The Temporal and Spatial Variability of Economic Losses Due to Intense Hurricanes - A Comparative Analysis

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Abstract

A summary of national hurricane exposure is presented. A natural disaster model is then used to calculate the economic losses that past hurricanes would have caused if the value and geographical distribution of property had been the same as that in the 1990's. Multidecadal and interannual variability is observed that is consistent with recorded hurricane activities. The geographical distribution of the modeled losses demonstrates that hurricanes have the potential to cause enormous economic losses in regions that have not seriously experienced such damages in the past. Lastly, the results of this study are compared with the results of previous studies. The conclusion is that the Eastern United States is exposed to devastating hurricane damage levels.

Section 1 - The Problem of Hurricane Exposure

1.1 Background

The estimation of local potential hurricane damage is of critical importance to regulators, planners, and the insurance industry. In response, there have been two general approaches to understanding the magnitude of this problem. The first approach has used reported loss information from historical hurricanes and adjusted for inflation. Some studies also include changes in population and/or the density of durable goods ownership as additional factors in the adjustment. The second approach has used natural disaster models, creating an input portfolio that reflects the current distribution of properties in exposed regions and then running the portfolio through the simulated storm set to observe the probabilistic loss output.

There are limitations to both approaches. The first approach uses many assumptions regarding consistent relationships between reported losses, insurance buying patterns (e.g. deductibles and amounts of coverage), and property exposure; among other variables. The second approach makes broad assumptions about the components of the portfolio (e. g. commercial versus residential) and departs from known storms to rely on simulated storms.

We combined both approaches by using a natural disaster model and a representative coastal property portfolio, which is then simulated through known historical storms. The results are then scaled to Hurricane Andrew for current dollar analysis (although Hurricane Betsy is used for comparison to other studies so that all studies can contain a common data point.)

1.2 Hurricane Risk.

Why is this research important? Since 1992, there has been general acceptance that the magnitude of damage that could result from a significant hurricane is greater than previously thought. A study completed in 1992 (prior to Hurricane Andrew) but published a year later (Landsea, 1993) indicated that during the period 1940 to 1991, there had been an observable decline in the number of severe hurricanes. Intense hurricanes in the 1970's and 1980's were definitely lower than the period of the 1940's and the 1950's. This decrease however followed a close association with other prolonged global weather anomalies such as Sahel drought conditions. The study indicated that historic analysis alone is insufficient to assess exposure to future severe events and that underlying climatology of intense hurricanes and not mere historical analysis must serve as the basis for future estimates and extrapolations. Prior to Hurricane Andrew, estimates of the potential damage that a major hurricane could bring to the eastern United States were on the order of $10 billion.

Then in 1993, after the tragedy of Hurricane Andrew, reassessment of the damage potential began in earnest. Andrew alone caused approximately $25 billion in actual damage (Sheets; 1994) and regulators and insurance industry analysts realized that the exposure to much larger loss events was very plausible. Early estimates using natural disaster models (Clark; 1993) indicated that the

potential loss could be several times the size of Hurricane Andrew. Those early estimates indicated that an intense hurricane making landfall in Florida or New England could cause more than $100 billion in damage and that a similarly intense hurricane making landfall near Virginia or Maryland could cause $70 billion in damage. Finally, estimates of damage from an event in Texas or Louisiana were put at $50 billion or more.

The toll on human life is far more grave than the pure economic consequences of intense hurricanes. In events such as these, local plans and facilities to protect and evacuate people are simply overburdened. Despite excellent early warning systems, many people can be trapped as a hurricane bears down on their area (Sheets; 1994). In addition, hurricanes do change in direction, intensity, and speed. Some, such as Hurricane Opal, have veered off their expected course at the last moment causing some residents to be prepared for a storm that did not come and some residents to be caught unprepared (Larson; 1998). In fact, recent analysis of the bend in the Atlantic coast near the border of New Jersey and New York (called the 'New York Bight') revealed alarming conclusions. The federal Sea, Lake and Overland Surges from Hurricanes "SLOSH" computer modeling program used to establish evacuation plans showed that the combination of a major hurricane storm surge and the unique coastal properties of the New York / New Jersey border could leave many people without an avenue for escape. A large, fast moving hurricane with an accompanying large storm surge making landfall in this area could lead to massive loss of life – especially if people mistakenly use the subways for shelter.

