson (SS) categories (tropical storm to category 5) at landfall.
- 2) For each SS category, develop Poisson distributions, with Poisson parameters equal to the average storm count per year as calculated from step 1.
- 3) Apply the Bender *et al* [S3] projected percentage changes in frequency by SS category (assuming an annual linear change in each) for the CMIP3 ensemble

and for the four individual CMIP3 models to the Poisson distributions in order to determine how many losses in each category to sample in a year. If necessary assume that the linear trends continue beyond the extent of the Bender *et al* [S3] 80-year projections. (We employed the CMIP3 ensemble-based storm projection based on a 27 season model run (1980-2006) whereas the four individual model-based storm projections were computed for the 13 odd years only during 1981-2005 [S3].)

- 4) Sample storm losses (with replacement) from the categorized normalized loss record as per each category's Poisson sampled value.
- 5) For each year sum the sampled storm losses within and across SS categories.

Synthetic loss time series testing

- 6) To test a 70-year, say, synthetic loss time series length: at each iteration steps 3 to 5 are executed for each of the years 1 to 70 and the gradient of the least-squares line fitted to this synthetic loss time series is calculated.
- 7) To estimate the emergence timescale of the ensemble- and the individual model-based storm projections in normalized damage, determine the earliest end year of the synthetic loss time series that yields less than 5% of positive (i.e. when testing for a negative trend) or negative (i.e. when testing for a positive trend) gradients. The statistical stability of the emergence timescale determination is enhanced by simulating 10,000 iterations.

A chi-squared test (table S3) indicates that, with the exception of tropical storms, a Poisson distribution for the annual number of storm losses in each SS category is appropriate over the period 1900-2005. Despite its inadequacy, our use of a Poisson distribution for tropical storms has a negligible effect on our results. Tropical storms accounted for only 2% of normalized damage over this period (table 1) and in four out of the five projections analysed the frequency decreases (table 1). Moreover the GFDL-based projected increase in frequency is a modest 4% in 80 years so that tropical storm losses do not feature prominently in our simulations.

We tested the sensitivity of emergence timescales to the 95% significance threshold and to the small number of SS category 5 losses. The CMIP3 signal emerges approximately 40 years earlier (220 years) at the 90% threshold and 60 years later (320 years) at the 99% threshold. We tested the small number of SS category 5 losses by sampling from category 4 and 5 normalized losses combined when a category 5 event was simulated. The rationale for doing this is that the mean and standard deviation of the normalized losses combined are larger than those for the category 5 losses alone. The combination has an immaterial effect on emergence timescales. For example, the MRI signal emerges less than 5 years earlier despite the 800% projected increase in category 5 frequency over 80 years (table 1) and the emergence timescale of the CMIP3 signal decreases by less than 10 years.

When testing a synthetic loss time series ending at year n , not only was the period from year 1 to n tested but so too were all sub-periods that begin in years $i = 2$ to $n-1$ (for $n > 2$). For example, if $n = 2$ then the time period is from year 1 to 2 and there are no sub-periods to be tested; if $n = 5$ then the time period is from year 1 to 5 and the sub-periods to be tested are 2 to 5, 3 to 5 and 4 to 5. Although the end year n was incremented annually from $n = 2$, emergence timescales were rounded to the nearest 10 years. Testing all sub-periods is important, especially for the CMIP3 ensemble and

MPI signals as some of the frequencies fall to zero prior to the signal emergence (table S4). The emergence timescale of the MPI signal is the only one that changes by testing sub-periods. It emerges approximately 10 years earlier (540 years rather than 550 years) during years 80 to 543.

Bender *et al* [S3] raise a number of issues also relevant to our study and we discuss some of these in the context of our emergence timescale analysis. For simplicity and in the absence of better knowledge, we have made no attempt to preserve the influence of El Niño-Southern Oscillation or any other cycles. Similarly Bender *et al* [S3] did not model any systematic temporal correlation but carried out a sensitivity test to show that the emergence timescale increased only slightly by doing so. We believe the inclusion of temporal correlation in our analysis would have a similar effect on the emergence timescale of anthropogenic signals in normalized losses.

Emergence timescales would be affected through the inclusion of historical data in our calculation of trend significance. The inclusion of historical losses could increase or decrease emergence timescales depending on the resulting trend, which is dependent on whether the anthropogenic signal increases (e.g., CMIP3 ensemble) or decreases (e.g., HadCM3) losses. In our calculation of trend significance, we looked only at projected losses, that is, we did not include the historical normalized losses from 1900-2005 – the inclusion of the entire data record would only increase emergence timescales due to the lack of a trend over this period. Similarly, we also did not examine trends by pre-pending any arbitrary subset of the data leading up to 2005. We disregard historical losses for the same reasons Bender *et al* [S3] omitted historical data – it is beyond the scope of our study to quantify the contributions of various influences including aerosols, greenhouse gases and natural variability etc. But perhaps more importantly, there is no trend in normalized losses 1900-2009.

