WMO/CAS/WWW

SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 5.2 : **Factors Contributing to Human and Economic Losses**

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5.2.1: **Understanding human and economic losses**

Human losses refer to the loss of life and injuries that result from the impacts of a catastrophic natural event, such as a wind storm for example. Losses from individual tropical cyclones have been catastrophic across centuries. Rappaport and Fernandez-Partagas (1995, updated by Beven 1997) have for example compiled human loss data for the Atlantic 1492-1997 that shows human impacts on early Europeans travelers for example.[6] The Center for Research on the Epidemiology of Disasters (CRED) also maintains a database of global disaster called EM-DAT (http://www.em-dat.net/index.htm).[7] CRED urges caution in using disaster data:

> Data on disaster occurrence, their effect upon people and cost to countries remain at best patchy. No single institution has taken on the role of prime provider of verified data. The data in

[6] http://www.nhc.noaa.gov/pastdeadly.shtml
[7] GUHA-SAPIR., D. HARGITT, D. HOYOIS, Ph. (2004). *Thirthy years of natural disasters 1974-2003: The numbers,* Presses Universitaires de Louvain: Louvain-la Neuve. http://www.em-dat.net/documents/Publication/publication_2004_emdat.pdf

EM-DAT is culled from a variety of public sources, including reports by governments, insurance companies, press agencies and aid agencies. The original information is not specifically gathered for statistical purposes and inevitably, even though CRED applies strict definitions for disaster events and parameters, the original suppliers of the information may not. The figures should be regarded as indicative.[8]

The U.S. National Hurricane Center maintains a database of economic losses related to hurricanes that impact the US and, to some extend, the Caribbean region and Central America (e.g., http://www.nhc.noaa.gov/Deadliest_Costliest.shtml). Several reinsurance companies also maintain global tropical cyclone loss databases (including Munich Re[9] and Swiss Re[10]). Economic damage is often defined as the direct damages associated with a hurricane's impacts as determined in the weeks (and sometimes months) after the event. Indirect damages and longer-term macro-economic effects, such as the surge in the price of materials and qualified workers after an event, are sometimes considered in a tabulation of losses. Inland flooding related to tropical cyclones is handled inconsistently across datasets. Different methods exist for calculating a disaster's impacts and result in correspondingly different estimates for the same event. Consequently extreme caution should be taken when integrating analyses or conclusions across datasets.

For these reasons, a major workshop held in May, 2006 in Hohenkammer, Germany organized to look at economic losses recommended the "creation of an open-source disaster database according to agreed upon standards."[11] [12] While this recommendation has a broad focus, tropical cyclones would form a substantial part of any such database given the magnitude of their associated human and economic losses. Munich Re has begun discussions about the creation of such an open-source database, built upon their NatCat Service. We recommend that the tropical cyclone community should collaborate on this, or other, efforts to create a centralized, comprehensive, peer-reviewed database. In particular, significant by their absence in this report, data on the non-economic human losses related to tropical cyclones are not readily available.

5.2.2: **Cost-benefit studies of disaster mitigation**

While there is general agreement among experts that reducing vulnerability to tropical cyclones through disaster mitigation is the most effective strategy for addressing human and economic losses, formal evaluation of specific options for reducing disaster vulnerability remains difficult because "natural hazards and related vulnerability are rarely considered in the design and appraisal of development projects. Similarly, monitoring and evaluation are still relatively neglected in disaster reduction, especially where impact evaluation is concerned."[13] There are a number of benefit-cost estimates that circulate in the disaster community that suggest "disaster mitigations pays," typically by a ratio of 3 to 1 or higher. Of such estimates made for disaster mitigation projects around the world, which

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[8] http://www.em-dat.net/documents/Publication/publication_2004_emdat.pdf

[9] http://www.munichre.com/publications/30203901_en.pdf?rdm=511#search=%22munich%20re%20natcat%20service%22

[10] http://www.swissre.com/INTERNET/pwsfilpr.nsf/vwFilebyIDKEYLu/EWAL6MBJQ2/$FILE/Sigma2_2006_e.pdf

[11] http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/workshop_report.pdf

[12] http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/workshop_report.pdf

[13] C. Benson and J, Twigg, 2004. 'Measuring Mitigation': Methodologies for assessing natural hazard risks and the net benefits of mitigation - A scoping study, ProVention Consortium. Jhttp://www.proventionconsortium.org/themes/default/pdfs/MM_scoping_study.pdf

includes tropical cyclones as well as other types of disasters, Benson and Twigg (2004, pp. 13-14)[14] write,

> However, there is surprisingly little evidence in support of many broad-brush statements. Detailed underlying calculations are not available, suggesting that they may, in fact, be no more than 'back-of the-envelope' – if informed – estimates. Even if they are based on more extensive calculations, the fact that the workings underlying them are not readily available can cast doubts on their legitimacy, particularly if figures involve some valuation of non-tangibles. Of course, financial analysis of loss and the cost of investments needed to avoid loss may not be sufficient to ensure greater attention to natural hazard risk, as demonstrated from experience elsewhere (for instance, in relation to disease, water pollution and illiteracy). But proof of net financial benefits is almost undoubtedly a first, very necessary step in making a case for the importance of analysing hazard-related risks.

The lack of a well-developed body of disaster mitigation cost-benefit analyses of the value of disaster mitigation sets the stage for a chicken-and-egg problem. Because such studies are rare, it can be difficult to compare projects or policies focused on disaster mitigation with other sorts of development policies; hence disaster mitigation policies are at risk of being overlooked in any systematic comparison of costs and benefits across different policy alternatives. But if such projects are overlooked, then there is less incentive to call for and support rigorous cost-benefit studies. One consequence of this dynamic is that funds for disaster relief in the aftermath of a horrific disaster are, in many cases, easier to secure than funds for long-term reduction of vulnerability to disasters, which may have supported efforts that would have reduced the need for post-disaster relief. This vicious cycle is well-appreciated by observers of disaster policy, but remains entrenched.[15]

Thus, one recommendation is for increasing attention to the need for rigorous cost-benefit analyses of disaster mitigation policy alternatives and practices. To put this another way, irrespective how such studies turn out (in terms of relative costs and benefits) there is a substantial benefit to decision making related to disasters to be gained from a more comprehensive and rigorous understanding of the value of disaster mitigation. More fundamentally, there is also a pressing need for more thorough information on the broad human and economic impacts of disasters,[16] as well as indicators of relative vulnerability[17] in order to help prioritize disaster mitigation investments. Even in the United States and Europe, where response to disasters is generally quite successful as measured by lives lost and community recovery from disasters there is little information available on the costs and benefits of disaster mitigation, as well as the role of government investments in disasters on outcomes.[18]

Actions to reduce the impacts of natural disasters are many and varied around the world. Some of these actions are developed in the longer-term, such as building codes, evacuation plans, and emergency response plans. Some of these longer-term plans require additional action in the

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[14] Ibid.

[15] B. Wisner, P. Blaikie, T. Cannon, and I. Davis, 2004. **At Risk - Natural hazards, people's vulnerability and disasters**, Wiltshire: Routledge, London, UK.

[16] For example, C. Benson and E. Clay, 2004, Understanding the Economic and Financial Impacts of Natural Disasters. Disaster Risk Management Series No.4. Washington DC: World Bank. http://www-wds.worldbank.org/servlet/WDS_IBank_Servlet?pcont=details&eid=000012009_20040420135752

[17] UNDRO 1990, Preliminary Study on the Identification of Disaster-Prone Countries Based on Economic Impact. New York/Geneva: United Nations Disaster Relief Organization.

[18] Meade, C. and Abbott, M.: 2003, Assessing Federal Research and Development for Hazard Loss Reduction, RAND, Santa Monica, CA.

short-term in the face of an impending threat, such as an order of evacuation.

In some instances not only has a cost-benefit analysis not been attempted, but neither has a more general risk assessment. Hurricane evacuation in the United States is an example of such a situation. Hurricane forecasts of storm tracks have improved steadily over the past three decades or so, yet at the same time the area of coastline warned per storm increased for much of this time, then decreasing in the last four years. This suggests that decisions makers (including forecasters and emergency managers) have possibly become more risk averse over time and have used advances in the science of forecasting to reduce the chances of leaving part of the population unwarned. Of course, such strategies have costs, in the form of a greater number of people warned unnecessarily. But to date there has been little demand for the quantification of the costs, benefits, and risks associated with different approaches to the challenge of hurricane evacuation in the face of uncertainty.[19] Arguably, the case of hurricane evacuation is representative of the broader challenges of evaluating existing disaster mitigation policies in terms of their costs, benefits, and risks.

