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SEVENTH INTERNATIONAL WORKSHOP ON TROPICAL CYCLONES

4.5: Economic Impacts of Tropical Cyclones

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4.4.1. 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 databases[1] 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.

4.4.2. Loss normalization

4.4.2.1 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

[1]Gross 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.

4.4.2.2 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.

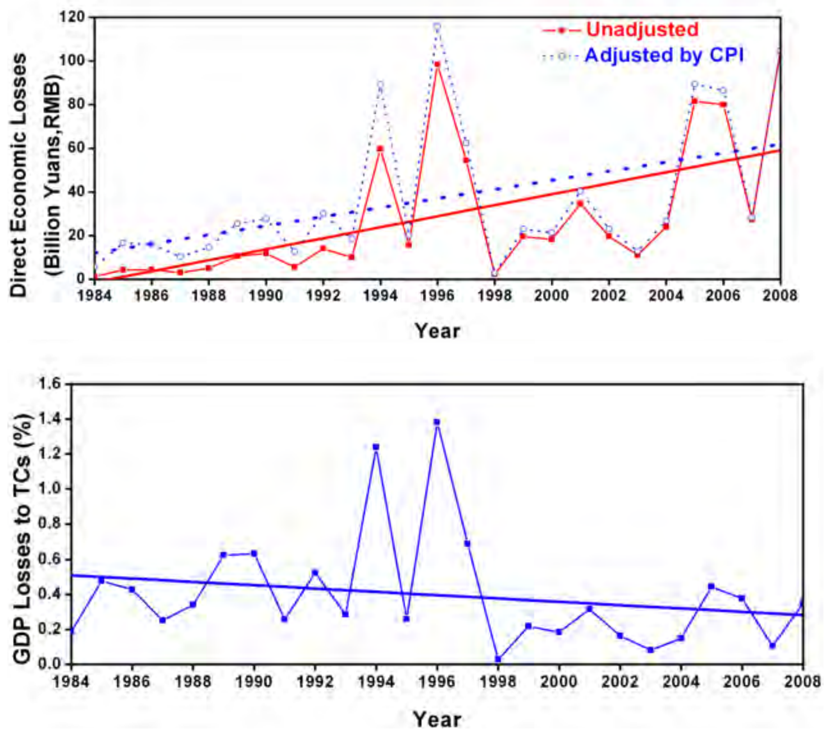


Figure 1: The economic losses released by the Department of Civil Affairs of China and the corresponding CPI-adjusted losses each year in billion yuans (top); the GDP-normalized losses in percentage (%) (bottom). Corresponding linear trends from 1984 to 2008 are also shown (source: Zhang et al. (2010)).

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.

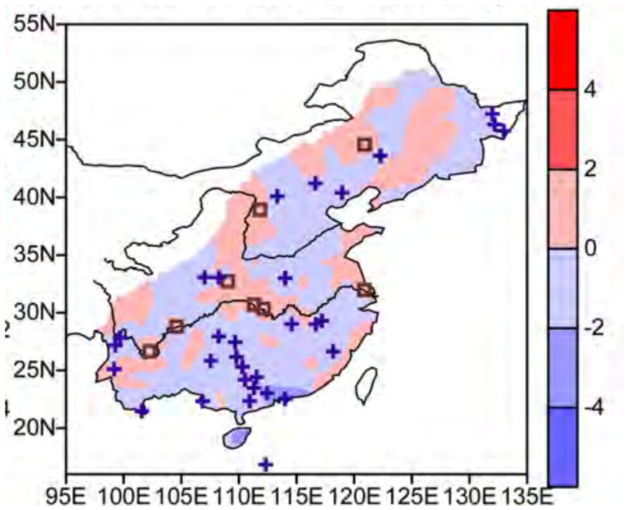


Figure 2: Trends (mm/year) in annual rainfall associated with landfalling tropical cyclones in China. The symbols indicate that the trends are statistically significant at the 95% level (source: Chen et al. (in prep.)).

