Normalized Hurricane Damages in the United States: 1900-2005

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Abstract

After more than two decades of relatively little Atlantic hurricane activity the past decade has seen heightened hurricane activity and more than $150 billion of dollars in damage in 2004 and 2005. This paper normalizes U.S. hurricane damage from 1900-2005 to 2005 values using two methodologies. A normalization provides an estimate of the damage that would occur if storms from the past made landfall under another year's societal conditions. Our methods use changes in inflation and wealth at the national level and changes in population and housing units at the coastal county level. Across both normalization methods, there is no remaining trend of increasing absolute damage in the dataset, although 2004 and 2005 are large loss years. The 1970s and 1980s were notable because of the extreme low amounts of damage compared to other decades. The decade 1996-2005 has the second most damage among the past 11 decades with only the decade 1926-1935 surpassing its costs. Over the 106 years of record, the average annual normalized damage in the continental United States is about $10-11 billion. The most damaging single storm is the 1926 Great Miami storm with $140-157 billion of normalized damage. The most damaging years are 1926 and 2005. Of the total damage, about 85% is accounted for by the intense hurricanes (Saffir–Simpson categories 3, 4, and 5), yet these have comprised only 24% of the U.S. landfalling tropical cyclones. Unless action is taken to address the growing concentration of people and properties (such as by strengthening the ability of buildings to withstand storms) in coastal areas where hurricanes strike, damage will increase, and by a great deal, as more and wealthier people increasingly inhabit these coastal locations.

Introduction

In the aftermath of Hurricane Katrina's devastating economic and human toll along the United States Gulf coast, renewed scientific and policy attention has focused on hurricanes and their impacts. This paper updates and extends work first presented by Pielke and Landsea (1998) and Collins and Lowe (2001) to provide estimates of the economic damage that past storms would have had under contemporary levels of population and development. The results presented here reinforce the conclusions of the earlier studies and illustrate clearly the effects of the tremendous pace of growth in societal vulnerability to hurricane impacts. Such growth in vulnerability is expected to continue for the foreseeable future, in the U.S. and around the world, and without effective disaster mitigation efforts, ever escalating hurricane damage will be the inevitable result.

The paper is organized into four sections: Part one describes the damage data that are used in the analysis, their origins and uncertainties. Part two describes the two normalization methodologies. Part three discusses the results of the normalizations. Part four discussed the significance of the findings and concludes the paper.

Data

This study focuses on total *economic* damage related to hurricane landfalls along the United States Gulf and Atlantic coasts from 1900 to 2005. Economic damage is defined as the direct losses associated with a hurricane's impact as determined in the weeks (and sometimes months) after the event (cf. Changnon 1996). Indirect damage and longer-

term macro-economic effects are not considered in this analysis. Different methods exist for calculating a disaster's impacts in which lead to correspondingly different loss estimates for the same event. Our focus is on utilizing a consistent approach over time that allows for a meaningful normalization methodology and results that are "apples to apples."

This paper builds upon work published originally by Pielke and Landsea (1998) which utilized historical economic damage compiled originally by Landsea (1991) from the Monthly Weather Review annual hurricane summaries and more recently the storm summary data archived on the National Hurricane Center (NHC) website (National Hurricane Center 2006a). We use loss data from Pielke and Landsea (1998) extended using NHC loss estimates for 1900-1924 and 1998-2005 contained in their storm summaries (National Hurricane Center 2006b). The original loss data are reported in current-year dollars, meaning that damage estimates are presented in dollars of the year of hurricane landfall.

Although this study uses *economic* loss figures as opposed to *insured* losses, official estimates of economic damage have been in part dependent on insured figures since about 1987. Edward Rappaport, Deputy Director of the National Hurricane Center, said in an email that ever since he came to NHC in 1987, the center has in many cases worked from a doubling of insured loss estimates to arrive at their estimate of economic damage (E. Rapaport, personal communication, November 8, 2005). Although this practice could have started earlier than 1987, this year is the earliest reference we have for the practice.

Our examination of the relationship of insured damages with official NHC totals since 1987 indicate that this practice is more of a guideline that is often modified on a storm-by-storm basis, rather than a formulaic application (cf. the comparison of insured and total losses reported in Pielke et al. 1999).   It should be expected that the relationship of economic and insured damages would vary, depending on the extent of flooding (which is an excluded peril on many insurance policies) and damages to infrastructure and uninsured properties in each storm.

Because damage normalization is a function of the original damage estimate, systematic biases in damage collection would be problematic. We find no evidence of such biases in the NHC damage dataset, with one exception. Before 1940 there were 32 storms that made landfall with no reported damages in the official government damage dataset. Only 8 such storms occur since 1940. Given current levels of coastal development, it is implausible that any hurricane could make landfall today and cause no damage. Hence, prior to 1940 there is an undercount of damaging storms.[7] In principle, one could substitute estimates for the zero-loss storms based on, for example, the relationship

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[7] The damage in the historical database includes seven storms with extensive inland flood damages (Agnes, 1972; Alberto, 1994; Diane, 1955; Doria, 1971; Eloise, 1975; Floyd, 1999; Frances, 1998). Due to the practical difficulties of distinguishing flood damages from non-flood damages, we have included them in our analysis as reported by the U.S. government. As a consequence, because the flooding from these storms includes a much wider area than just a few coastal counties affected at landfall, the population and housing unit multipliers were expanded to consider the entire state(s) affected by each storm. In each case this has the effect of maintaining or reducing the normalized adjustment, as population and housing growth has generally been more rapid along the desirable coastal counties than averaged for an entire state. In any case, the inclusion of flood damage associated with these seven storms is not a significant factor in interpreting the results of the analysis.

between storm intensity and population of affected counties documented for comparable storms in the dataset.[8] Our results do not include such estimates.

There are of course uncertainties in damage estimates. Some insight on such uncertainties in disaster estimates is provided by Downton and Pielke (2005) and Downton et al. (2005) which discuss the collection of and errors in the U.S. National Weather Service's flood damage database, which is kept separately from the hurricane loss record. The historical record of flood damage is relevant because it is collected and reported in the same manner as is hurricane damage and by the same government agency. Downton and Pielke (2005) found that for the largest floods (i.e., inflation adjusted to $500 million in 1995 dollars) independent estimates (e.g., between states and the federal government, over various time periods) of damage for the same event differed by as much as 40%.[9] However, Downton et al. (2005) suggested that the long-term record of flood damage is of sufficient quality to serve as the basis for long-term trend analysis as there was no evidence of systematic biases over time. Thus, we conclude that there are likely to be large uncertainties in the loss estimates for individual storms, but there is no evidence of a systematic bias in loss through the dataset. For instance, normalized damage by storm Saffir/Simpson category over the entire period of the two normalized datasets indicates no evidence of trends in damage as a function of time, which would be expected if there was a significant bias, e.g., in reporting practices, in the dataset.

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[8] Such an approach was used by Collins and Lowe (2001). Table 6 breaks out damages by storm category and population of affected counties.

[9] The 40% maximum difference refers to events with more than $500 million in damage. Because landfalling hurricanes are relatively rare (as compared to floods) it is reasonable to expect that damage collection would be of similar quality to those observed in major flood events.

It is also important to mention the uncertainties in the normalized losses that arise from assumptions in the normalization schemes themselves. Both normalization methods described in this paper - Pielke/Landsea and Collins/Lowe - rely on national wealth data which has been collected systematically by the U.S. government since 1925. We extrapolate this dataset back to 1900 to generate estimates of wealth prior to 1925. Varying the assumptions underlying this extrapolation will have a large effect on pre-1925 normalized losses. Similarly, the Collins/Lowe methodology requires an assumption-based extrapolation of county-level housing units prior to 1940. We therefore recommend that any analysis that uses the Pielke/Landsea normalized loss estimates prior to 1925 and the Collins/Lowe normalized loss estimates prior to 1940 recognize the larger uncertainties in the data at these earlier times compared to later periods which benefit from original wealth and county unit housing data. Quantifying the uncertainty ranges around these normalized loss estimates would require further research which is beyond the scope of this paper.

Normalization Methodologies

Pielke and Landsea (1998) used a single approach to adjusting past storm damage for changing societal conditions. Here we present two different approaches to normalize damages, which result in broadly consistent results. The two approaches are (a) the methodology used by Pielke and Landsea (1998) adjusting for inflation, wealth, and population updated to 2005, called PL05, and (b) the methodology used by Collins and Lowe (2001) adjusting for inflation, wealth, and housing units updated to 2005, called CL05. Each approach is described in detail in the following two subsections.