There are new and innovative policy options that have been proposed for disaster mitigation that will likely stimulate demand for greater attention to costs and benefits. Among these are the securitization of risk through financial products such as catastrophe bonds and derivatives[20] and the provision of micro-finance[21] in developing countries as a tool of disaster recovery in ways that reduce long-term vulnerabilities. Such policies are not widespread, however, and they have not been subject to rigorous evaluation of costs and benefits, but nonetheless have strong support among many disaster experts.

Any effort to prioritize investments in improving preparation for and responses to tropical cyclone impacts – including the scientific and technological resources at the focus of the IWTC – would benefit from greater rigor in the collection of human and economic loss data, as well as research on the role that various policies, strategies, technologies, and other interventions have in shaping patterns of loses in particular locations.

5.2.3: **Tropical Cyclone Case Studies**

The following three sections describe the economic losses related to tropical cyclones in India, Australia, and the United States. The omission of the northwest pacific basin in the following cases is a reflection more of the state of the literature in this area than that basin's significance for tropical cyclone landfalls.

a) India (prepared by S. Raghavan)

Andhra Pradesh (location shown in Fig. 5.2.1) is one of the most tropical cyclone-prone states in India with a coastline of about 1030 km. Reliable meteorological and economic data are available from around 1970. In a study of tropical cyclones hitting the state in the period 1971-2000 Raghavan and Rajesh (2003)[22] showed that there was no increasing trend in tropical cyclone frequency or intensity, (actually there was a negative trend during these three decades) but the estimated damage increased over the period. However after the damage was normalized using changes in inflation, increases in population and economic activity in the region, there was no corresponding trend in the normalized

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[19] Pielke, Jr., R. A., 1999: Hurricane Forecasting. Science, 284, 1123.

[20] http://www.axa.com/lib/axa/uploads/cpsocietes/2006/United_nations_PR_20060306.pdf

[21] http://www.proventionconsortium.org/themes/default/pdfs/microfin_guidebook.pdf

[22] Raghavan S. and S. Rajesh, 2003, "Trends in tropical cyclone impact:: A study in Andhra Pradesh, India", *Bull. Amer. Meteor. Soc.*, **84**, 635-644.

damage values. This is consistent with similar studies of U.S., Caribbean, and Latin American hurricane impacts (Pielke and Landsea, 1998[23]; Pielke et al., 2003[24]) and highlights the key factors contributing to increased losses. Losses are largely attributed to societal factors elsewhere as well [25] [26] [27] [28]. The study could not be extended to other coastal states in India because reliable damage data is not available. There is however no reason to expect very different results in those states. Further increases in damage is expected from future tropical cyclones.

Funds directed by administrators towards disaster *preparedness* and *post-disaster relief* have also been examined. The figures for Andhra Pradesh (Source: Government of Andhra Pradesh) are as below.

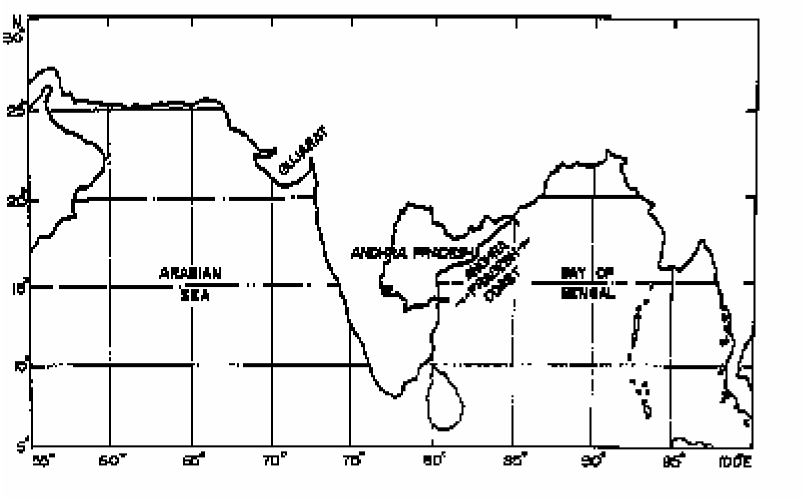

Fig. 5.2.1 Locator Map of Andhra Pradesh, India.

[23] Pielke, R. A. Jr., and C. W. Landsea, 1998, "Normalized hurricane damages in the United States: 1925–95", *Wea Forecasting,* **13**, 621-631.

[24] Pielke R.A. Jr., J. Rubiera; C. Landsea, M. L. Ferna´ndez, and R. Klein, 2003, "Hurricane Vulnerability in Latin America and The Caribbean: Normalized Damage and Loss Potentials", *Natural Hazards Review*, 101-114.

[25] Association of British Insurers (ABI) , 2005, "Financial risks of climate change", Summary Report, 40 pp., www.abi.org.uk

[26] R. Crompton, J. McAneney and R. Leigh, 2006, "Natural disaster losses and climate change: An Australian perspective", Climate change and disaster losses workshop, Hohenkammer, Germany, 25-26, May 2006, pp 36-44.

[27] Shi Jun, 2006, Climate change and disaster losses workshop, Hohenkammer, Germany, 25-26, May 2006, pp 118-120.

[28] http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/workshop_report.pdf

EXPENDITURE[29]	Indian Rupees Crore (Crore means 10^7)
Relief following an event (includes tropical cyclones, floods and droughts), from 1979-80 to 1999-2000.	**2781**
Estimated damage due to a single tropical cyclone in 1996	**6129**
Expenditure on preparedness	**Not available**
World Bank-aided Project (1990's), mostly dedicated to infrastructure development	**801**

Apart from the amount contributed under the World Bank project, the level of expenditure allocated to preparedness was not available. This shows that much more importance is placed on relief *after* the event rather than proactive preparedness *before* it. This attitude is understandable in the sociopolitical context and is not confined to Andhra Pradesh. One only has to draw a parallel to the level of preparedness in New Orleans, U.S., prior to Hurricane Katrina, despite elaborate plans being available.

Although in recent decades people in the region have become more aware of the need to be prepared for future tropical cyclones, there remains a "Fading Memory Syndrome" where the level of disaster preparedness diminishes in the absence of a recent event (of the order of a few years) impacting the area.[30] The phenomenal damage and deaths resulting from the "super cyclone" (defined as an event with maximum sustained surface wind in excess of 62 m s^{-1}) which struck the Indian State of Orissa with 72 m s^{-1} maximum sustained surface winds in October 1999, may be largely attributed to lack of preparedness.

b) Australia (prepared by R. Crompton)

The Insurance Council of Australia (ICA) Natural Disaster Event List is a comprehensive database of insured losses due to natural hazards. The Disaster List begins in 1967 and includes details of each event including date; areas affected; and total insured (industry) cost in "original" dollars. Unfortunately, no equivalent record of economic losses exists in Australia.

Factors contributing to losses over time need be considered when estimating the current loss that would be sustained if each event in the Disaster List were to reoccur today. By way of example, imagine a repeat of Tropical Cyclone Tracy, which destroyed the city of Darwin in the Northern Territory. Along with inflation, the population of Darwin has increased considerably since Tracy made landfall in 1974, as has the number of dwellings. There has also been an increase in both the average dwelling price and average wealth per person. Building standard amendments specifying more wind resistant construction designs were also introduced following Tracy and as a result of this, the general construction quality in Darwin (assuming the code has been enforced) will be higher today than in

[29] At present 45 Indian Rupees are equal to a U.S. Dollar but the exchange rate has varied considerably over the years. Hence conversion of the above figures to U.S. Dollars may be misleading.

[30] Raghavan S. and A. K. Sen Sarma, 2000: Tropical cyclone impacts in India and neighbourhood. *Storms,* Vol. 1, R. A. Pielke Sr. and R. A. Pielke Jr., Eds., Routledge , 339-356.

1974.

An indexation (normalization) methodology incorporating two surrogate factors to account for changes in population, inflation, and wealth since the date of the original event has been applied to event losses in the Disaster List (Crompton 2005)[31]. The approach is based on changes in both the number and nominal value of dwellings over time, where the nominal dwelling value excludes land value. These adjustments grow rapidly, for example, the nominal value of new dwellings in Australia increased by about a factor of 11 over the past 30 years.