For the CMIP3, GFDL and MRI signals we have also tested the effect of applying a square root transformation to the annual losses prior to calculating the gradient (least-squares estimate) and found that our emergence timescales are not significantly impacted by this. The CMIP3 and MRI signals emerge approximately 30 years and 10 years later at 290 years and 160 years respectively. On the other hand, the GFDL signal emerges approximately 10 years earlier at 140 years.

There are additional issues to consider when estimating the emergence timescale of anthropogenic signals in normalized losses. We have assumed no change in risk reducing measures such as improved land-use planning that would introduce a bias into future normalized loss data. Successful risk reduction and/or climate adaptation policies would reduce the severity of losses over time. To the extent that such actions lead to a divergence in geophysical and loss trends, this would mask the influence of anthropogenic signals that act to increase losses (e.g., CMIP3) and accelerate the influence of the HadCM3 signal that has a decreasing effect on losses over time. Such societal effects reinforce the difficulty of signal detection in loss data.

To estimate emergence timescales we use losses normalized to year 2005 values but our results are independent of values at this year. If during simulation we apply projected national level changes in population, inflation and wealth to the losses and normalize them to values at any year throughout the synthetic loss time series the same emergence timescales are obtained. The only effect subsequent normalization

has on the synthetic loss time series (assuming national level factors are employed) is to ultimately multiply each of the losses by a constant factor and this does not affect the sign of the least-squares gradient fitted to the time series and therefore emergence timescales. We note that losses from the 2006-2009 hurricane seasons were relatively benign and are not expected to significantly alter our results.

Pielke *et al* [S1] refers to 40 storms that made landfall with no reported damages and our analysis ignores these even though a repeat of them in 2005 would almost certainly have produced a loss. Their neglect is expected to have a minimal influence on emergence timescales as these losses would have been relatively small. We could have included these as zero loss storms to create a complete catalogue of landfalling storms but this would have had an even smaller effect on emergence timescales. There are no other zero-loss storms in Pielke *et al* [S1], but some are listed as zero because of rounding.

We have applied our Poisson-based emergence timescale approach to the time series of category 4-5 hurricane counts from 1944-2008 given in Bender *et al* [S3]. A chi-squared test determined that it was appropriate to use the Poisson distribution for the annual hurricane counts. We estimate the emergence timescale ($p = 0.05$) to be approximately 70 years for an 81% increase in category 4-5 hurricane frequency over 80 years (assuming an annual linear trend). The slight difference between our estimate and the 60-year emergence timescale estimate from Bender *et al* [S3] stems from our use of the Poisson distribution that introduces greater variability into our simulation.

Table S1. Pearson product-moment correlation coefficients (r) between inflation-adjusted (2005 dollars) US tropical cyclone economic losses and both Munich Re's and Swiss Re's global weather-related natural disaster losses. The Munich Re correlations were made over the period 1980-2005 whereas Swiss Re's were calculated between 1970 and 2005. Numbers in brackets are the correlation coefficients for original losses. The t -statistics for the correlation coefficients are also shown and the numbers in brackets are the t -statistics for original loss correlation coefficients.

	Munich Re Global Weather		Swiss Re Global Weather
	Economic	Insured	Insured
	r		
US TC Economic	0.82 (0.89)	0.97 (0.98)	0.93 (0.96)
	t_{24}		t_{34}
US TC Economic	7.07 (9.41)	18.84 (25.01)	15.22 (19.00)

Table S2. Simulation model written in Scilab. Scilab is a free open source software for numerical computation (Scilab - <http://www.scilab.org/>).

```

clear;
stacksize('max');
no_years = 106, no_iterations = 10000, test_years = 280;

no_ts_losses = 57, no_cat1_losses = 44, no_cat2_losses = 34,
no_cat3_losses = 53, no_cat4_losses = 14, no_cat5_losses = 3;

aad = 10303022044.7246;

freq_ts = no_ts_losses/no_years, freq_cat1 = no_cat1_losses/no_years,
freq_cat2 = no_cat2_losses/no_years, freq_cat3 = no_cat3_losses/no_years,
freq_cat4 = no_cat4_losses/no_years, freq_cat5 = no_cat5_losses/no_years;

freq_signal_ts = -13/(80*100), freq_signal_cat1 = -52/(80*100),
freq_signal_cat2 = -17/(80*100), freq_signal_cat3 = -45/(80*100),
freq_signal_cat4 = 83/(80*100), freq_signal_cat5 = 200/(80*100);

ts_losses = fscanfMat("ts_losses.csv");
cat1_losses = fscanfMat("cat1_losses.csv");
cat2_losses = fscanfMat("cat2_losses.csv");
cat3_losses = fscanfMat("cat3_losses.csv");
cat4_losses = fscanfMat("cat4_losses.csv");
cat5_losses = fscanfMat("cat5_losses.csv");

uu = file('open','ets_pos.txt','unknown');
vv = file('open','ets_neg.txt','unknown');
xx = file('open','80yr_av.txt','unknown');

for r = 1:test_years,

    for i = 1:no_iterations,
        random_total_loss = 0;

        no_ts = grand(1,1,'poi',maxi(freq_ts*(1+r*freq_signal_ts),0));
        no_cat1 = grand(1,1,'poi',maxi(freq_cat1*(1+r*freq_signal_cat1),0));
        no_cat2 = grand(1,1,'poi',maxi(freq_cat2*(1+r*freq_signal_cat2),0));
        no_cat3 = grand(1,1,'poi',maxi(freq_cat3*(1+r*freq_signal_cat3),0));
        no_cat4 = grand(1,1,'poi',maxi(freq_cat4*(1+r*freq_signal_cat4),0));
        no_cat5 = grand(1,1,'poi',maxi(freq_cat5*(1+r*freq_signal_cat5),0));

        if no_ts > 0,
            for k = 1:no_ts,
                random_loss = ts_losses(ceil(rand()*no_ts_losses));
                random_total_loss = random_total_loss + random_loss;
            end
        end
    end
end