1.3 Today's Exposure.

One may ask, is the SLOSH analysis of the New York Bight an indication of severely underestimated exposure to hurricanes or rather identification of an anomaly? To this end, there is ample literature to suggest that the exposure problem is severe and generally misunderstood. A number of respected authorities, following the work of Landsea, Clark, and Sheets, have provided ample evidence that the exposure problem was real.

Early in the spring of 1995, one set of authors (Durham, 1995) published a study stating that during the period 1986 to 1995, 87% of all property catastrophe losses were due to wind. Then, reviewing vulnerability relationships between structures and wind speed, the authors discussed how a 15% increase in wind speed could cause a doubling in damage. From this perspective, the authors then cited work commissioned by the Insurance Institute for Property Loss Prevention and performed by Applied Insurance Research (AIR) of Boston, Massachusetts. This study relied on simulated hurricanes and property distributions along the eastern coast of the United States to estimate that a class 5 hurricane making landfall in Miami could cause $50 billion in damage. Likewise a simulated class 4 hurricane making landfall near the New York / New Jersey border would also cause more than $50 billion in damage. Hurricanes in this study making landfall in Texas also caused significant damage – some in excess of $30 billion. The authors concluded that immediate improvements were needed in building codes and funding arrangements.

The Insurance Research Council performed a property analysis from another perspective, complementing research by Durham (Insurance Research Council, 1995.) This paper examined

the alarming trend of the population to move toward disaster prone areas. Specifically, from 1988 to 1993, the Florida population increased by 37%. During that time, the value of insured properties rose by 69%. More alarming is the trend from 1980 to 1993: Insured residential exposures increased by more than 150% and insured commercial exposures increased by almost 200%. The authors concluded that storms like hurricanes Hugo and Andrew could cause more than $50 billion in damage if landfall was made at a particularly vulnerable point.

Earlier AIR research was refined a year later with a full probabilistic analysis of the US property portfolio as a whole (Clark, 1996.) Again using computer simulation and a database of US property values, AIR estimated the return period of various size losses. For instance, according to this work, single hurricane losses of $8 billion or more can be expected to occur every 10 years. Similarly, losses of $25 billion or more can be expected to occur about every 50 years. Lastly, losses of $50 billion or more can be expected to occur every 500 years.

In 1997, acceptance of the exposure problem was beginning to take hold not only in the insurance industry but also the scientific community. Research financed by the insurance industry and performed by scientists (mostly from the Bermuda Biological Research Station) produced an assessment that Hurricane Andrew losses could have been between $50 billion and $100 billion if the storm had made landfall just to the north of the city of Miami (Risk Prediction Initiative, 1997.)

Summarizing these efforts with his own work and the work of others, Professor William Gray then appeared before Congress in the spring of 1997 and made several very important observations (Gray, 1997.) Dr. Gray's remarks clearly explained the explosion of values at our coastline. Many people were moving to the coast and these people tended to be among the most affluent. They brought with them a much higher per capita amount of durable goods. From the period 1900 to 1996, the per capita durable goods ownership rate increased by over 400%. Additionally, these population and wealth migrations occurred at a time that hurricanes were at all time lows for frequency and severity due to normal inter-decadal volatility. The result was that a huge increase in coastal exposure was being masked by a temporary lull in hurricane activity. In fact, he stated that a 1960 hurricane, if normalized for these effects would be 1500% greater in 1997 than in 1960. And he made this statement while indicating that we are returning to a more normal period of intense hurricanes as seen in the 1940's and 1950's.