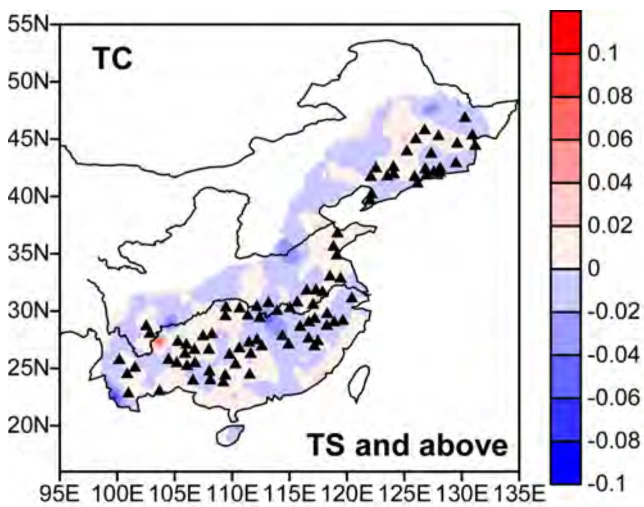


Figure 3: Trends (day/year) in extreme rainfall days associated with landfalling tropical cyclones in China. The symbols indicate that the trends are statistically significant at the 95% level (source: Chen et al. (in prep.)).

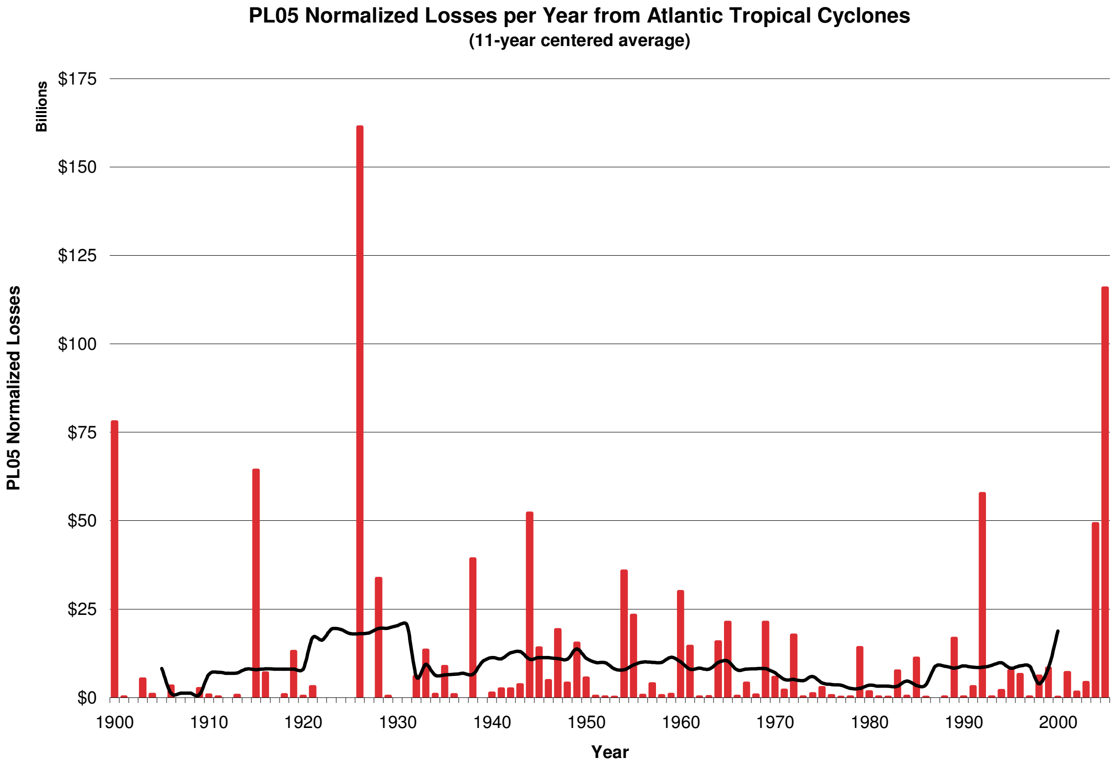
b) US

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.