```

```

if no_cat1 > 0,
    for k = 1:no_cat1,
        random_loss = cat1_losses(ceil(rand()*no_cat1_losses));
        random_total_loss = random_total_loss + random_loss;
    end
end

if no_cat2 > 0,
    for k = 1:no_cat2,
        random_loss = cat2_losses(ceil(rand()*no_cat2_losses));
        random_total_loss = random_total_loss + random_loss;
    end
end

if no_cat3 > 0,
    for k = 1:no_cat3,
        random_loss = cat3_losses(ceil(rand()*no_cat3_losses));
        random_total_loss = random_total_loss + random_loss;
    end
end

if no_cat4 > 0,
    for k = 1:no_cat4,
        random_loss = cat4_losses(ceil(rand()*no_cat4_losses));
        random_total_loss = random_total_loss + random_loss;
    end
end

if no_cat5 > 0,
    for k = 1:no_cat5,
        random_loss = cat5_losses(ceil(rand()*no_cat5_losses));
        random_total_loss = random_total_loss + random_loss;
    end
end

array(r,i) = random_total_loss;

end
end

for r = 2:test_years,

    for j = 1:r-1
        no_negative_grads = 0, sum_loss_change = 0;

        for i = 1:no_iterations,
            sum_y = sum(array(j:r,i));
            sum_x_times_y = sum(((1:(r - j + 1)).* array(j:r,i)'));
            sum_x = sum(1:(r - j + 1));

```



```

sum_x_squared = sum((1:(r - j + 1)).^2);

gradient = ((r - j + 1) * sum_x_times_y - sum_x * sum_y)/((r - j + 1) *
sum_x_squared - (sum_x^2));

if gradient < 0,
    no_negative_grads = no_negative_grads + 1
end

loss_change = ((gradient * (r - j + 1) + (sum_y - gradient * sum_x)/(r - j + 1)) -
aad)/aad;
sum_loss_change = sum_loss_change + loss_change;

end

if r == 80,
    average_loss_change = sum_loss_change / no_iterations
    write(xx,[r j average_loss_change],'f8.0,f8.0,f8.4')
end

if no_negative_grads / no_iterations < 0.05,
    average_loss_change = sum_loss_change / no_iterations
    write(uu,[r j average_loss_change],'f8.0,f8.0,f8.4')
elseif no_negative_grads / no_iterations > 0.95,
    average_loss_change = sum_loss_change / no_iterations
    write(vv,[r j average_loss_change],'f8.0,f8.0,f8.4')
end

end

end

file('close',uu);
file('close',vv);
file('close',xx);

```

Table S3. Poisson parameter (λ) representing the average annual number of storm losses in each Saffir-Simpson category over the period 1900-2005 and the corresponding chi-squared goodness-of-fit test statistics and P -values. Numbers in brackets are the numbers of degrees of freedom (df).

Saffir-Simpson Storm Category	Tropical	1	2	3	4	5
λ	0.538	0.415	0.321	0.500	0.132	0.028
χ^2_{k-2}	7.901 (1)	0.00035 (1)	0.03956 (0)	0.44205 (1)	0.00115 (0)	N/A
P -value ($k - 2$ df)	0.005	0.985	N/A	0.506	N/A	N/A
P -value ($k - 1$ df)	0.019	1.000	0.842	0.802	0.973	N/A

Table S4. The number of years it takes for frequencies to reach zero. Calculations were made based on the projections in table 1 assuming the annual linearly decreasing trends continue beyond the 80-year projections. Emergence timescales (rounded to the nearest 10 years) are also shown.