Indexed tropical cyclone losses were further adjusted, where appropriate, to account for the greatly improved building standards in tropical cyclone-prone areas that occurred in the early 1980's (work in progress – upcoming publication by Ryan P. Crompton). As a result of the improved wind resistant design of housing, dramatic reductions in tropical cyclone-induced losses were observed following Tropical Cyclones Winifred (1986) and Aivu (1989) (Walker 1999)[32] and more recently, Larry (2006) (Guy Carpenter 2006; Boughton et al. 2006)[33,34].

Figures 5.2.2a and 5.2.2b show annual losses aggregated by original and current (2006) loss values for weather-related events in the Disaster List. When indexed, the time series of insured losses exhibit no obvious trend over time. Figures 2a and b show that the increasing trend in unadjusted losses is largely attributable to changes in the: number of dwellings; nominal values of dwellings; and building standards in tropical cyclone-prone regions. Annual losses have been calculated for seasons ending 30 June to take account of the seasonality of the main meteorological hazards. The analysis begins from the 1966 season (1966/67) and ends at the current 2005 season.

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[31] *Crompton, R.P. 2005. Indexing the Insurance Council of Australia Natural Disaster Event List. Report prepared for the Insurance Council of Australia, Risk Frontiers.*

[32] http://www.aon.com.au/pdf/reinsurance/Aon_Designing_Disasters.pdf

[33] *http://gcportal.guycarp.com/portal/extranet/popup/pdf/GCPub/Tropical%20Cyclone%20Larry%20051906.pdf?vid=1*

[34] http://www.abcb.gov.au//documents/General/CTS_summary_TCLarry.pdf

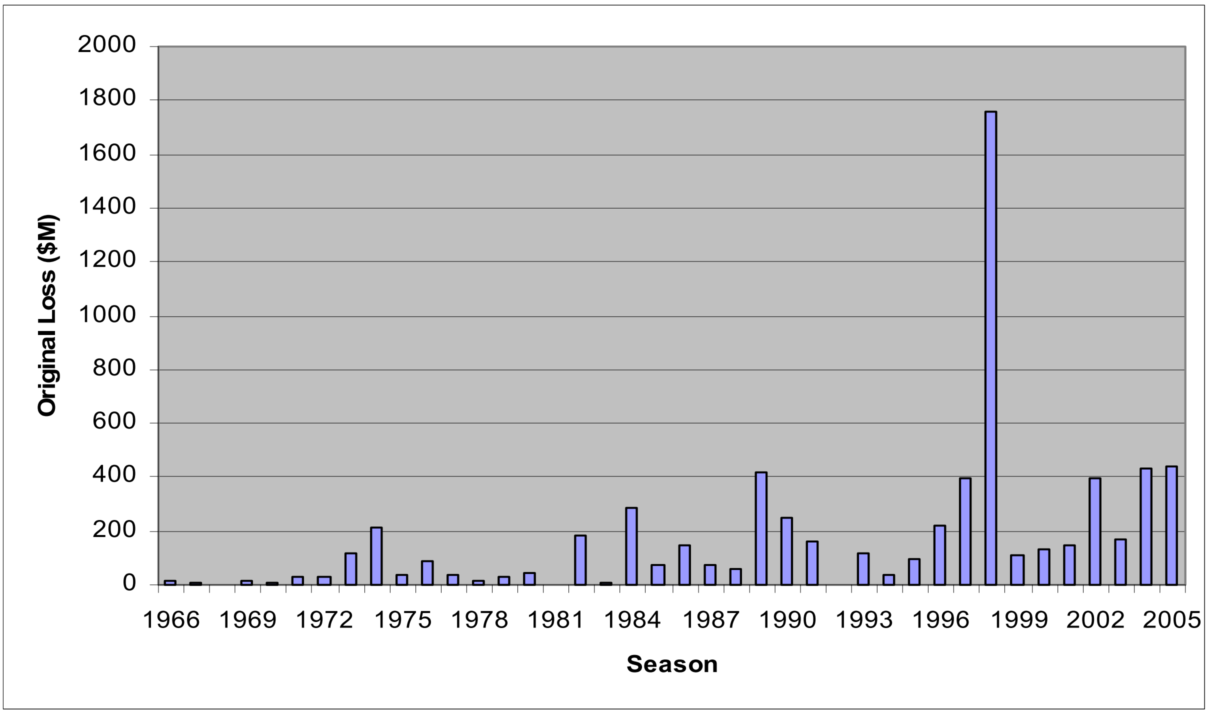

Figure 5.2.2a: Original annual aggregate insured losses ($M) for weather-related events in the Disaster List for 12-month seasons ending 30 June.

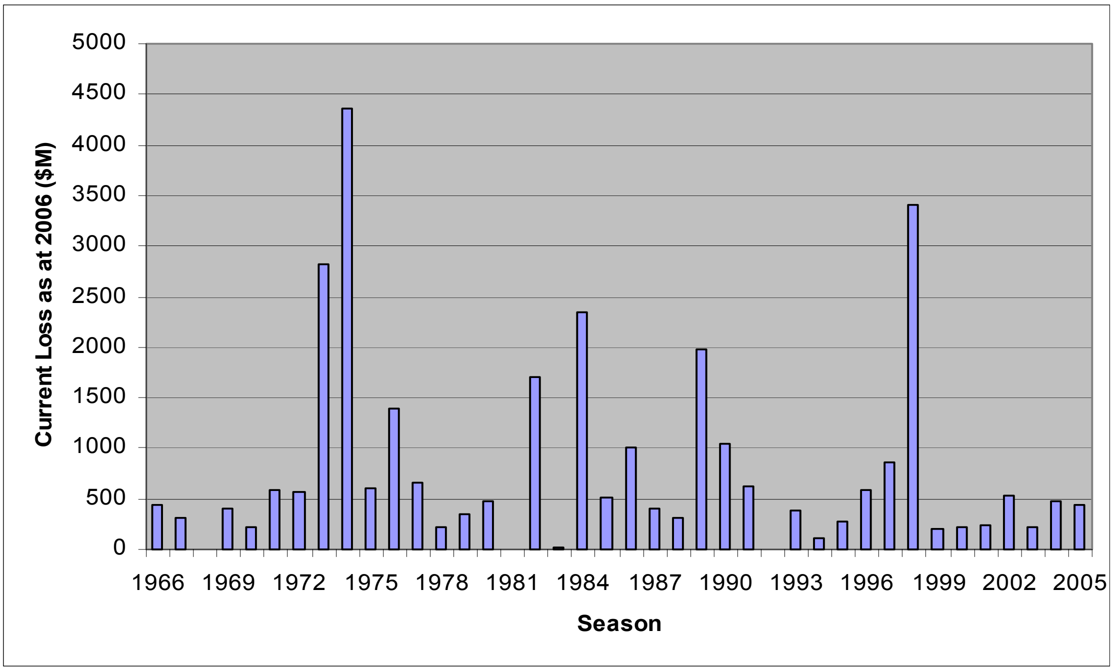

Figure 5.2.2b: As for (a) above but losses have been indexed to 2006 dollars. Tropical cyclone losses have been adjusted for changes in building standards.

While the indexation methodology does not incorporate every factor that may contribute to natural disaster losses, for example, how El Niño - Southern Oscillation (ENSO) affects tropical cyclone activity in the South-Western Pacific region, it does include the most significant ones. The importance of wind code adjustments in the Australian context should not be underestimated. For Tropical Cyclone Tracy, the indexed loss is halved after this is made, with a unique adjustment applied to each event.

Analysing the tropical cyclone losses in the Disaster List alone tells us little about factors contributing to losses owing to the limited number of losses resulting from Australia's sparsely populated tropical cyclone exposed coast. To explore tropical cyclones specifically, the focus is shifted to the time series of events that crossed the east coast of mainland Australia during the last 45 years. Only events having a central pressure less than or equal to 995hPa were included. The analysis begins from the 1961 season (1961/62) and ends at the current 2005 season.

Figure 5.2.3 shows successive five-season period frequencies of tropical cyclones that have crossed the east coast. Within each of the five-season periods there are different numbers of El Niño, La Niña, and neutral events. With the exception of 1971-75, there have been between two and four tropical cyclones for each period. It comes as no surprise that La Niña episodes dominated during this period.