Pielke and Landsea (1998) Updated to 2005 – PL05

Pielke and Landsea (1998) estimated the damage that historical storms would have

caused had they made landfall under contemporary levels of societal development by

adjusting historical damages by three factors: inflation, wealth, and population. The

factors are described below and illustrated with the example of Hurricane Frederic from

1979 which made landfall along the Gulf Coast.

Inflation

In order to adjust for changes in national inflation (i.e., the decrease in value of a

currency over time) we use the Implicit Price Deflator for Gross Domestic Product

(IPDGDP) for the years 1929-2005 (Bureau of Economic Analysis 2006a). For inflation

data 1900-1928 the BEA recommends Johnston and Williamson (2006) as there are no

official government inflation data during these years (V. Mannering, personal

communication, January 19, 2006). From this data, the inflation adjustment is a ratio of

the 2005 IPDGDP to that in the year in which the storm made landfall. For example, the

2005 IPDGDP was 112.737 and the IPDGDP for 1979 was 49.548. Thus, to convert

damages expressed in 1979 dollars to 2005 dollars requires that 1979 damages be

multiplied by 2.275 = 112.737 / 49.548.

Wealth per Capita

The second adjustment to the economic loss data is to adjust for the growth in wealth;

increasing "wealth" simply means that people have more "stuff" today as compared to

the past and the real value of their "stuff" has in some cases increased. National wealth is captured by the estimate of "Current-Cost Net Stock of Fixed Assets and Consumer Durable Goods" produced each year by the U.S. Department of Commerce's Bureau of Economic Analysis (Bureau of Economic Analysis 2006b).[10] Wealth from 1900-1924 was estimated to increase based on the average annual change in wealth from 1925-2005 (6%) and from 1925-1928 (3%). We use a value between these of 4% per year.[11]

Because the wealth data are reported in billions of current-year dollars for the entire nation, we adjust these data for; 1) inflation and 2) population. We disaggregate wealth to a non-inflated (real) per capita metric in order to allow us to distinguish the independent roles of inflation, wealth, and population in the normalization.

For example, wealth in 2005 was $40.99 trillion and for 1979, $8.91 trillion. The ratio of 2005 to 1979 is 4.599. The inflation multiplier for 1979 was 2.275, so the inflation-corrected wealth adjustment (i.e. real wealth) for 1979 = 4.599 / 2.275 = 2.021. Finally, the U.S. population in 1979 is estimated to be 224,212,417 people (based on a linear interpolation between 1970 and 1980). The U.S. Population in 2005 was estimated to be 297,777,921 (using a linear extrapolation from 1990-2000). The U.S Population multiplier is thus the ratio of the 2005 estimate to the 1979 estimate, or 1.328. Thus, the final wealth multiplier for 1979 is the real wealth multiplier of 2.021 divided by the U.S.

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[10] Note that Pielke and Landsea (1998) used a different metric from the BEA – Fixed Reproducible Tangible Wealth. We use a slightly different metric here because of its greater longitudinal availability. Over the period that both metrics are available they are correlated at 0.9916.

[11] Real GDP also increased by approximately 3% per year 1900-1924 (Johnston and Williamson 2006).

Population multiplier of 1.328 which equals 1.522. Therefore, each person in the United

States has (on average) 1.522 times more wealth in 2005 than did each person in 1979.

Affected County Population

A third adjustment to the economic loss data is to adjust for population changes in the

affected counties for each hurricane or tropical storm. The NOAA Coastal Services

Center (2006) provides a detailed list of affected counties for each storm from 1900-2002

and using a similar approach we estimated the affected counties for storms of 2003-2005.

County level population data for 1900-2000 was obtained from the U.S. Department of

Census.[12] Census data are reported every ten years, so linear interpretation (extrapolation

for 2001-2005) was used to generate a full population dataset for each year 1900-2005.

Figure 1 maps coastal county population for 2005 while Figure 2 shows coastal county

population for 1930, 1960, 1990, and 2005. Table 1 contains the coastal counties used to

generate Figure 2.[13]

From the county-level population data, a population multiplier was calculated based on

the ratio of county population in 2005 to that of the year in which the storm originally

made landfall. For example, the 1979 storm Frederic affected Baldwin and Mobile

counties in Alabama and Jackson County in Mississippi. The sum of the population for

these counties in 2005 is 711,434 compared to 551,862 in 1979. Thus the population

adjustment for the 1979 storm Frederic is 711,434 / 551,862 = 1.289.

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[12] Data for 1900-1990: U.S. Census Bureau (2000), and data from 2000: U.S. Census Bureau (2002).
[13] The NOAA Coastal Services Center defines 174 coastal counties from Texas to Maine, available by
selecting each state from the drop-down menu on their home page and counting the listed counties. This
analysis uses 177 counties with small adjustments in New York and Virginia.

Putting the Pieces Together: A Normalization Example with PL05

Using base year economic damage, and the inflation, wealth, and population multipliers,

we generate the 2005 normalized damage estimate as follows:

$$D_{2005} = D_y \times I_y \times RWPC_y \times P_{2005/y} \qquad (1)$$

where

D$_{2005}$:   normalized damages in 2005 dollars

D$_y$:   reported damages in current-year dollars

I$_y$:   inflation adjustment

RWPC$_y$:   real wealth per capita adjustment

P$_{2005/y}$:   coastal county population adjustment

As an example, here is how damage from Hurricane Frederic is calculated:

D$_y$: $2,300,000,000

I$_y$:   2.275

RWPC$_y$:   1.522

P$_{2005/y}$:   1.289

2005 Normalized Loss = $2,300,000,000 (x) 2.275 (x) 1.522 (x) 1.289 = $10,267,559,526

(this is the actual normalized damage result for Frederic calculated using non-rounded

multipliers)

Frederic caused $2.3 billion in total damage when it made landfall in 1979. If this same storm were to occur in 2005, it would cause an estimated $10.3 billion dollars in total damage, under the PL05 approach to normalization.

Collins and Lowe (2001) updated to 2005 – CL05

Several studies suggested that a normalization methodology based on inflation, wealth, and population could underestimate the magnitude of contemporary losses because in many exposed coastal locations the amount of property at risk to damage has increased at a rate that exceed local population growth (e.g., Collins and Lowe, 2001; Pielke et al. 1999). The Collins and Lowe (2001) normalization methodology differs from PL05 in its use of coastal county housing units rather than population.[14] The calculation of CL05 involves the same inflation multiplier as PL05. The wealth multiplier is different, however, as it corrects for national changes in housing units – rather than population – to determine a change in wealth per housing unit.

For example, wealth in 2005 was $40.99 trillion and $8.912 trillion in 1979. The ratio of 2005 to 1979 is 4.599. The inflation multiplier for 1979 was 2.275, so the inflation-corrected wealth adjustment for 1979 = 4.599 / 2.275 = 2.021, exactly as in PL05. The number of U.S. Housing Units in 1979 is estimated to be 86,438,040 units (based on a linear interpolation of 68,679,030 in 1970 and 88,411,263 in 1980). U.S. Housing Units in 2005 were estimated to be 122,725,123 (using a linear extrapolation from 1990-2000).

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[14] The original Collins and Lowe methodology also differed in two respects from the method used here: normalized damages were based on estimates of insured losses rather than total economic losses, and losses were allocated to county based on the damage indices derived from the ToPCat hurricane model rather than applying the damage evenly over all affected counties. These changes were made so that losses could more easily be compared to the Pielke and Landsea methodology estimates.

The U.S Housing Unit multiplier is thus the ratio of the 2005 estimate to the 1979 estimate, or 1.420. Thus, the final wealth multiplier for 1979 is the real wealth multiplier of 2.021 divided by the U.S. Housing Unit multiplier of 1.420 which equals 1.424. Therefore, each housing unit in the United States contains (on average) 1.424 times more wealth in 2005 than did each housing unit in 1979.

The final multiplier in CL05 is county housing units, and as with other U.S. Census information, housing unit data are provided by decade, and linear interpolation (extrapolation) provides the data for all years 1940-2005. [15] Housing units for 1900-1939 were estimated based on extrapolating back in time the county-level relationship of population and housing units from 1940-2005.

From the county-level housing unit data, a housing unit multiplier was calculated based on the ratio of county housing units in 2005 to that of the year in which the storm originally made landfall. For example, the 1979 storm Frederic affected Baldwin and Mobile counties in Alabama and Jackson County in Mississippi. The sum of the housing units for these counties in 2005 is 312,749 compared to 201,946 in 1979. Thus the population adjustment for the 1979 storm Frederic is 312,749 / 201,946 = 1.549.

The general formula for the CL05 normalized losses:

$$D_{2005} = D_y \times I_y \times RWPHU_y \times HU_{2005/y} \tag{3}$$

where

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[15] Specifically, Joel Gratz updated a spreadsheet of housing united data compiled by D. Collins for Collins and Lowe (2001) based on U.S. Census Bureau (2006). At the time of our research the Census only had this information by county by decade in PDF form (Bureau of the Census, 1990).