Saffir-Simpson Storm Category	CMIP3 ensemble	GFDL	MRI	MPI	HadCM3
Tropical	615	-	500	571	571
1	154	200	178	167	121
2	471	533	286	222	151
3	178	-	235	157	125
4	-	-	-	-	143
5	-	-	-	-	-
Emergence timescale	260	150	150	550	120

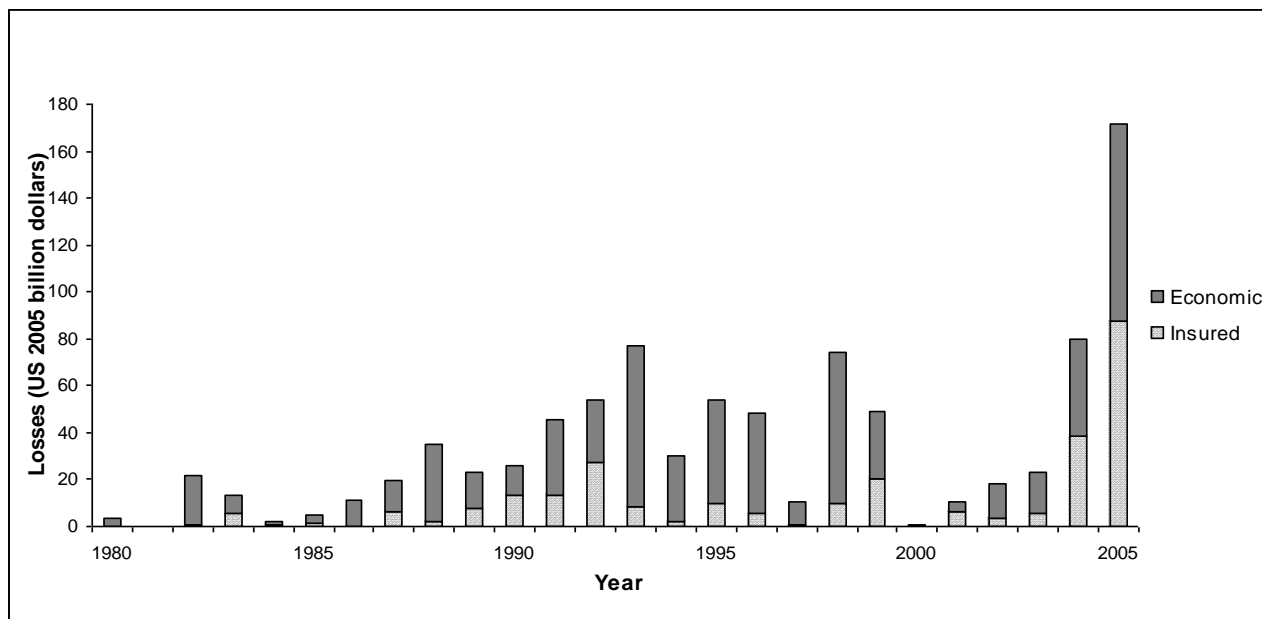


Figure S1. Total inflation-adjusted economic and insured losses (2005 dollars) per year from Munich Re’s global weather-related Great Natural Catastrophes. Natural disasters are classified as Great Natural Catastrophes when any of the following occurs: the number of fatalities exceeds 2,000; the number of homeless exceeds 200,000; overall losses exceed 5% of that country’s per capita GDP, and the country is dependent on international aid [S4].

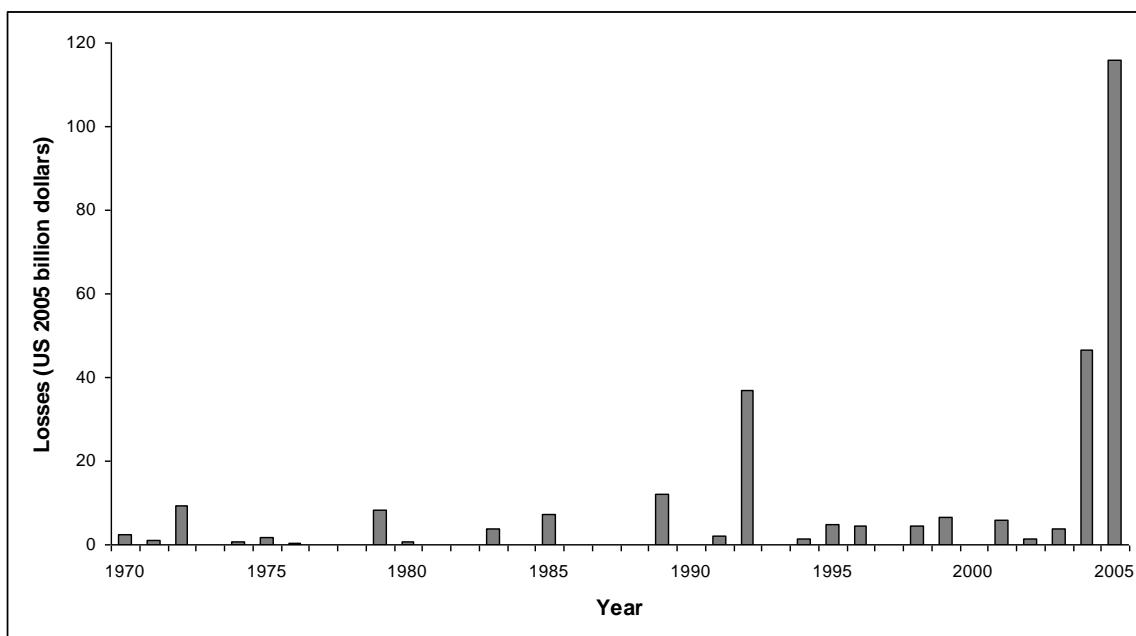


Figure S2. Total inflation-adjusted US economic losses (2005 dollars) per year from Atlantic tropical cyclones.