Then, in 1998, the perceptions of Dr. Gray were further ratified by others. In April 1998, there was additional testimony before Congress by an insurance industry group (American Insurance Association "AIA", 1998). The AIA statement said that, due to population changes, 7 of the 8 worst natural disasters in the United States occurred during the last 10 years. Moreover, their projections indicate that by the year 2000, 75% of the US population will live less than 10 miles from a coastline or a major active earthquake fault.

1.4 Economic Impact.

The AIA testimony points to the final part of the problem. The problem is not merely that exposures are increasing. The problem is that this increase is disproportionate to the economy's ability to cope. AIA concluded that the US economy (including the insurance industry) was simply not prepared for the massive hurricane and its socioeconomic toll, emphasizing a point made only recently in other research. From as early as 1996, there were papers indicating that the insurance capital base was inadequate to support the losses from these hurricanes. One early work (Litzenberger et. al. 1996) indicated that the capital markets were the only logical alternative given the size of the exposure and the lack of insurance industry capital.

In 1997, some peculiar aspects of the economics of insurance were well highlighted in an industry publication (Meyer, 1997.) The availability of insurance protection compounds the fact that many consumers make choices about where to live and work based on a very short-term memory of disaster events. The effect of insurance is not solely the indemnification of consumers and businesses that have suffered a loss. Rather, it facilitates the process whereby initial awareness gives way to actual ignorance of the danger. As people migrate to an exposed area, they do tend to be aware of the peril initially. However, as they purchase insurance and an event does not affect them directly, their awareness and concern drops because feel financially protected. Subsequently, as years of insured protection go by and risk awareness continues to drop, people also begin to lose interest in loss prevention and prudent risk avoidance. As each catastrophe-free year passes, consumers feel progressively more comfortable relying exclusively on financial protection and as a result, they build more, newer and costlier properties in disaster-prone areas.

Experts have continued to highlight the danger, even as consumers continue moving to exposed areas and the insurance industry struggles with the question of adequate financial capacity. Extensive testimony was offered to Congress in early 1998 regarding the need to address this issue (Nutter, 1998.)

A president of a reinsurance industry group (the source of most of the capacity used to fund disaster losses) said simply that the threat of a huge loss such as a $50 billion hurricane exceeds the resources of the insurance and reinsurance markets. Furthermore, at levels of about $45 billion, one could expect significant insolvencies in the marketplace. Lastly, FEMA director James Lee Witt stated in late 1998 that the cost of natural disasters is skyrocketing due to the migration of wealthy people to our coastlines (Schmid, 1998.)

1.5 The Need To Quantify Societal Risk

The case then is clearly made – hurricanes are a significant danger to our society and we may be at risk for inadequate financial protection after a major hurricane. How large then could such an event be? To understand the problem, we have conducted a normalization exercise of historical hurricanes in the following section. Recognizing that the approach to this exercise greatly influences the results, we then compare our results to the work done in five other studies in the final section.

Section 2 - A New Study of Normalized Hurricanes

2.1 Introduction

Understanding the temporal and spatial variability of hurricane activity and its economic consequences is an extremely important task for anyone with a stake in areas prone to hurricanes. This is especially true for risk managers, emergency management agencies and the whole insurance industry because of the widely spread aggregate damage and relatively high frequency associated with intense hurricanes compared to other natural disasters such as damaging earthquakes.

Historical data are the first and most direct source for studying this problem. In fact, they provide the basis for the current understanding of hurricane climatology, including the frequency and severity distributions at various locations (e.g. Ho et al., 1987; Landsea, 1993; Neumann, 1987). However, for studying economic losses due to hurricanes, historical data are not necessarily adequate and, sometimes, can be even misleading. For example, as shown in Pielke and Landsea (1998), analyses relying primarily on historical economic losses would conclude that hurricanes have become more intense and frequent. However, when the economic losses are adjusted with respect to inflation and population and wealth changes, such a trend no longer exists.