D_{2005}:   normalized damages in 2005 dollars

D_y: reported damages in current-year dollars

I_y: inflation adjustment

$RWPHU_y$:   real wealth per housing unit adjustment

$HU_{2005/y}$:   coastal county housing unit adjustment

As an example, here is how damage from Hurricane Frederic is calculated:

D_y: $2,300,000,000

I_y: 2.275

$RWPHU_y$:   1.424

$HU_{2005/y}$:   1.549

$2,300,000,000 (x) 2.275 (x) 1.423 (x) 1.549 = $ 11,537,923,783

(this is the actual normalized damage result for Frederic calculated using non-rounded multipliers)

Frederic caused $2.3 billion in total damage when it made landfall in 1979. If this same storm were to occur in 2005, it would cause an estimated $11.5 billion dollars in total damage, under the CL05 approach to normalization.

Discussion of the Results of Normalization

Figure 3 shows U.S. hurricane damages from 1900-2005 adjusted only for inflation, showing a clear increase in losses. The dark line represents an 11-year centered moving

average. Figures 4a-c show the summary and individual results for the two different

approaches to normalization for the complete dataset. The results of PL05 and CL05

tend to be very similar, with larger differences further back in time.

Further details can be seen in the tables. Table 2 shows the top 30 damaging events,

ranked by PL05, along with the corresponding ranking of CL05. Under both approaches

the 1926 Great Miami hurricane is estimated to result in the largest losses at $140-157

billion. Hurricane Katrina is third under both normalization schemes. The years 2004

and 2005 stand out as particularly extreme with 6 of the top 30 most damaging

(normalized) storms over 106 years. No other two-year period has more than 3 top 30

storms (1944-1945). Of particular note is the rapid increase in estimated damage for

historical storms as compared to Pielke and Landsea (1998). For instance, Pielke and

Landsea (1998) estimated that the 1926 Great Miami hurricane would have resulted in

$72.3 billion in 1995. Normalized to 2005, the estimate jumps to $157.0 billion. This is

consistent with independent analyses which have found in some locations that losses are

doubling every ten years (e.g., Association of British Insurers 2005). According to one

current report (Insurance Journal 2006),

> ". . . analyses by ISO's catastrophe modeling subsidiary, AIR Worldwide, indicate
>
> that catastrophe losses should be expected to double roughly every 10 years
>
> because of increases in construction costs, increases in the number of structures
>
> and changes in their characteristics. AIR's research shows that, because of
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> exposure growth, the one in one-hundred-year industry loss grew from $60 billion

in 1995 to $110 billion in 2005, and it will likely grow to over $200 billion during

the next 10 years."

Note that the numbers above are estimates of insured damages, as opposed to total

economic damages.

Table 3 shows normalized damages for each of the three approaches by month over 1900-

2005. While PL05 and CL05 differ by about 2% over the entire period, the monthly

distribution of damages is almost identical in both cases, with August and September

accounting for approximately 85% of normalized damages. September alone accounts

for greater than 50% of normalized damages. October has approximately 9.5-10% of

normalized damages, and the other months much smaller amounts. Of note, June has

40% more normalized damages than does July. This somewhat surprising result is

primarily due to Agnes (June 1972), which was mainly a flood event, being by far the

largest normalized storm in these months.

Table 4 shows normalized damages by decade for both approaches. The decade 1996-

2005 has the second highest normalized damage compared to any other such period.

While 1996-2005 is similar to 1926-1935, the table also underscores how anomalously

benign the 1970s and 1980s were in comparison to the rest of the record, with about 5%

of the dataset total damages in each decade. Decadal totals are dominated by the effects

of a single or several individual storms. For instance, 70% of the 1926-1935 damage

total comes from the 1926 Miami hurricane and about 40% of the 1996-2005 total comes

from Katrina.

Table 5 shows damage for each approach to normalization by Saffir/Simpson category at the time of hurricane landfall. The normalizations each indicate that storms of Category 3 or stronger are responsible for more than 85% of the total normalized damages. PL05 and CL05 indicate a similar distribution and magnitude of normalized damages by category, but with only three Category 5 landfalls, little can be said with specificity about the relative effects of a Category 5 impact beyond the observation that its impacts in any situation will be huge. Table 6 shows damage by different populations inhabiting the coastal counties directly affected by the storm and illustrates the large sensitivity of damage to population of the affected area.

A Note on Demand Surge and Loss Mitigation

The normalization methodologies do not explicitly reflect two important factors driving losses: demand surge and loss mitigation. Adjustments for these factors are beyond the scope of this paper, but it is important for those using this study to consider their potential effect.

Demand surge refers to the increase in costs which often occurs after very large events due to shortages of labor and materials required for reconstruction. The actual effect of demand surge is the result of a complex interaction of local and national economic conditions which is not uniform between events. For example, demand surge will be greater in periods of strong economic activity and low unemployment due to the lack of slack resources. Local economic conditions will also have an effect, as will the proximity

of losses in time and space (the demand surge in the 2004 Florida hurricanes was greater than would have been the case had the four major loss events occurred in different years).

The normalization methodologies used in this paper assume that demand surge is uniform over time. To the degree that past losses were relatively smaller in the context of the economy of the time than they would be today, the methodology may understate the size of the loss in current dollars and vice versa. A good example of this might be the Miami hurricane of 1926, which was a smaller proportion of the national economy than a similar event would be in 2005. Certainly, an event larger than $100 billion today would lead to significant shortages in the affected areas and result in inflationary pressures. Thus, our historical estimates may be considered conservative.

Another important factor is mitigation and the implementation of stronger building codes. There is considerable evidence that strong building codes can significantly reduce losses; for example, data presented to the Florida Legislature during a debate over building codes in 2001 indicated strong codes could reduce losses by over 40% (IntraRisk 2002). As strong codes have only been implemented in recent years (and in some cases vary significantly on a county-by-county basis), their effect on overall losses is unlikely to be large, but in future years efforts to improve building practices and encourage retrofit of existing structures could have a large impact on losses.

Conclusions

Our analysis of normalized damage associated with U.S. mainland hurricane landfalls 1900-2005 underscores the results of previous research and highlights the tremendous importance of societal factors in shaping trends in damage related to hurricanes. As people continue to flock to the nation's coasts and bring with them ever more personal wealth losses will continue to increase. A simple extrapolation of the current trend of doubling losses every 10 years suggests that a storm like the 1926 Great Miami hurricane could result in perhaps $500 billion in damage as soon as the 2020s. Efforts to mitigate hurricane losses do have significant potential to affect the future growth in losses such that future storms cause less damage than a simple extrapolation may imply.

A detailed analysis of the relationship of climatic factors in the loss record in the context of societal trends is the subject of a follow-on paper. However, it should be clear from the normalized estimates that while 2004 and 2005 were exceptional from the standpoint of the number of very damaging storms, there is no long-term trend of increasing damaging storms over the time period covered by this analysis. Even Hurricane Katrina is not outside the range of normalized estimates for past storms. The analysis here should provide a cautionary warning for hurricane policy makers. Potential damage from storms is growing at a rate which may place severe burdens on society. Avoiding huge losses will require either a change in the rate of population growth in coastal areas, major improvements in construction standards, or other mitigation actions. Unless such action is taken to address the growing concentration of people and properties in coastal areas where hurricanes strike, damage will increase, and by a great deal, as more and wealthier people increasingly inhabit these coastal locations.