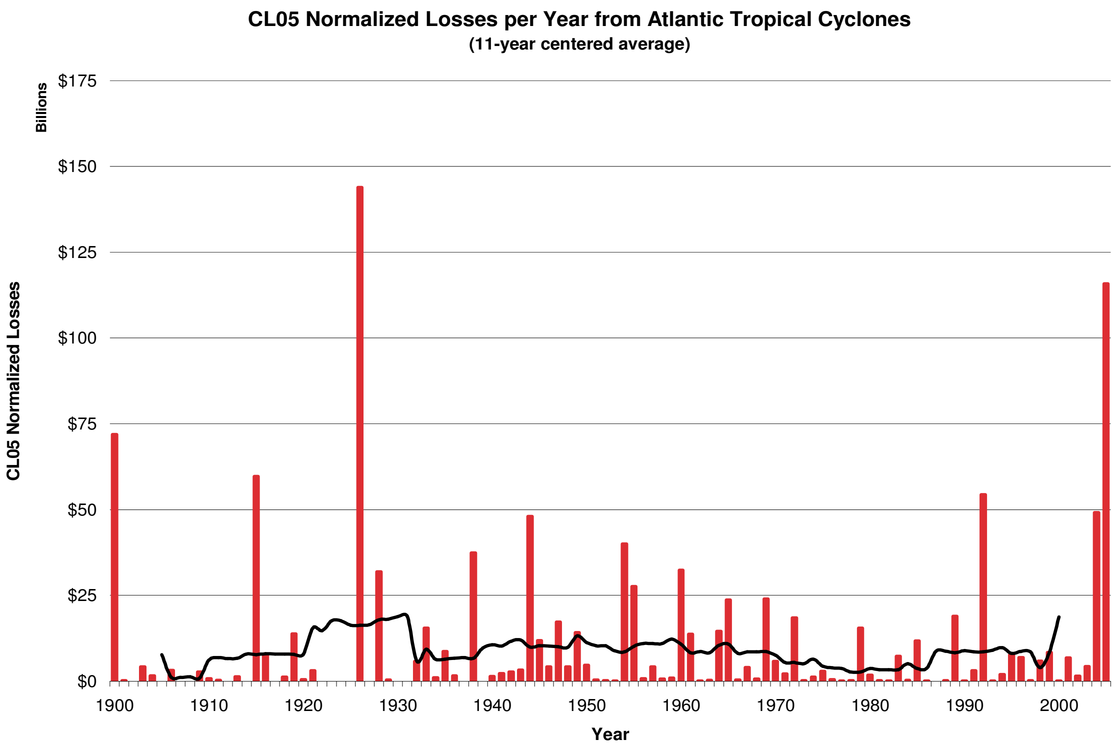


Figure 4: US Gulf and Atlantic damage, 1900-2005, normalized: PL05 methodology (top) and CL05 methodology (bottom) (source: Pielke et al. (2008)).

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 year[2] 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.