The goal of this study is, under a uniform modeling framework, to analyze the temporal and spatial variability of economic losses caused by intense hurricanes with Saffir-Sampson Intensity (SSI) of 3 and above. We focus on the coastal states in the eastern and southeastern US (from Texas to Maine). Our data and methodology are described in Section 2. Results are presented in Section 3. A summary is provided in Section 4.

2.2 Methodology and Data

A natural disaster model is used to calculate economic losses caused by intense hurricanes in this study. The model, USWIND version 4.0 by EQECAT, Inc. of San Francisco California is similar to most other natural disaster models in that it contains both publicly available and proprietary information. The former includes historical hurricane path and intensity data and wind field models. The latter includes damage functions (i.e. percent damage as a function of wind speed) for various structures types. These functions are usually derived from claim data collected by the insurance industry and engineering studies.

Although most natural disaster models available today are essentially proprietary, independent users have carefully evaluated selected models before making multi-million dollar decisions based on their results (e.g. Kelly and Zeng, 1996; Zeng and Kurtz, 1997). These studies show that these models generally produce credible results for a portfolio consisting of a large number and geographically diversified locations.

To study the overall economic impact due to intense hurricanes, the geographical location, structure and content characteristics and values of all properties would ideally be included in the input to the natural disaster model. However, this is not plausible because no such data are

available. To alleviate this shortfall, we opt for an alternative data set: the residential housing value, at the county level, as of 1990. This data set is available from the US Census Bureau. The total housing value for a county is then partitioned evenly to zip codes within the county, producing a data set of total housing value at the zip code level. This partition is based on the assumption that, overall, the denser the zip codes, the denser the population (and hence the higher the property concentration). This data set is used as the input to the natural disaster model.

To measure the economic losses due to hurricanes, we use a normalized loss index L_A^i , defined as

$$L_A^i = L^i / L^{AND} \qquad \text{eq. 1}$$

where L^i and L^{AND} are, respectively, the natural disaster model outputs for Hurricane No. *i* and Hurricane Andrew of 1992. Andrew is chosen as the norm because of well-documented loss information about this event, which caused approximately $25 billion in economic loss. L_A^i is a quantitative measure of the economic loss associated with a hurricane relative to that with Hurricane Andrew.

The input data set represents a subset of all properties because it does not include commercial or governmental properties or the value of contents. When this data set is used as the input to the natural disaster model, the output also represent only a subset of the overall economic losses. Nevertheless, the housing value data closely approximate the geographical concentration of all properties. Consequently, the natural disaster model output (based on residential housing values) provides a fairly representative description of the concentration of total economic losses. As a result, we believe that the quantity L_A^i defined above is an adequate measurement of the temporal and spatial variability of hurricane-associated economic losses.

2.3 Analyses

The geographical distribution of the input data is shown in Figures 1A and 1B. It reflects the relatively high concentration of property values along the coast prone to hurricanes.