Appendix A: Normalized damages for all storms

Rank	Hurricane	Year	Category	PL05 Damage U.S. billions $	CL05 Damage U.S. billions $		AIR Top 10 Events U.S. billions $	
1	Great Miami (FL-SE)	1926	4	157.0	139.5	(1)	160.0	(1)
2	Galveston (TX-No)	1900	4	99.4	91.6	(2)	66.0	(6)
3	Katrina (LA,MS)	2005	3	81.0	81.0	(3)	82.0	(3)
4	Galveston (TX-No)	1915	4	68.0	63.0	(4)		
5	Andrew (FL-SE)	1992	5	55.8	52.3	(5)	84.0	(2)
6	New England (CT,MA,NY,RI)	1938	3	39.2	37.3	(6)	70.0	(4)
7	11 (FL-SW)	1944	3	38.7	35.6	(7)		
8	Lake Okeechobee (FL-SE)	1928	4	33.6	31.8	(8)	66.0	(7)
9	Donna (FL-SW)	1960	4	26.8	28.9	(9)	52.0	(8)
10	Camille (LA,MS)	1969	5	21.2	24.0	(10)		
11	Wilma (FL-SW)	2005	3	20.6	20.6	(12)		
12	Betsy (LA)	1965	3	17.9	19.0	(13)	68.0	(5)
13	Diane (NE United States)	1955	1	17.2	17.8	(15)		
14	Agnes (NE United States)	1972	1	17.2	18.0	(14)		
15	Hazel (NC,SC)	1954	4	16.5	23.2	(11)		
16	Charley (FL-SW)	2004	4	16.3	16.3	(17)		
17	Carol (CT,NY,RI)	1954	3	16.1	15.1	(19)		
18	Ivan (FL-NW)	2004	3	15.5	15.5	(18)		
19	Hugo (SC)	1989	4	15.3	17.5	(16)		
20	2 (FL-SE)	1949	3	14.7	13.5	(21)		
21	Carla (TX-Ce)	1961	4	14.2	13.5	(22)		
22	4 (FL-SE)	1947	4	13.7	11.6	(24)	48.0	(9)
23	7 (CT,NC,NY,RI,VA)	1944	3	13.2	12.1	(23)		
24	2 (TX-So)	1919	4	13.2	13.9	(20)		
25	9 (FL-SE)	1945	3	12.3	10.1	(27)	40.0	(10)
26	Frederic (AL,MS)	1979	3	10.3	11.5	(25)		
27	Rita (TX-No)	2005	3	10.0	10.0	(28)		
28	Frances (FL-SE)	2004	2	9.7	9.6	(30)		
29	8 (VA)	1933	2	8.2	9.8	(29)		
30	Dora (FL-NE)	1964	2	7.7	6.6	(34)		
31	Jeanne (FL-SE)	2004	3	7.5	7.5	(31)		
32	Alicia (TX-No)	1983	3	7.5	7.2	(32)		
33	Floyd (NC)	1999	2	6.7	6.8	(33)		
34	Allison (TX-B)	2001	TS	6.6	6.4	(35)		
35	3 (FL-SE)	1903	1	6.5	5.2	(42)		
36	6 (FL-SE)	1935	2	6.4	5.6	(41)		
37	Opal (FL-SE)	1995	3	6.1	6.3	(36)		
38	2 (TX-No)	1932	4	5.9	5.7	(39)		
39	1 (AL,MS)	1916	3	5.8	6.9	(32)		
40	Fran (NC)	1996	3	5.8	6.2	(37)		
41	Celia (TX-So)	1970	3	5.6	5.7	(40)		
42	Cleo (FL-SE)	1964	2	5.2	4.7	(43)		
43	King (FL-SE)	1950	3	4.4	3.7	(52)		
44	Beulah (TX-So)	1967	3	4.0	4.0	(46)		
45	Isabel (NC)	2003	2	4.0	4.0	(48)		
46	Juan (LA)	1985	1	3.9	4.2	(44)		
47	Audrey (LA,TX-No)	1957	4	3.8	4.1	(45)		
48	Ione (NC)	1955	3	3.7	6.0	(38)		
49	1 (FL-NE)	1926	2	3.7	3.6	(54)		
50	6 (FL-SE)	1946	TS	3.7	3.1	(58)		
51	Elena (AL,FL-NW,MS)	1985	3	3.6	3.8	(51)		
52	1 (TX-No)	1943	2	3.6	3.3	(55)		
53	11 (TX-So)	1933	3	3.5	3.8	(50)		
54	7 (FL-SW)	1948	3	3.3	3.6	(53)		
55	6 (FL-SW)	1921	3	3.2	3.2	(56)		

Rank	Hurricane	Year	Category	PL05 Damage U.S. billions $	CL05 Damage U.S. billions $		AIR Top 10 Events U.S. billions $
56	4 (LA,MS)	1947	3	3.1	3.1	(57)	
57	Bob (CT,MA,NY,RI)	1991	2	3.0	3.1	(60)	
58	Edna (MA)	1954	3	3.0	1.7	(77)	
59	Betsy (FL-SE)	1965	3	2.9	4.0	(47)	
60	Donna (NC,NY)	1960	3	2.8	3.0	(61)	
61	Eloise (FL-NW)	1975	3	2.8	2.8	(62)	
62	Georges (AL,MS)	1998	2	2.8	2.5	(66)	
63	5 (LA)	1915	4	2.7	2.8	(63)	
64	Gloria (NC,NY)	1985	3	2.4	2.4	(68)	
65	Connie (NC)	1955	3	2.3	3.8	(49)	
66	2 (FL-SW)	1935	5	2.3	3.1	(59)	
67	David (FL-NE,FL-SE,GA,SC)	1979	2	2.3	2.2	(70)	
68	Dennis (FL-NW)	2005	3	2.2	2.2	(69)	
69	2 (TX-Ce)	1942	3	2.2	2.6	(64)	
70	Hilda (LA)	1964	3	2.2	2.6	(65)	
71	5 (AL,MS)	1906	2	2.1	2.4	(67)	
72	2 (TX-No)	1941	3	2.0	1.8	(73)	
73	Andrew (LA)	1992	3	1.9	2.0	(71)	
74	8 (FL-SE)	1906	3	1.7	1.4	(82)	
75	4 (TX-So)	1916	3	1.7	1.8	(74)	
76	5 (TX-Ce)	1945	2	1.6	1.7	(76)	
77	Allen (TX-So)	1980	3	1.6	1.7	(75)	
78	Ophelia (NC)	2005	1	1.6	1.6	(78)	
79	Claudette (LA,TX-No)	1979	TS	1.5	1.6	(79)	
80	12 (FL-SE)	1933	3	1.5	1.4	(83)	
81	Doria (NC)	1971	TS	1.3	1.3	(86)	
82	4 (TX-No)	1909	3	1.3	1.3	(85)	
83	8 (LA,MS)	1909	3	1.3	1.3	(84)	
84	Irene (FL-SW)	1999	1	1.2	1.2	(91)	
85	8 (GA,SC)	1947	2	1.2	1.4	(81)	
86	Bonnie (NC)	1998	2	1.2	1.2	(90)	
87	Easy (FL-NW)	1950	3	1.1	1.0	(99)	
88	2 (Sc)	1904	1	1.1	1.9	(72)	
89	Lili (LA)	2002	1	1.1	1.1	(94)	
90	Allison (TX-Ce)	1989	TS	1.0	1.0	(96)	
91	5 (FL-SW)	1946	1	1.0	1.0	(98)	
92	Kate (FL-NW)	1985	2	1.0	1.1	(93)	
93	Alberto (FL-NW)	1994	TS	1.0	1.0	(97)	
94	Georges (FL-SW)	1998	2	1.0	1.0	(95)	
95	3 (GA,SC)	1940	2	1.0	1.2	(89)	
96	Carmen (LA)	1974	3	1.0	1.1	(92)	
97	Erin (FL-NW)	1995	2	1.0	1.0	(100)	
98	1 (LA)	1918	3	0.8	1.3	(88)	
99	4 (FL-SW)	1910	2	0.8	0.8	(101)	
100	Frances (TX-Ce)	1998	TS	0.8	0.8	(102)	
101	Gordon (FL-SW)	1994	TS	0.8	0.8	(103)	
102	10 (TX-No)	1949	2	0.7	0.6	(108)	
103	2 (NC)	1913	1	0.7	1.5	(80)	
104	8 (FL-SE)	1948	2	0.7	0.6	(111)	
105	8 (FL-SE)	1947	2	0.6	0.5	(112)	
106	Isabel (FL-SE,FL-SW)	1964	2	0.6	0.6	(109)	
107	3 (LA)	1926	3	0.6	0.7	(105)	
108	Gladys (FL-NW)	1968	2	0.6	0.5	(117)	
109	Flossy (LA)	1956	2	0.6	0.7	(106)	
110	13 (NC)	1936	2	0.6	1.3	(87)	