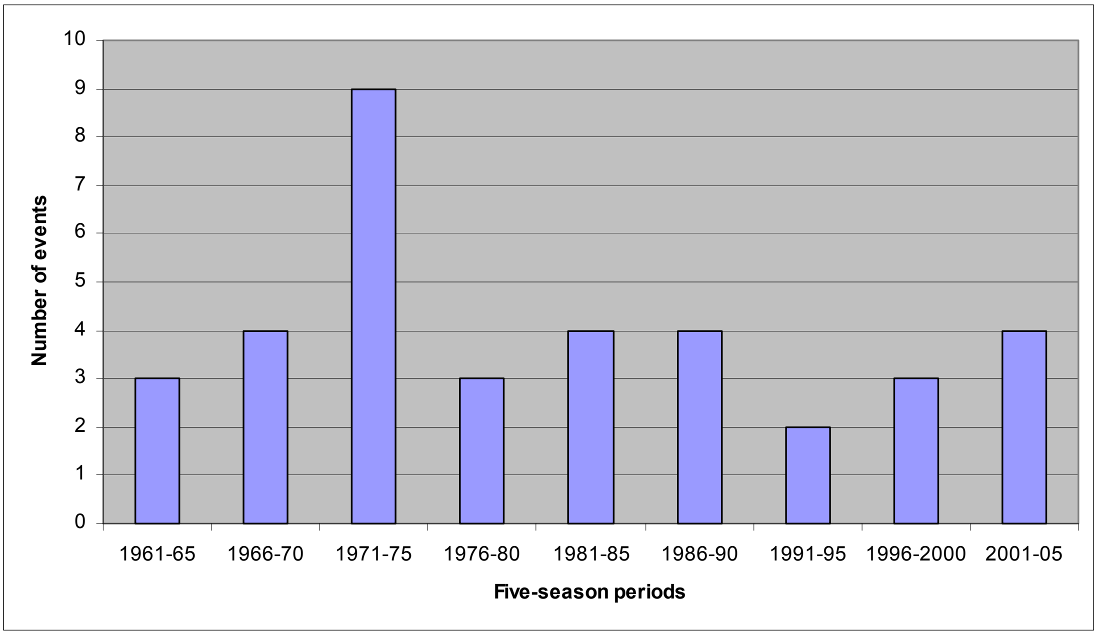

Figure 5.2.3: Number of tropical cyclones to cross the east coast during five-year periods.

Figure 5.2.3 only tells part of the story. Of more interest is the combination of frequency and intensity. According to Gray (2003)[35], when normalized for coastal population, inflation, and wealth per capita, tropical cyclone-spawned damage in the U.S. rises by a factor of four for each successive increase in Saffir-Simpson intensity category. Thus a landfalling Category-3 hurricane typically causes about four times the normalized damage of a Category-2 hurricane and so forth. Assuming that this same ratio between cyclone categories holds true for Australian conditions, Figure 5.2.4 takes this weighting into account. In calculating these figures, Category-5 and -4 events have each been assigned an equal weighting of 1/4; Category-3 a weighting of 1/16; Category-2 a value of 1/64 and Category-1 events 1/256. These are then summed for each 5-year period to obtain a relative potential destructiveness index.

By concentrating on the damage potential of the hazard alone, Figure 5.2.4 assumes a uniform portfolio of assets at risk. It also allows for Australia's low population density and the large physical distances between population centres on the exposed east coast. Actual damage arising from individual tropical cyclones will vary widely as a result of differences in population, terrain, topography, proportions of construction conforming to improved (wind loading) building standards, wealth per capita, direction and forward speed of the tropical cyclone, storm surge, and rainfall.

Again we see no obvious change (increase or decrease) in the potential destructiveness over the time periods represented in Figure 5.2.4. Figures 5.2.3 and 5.2.4 focus on the east coast because this is where most of the exposure is located; however, similar results hold for the western and north coasts of Australia or for the entire coastline. Nonetheless we do acknowledge that the small number of cyclones per five–year time interval makes it difficult to draw very robust conclusions.

[35] Gray, W.M. 2003: Twentieth century challenges and milestones, In Hurricane! Coping with Disaster edited by Robert Simpson, American Geophysical Union, Washington DC 2003.

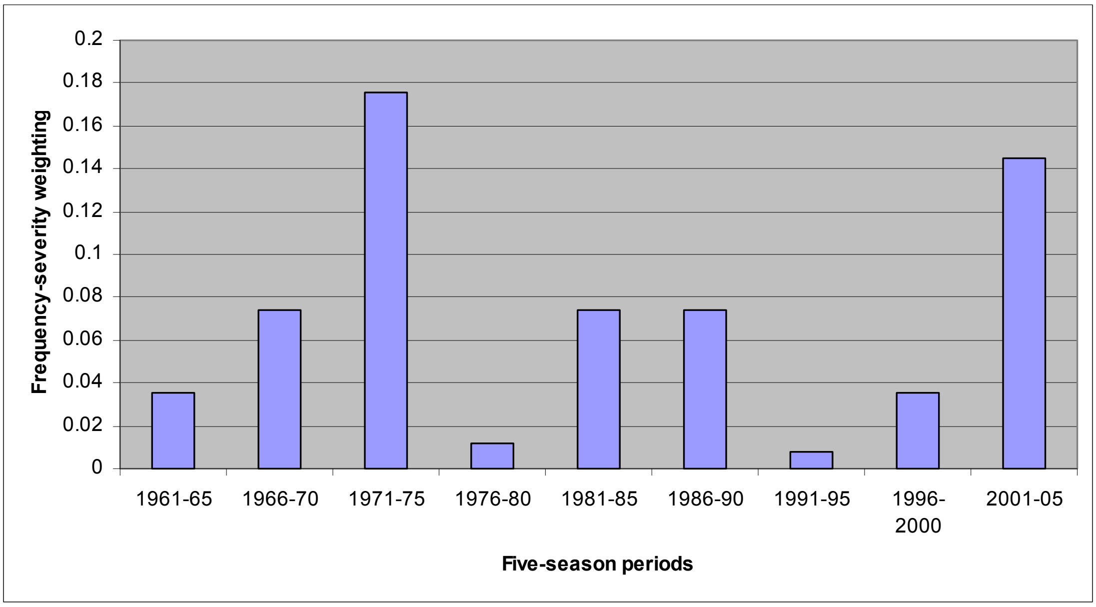

Figure 5.2.4: Combined frequency-severity of tropical cyclones that have crossed the east coast of Australia during five-year periods.

c) United States (prepared by R. Pielke, Jr., J. Gratz, and E. Faust)

Consider economic damage (adjusted for inflation) related to hurricane landfalls in the United States, 1900–2005, as shown in Figure 5.2.5. Although damage is growing in both frequency and intensity, this trend does not reflect increased frequency or strength of hurricanes. In fact, while hurricane frequencies have varied a great deal over the past 100+ years, they have not increased in recent decades in parallel with increasing damages. To the contrary, although damage increased during the 1970s and 1980s, hurricane activity was considerably lower than in previous decades.

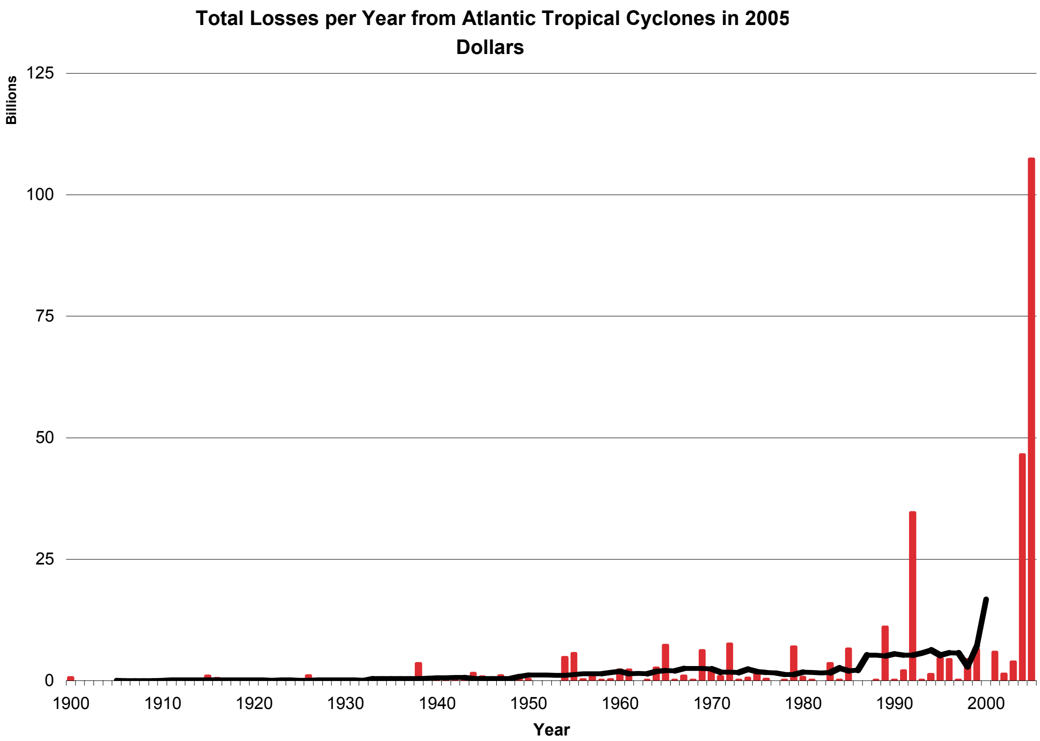

Figure 5.2.5. Trend in U.S. hurricane damage, 1900-2005. Source: NOAA/NHC

To explain the increase in damage, it is therefore necessary to consider factors other than variability or change in climate. Society has changed enormously during the past century and coastal development has taken pace at an incredible pace.