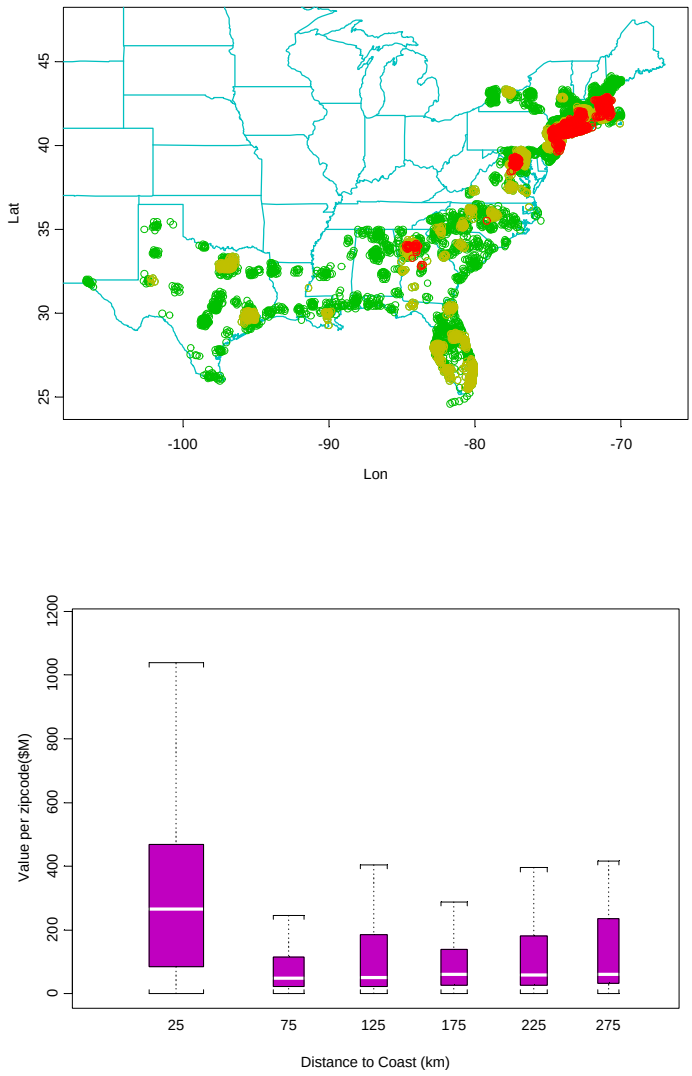

Figure 1. Housing value distribution. (A, top panel): green, yellow and red dots represent zip codes with housing values above the 50th, 75th and 90th percentiles, respectively. (B, bottom panel): box-plot of housing value distribution as a function of distance form coast. For example, the first box from left includes the zip codes whose distance from the coast is between 0 and 50 km. The width of a box is proportional to the number of zip codes in the category. The white line represents the median housing value. The upper and lower bounds of the box represent the lower and upper quartile of housing values. The upper and lower brackets represent 1.5 times of inter-quartile from the upper and lower quartiles, respectively.

The model output consists of economic losses on the zip code level associated with the 70 intense hurricanes between 1990 and 1996. A sample natural disaster model output for Hurricane Andrew is shown in Figure 2.

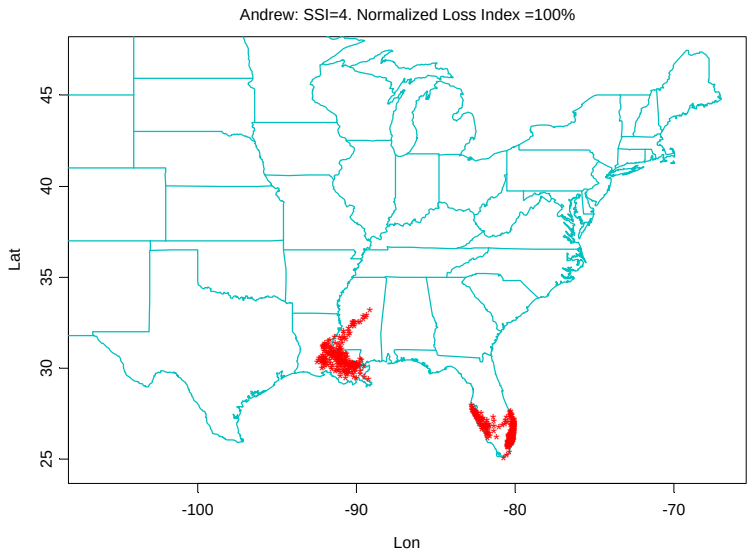

Figure 2. Zip codes (in red) affected by Hurricane Andrew of 1992, a SSI 4 hurricane.

We first examine the temporal variability of economic losses (Figure 3).