Rank	Hurricane	Year	Category	PL05 Damage U.S. billions $	CL05 Damage U.S. billions $		AIR Top 10 Events U.S. billions $
111	Debbie (MS)	1965	TS	0.6	0.6	(110)	
112	2 (FL-SW)	1919	4	0.5	0.7	(104)	
113	Helene (NC)	1958	3	0.5	0.6	(107)	
114	Bertha (NC)	1996	2	0.5	0.5	(114)	
115	Belle (NY)	1976	1	0.5	0.5	(118)	
116	2 (LA)	1934	3	0.4	0.5	(113)	
117	5 (FL-SE,FL-SW)	1941	2	0.4	0.4	(126)	
118	Erin (FL-SE)	1995	1	0.4	0.4	(121)	
119	3 (TX-So)	1934	2	0.4	0.4	(120)	
120	Isidore (LA)	2002	TS	0.4	0.4	(124)	
121	Gracie (SC)	1959	3	0.4	0.5	(115)	
122	How (FL-SW)	1951	TS	0.4	0.3	(129)	
123	2 (LA)	1920	2	0.3	0.4	(122)	
124	Agnes (FL-NW)	1972	1	0.3	0.4	(123)	
125	Fern (TX-Ce)	1971	1	0.3	0.3	(127)	
126	Cindy (LA)	2005	1	0.3	0.3	(130)	
127	Debra (TX-NO)	1959	1	0.3	0.3	(133)	
128	10 (FL-SW)	1909	3	0.3	0.4	(119)	
129	Gabrielle (FL-SW)	2001	TS	0.3	0.3	(132)	
130	7 (FL,GA)	1947	TS	0.3	0.3	(128)	
131	2 (FL-SE)	1929	3	0.3	0.3	(137)	
132	Diana (NC)	1984	3	0.3	0.3	(131)	
133	Edith (LA)	1971	2	0.3	0.3	(135)	
134	Esther (MA)	1961	TS	0.3	0.2	(147)	
135	Dennis (NC)	1999	TS	0.2	0.2	(139)	
136	Cindy (TX-No)	1963	1	0.2	0.2	(141)	
137	3 (NC)	1944	1	0.2	0.4	(125)	
138	Alma (FL-NW)	1966	2	0.2	0.3	(138)	
139	Chantal (TX-No)	1989	1	0.2	0.2	(143)	
140	Josephine (FL-NW)	1996	TS	0.2	0.2	(142)	
141	2 (GA,SC)	1911	2	0.2	0.3	(134)	
142	13 (NC)	1933	3	0.2	0.5	(116)	
143	Claudette (TX-B)	2003	1	0.2	0.2	(145)	
144	4 (LA,MS)	1901	1	0.2	0.2	(140)	
145	Brenda (SC)	1960	TS	0.2	0.3	(136)	
146	2 (LA, TX-No)	1940	2	0.2	0.2	(146)	
147	Dennis (FL-SW)	1981	TS	0.2	0.2	(151)	
148	Jerry (TX-No)	1989	1	0.2	0.2	(149)	
149	Danny (AL,LA)	1997	1	0.2	0.2	(148)	
150	Ginger (NC)	1971	1	0.2	0.2	(144)	
151	Gilbert (TX-So)	1988	TS	0.2	0.2	(150)	
152	Beryl (FL-NW)	1994	TS	0.1	0.2	(154)	
153	Amelia (TX-So)	1978	TS	0.1	0.2	(153)	
154	Delia (TX-Ce)	1973	TS	0.1	0.2	(155)	
155	1 (TX-No)	1942	1	0.1	0.1	(161)	
156	Unnamed (FL-SW)	1959	TS	0.1	0.1	(160)	
157	Gaston (SC)	2004	1	0.1	0.1	(157)	
158	Unnamed (TX-So)	1960	TS	0.1	0.1	(159)	
159	Danny (LA)	1985	1	0.1	0.1	(156)	
160	3 (TX-So)	1936	1	0.1	0.1	(158)	
161	Marco (FL-SW)	1990	TS	0.1	0.1	(165)	
162	Earl (FL-NW)	1998	1	0.1	0.1	(163)	
163	Able (SC)	1952	1	0.1	0.2	(152)	
164	Bob (SC)	1985	1	0.1	0.1	(166)	
165	5 (FL-NW)	1936	3	0.1	0.1	(164)	

Rank	Hurricane	Year	Category	PL05 Damage U.S. billions $	CL05 Damage U.S. billions $		AIR Top 10 Events U.S. billions $
166	Sub-trop (FL-SE)	1974	TS	0.1	0.1	(167)	
167	3 (TX-No)	1947	1	0.1	0.1	(171)	
168	Inez (FL-SW)	1966	1	0.1	0.1	(162)	
169	Emily (NC)	1993	3	0.1	0.1	(175)	
170	1 (TX-Ce)	1929	1	0.1	0.1	(168)	
171	Charley (TX-Ce)	1998	TS	0.1	0.1	(173)	
172	Alma (NC)	1962	TS	0.1	0.1	(172)	
173	Esther (LA)	1957	TS	0.1	0.1	(170)	
174	Bret (TX)	1999	3	0.1	0.1	(169)	
175	Mitch (FL-SW)	1998	TS	0.1	0.1	(177)	
176	Bob (LA)	1979	1	0.1	0.1	(178)	
177	Babe (LA)	1977	1	0.1	0.1	(179)	
178	Jerry (FL-SE)	1995	TS	0.1	0.0	(180)	
179	6 (FL-NW)	1947	TS	0.1	0.0	(182)	
180	1 (SC)	1934	TS	0.0	0.1	(174)	
181	Charley (NC,VA)	1986	1	0.0	0.0	(181)	
182	Arlene (TX-So)	1993	TS	0.0	0.0	(183)	
183	Barbara (NC)	1953	1	0.0	0.1	(176)	
184	Barry (FL-NW)	2001	TS	0.0	0.0	(184)	
185	5 (LA)	1948	1	0.0	0.0	(186)	
186	Carrie (MA)	1972	TS	0.0	0.0	(189)	
187	Sub-trop (FL-NE)	1982	STS	0.0	0.0	(190)	
188	Elena (TX-Ce)	1979	TS	0.0	0.0	(185)	
189	Bill (LA)	2003	TS	0.0	0.0	(188)	
190	Candy (TX-Ce)	1968	TS	0.0	0.0	(187)	
191	Abby (FL-SW)	1968	TS	0.0	0.0	(193)	
192	Ethel (MS)	1960	1	0.0	0.0	(191)	
193	Arlene (LA)	1959	TS	0.0	0.0	(192)	
194	Hanna (MS)	2002	TS	0.0	0.0	(194)	
195	Harvey (FL-SW)	1999	TS	0.0	0.0	(195)	
196	Helene (FL-NW)	2000	TS	0.0	0.0	(196)	
197	Abby (TX-Ce)	1964	TS	0.0	0.0	(199)	
198	2 (LA)	1938	1	0.0	0.0	(197)	
199	Unnamed (TX-No)	1987	TS	0.0	0.0	(200)	
200	Daisy (ME)	1962	TS	0.0	0.0	(198)	
201	Gordon (FL-NW)	2000	TS	0.0	0.0	(202)	
202	Florence (FL-NW)	1953	1	0.0	0.0	(201)	
203	Keith (FL-SW)	1988	TS	0.0	0.0	(203)	
204	Kyle (SC)	2002	TS	0.0	0.0	(204)	
205	Fay (TX-B)	2002	TS	0.0	0.0	(206)	
206	Beryl (LA)	1988	TS	0.0	0.0	(207)	
207	Chris (LA,TX)	1982	TS	0.0	0.0	(205)	
208	Bonnie (TX-No)	1986	1	0.0	0.0	(208)	
209	Alex (NC)	2004	1	0.0	0.0	(210)	
210	Isadore (FL-SE)	1984	TS	0.0	0.0	(211)	
211	Florence (LA)	1988	1	0.0	0.0	(209)	
212	Allison (FL-NW)	1995	TS	0.0	0.0	(212)	
213	Chris (GA,SC)	1988	TS	0.0	0.0	(213)	
214	Floyd (FL-SW)	1987	1	0.0	0.0	(214)	
215	Dean (TX-Ce)	1995	TS	0.0	0.0	(215)	
216	Gustav (NC)	2002	TS	0.0	0.0	(216)	

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Table 1. Coastal Counties Used in this Study

State	Number of Counties - NOAA	Number of Counties - P&L[16]
Maine	8	8
New Hampshire	1	1
Massachusetts	8	8
Rhode Island	5	5
Connecticut	4	4
New York	7	8*
New Jersey	10	10
Delaware	3	3
Maryland	14	14
Virginia	15	17**
North Carolina	17	17
South Carolina	5	5
Georgia	6	6
Florida	38	38
Alabama	2	2
Mississippi	3	3
Louisiana	11	11
Texas	17	17
	174	177

Table 1

The 177 coastal counties used to generate Figure 1. Some small differences exist

between our list and that NOAA list due to data availability and the use of near-ocean

bays and inlets for coastlines.

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[16] * In New York, Richmond county was added

** In Virginia, Hampton City, Newport News City, Norfolk City, Portsmouth City, Williamsburg City were added. Chesapeake (no data until 1961), Virginia Beach (no data until 1951), and Surry were removed.