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

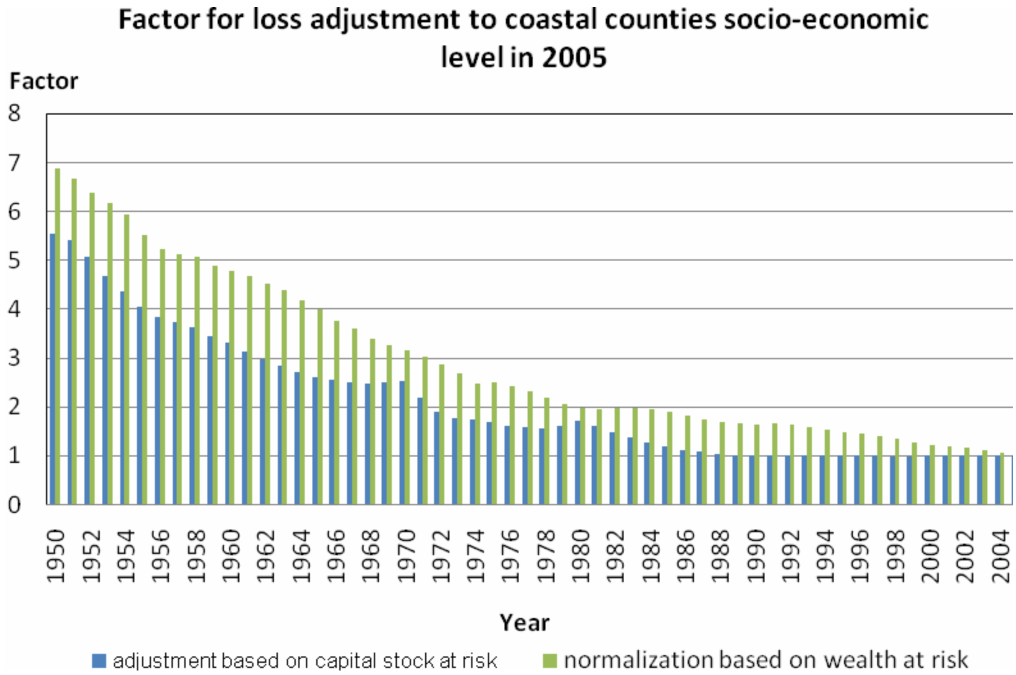


Figure 5: Blue bars show the factors applied for adjustment of losses to 2005 socio-economic level based on capital stock at risk (e.g. losses in year 1962 will be multiplied by factor 3). Green bars show the factors applied based on wealth at risk (population in 177 coastal counties and real wealth 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-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.