Given the significance of societal change in trends of hurricane damage, one way to present a more accurate perspective on such trends is to consider how past storms would affect present society. We developed a methodology for "normalizing" past hurricane damage to present day values (using wealth, population, and inflation).[36] Figures 5.2.6a and 5.2.6b shows the historical losses of Figure 5.2.5 normalized to 2005 values. The normalized record shows that the impacts of Hurricane Andrew, at close to $53 billion (2005 values) (unpublished analysis by author, updated from Pielke and Landsea, 1998), would have been far surpassed by the Galveston, TX hurricane of 1900 which would have caused an estimated $159.8 billion damage or the Great Miami Hurricane of 1926, which would have caused an estimated $148.1 billion damage (preliminary estimate, work in progress) had it occurred in 2005, exceeding similarly accounted costs of Katrina. We can have some confidence that the normalized loss record accounts for societal changes because, unlike the unadjusted data, the adjusted damage data accurately reflect well-understood patterns of climate variability, such as the signal of El Niño and La Niña in hurricane frequencies.[37]

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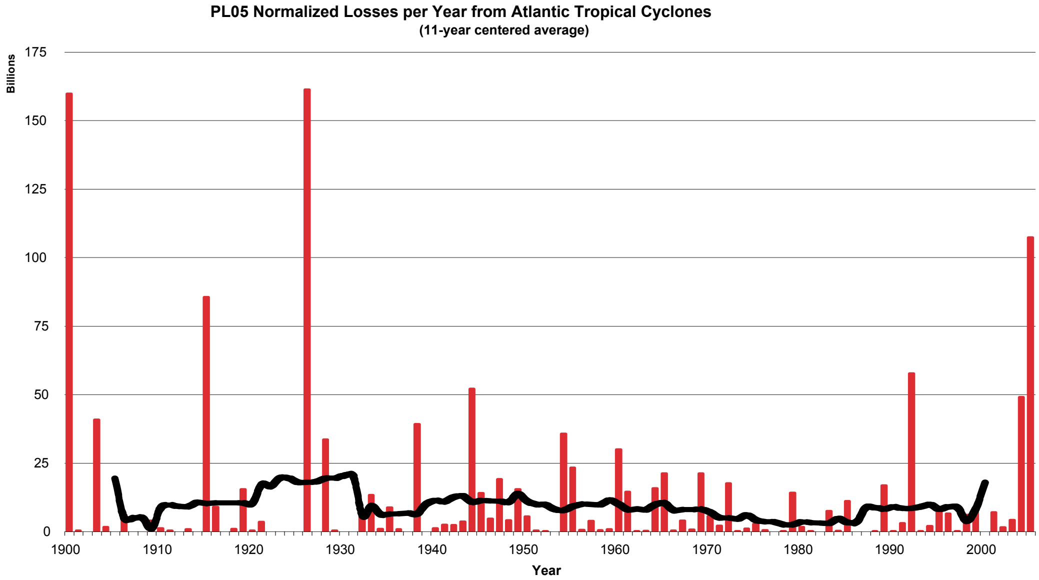
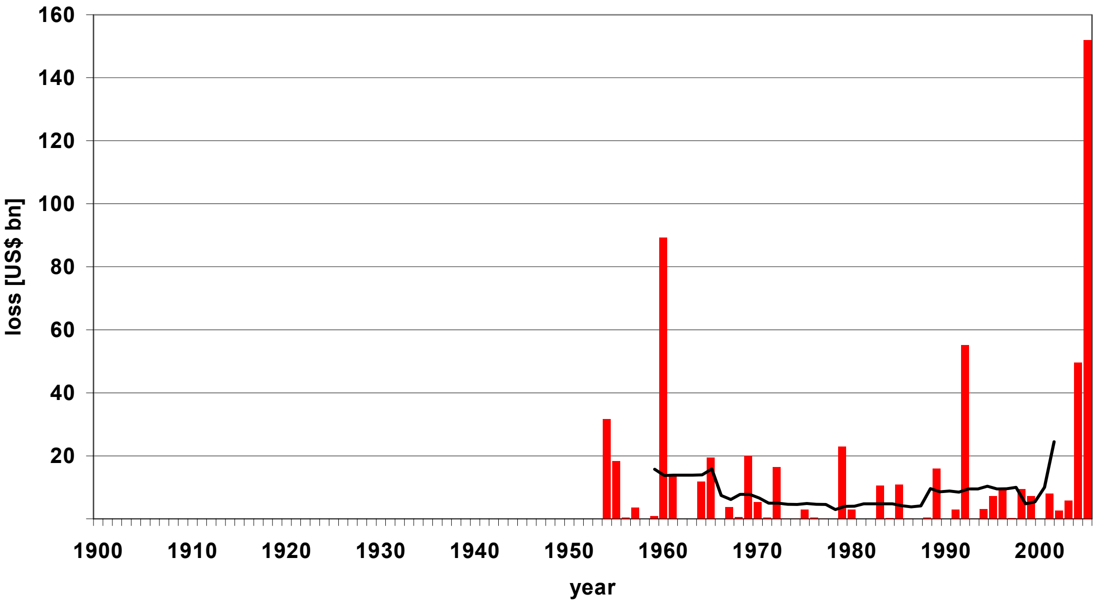
[36] Pielke, Jr., R. A. and C. W. Landsea, 1998. Normalized Hurricane Damages in the United States: 1925-95. Weather and Forecasting, American Meteorological Society, Vol. 13, 621-631. http://sciencepolicy.colorado.edu/admin/publication_files/resource-168-1998.11.pdf

[37] Katz, R.W., 2002. Stochastic modeling of hurricane damage. Journal of Applied Meteorology, 41:754-762. http://www.isse.ucar.edu/HP_rick/pdf/damage.pdf

Figure 5.2.6b shows the historical losses from Munich Re's database since 1954 normalized by the Pielke/Landsea methodology to 2005 values. In most of these years – with the exception of 1960, 1979 and 2005 – the differences are not large. In particular for hurricane Donna in 1960 Munich Re provides a historical loss estimate of US$1,250 m compared to US$397 m in the NHC data. Equally for 2005 Munich Re has some US$ 125 bn for economic losses of Katrina only instead of US$107 Billion in the NHC dataset, which accounts for the 2005 difference.





Figures 5.2.6a, 5.2.6b: The upper graphic (6A) displays estimated hurricane damages 1900-2005 if storms of the past made landfall with coastal development of 2005. A filtered curve is given by the black solid line. Source: Roger A. Pielke, Jr., work in progress. The bottom graphic (6B) displays the same calculated from Munich Re's base loss data (1954 – 2005). The black solid line shows a 10-year running mean. Source: Munich Re 2006.

5.2.4: Differing views of the role of global warming on losses

As indicated in the above case studies, in many locations around the world, especially in the Atlantic basin, economic losses from tropical cyclones has increased dramatically in recent decades even after accounting for the effects of inflation. This has led to some discussion of the relative role of changes in storms themselves in the context of rapid growth in wealth and population in locations exposed to tropical cyclone risks. While this subject will no doubt be covered in greater depth in other parts of the IWTC, we though it important to include a brief discussion of the subject as related to losses.

Research on tropical cyclones has advanced rapidly since the last IPCC assessment. In 2005 Massachusetts Institute of Technology's Kerry Emanuel published a study in the journal Nature that described an increase in the intensity of hurricanes in the North Atlantic and North Pacific.[38] Another prominent study by Webster et al. has found an increase in the proportion of the strongest storms since 1970.[39] These two papers, published in the midst of a record Atlantic hurricane season in terms of both activity and damages have prompted much discussion about trends in tropical cyclone behavior. Both the Emanuel and Webster et al. papers have prompted a vigorous discussion with responses to each subsequently published by Landsea[40] and Chan[41], respectively.