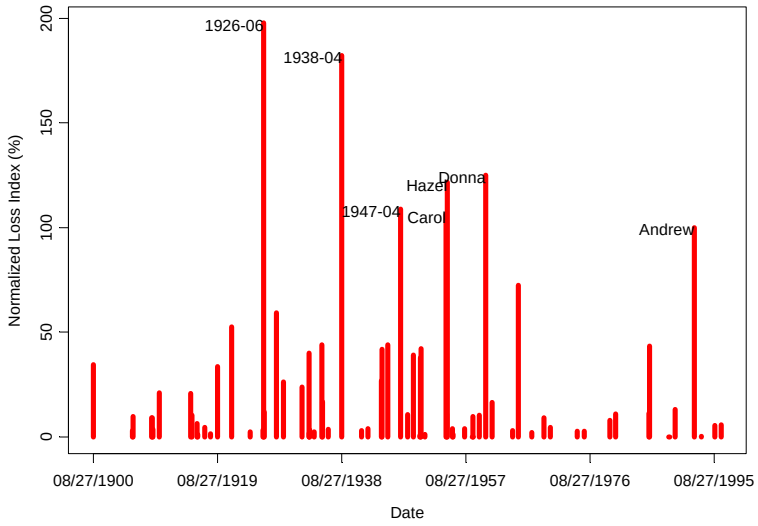

Figure 3. Normalized Loss Indices (L_A^i) for past hurricanes (those with L_A^i greater than or equal to that of Hurricane Andrew are labeled).

As actual past hurricanes are applied to the same underlying properties, strong multi-decadal variability becomes evident, which is consistent with the findings of Landsea (1993). Furthermore, no strong increase in frequency or severity is apparent. This lack of an increasing trend is

consistent with the consensus findings of a group of researchers at the United Nations World Meteorology Organization (IPCC, 1996.) In fact, our study shows that Hurricane Andrew is no longer the 'worst' hurricane to have hit the United States. Restated using our normalization scheme, Andrew is surpassed by the following hurricanes in terms of damage.

Year	Name	SSI	Normalized Loss Index L_A^i
1926	1926-06	4	198
1938	1938-04	3	182
1960	Donna	4	125
1954	Hazel	4	122
1947	1947-04	4	109
1954	Carol	3	106
1992	Andrew	4	100

Table 1. Normalized hurricane losses, using actual hurricanes and a property portfolio that reflects the current US distribution of property values.

From this analysis and the assumption that the Hurricane Andrew baseline economic loss is approximately $25 billion, we can infer that actual normalized economic hurricane losses of $25 to $50 billion would have occurred 7 times during the last century. This is well within the range suggested by the study referenced in section 1.3 above (Clark, 1996). In fact using this historical analysis, the return period of losses in excess of $25 billion based on this analysis is roughly every 14 years so one may ask whether that study's return period of 50 years actually underestimates the probability of a loss in that magnitude. This approach would make the same mistake as those who in the late 1980's concluded that large hurricanes could cause a maximum of $8 billion in damage. We must remember that the Landsea study (1993) made it clear that the underlying climatology of intense hurricanes and not mere historical analysis must serve as the basis for future estimates and extrapolations (section 1.2 above.)

The geographical distribution of actual past hurricane losses are analyzed next. The intense hurricanes are categorized with respect to their entry point measured by mile post (i.e. approximate mileage from the Texas/Mexico boarder along a smoothed coast line). The result is demonstrated in Figure 4. It is evident that southern Florida experienced the most and worst hurricanes. Although the region that experienced the next most frequent hurricanes is the Gulf coast, the northern Atlantic coast experienced the next most damaging hurricanes.