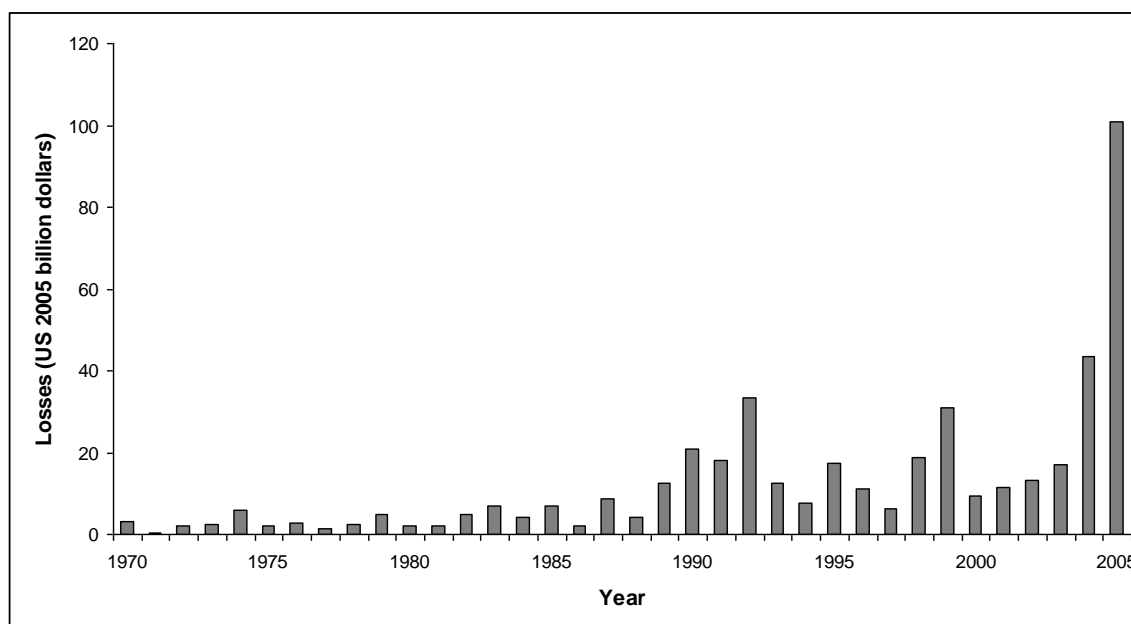


Figure S3. Total inflation-adjusted major insured losses (2005 dollars) per year from Swiss Re's global weather events.

Supplementary References

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CHAPTER 8

Discussion, Conclusions and Future Work

8.1 Discussion

The impacts of natural hazards on society can be devastating and there has been considerable concern as to whether anthropogenic climate change has already worsened some of these impacts and/or could worsen them in the future. New analyses presented in this thesis build and expand upon previous research and explore current and projected relationships between weather-related natural disaster losses and climate change (natural variability and anthropogenic). Previous chapters addressed the research questions and more broadly tested the ongoing validity of the four Hohenkammer workshop consensus statements emphasised in Chapter 1. The key results are discussed below and the implications they have for policy are detailed in the next section.

8.1.1 Research questions

- 1) *What factors are responsible for the increase in Australian weather-related insured losses and to what extent has anthropogenic climate change influenced this trend?*

Chapters 2 and 3 showed that societal factors have been the main drivers of the increasing trend in Australian weather-related insured losses. Moreover, there was no obvious trend in normalised losses that might be attributed to other factors including anthropogenic climate change. This finding is entirely consistent with Hohenkammer consensus statements (HCSs) 1.1 and 1.3.

The loss normalisation methodology applied to Australian weather-related insured losses included an adjustment applied to tropical cyclone losses to account for the reduction in vulnerability of construction in tropical cyclone-prone areas. To our knowledge this is the first time such an adjustment has been included in loss normalisation studies. Most methodologies haven't included adjustments for changes in vulnerability because they are harder to quantify than changes in exposure (Bouwer, 2011).