A vigorous debate continues within the community about the trends themselves. Support for the findings of Emanuel and Webster et al. a study of globally integrated power dissipation of TCs based on reanalysis data.[42] In contrast, a paper in *Geophysical Research Letters* in May, 2006 which find no trends in global tropical cyclone intensity from 1986-2005, with the exception of a dramatic increase in intense storms in the Atlantic Basin.[43] Its author concludes,

> These findings indicate that there has been very little trend in global tropical cyclone activity over the past twenty years, and therefore, that a large portion of the dramatic increasing trend found by Webster et al. [2005] and Emanuel [2005] is likely due to the diminished quality of the datasets before the middle 1980s. One would expect that if the results of Webster et al. and Emanuel were accurate reflections of what is going on in the climate system, than a similar trend would be found over the past twenty years, especially since SSTs have warmed considerably (about 0.2°C – 0.4°C) during this time period.[44]

Given these various results, a position paper by the World Meteorological Organization's Commission on Atmospheric Sciences, its Tropical Meteorology Research Program Panel (whose authorship included Emanuel, Holland, Knutson, Landsea, among other prominent scientists) concluded:

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[38] Emanuel, K. 2005. Increasing destructiveness of tropical cyclones over the past 30 years. Nature 436:686-688.

[39] Webster, P.J., G.J. Holland, J.A. Curry, and H.R. Chang. 2005. Changes in tropical cyclone number, duration, and intensity in a warming Environment. Science 309:1844-1846.

[40] Landsea, C. W., 2005. Hurricanes and global warming, Nature, 438:E11-13. http://www.aoml.noaa.gov/hrd/Landsea/landseanaturepublished.pdf

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[43] http://tropical.atmos.colostate.edu/Includes/Documents/Publications/klotzbach2006.pdf

[44] http://tropical.atmos.colostate.edu/Includes/Documents/Publications/klotzbach2006_talkingpoints.pdf

> The research issues discussed here are in a fluid state and are the subject of much current investigation. Given time the problem of causes and attribution of the events of 2004-2005 will be discussed and argued in the refereed scientific literature. Prior to this happening it is not possible to make any authoritative comment.[45]

However, it seems reasonable to conclude that, at the present time, while detection of trends in tropical cyclone behavior may yet achieve a scientific consensus, attribution of such trends to human causes remains to be settled in the scientific literature. This area of science is undergoing rapid change as new research results are published, so it may be that detection and attribution will soon be unambiguously achieved. But until that occurs claims of definitive detection and attribution are premature, and thus so too would be any definitive link between trends in damage and human effects on tropical cyclones.

Even with the unsettled state of the science, differences exist in how to interpret recent loss trends, even among the contributors to this report. The below subsections provide two different perspectives on the role that global warming may have on recent loss trends in the United States.

Perspective #1: Little evidence for global warming effects on losses (prepared by R. Pielke, Jr.)

It is tempting to look at aggregate loss data and conclude that higher August, September, October (ASO) SSTs cause increased U.S. damage. For instance, for the period 1950-2005[46] the top 19 warmest SST years have an average of $12.5B in damage, the next 19 have an average of $9.0 billion, and the next 18 have an average of $6.3 billion. But this pattern depends entirely upon the influence of the large losses of 2005. Through 2004 the results of such a binning are $7.2B, 9.0B, and 6.3B respectively. The nature of loss data, and its highly skewed distribution in particular, makes analyses with untransformed data problematic when seeking to establish robust statistical relationships. The Spearman (rank) correlation coefficient between ASO SSTs and damage 1950-2005 is low at 0.098.

Figures 5.2.7a and 5.2.7b shows the lack of meaningful relationship between normalized U.S. hurricane damages (NHC data, transformed with the natural log) and North Atlantic sea surface temperatures 1950-2005 and 1950-2004.[47] The r-squared values are low with or without 2005 included, and the regression results are not statistically significant ($p = 0.28$ and 0.69 respectively). There is consequently no systematic evidence that higher SSTs are systematically associated with larger losses.

One reason for the lack of a significant relationship is that any signal that exists between SSTs and hurricane behavior is lost in the randomness of each relationship in the sequence of:

ΔBasin SSTs → ΔBasin PDI →ΔLandfall PDI →ΔEconomic damage[48]

So while there is undoubtedly a relationship between SSTs and hurricane activity, it may nonetheless be difficult to observe any relationship between trends in SST, trends in hurricane behavior, and trends

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45 http://www.bom.gov.au/info/CAS-statement.pdf

46 We use this period because it avoids many years pre-1950 in which there were no recorded damages. This is due to the lack of development on the coast, rather than a lack of hurricanes. Such non-damage years skew the analysis. If one looks only at years in which damage occurred then the relationships for 1950-2005 hold in the earlier period.

47 http://www.cpc.noaa.gov/data/indices/sstoi.atl.indices

48 Thanks to Kerry Emanuel for proposing this explanation.

in economic damage data.

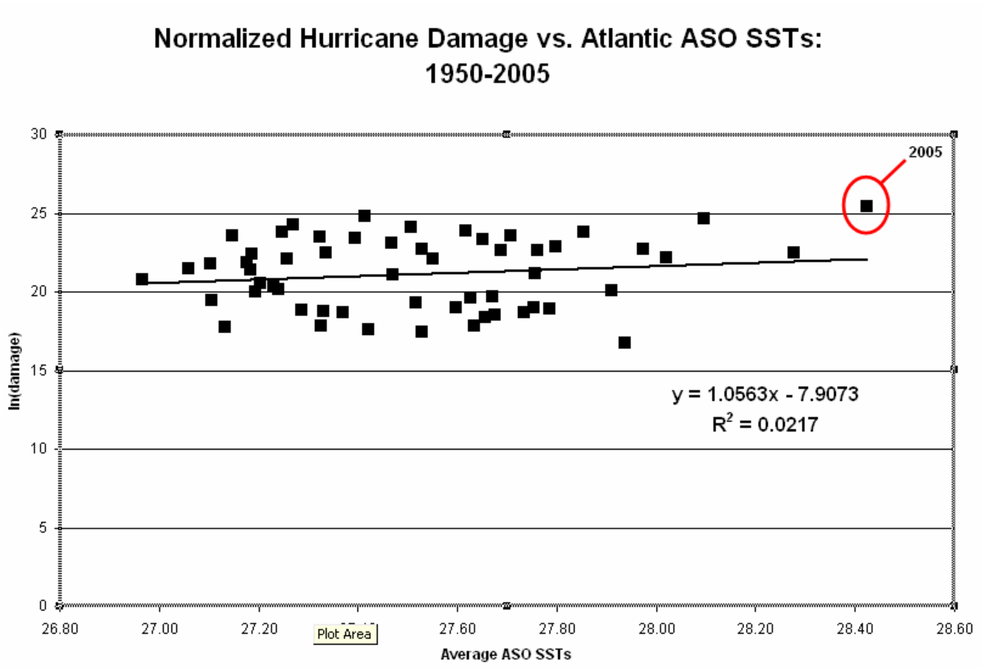
In the loss vs. SST data, 2005 clearly stands out as an outlier from the rest of the dataset. Expectations that future hurricane seasons will look more like 2005 rather than the rest of the dataset may turn out to be correct, but such expectations are not supported by the historical record of the relationship of SSTs and damage. Consequently, it is premature to attribute any part of the historical trend in losses to global warming, though such a connection may be made in the future. As the Hohenkammer Workshop concluded:

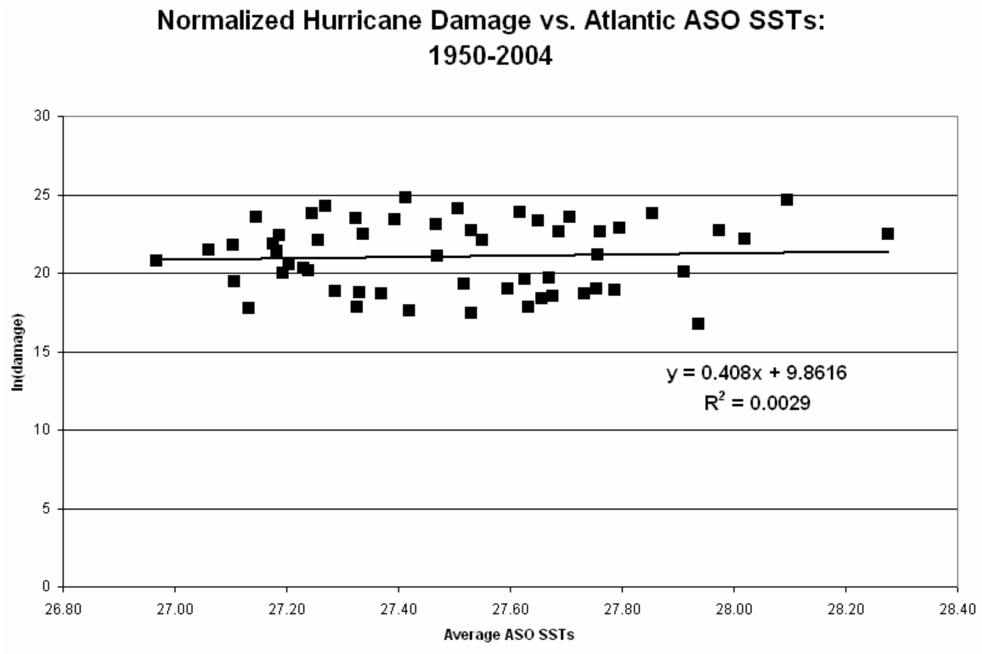
> Because of issues related to data quality, the stochastic nature of extreme event impacts, length of time series, and various societal factors present in the disaster loss record, it is still not possible to determine the portion of the increase in damages that might be attributed to climate change due to GHG emissions.[49]

[49] http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/workshop_report.pdf

Figure 5.2.7a and 5.2.7b. Damage versus August, September, October (ASO) North Atlantic SSTs. 1950-2005 (a) and 1950-2004 (b), R. Pielke, Jr.

(a)





(b)

Perspective #2: Remarkable evidence for global warming effects on losses (prepared by E. Faust)

The running means in Figures 5.2.6a and 5.2.6b show no obvious longitudinal trend in losses related to tropical cyclones, even with the extreme losses of 2004 and 2005. But if analyzed more closely, the normalized loss data show nonetheless systematic changes over time. Fundamental to these changes is the presence of a correlation between normalized annual losses and June-October annual tropical sea surface temperatures. Munich Re analyzed the respective annual SST anomalies and annual normalized losses since 1900. Figure 5.2.8 simply displays the normalized losses against the SST anomalies. Also, the average loss calculated for a running window of 0.2°C in width is displayed (red line). The running average is shown over a range where the 0.2°C windows are populated densely enough (at least 12 data points, i.e. half the maximum population, see the dashed black line). A remarkable general increase in average annual normalized losses with increasing SST can be observed over the -0.4°C to +0.4°C anomaly range. Spearman's rank correlation coefficient, which is independent of the distributions involved, gives 0.26 for the range from -0.4°C to +0.4°C and 0.28 for all of the data. This positive correlation prompted further analysis. In order to perform a regression analysis on the data we need to transform the loss data, which are heavily skewed (skewness of 4.03), into a Gaussian distribution. This was done by applying the natural logarithm and cutting the data at the smallest positive loss – thereby excluding all years with zero losses from the distribution (including them would have retained the strong skewness). The result of the regression analysis is displayed in Figure 5.2.9, which depicts an increase in losses with SST – with a strong scatter of data, as has to be expected, and therefore only a small R-square. The slope of the regression line is approx. retained if the high LN-value for 2005 is excluded from the data (the slope changes from +0.14 to +0.11) – but this need not be done because the data conform to a Gaussian-like distribution. The scatter is accounted for by a strong year-to-year variability in the ratio of landfalling storms to basin-wide storms, by varying landfall locations and loss amounts, and by effects of natural climate variability like ENSO: El Nino episodes would weaken hurricane activity regardless of SSTs in the Atlantic, La Nina episodes would have the opposite effect. It should be remembered that years with zero losses are excluded from the data in Figure 5.2.9 in order to achieve an un-skewed distribution. Hence, considering the fact that the percentage of years with zero losses in the cold half of the SST spectrum (21%) is more than double the percentage in the warm half (9.1%) (13 zero years in the cold half of the SSTA range from -0.68°C to +0.11°C in 62 years versus only 4 zero years in the warm half from +0.11°C to +0.91°C in 44 years), it turns out that the increase in losses with SST is even larger – as depicted by the reduced data in the scatter plot of Figure 5.2.9. Taken together with arguments and observations from meteorology –warmer oceans foster more intense and, in the North Atlantic, more frequent storms in the long term – the possibility cannot be ruled out that tropical SSTs act as an additional driver for increasing losses besides changing societal exposures and vulnerabilities.

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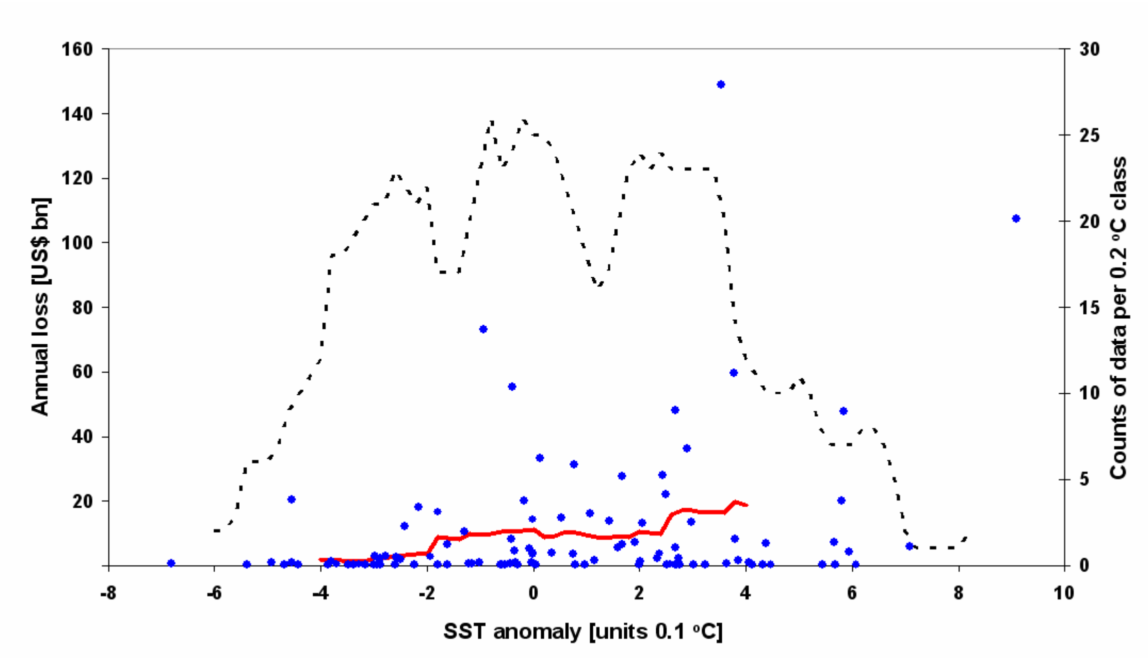

Figure 5.2.8 Mean annual normalized US hurricane losses per SST anomaly (blue points, projecting on left-hand axis) (Hadley Centre data set for 10°N–20°N, east of 80°W). Red curve indicates the annual loss average calculated over a running window of 0.2°C in width (projecting on left-hand axis); dashed black line displays the count of data points per running 0.2°C window (projecting on right-hand axis). For a more detailed explanation, see the text. Source: Munich Re 2006, work in progress.