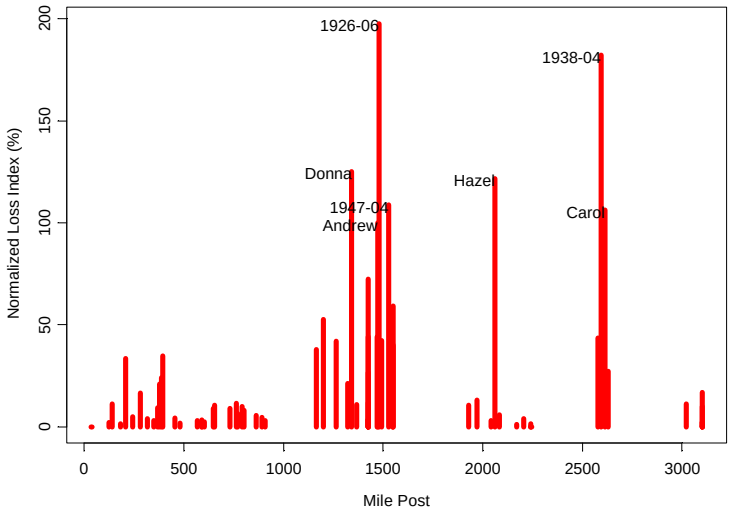

Figure 4. Normalized Loss Indices (L_A^i) for the past hurricanes vs. their respective entry points (those with L_A^i greater than or equal to that of Hurricane Andrew are labeled). For example, mile posts 1500, 2000, and 2600 are roughly located in southern Florida, South Carolina, and Suffolk, New York.

Figure 5 shows the temporal-spatial distribution of the Normalized Loss Indices for the past hurricanes. In fact, Figures 3 and 4 are effectively based on the aggregates along the vertical and horizontal axes of Figure 5, respectively. This two-dimensional perspective illustrates that temporal (e.g. multi-decadal) variability is region-dependent. For example, the period between 1920 and 1960 is characterized by both a high frequency of huge losses in southern Florida and a low frequency of losses along the Gulf coast. However, the relatively short record does not allow the spatial correlations to be meaningfully investigated.

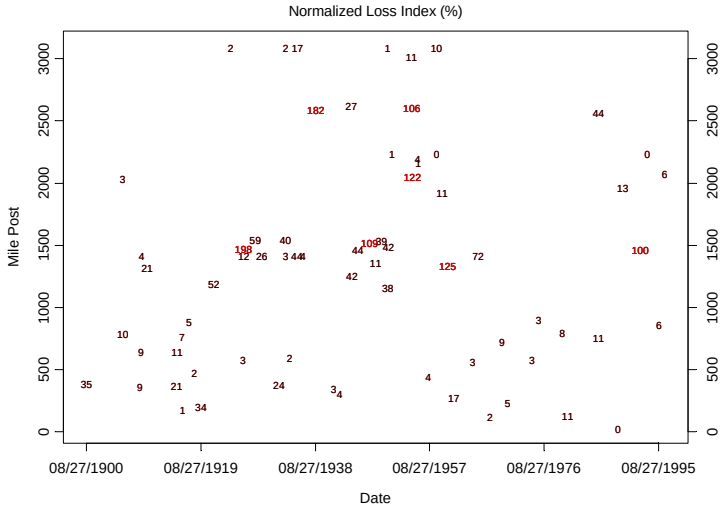

Figure 5. The temporal-spatial distribution of Normalized Loss Indices (L_A^i) for past hurricanes (those with L_A^i greater than or equal to that of Hurricane Andrew are labeled in red).

Finally, we analyze the accumulated hurricane loss on a zip code level, defined as

$$A_Z = \Sigma_i \, [L_A^{\,i}(z)], \; i = 1, M \qquad \text{eq. 2}$$

where z is a zip code, $L_A^{\,i}(z)$ is the normalized loss index for zip code z caused by hurricane No. i. M is the total number of intense hurricanes used by the model. A_Z measures the overall hurricane exposure of a location with both frequency and intensity considered. Figure 6 illustrates the zip codes with high A_Z values.