Table 2. Top 30 Damaging Storms[17]

Rank	Hurricane	Year	Category	PL05 Damage U.S. billions $	CL05 Damage U.S. billions $		AIR Top 10 Events U.S. billions $	
1	Great Miami (FL-SE)	1926	4	157.0	139.5	(1)	160.0	(1)
2	Galveston (TX-No)	1900	4	99.4	91.6	(2)	66.0	(6)
3	Katrina (LA,MS)	2005	3	81.0	81.0	(3)	82.0	(3)
4	Galveston (TX-No)	1915	4	68.0	63.0	(4)		
5	Andrew (FL-SE)	1992	5	55.8	52.3	(5)	84.0	(2)
6	New England (CT,MA,NY,RI)	1938	3	39.2	37.3	(6)	70.0	(4)
7	11 (FL-SW)	1944	3	38.7	35.6	(7)		
8	Lake Okeechobee (FL-SE)	1928	4	33.6	31.8	(8)	66.0	(7)
9	Donna (FL-SW)	1960	4	26.8	28.9	(9)	52.0	(8)
10	Camille (LA,MS)	1969	5	21.2	24.0	(10)		
11	Wilma (FL-SW)	2005	3	20.6	20.6	(12)		
12	Betsy (LA)	1965	3	17.9	19.0	(13)	68.0	(5)
13	Diane (NE United States)	1955	1	17.2	17.8	(15)		
14	Agnes (NE United States)	1972	1	17.2	18.0	(14)		
15	Hazel (NC,SC)	1954	4	16.5	23.2	(11)		
16	Charley (FL-SW)	2004	4	16.3	16.3	(17)		
17	Carol (CT,NY,RI)	1954	3	16.1	15.1	(19)		
18	Ivan (FL-NW)	2004	3	15.5	15.5	(18)		
19	Hugo (SC)	1989	4	15.3	17.5	(16)		
20	2 (FL-SE)	1949	3	14.7	13.5	(21)		
21	Carla (TX-Ce)	1961	4	14.2	13.5	(22)		
22	4 (FL-SE)	1947	4	13.7	11.6	(24)	48.0	(9)
23	7 (CT,NC,NY,RI,VA)	1944	3	13.2	12.1	(23)		
24	2 (TX-So)	1919	4	13.2	13.9	(20)		
25	9 (FL-SE)	1945	3	12.3	10.1	(27)	40.0	(10)
26	Frederic (AL,MS)	1979	3	10.3	11.5	(25)		
27	Rita (TX-No)	2005	3	10.0	10.0	(28)		
28	Frances (FL-SE)	2004	2	9.7	9.6	(30)		
29	8 (VA)	1933	2	8.2	9.8	(29)		
30	Dora (FL-NE)	1964	2	7.7	6.6	(35)		

Table 2

Storms with the highest normalized damages based on the PL05 methodology. The CL05

normalized damage figures are also included, with the ranking for this dataset in

parenthesis. The private catastrophe modeling company AIR-Worldwide provided an

estimate of the top 10 insured losses normalized to 2005. These values were doubled to

approximate the total economic loss.

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[17] AIR data from 9/12/2006 press release (AIR 2006). According to AIR, "Modeled loss to property, contents and direct business interruption and additional living expenses for residential, mobile home, commercial, and auto exposures as of December 31, 2005. Losses include demand surge."

Table 3. Normalized Damage by Month

PL05 Normalization

Month	Total Damage ($m)	Total Damage (%)
May	80	0.0%
June	30,300	2.7%
July	21,700	1.9%
August	346,500	30.8%
September	606,000	53.9%
October	108,000	9.6%
November	12,000	1.1%
Total	1,124,600	100.0%

CL05 Normalization

Month	Total Damage ($m)	Total Damage (%)
May	110	0.0%
June	31,500	2.9%
July	22,500	2.0%
August	343,300	31.1%
September	583,500	52.9%
October	111,500	10.1%
November	10,600	1.0%
Total	1,103,100	100.0%

Table 3

Normalized losses for both schemes summed by month of tropical cyclone landfall.

About 85% of all normalized damage occurs during the months of August and

September.

Table 4. Normalized Damage by Decade

PL05 Normalization

Year Range	Count > $1B	Count > $5B	Count > $10B	Avg Damage Per Year ($m)	Total Damage ($m)	% Total Damage
1900-1905	3	2	1	17,900	107,100	9.5%
1906-1915	6	1	1	7,900	79,300	7.1%
1916-1925	4	2	1	2,600	25,600	2.3%
1926-1935	10	6	2	22,400	224,200	19.9%
1936-1945	8	4	4	11,600	115,600	10.3%
1946-1955	15	5	5	10,800	108,300	9.6%
1956-1965	9	5	3	8,800	87,500	7.8%
1966-1975	6	3	2	5,600	55,500	4.9%
1976-1985	9	2	1	3,500	35,400	3.2%
1986-1995	7	3	2	8,700	87,400	7.8%
1996-2005	17	10	4	19,900	198,600	17.7%
Total	94	43	26		1,124,600	100.0%

CL05 Normalization

Year Range	Count > $1B	Count > $5B	Count > $10B	Avg Damage Per Year ($m)	Total Damage ($m)	% Total Damage
1900-1905	3	2	1	16,500	98,900	9.0%
1906-1915	7	1	1	7,500	75,200	6.8%
1916-1925	5	2	1	2,800	28,200	2.6%
1926-1935	10	6	3	20,700	206,900	18.8%
1936-1945	10	4	4	10,800	108,300	9.8%
1946-1955	13	6	5	11,300	112,600	10.2%
1956-1965	9	4	3	9,100	91,000	8.2%
1966-1975	7	3	2	5,900	59,500	5.4%
1976-1985	9	2	1	3,700	37,300	3.4%
1986-1995	7	3	2	8,700	86,500	7.8%
1996-2005	18	10	4	19,900	198,700	18.0%
Total	98	43	27		1,103,100	100.0%

Table 4

Normalized losses for both schemes summed by (partial) decade of tropical cyclone landfall. The highest loss decade occurred between 1926-1935, with 1996-2005 as the second highest decade. The count of events exceeding certain loss thresholds is also shown.

Table 5. Damage by Saffir/Simpson Category

PL05 Normalization

Category of Storm	Count	Total Damage ($m)	Mean Damage ($m)	Median Damage ($m)	Potential Damage*	% of Total Damage	% Total for Each Storm
Tropical / Subtropical	157	21,800	140	-	0.0	1.9%	0.0%
Category 1	46	56,700	1,200	160	1.0	5.0%	0.1%
Category 2	36	81,100	2,300	1,000	6.2	7.2%	0.2%
Category 3	58	407,500	7,000	2,800	17.7	36.2%	0.6%
Category 4	15	478,100	31,900	15,300	96.1	42.5%	2.8%
Category 5	3	79,300	26,400	21,200	133.1	7.0%	2.3%
Total	315	1,124,600					

CL05 Normalization

Category of Storm	Count	Total Damage ($m)	Mean Damage ($m)	Median Damage ($m)	Potential Damage*	% of Total Damage	% Total for Each Storm
Tropical / Subtropical	157	21,300	140	-	0.0	1.9%	0.0%
Category 1	46	59,200	1,300	170	1.0	5.4%	0.1%
Category 2	36	81,100	2,300	1,200	6.9	7.4%	0.2%
Category 3	58	408,700	7,000	3,100	18.4	37.1%	0.6%
Category 4	15	453,400	30,200	16,300	97.9	41.1%	2.7%
Category 5	3	79,400	26,500	24,000	143.9	7.2%	2.4%
Total	315	1,103,100					

Table 5

The major hurricanes (CAT 3,4,5) account for only 24% of landfalls but 85% of

normalized damage. *The potential damage is the ratio of the median damage for a

Category X to the median damage for a Category One.

Table 6. Damage by 2005 Population

Category of Storm	Mean Damage ($m)	PL05 Average Damage ($m) by 2005 Population Value					
		<1m people		1-3m people		>3m people	
Tropical / Subtropical	140	170	(45)	90	(7)	1,900	(7)
Category 1	1,200	370	(35)	8,500	(5)	6,000	(6)
Category 2	2,300	1,400	(21)	3,000	(9)	4,300	(6)
Category 3	7,000	5,400	(38)	5,700	(11)	14,200	(9)
Category 4	31,900	12,200	(8)	18,500	(2)	84,000	(5)
Category 5	26,400	11,700	(2)	55,800	(1)	-	(0)

Category of Storm	Mean Damage ($m)	CL05 Average Damage ($m) by 2005 Population Value					
		<1m people		1-3m people		>3m people	
Tropical / Subtropical	140	180	(45)	90	(7)	1,800	(7)
Category 1	1,300	460	(35)	6,900	(5)	6,300	(6)
Category 2	2,300	1,600	(21)	2,800	(9)	4,000	(6)
Category 3	7,000	5,600	(38)	5,800	(11)	13,400	(9)
Category 4	30,200	13,700	(8)	17,600	(2)	76,000	(5)
Category 5	26,500	13,500	(2)	52,300	(1)	-	(0)