2) *How has climate change influenced Australian bushfire building damage and fatalities?*

Relationships between the time series of normalised Australian bushfire building damage and the El Niño-Southern Oscillation (ENSO) and Indian Ocean dipole (IOD) phenomena were identified in Chapter 4 and reinforce HCS 1.2. These relationships give greater confidence in the normalisation methodology and results as they are consistent with those to geophysical bushfire indicators. While an anthropogenic climate change influence was not ruled out in the analysis, there was no discernable evidence that normalised data were influenced by it. If it did exist, it was not resolvable in the context of the large societal change and year-to-year variation in impacts. Again, this adds further weight to HCSs 1.1 and 1.3.

The 2009 Black Saturday bushfire impacts were shown not to be anomalous once normalised. Key features of the Black Saturday fires include a high ratio of normalised fatalities to building damage and the large proportion of buildings destroyed either within bushland or at very small distances from it (<10 m). In Marysville and Kinglake, about 25% of destroyed buildings were located physically within the bushland boundary, and 60% and 90% were within 10 and 100 m of bushland. This being the case, it is not surprising that few of such buildings survived exposure to flames, radiant and convective heating and ember attack. Australia has a history of development in high risk areas that is reflected in analyses of major bushfires over the last 50 years.

3) *Has societal vulnerability to bushfires in Australia changed and could this be masking an upward trend in building damage that would otherwise exist due to any increases in the frequency or intensity of bushfires?*

Possible sources of reductions in vulnerability in relation to bushfire risk in Australia were discussed in Chapter 5. These included improved building construction and/or regulation; emergency preparations and response, and skill of weather forecasting. The result from Chapter 4 – that there was no discernable evidence that normalised building damage had been influenced by anthropogenic climate change – was upheld after consideration of each of these factors as they either missed the most important points, were uncertain and unquantifiable, or were negligible in extreme impact events such as the Black Saturday fires. It was the most extremely damaging bushfires that dictate the pattern in normalised building damage.

Chapter 5 identified areas, in addition to land use planning, that require further attention in future attempts to reduce vulnerability to bushfires. These include better informing residents in the urban-bushland interface in Australia of the risk they face. Many of these residents have very limited experience and knowledge of bushfires. Recent experience has shown that many of those whose homes were destroyed in bushfires were unaware that they were at any risk. This is problematic under the current climate, and potentially will be even more so under a future climate should there be any increases in the frequency and/or intensity of bushfires in particular locations.

There is also a need to improve people's preparedness in the lead up to bushfire seasons and their responsiveness during actual events. The vast majority of people were well aware of the accurately forecasted bushfire risk on Black Saturday yet events suggested people did not respond accordingly.

4) Can climate change signals be detected in tropical cyclone loss databases and what role do various factors have in shaping tropical cyclone losses in the future?

It is evident from studies reviewed in Chapter 6 that to date there has been an increasing trend in tropical cyclone losses across many basins (Northwest Pacific, North Atlantic, North Indian, South Pacific, Southeast Indian) and that the main drivers of this have been societal factors. No study was able to detect an anthropogenic climate change influence on normalised data but it was possible to identify natural climate variability (consistent with geophysical trends). These findings are consistent with those in previous chapters and HCSs 1.1 - 1.3.

Chapter 6 also reviewed studies that projected US tropical cyclone losses. The expectation for the future was that societal factors will continue to be the principal loss drivers and that long term effects of anthropogenic climate change would likely exacerbate future impacts.

5) *When will anthropogenic climate change signals be detected in US tropical cyclone loss data and what implications does this have for global weather-related natural disaster losses?*

Chapter 5 explained why it should not be surprising that there was no discernable evidence that normalised Australian bushfire building damage was being influenced by anthropogenic climate change. Put simply, there are numerous factors in addition to bushfire weather that collectively lead to damage and these add a large amount of variability to eventual losses. HCS 1.4 can be justified on the same basis and the research question above follows from this and Chapter 6.

Chapter 7 revealed that the detection or attribution of anthropogenic climate change signals in US normalised tropical cyclone loss data was extremely unlikely to occur over periods of several decades (and even longer) under the projections examined. This caution was extended more generally to global weather-related natural disaster losses. Depending on the global climate model(s) underpinning the projection, emergence timescales ranged between 120 and 550 years and it took 260 years for an 18-model ensemble-based signal to emerge. This result confirmed the general agreement that it is far more efficient to seek to detect anthropogenic signals in geophysical data directly rather than in loss data.

8.1.2 Current consensus

This thesis reinforces the current legitimacy of the four HCSs examined as do other recent studies. Bouwer (2011) reviewed and analysed 21 recent weather-related loss normalisation studies (including the papers contained in Chapters 2 and 4) from around the world. The analyses spanned weather-related losses from hazards such as bushfires, floods, storms, tropical cyclones, etc and all 21 of them showed that societal factors were the principal factors responsible for the increase in losses. None of the studies were able to detect (much less attribute) an anthropogenic climate change influence on losses.