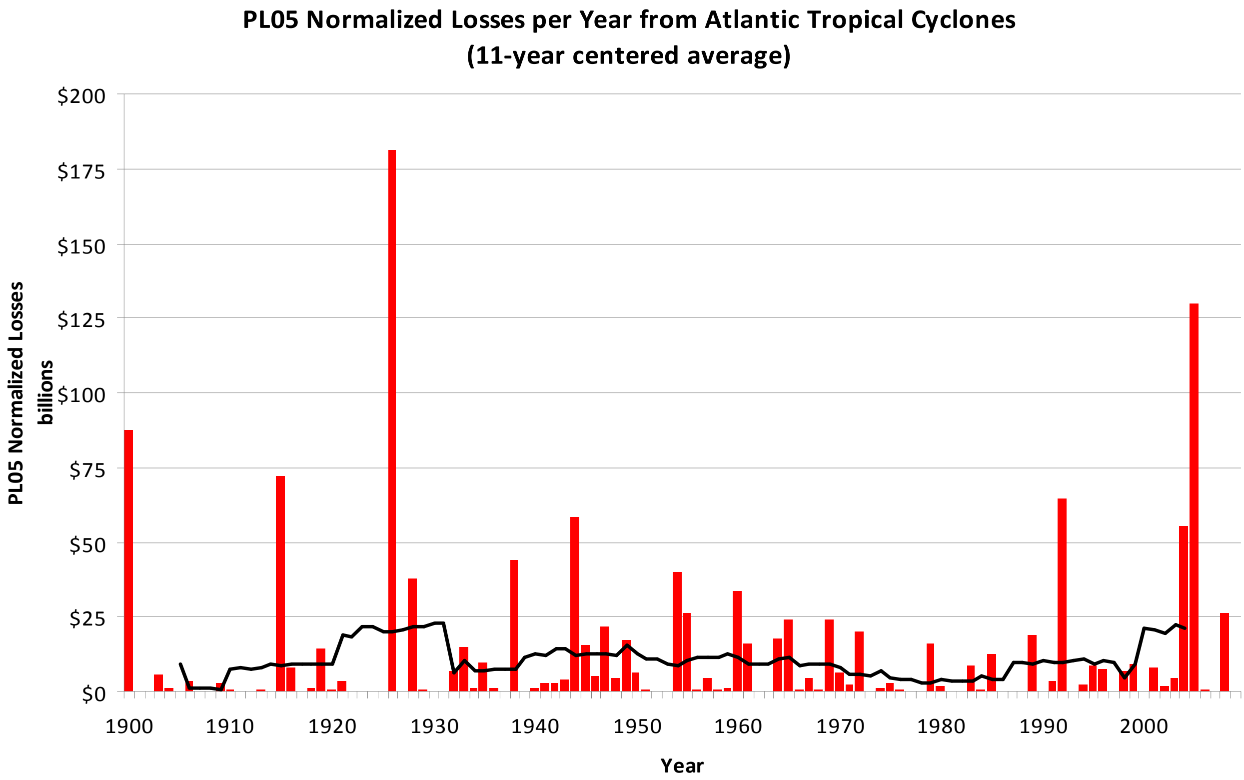


Figure 6: US Gulf and Atlantic damage, 1900-2009, normalized (2009 values) using the PL05 methodology.

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.

4.4.3. 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]	$d = \alpha \times wind\ speed^8$	Increase of maximum wind speeds of 8.7% with warming of 2.5°C	constant	Average loss increases by 104%
Stern et al. (2006)	$d = \alpha \times wind\ speed^3$	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 $d = \alpha \times (s) \times wind\ speed^3$	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)	$d = \alpha \times wind\ speed^3$ (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.

		Anthropogenic climate change effect				**Exposure effect**		**Total effect**
Study	**Year**	**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.

<u>Elasticity</u>

- 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^{o}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.

4.4.4. 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.

4.4.4.1 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.

4.4.4.2 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.

4.4.4.3 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.

Musulin 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. Musulin 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.

Musulin 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 (Musulin 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 (Musulin et al., 2009).

Musulin 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 (Musulin et al., 2009).

4.4.4.4 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.

4.4.5. 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 an effective tool to minimize future losses.