Table 6

Although only 14 major hurricanes have made landfall in an area with greater than one million people, this table illustrates the pronounced increase in vulnerability from a larger population. The average damage of a Category Four hurricane increases 4-5 times when making landfall in an area with 1-3 million people compared to >3 million people. [the parenthesis denote the number of storms in that cell]
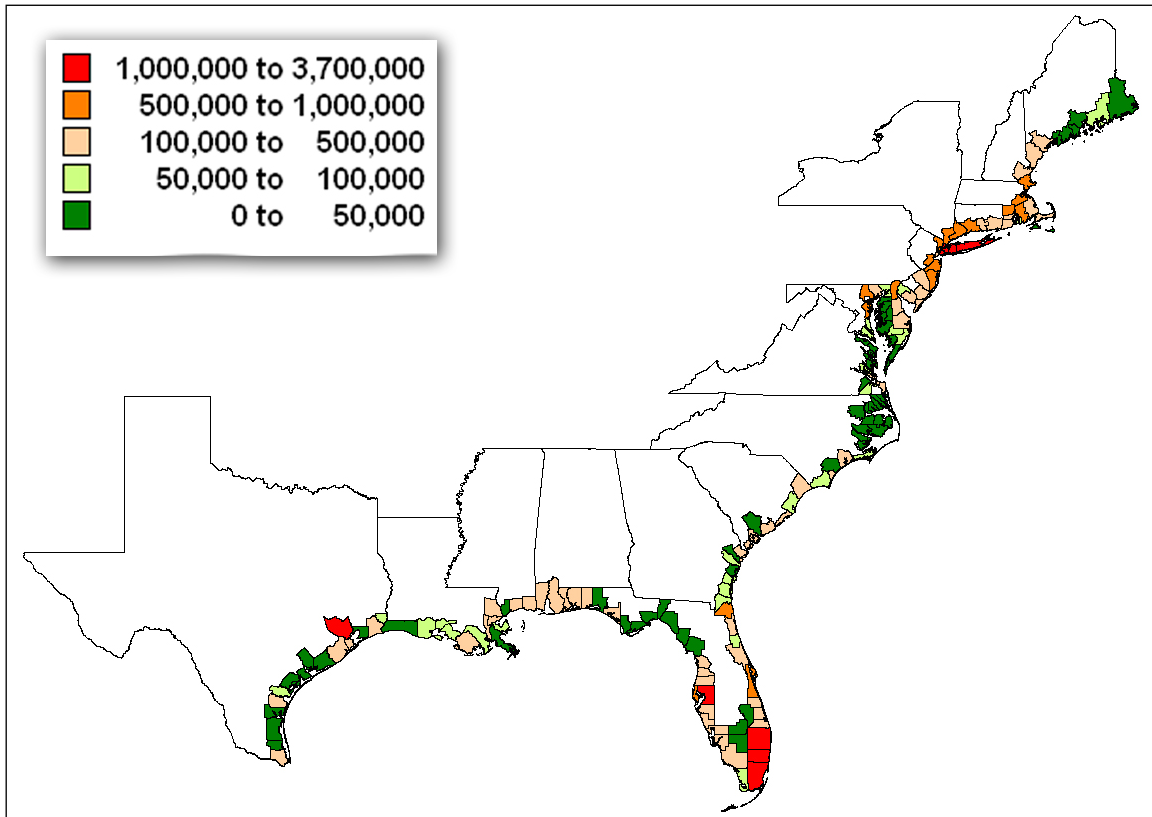
Figure 1. 2005 Population by county

Figure 1

The Galveston/Houston area of Texas, the Tampa and Miami area of Florida, and the

Northeast coastline stand out as areas with high vulnerability due to exceedingly large
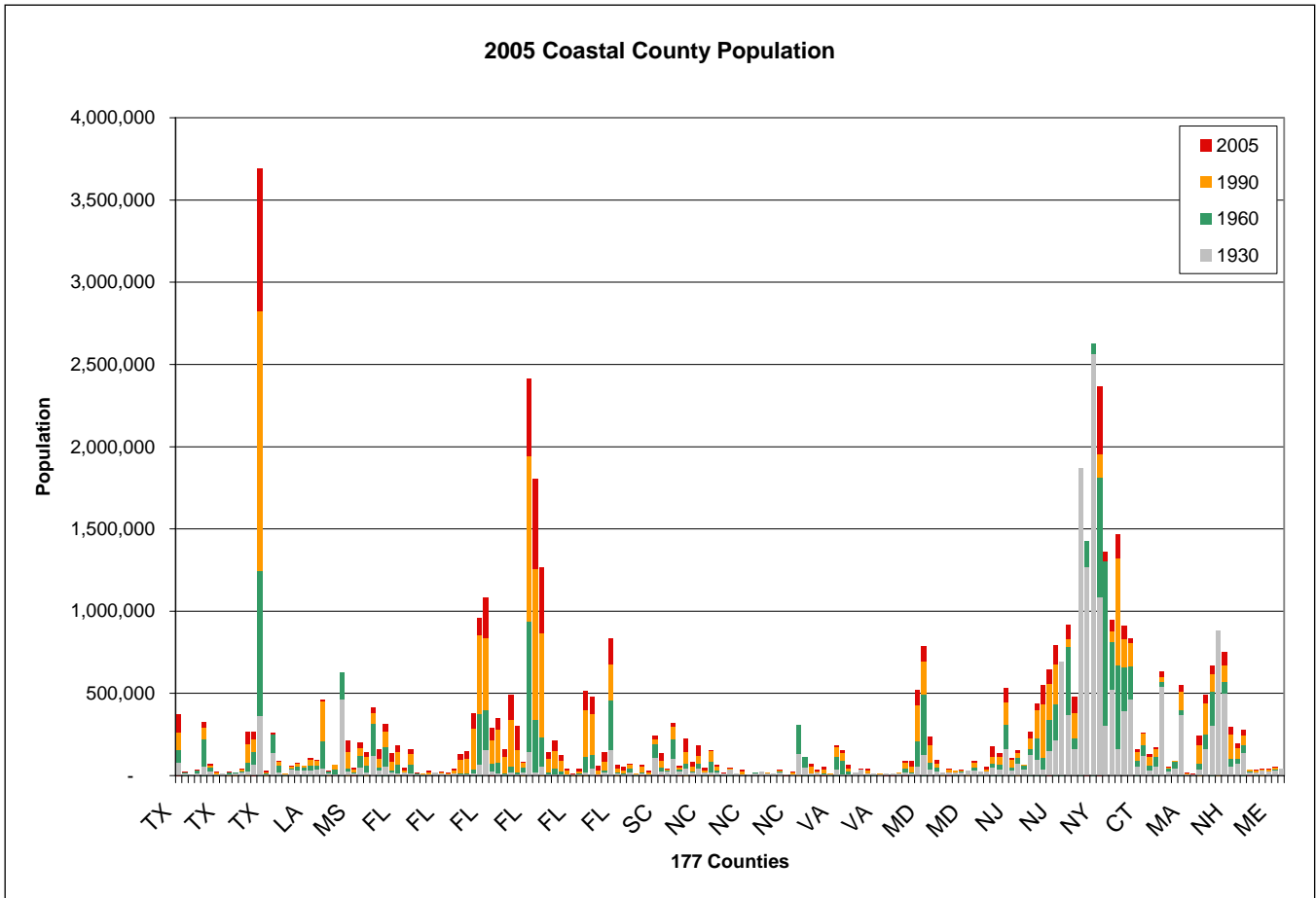
populations.

Figure 2

Figure 2

Coastal county population has grown rapidly since 1930, especially from the east coast of
Florida through the gulf coast. The population of Harris County, TX has grown nearly
three times since 1960, with the 2005 population of Harris County equaling the entire
1955 coastal county population from the Florida panhandle northward to South Carolina.