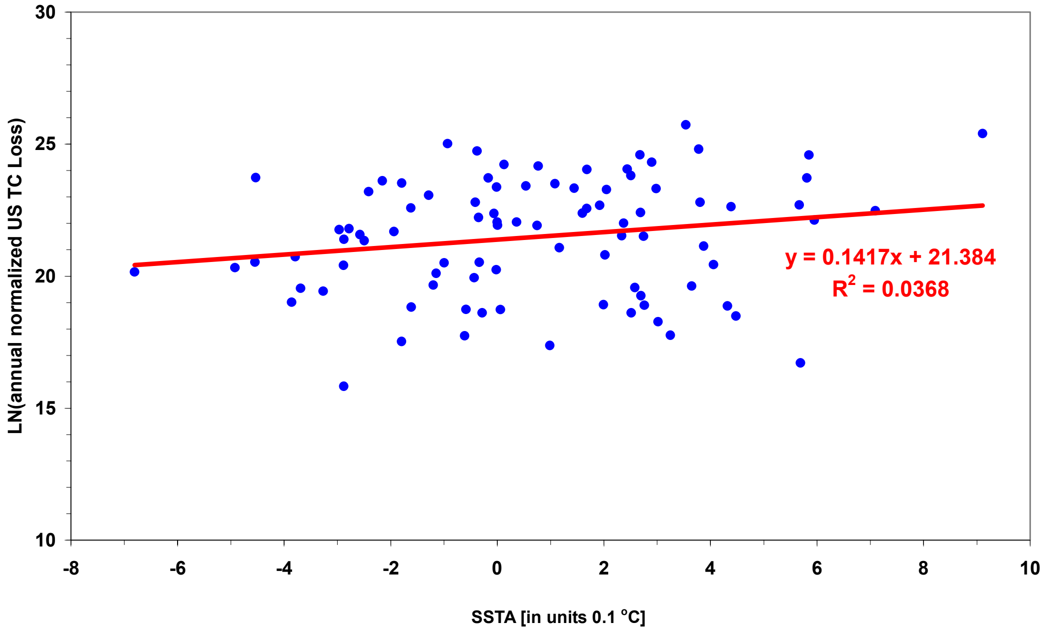

Figure 5.2.9 Natural logarithm of annual normalized US hurricane losses since 1900 versus SST anomalies of the tropical North Atlantic (Hadley Centre data set for 10°N–20°N, east of 80°W). Years without any losses were omitted in order to obtain an un-skewed Gaussian distribution by logarithmic transformation, which is a precondition for performing a linear regression analysis. Source: Munich Re 2006, work in progress.

Even using the much shorter CPC SST time series, which covers only the years from 1950 onward, results in almost the same increasing slope of the regression line. Transforming the normalized losses by applying the natural logarithm in the original data yeilds a Gaussian-like distributed data and a positive slope of the regression line (Figure 5.2.10). We get almost the same slope (0.13 vs. 0.14) and the same small order of R-square as with the SST data since 1900. So making use of the shorter CPC SST time series (from 1950 onward) produces results which are quite consistent with those using the longer time series of SSTs from the Hadley Centre.

warm phase (n = 56 years)		
mean US$ 13.1 bn	median US$ 3.9 bn	std dev US$ 25.7 bn

cold phase (n = 47 years)		
mean US$ 5.1 bn	median US$ 0.5 bn	std dev US$ 12.2 bn

U-test acc. to WILCOXON/MANN/WHITNEY:
both loss-frequency distributions and respective median values are different in a statistically significant way ($\alpha = 1\%$).
($\zeta = 2,93 > z_{\alpha=1\%} = 2,33$)

Table
Properties of loss-frequency distributions of annual losses from warm and cold phase years.

Data base: Pielke/Landsea normalized US TC losses. Source: Munich Re 2006, work in progress.

	cold phase years	**warm phase years**
> US$ 1 bn	19 (of 47) 40%	36 (of 56) 64%
> US$ 5 bn	10 (of 47) 21%	26 (of 56) 46%
> US$ 10 bn	8 (of 47) 17%	17 (of 56) 30%

Table
Percentages of years exceeding specified annual loss thresholds in warm and cold phases of the 20th century.

Data base: Pielke/Landsea normalized US TC losses. Source: Munich Re 2006, work in progress.

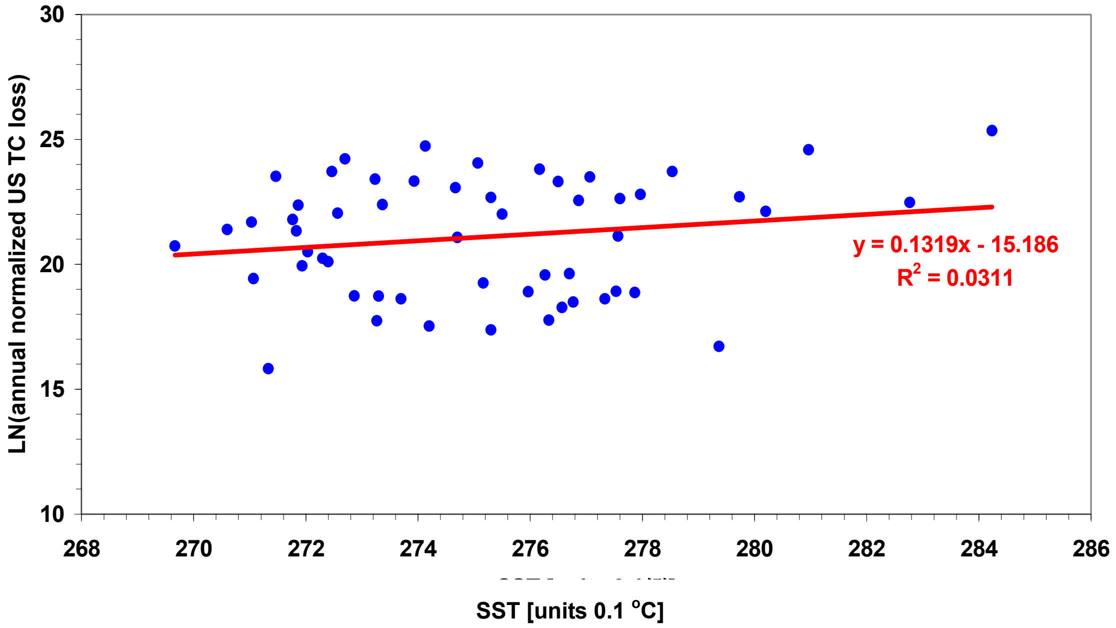

Figure 5.2.10 Natural logarithm of annual normalized US hurricane losses since 1950 versus SST anomalies of the North Atlantic (CPC ASO SSTs). The year 1958 without any loss is omitted in order to obtain an un-skewed approx. Gaussian distribution by logarithmic transformation, which is a precondition for performing a linear regression analysis. Source: Munich Re 2006, work in progress.

By analyzing the SSTs of the tropical North Atlantic phases of – on average – warmer (1926–1970; 1995–today) and cooler water temperatures (1903–1925; 1971–1994) can be identified. Given the demonstrated correlation of mean annual US losses and tropical cyclones on SSTs in the tropical North Atlantic, these SST phases should project on phases of different loss frequency distributions over the respective phases, which in turn materialize in differing distribution means. In order to check this hypothesis, a comparison of the frequency distributions of normalized annual TC losses in the warm phase years and the cold phase years of the 20th century was performed. The analysis assumes loss data covering all of the 20th century, so that normalized NHC data were chosen. As a result, median and mean values are much higher in the warm phase distribution, and these distributions and the respective medians are different in a statistically significant way (α = 1 %; the WILCOXON-MANN-WHITNEY test was chosen which has no requirements regarding data distribution). In addition one can find that the percentage of years exceeding specified loss thresholds – US$ 1bn, 5bn and 10bn – is much higher in warm phases than in cold phases.

So even if there is no year-to-year increase in loss amount in the normalized data, there is a shift in terms of the loss distributions accompanying periods of cooler and warmer tropical waters. As seen before the percentage of years with zero losses in the cold half of the SST spectrum (21%) is more than double the percentage in the warm half (9.1%) – it seems more likely to have years with no losses while SSTs are cooler than on average. We found a general increase in mean annual normalized TC losses with increasing SSTs as visualized by the running mean in Figure 5.2.8 (rank correlation coefficient of 0.3) and the linear regression analysis identified positive correlations of SSTAs (Hadley Centre and CPC data) and logarithmically transformed US normalized TC losses. Admittedly the data scatter is quite substantial resulting in small R-square, but this has to be expected. Taken together with climatological evidence on changing intensities/frequencies of TCs with changing SST in the tropical North Atlantic, our findings are in line with conclusion no. 10 of the Hohenkammer Workshop:

> There is evidence that changing patterns of extreme events are drivers for recent increases in global losses.[50]

Hence, the conclusion cannot be ruled out that if the increases in tropical Atlantic SSTs were to continue in the long term due to anthropogenic climate change[51], we would have to expect a shift towards hurricane loss distributions with ever increasing high-loss portions. This would be an additional case of increase besides the strong impact of increasing exposures and vulnerabilities on increasing losses due to societal changes over time.

[50] http://sciencepolicy.colorado.edu/sparc/research/projects/extreme_events/munich_workshop/workshop_report.pdf

[51] Barnett, T. P. et al. (2005), A Warning from Warmer Oceans, Science 309, S. 284-287