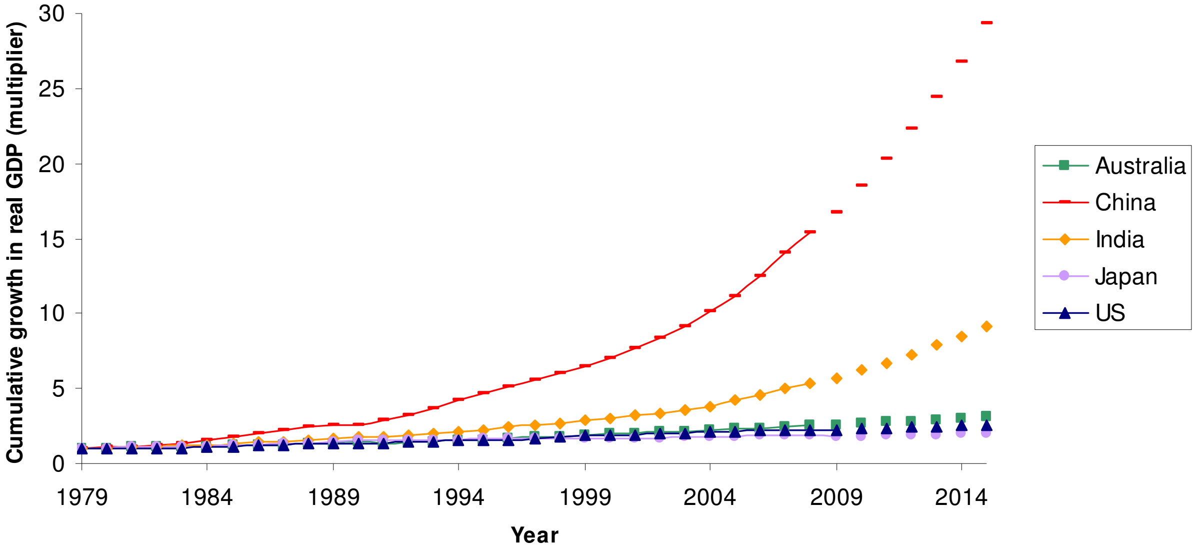


Figure 7: The cumulative effect of growth in real GDP (GDP in constant prices) relative to 1979 for selected countries. Points on each country's curve that are not connected are estimated (projected) values (data source: International Monetary Fund World Economic Outlook Database (IMFWEO) - http://www.imf.org/external/ns/cs.aspx?id=28).