Figure 3
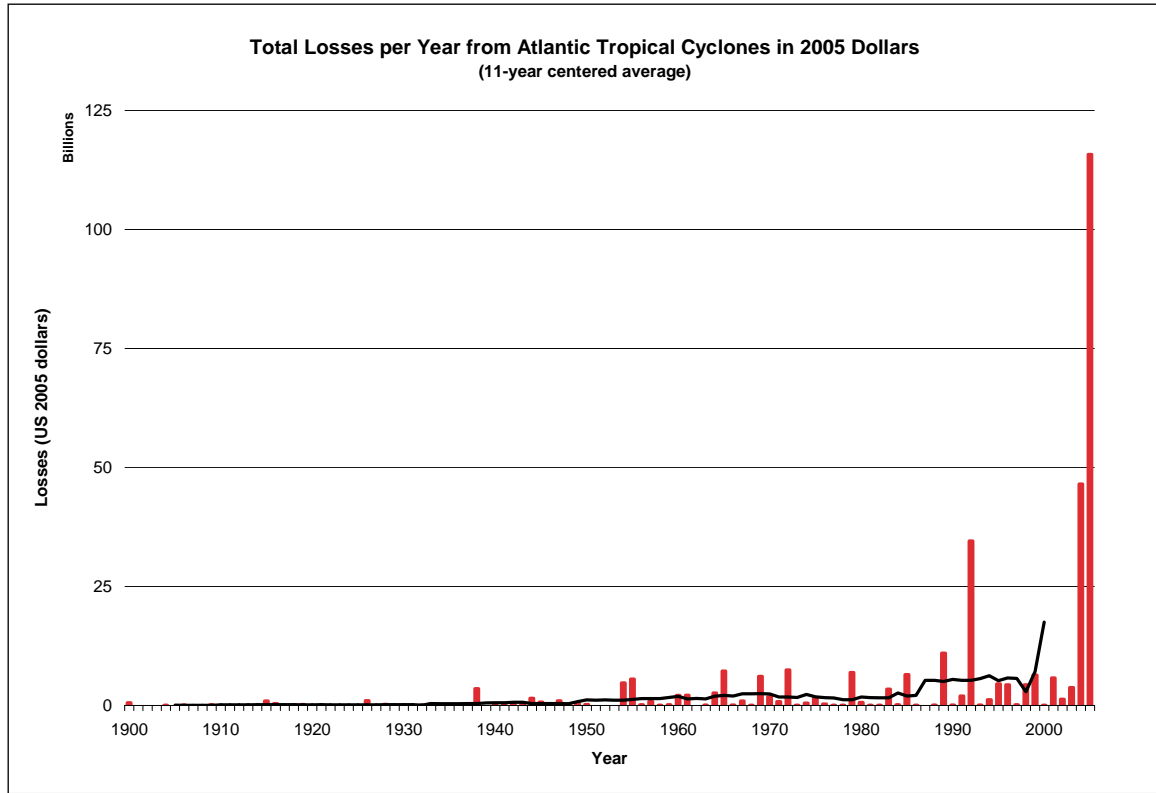
Figure 3

The total United States tropical cyclone losses adjusted only for inflation to 2005 dollars.

An upward trend in damages is clearly evident, but this is misleading since increased

wealth, population, and housing units are not taken into account.
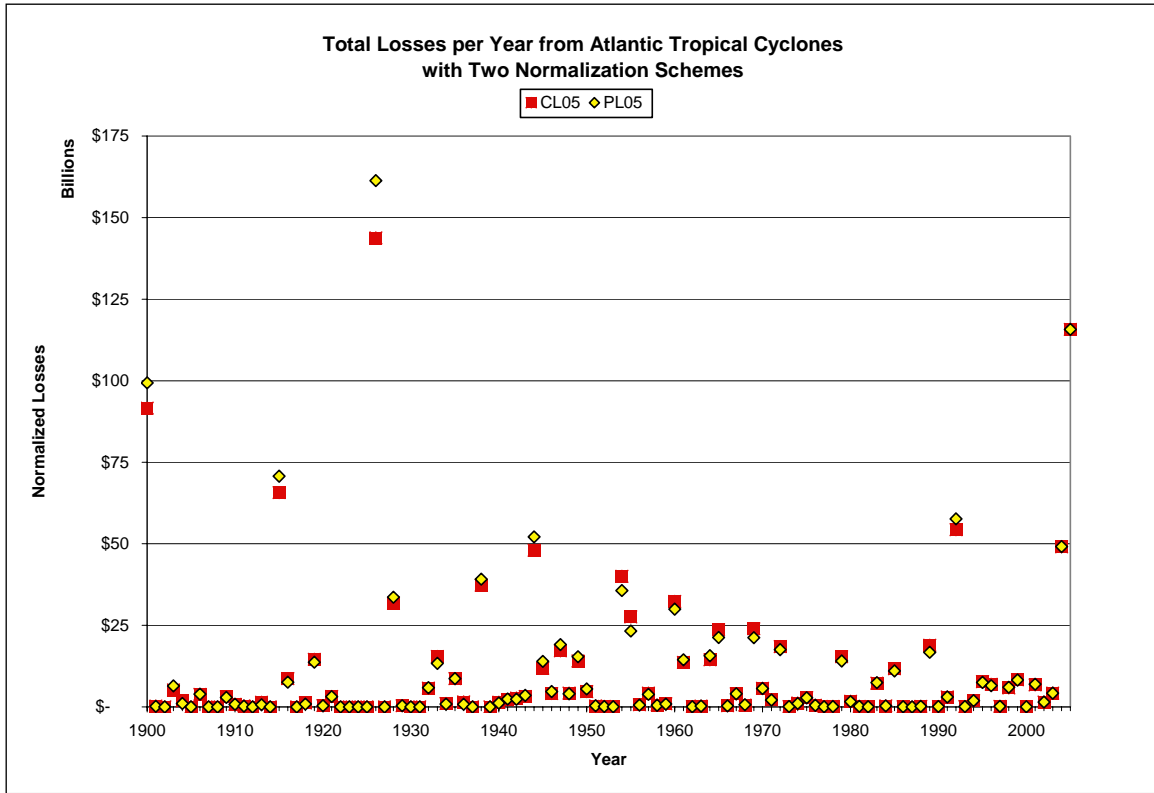
Figure 4a

Figure 4a-c

The total United States tropical cyclone losses normalized with both schemes (4a), only

the PL05 methodology (4b), and only the CL05 methodology (4c). Both schemes present

very similar results though PL05 focuses on population change whereas CL05 focuses on

changes in housing units. Although the 2004 and 2005 seasons produced high losses,

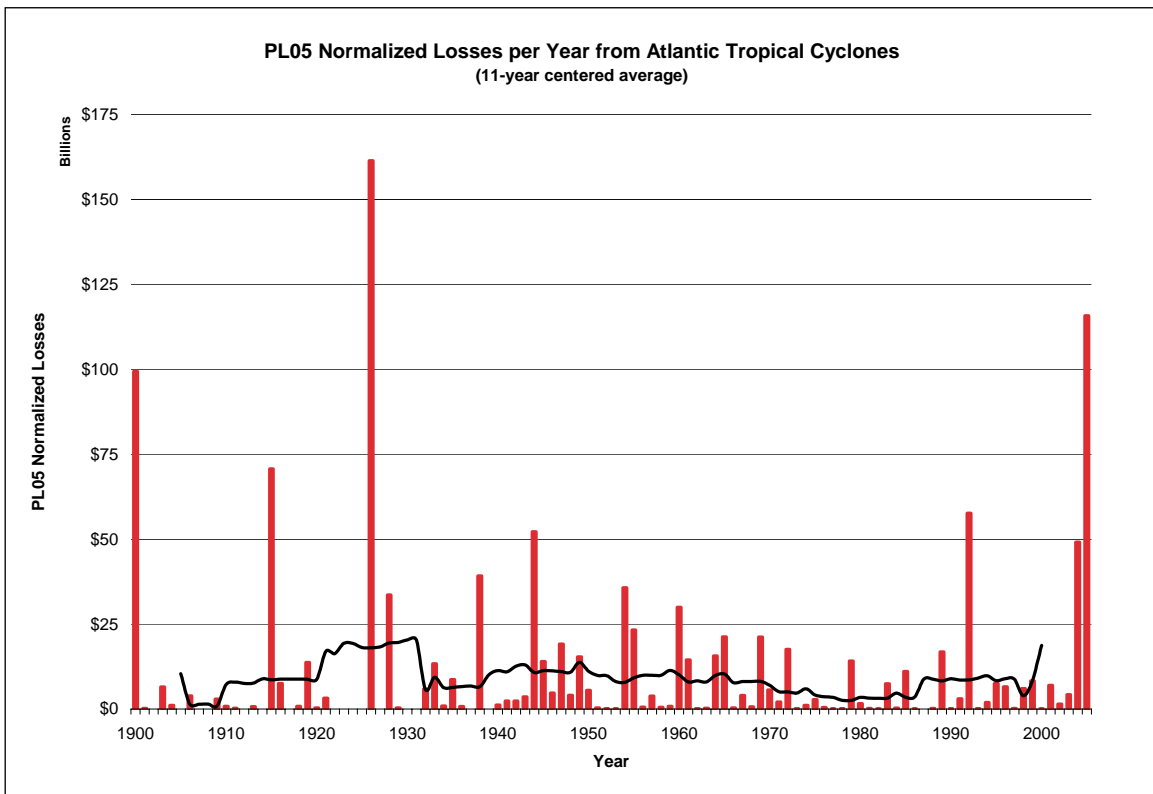these years are not unprecedented when considering normalized losses since 1900.

Figure 4b

Figure 4c