A study by Emanuel (2011), motivated by the paper presented in Chapter 7, used an alternative methodology and different data to assess Research Question 5: When will anthropogenic climate change signals be detected in US tropical cyclone loss data? Of the four model projections Emanuel (2011) analysed, three produced increasing losses with emergence timescales of 40, 113 and 170 years. The other produced a small decrease in loss and the signal did not emerge within the 200-year period analysed. Despite the detection time being shorter than that reported in Chapter 7 there is agreement that attribution is unlikely to be achieved in the near future assuming that recent projections are correct.

The recently released Special Report of the Intergovernmental Panel on Climate Change (IPCC) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (SREX) (IPCC, 2012) offers the most up-to-date consensus on the science of extreme events and disasters. The report contains various statements relating to disaster losses that reflect and also reaffirm the HCSs and key findings of this thesis. (Note that the papers contained in Chapters 2, 4 and 7 are cited in SREX.) These include:

Increasing exposure of people and economic assets has been the major cause of long-term increases in economic losses from weather- and climate-related disasters (high confidence). Long-term trends in economic disaster losses adjusted for wealth and population increases have not been attributed to climate change, but a role for climate change has not been excluded (high agreement, medium evidence) (IPCC, 2012).

There is medium evidence and high agreement that long-term trends in normalized losses have not been attributed to natural or anthropogenic climate change (IPCC, 2012).

In many regions, the main drivers of future increases in economic losses due to some climate extremes will be socioeconomic in nature (medium confidence, based on medium agreement, limited evidence) (IPCC, 2012).

Some studies indicate that the expected changes in exposure are much larger than the effects of climate change (see Table 4-3), which is particularly true for tropical and extratropical storms (IPCC, 2012).

8.2 Conclusions

The relationships between weather-related natural disaster losses and climate change (natural variability and anthropogenic) explored in the context of the research questions and detailed in previous chapters have important implications for policy aimed at minimising future losses. It has been shown that societal factors have been the main drivers of the increasing trend in disaster losses to date and in the absence of effective policy, future losses in many regions will rise rapidly due to expected societal changes and economic development. Anthropogenic climate change effects may exacerbate this trend.

Policy responses need to consider and respond to multiple drivers of change. In general, the policy implications in this thesis are closely aligned to those of the Hohenkammer workshop (Table 1.1) and include employing both mitigation and adaptation contemporaneously to benefit society now and into the future. This similarity is expected given the key results of this thesis mirror the four HCSs examined. However, there are also policy implications specific to the research in this thesis.

It is clear that there is much to be gained in both the short and long term from reducing societal vulnerability to natural hazards. This thesis emphasises improved building standards and better land use planning as ways to achieve this. Chapter 2 demonstrated the important role improved building standards can play in reducing losses. The dramatic reductions in wind-induced losses observed following Tropical Cyclones Winifred (1986) and Aivu (1989) and more recently, Larry (2006) and Yasi (2011) in Australia underlines the important gains that can be made through disaster risk reduction and why there is a need to expand the role of it in adaptation.

Societal vulnerability is also influenced by land use planning. Chapter 4 showed the severe consequences that can stem from poor land use planning. In the towns where the majority of building damage occurred in the 2009 Black Saturday fires, 25% of destroyed buildings were literally located within bushland and 60% were within 10m of the bushland boundary. Land use planning policies in bushfire-prone parts of Australia that allow such development increase the risk that bushfires pose to the public and the built environment. The same applies to other countries and natural hazards.

The idea that anthropogenic climate change might have already increased or will increase the frequency and intensity of disaster losses from some weather-related natural hazards is part of the evidence that is used to support policy intervention on climate change. However, this relationship has not yet been detected in normalised insured or economic loss data across a range of hazards and locations around the world. Looking to the future, the detection or attribution of anthropogenic climate change signals in economic loss data is extremely unlikely to occur over periods of several decades, at least for US tropical cyclone and global weather-related natural disaster losses. There are far better justifications than natural disaster losses for policy responses to anthropogenic climate change.

Policy making related to climate necessarily must occur under uncertainty and ignorance and it is likely that this will persist on timescales longer than those of decision making, strengthening the case for expanding disaster risk reduction in climate adaptation policy. Reducing the vulnerability of people and property to extreme events makes sense regardless of whether increasing losses can be linked to anthropogenic climate change. Financial solutions that encourage vulnerability reduction can be used as an effective tool to minimise future losses.

8.3 Areas for Further Research

This thesis has emphasised the importance of reducing societal vulnerability to minimising future disaster losses. This being the case, there is a need to continue efforts to enhance our understanding of vulnerability as well as past and future exposure to help guide policy and inform future financing needs.

One of the limitations of the studies underlying the first two SREX statements in section 8.1.2 is that vulnerability is a key factor in disaster losses but is not yet well accounted for (IPCC, 2012). Bouwer (2011) echoes this sentiment stating that measures that change vulnerability are typically not included in normalisation studies because they are harder to quantify than changes in exposure. However, Bouwer (2011) cites the paper in Chapter 2 as an example of a study that does account for changing vulnerabilities as the normalisation methodology includes an adjustment for improved building standards in tropical cyclone-prone areas of Australia.