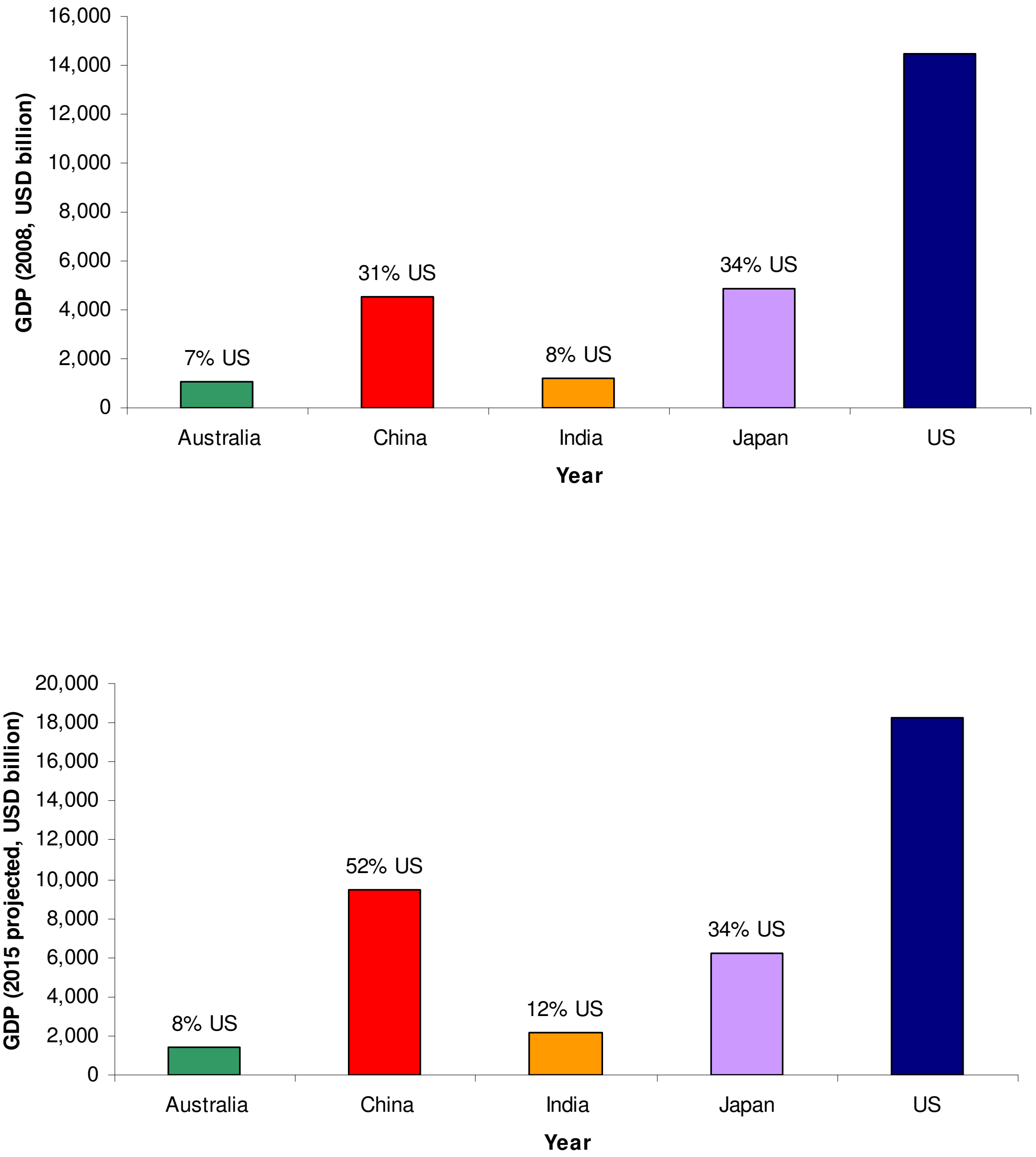


Figure 8: GDP in current prices (nominal values) as at 2008 (top) and estimated values for 2015 (bottom) for selected countries. The most recent year there is actual GDP values (as opposed to estimated values) across all selected countries is 2008. Also shown is each country's GDP relative to US GDP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

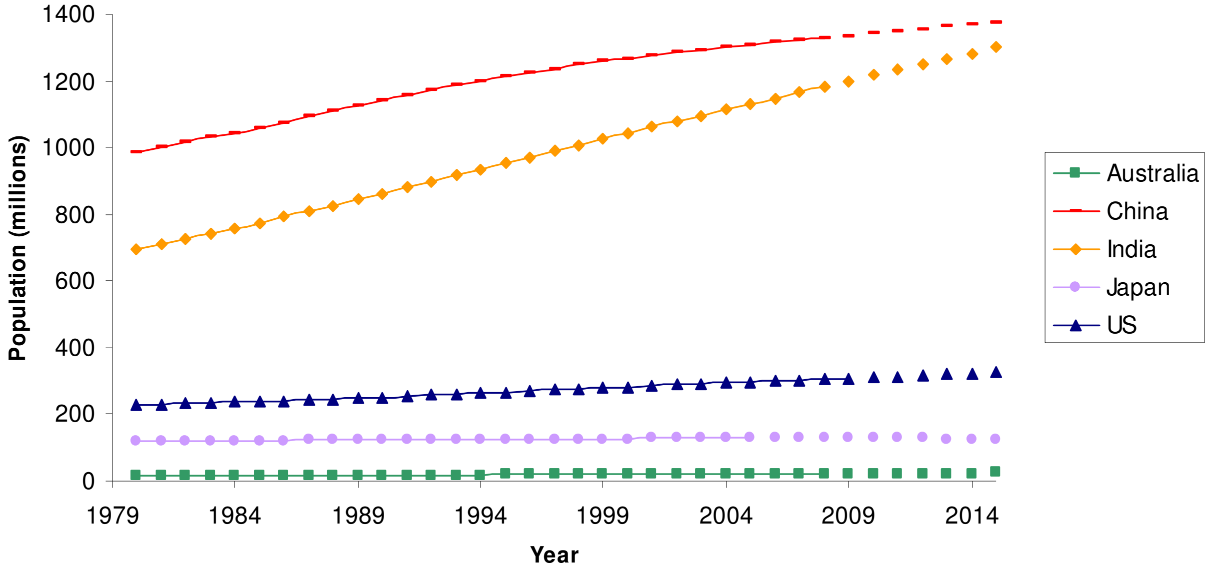


Figure 9: Population in selected countries. Points on each country's curve that are not connected are estimated (projected) values (data source: IMFWEO - http://www.imf.org/external/ns/cs.aspx?id=28).

4.4.6. 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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