Although improved building standards are incorporated in Chapters 2 and 3 and other sources of changing vulnerability relating to bushfire are discussed in Chapter 5, there is a need for a greater understanding of vulnerability so that measures that change it can be included in normalisation studies. Moreover, studies need to identify additional measures that might reduce vulnerability in the future. These need to be implemented in policy and their effects measured through time. Future normalisations would also need to incorporate these measures.

Other areas for further research include exploring relationships between the normalised insured disaster losses in Chapter 3 and the El Niño-Southern Oscillation and Indian Ocean Dipole. The role of the uncertainty surrounding the current and future influence of anthropogenic climate change on natural disaster losses in the decision making of various stakeholders (policy makers, insurance companies, disaster planners, etc) also warrants further investigation.

8.4 References

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APPENDIX 1

Nicholls, N., 2011. **Comments on “Influence of location, population, and climate on building damage and fatalities due to Australian bushfire: 1925-2009.”** *Wea. Climate Soc.*, 3, 61-62.

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Comments on “Influence of Location, Population, and Climate on Building Damage and Fatalities due to Australian Bushfire: 1925–2009”

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ABSTRACT

The absence of an upward trend in normalized building damage in Australian bushfires may reflect reduced vulnerability (due to improved weather forecasts and other factors) offsetting increases in the frequency or intensity of bushfires.

Crompton et al. (2010) examine trends in bushfire damage in Australia after normalizing historical damage data to take into account increases in building numbers (i.e., to estimate building damage had bushfires in earlier years occurred under the societal conditions of 2008/09). They find no upward trend in normalized damage and therefore conclude that “. . .there is no discernable evidence that the normalized data are being influenced by climate change due to the emission of greenhouse gases.” However, their normalization does not take into account several factors that may have led to a reduction in vulnerability over the period they examined. Each of these factors, in the absence of an upward trend in the intensity or extent of bushfires, might have been expected to result in a decline in the normalized damage from bushfires.

For instance, Crompton et al. (2010) do not factor the increasing urbanization of Australia into their normalization of damage. They normalize the time series of building damage by using changes in the total numbers of buildings across an entire state, without taking into account that the proportion of the state population residing in the capital city has increased substantially over time. In 1958 about 45% of the population of the State of Victoria lived outside the capital city Melbourne. By 2008 this proportion had fallen to about 25%. Presumably this means that, over several decades, the number of

buildings outside the capital city has fallen relative to the total numbers of buildings in the state. Apart from those residing on the very fringe of the city, capital city populations (and the houses in which they live) are far less vulnerable to bushfires than are buildings in small towns or isolated communities. The increasing urbanization of southeast Australia over the past 50 years or more might well have led to a decline in the number of buildings damaged by bushfires, unless another factor was operating to offset this decline.

Crompton et al. (2010) also do not take into account possible reductions in vulnerability due to improved building construction and/or regulation. After every major bushfire disaster official enquiries considered what could be done to reduce future vulnerability and recommend actions. As well, individual householders may install systems to reduce bushfire vulnerability (e.g., spray systems to wet houses prior to and during fire attack). Any activities in response to previous bushfire disasters, whether through official changes in building or planning regulations or autonomous actions by householders to reduce building vulnerability, would presumably have led to a decline in bushfire damage, unless the decline in vulnerability was offset by some other factor.

Neither do Crompton et al. (2010) take account of possible reductions in vulnerability due to improved emergency preparations and response, such as improved fire-fighting equipment and management. We should include here the reduced vulnerability that might have resulted from substantial improvements in the skill of weather forecasting over several decades (Nicholls 2001;

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Stern 2008). Such improved forecasts, available with much longer lead times than were possible in the past, could have allowed building owners to prepare more effectively (e.g., by removing fuel from the immediate environs of the building). It seems possible that such systems might have reduced vulnerability, and thus led to a decline in bushfire damage (unless other factors were increasing the threat of bushfire damage).

The above discussion indicates that there are several factors that might have reduced vulnerability to bushfires over the 1925–2009 period examined by Crompton et al. (2010). Any of these factors could have, in the absence of factors increasing the threat of damage, led to a reduction over decades in the damage caused by bushfires. Thus the absence of a decline in normalized damage may reflect an increased threat (perhaps due to a trend toward more frequent or more intense fires) offset by a decrease in vulnerability to fire. Of course, it is feasible that increasing urbanization, improved building/planning standards and techniques, improved emergency planning and response, and improved weather forecasts have not had any success whatsoever in reducing economic

vulnerability to bushfires. But until research demonstrates that such decreased vulnerability has not occurred it would be safer to add a caveat to the conclusions of Crompton et al. thus: "...there is no discernable evidence that the normalized data are being influenced by climate change due to the emission of greenhouse gases (*assuming that increasing urbanization, improved building/planning standards and techniques, improved emergency/bushfire planning, equipment and response, and improved weather forecasts have had no effect in reducing economic vulnerability to bushfires*)."

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