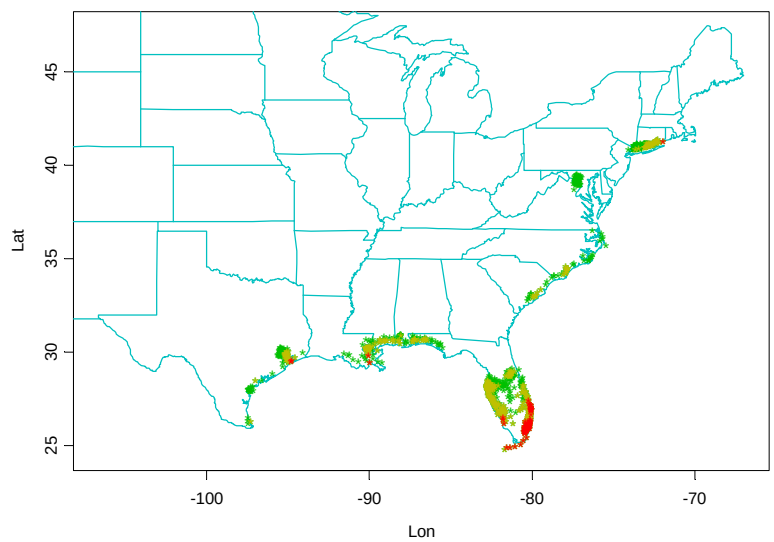

Figure 6. Zip codes with high accumulated losses. Green, yellow and red dots represent zip codes with accumulated losses above the 90th, 95th and 99th percentiles, respectively.

2.4 Kelly/Zeng Study Summary

Using the approach of a uniform modeling framework, this study analyzed the temporal and spatial variability of economic losses caused by intense hurricanes. From a temporal point of view, there is no trend toward more frequent and damaging hurricane, although strong multi-decadal variability is evident. Furthermore, there also exists significant spatial variability. Southern Florida is identified as the region where the most frequent and severe economic losses are expected due to intense hurricanes. The Gulf coast is expected to experience frequent but less severe losses. Importantly, the northern Atlantic coast, including New York City, is exposed to infrequent but huge hurricane losses primarily due to the high property value concentration in this region.

Section 3 - Comparing Various Studies of Normalized Hurricane Losses

3.1 Normalizing Across Studies

How does this study compare with works done by others to estimate how large losses would be if they occurred today? This is a difficult comparison since the studies took place at different points in time and all the authors published results in absolute dollar terms, restating results for the year of the study (which varied form 1987 to 1998.) Furthermore, since the mechanism used to inflate the older hurricane losses is the very issue being examined, restating the works done by others to reflect subsequent changes in inflation and/or population would introduce another possible (and independent) reason for any differences. To overcome this difficulty, the results of the study in section 2 above and all results from studies were further normalized against a data point included in all studies: Hurricane Betsy. Following the convention established in equation 1 of section 2.2, results from the following studies will utilize the following internal normalization scheme:

$$L_B^{\,i} = L^i / L^{BET} \qquad \text{eq. 3}$$

where L^i and L^{BET} are, respectively, the natural disaster model outputs for Hurricane No. *i* and Hurricane Betsy of 1965.

3.2 Other Hurricane Normalization Studies

Four additional studies will be used for comparison purposes. The first was done in a landmark volume during the quiet hurricane period of the late 1980's (Friedman, 1987.)
In this study, researchers started with original reported losses from historical hurricanes. They then used two inflation factors; the first for changes in dollar inflation and the second for changes in market size (population.) Their results, stated in terms of L_B^i as defined in equation 3 appear in figure 7.

Friedman Study - 1987

Rank	Year	Name	L_B^i
1	1965	Betsy	100
2	1954	Hazel	44
3	1954	Carol	39
4	1970	Celia	25
5	1960	Donna	21
6	1961	Carla	20
7	1979	Frederic	20
8	1950	King	16
9	1983	Alicia	14
10	1949	1949-FL	13
11	1969	Camille	13
12	1964	Cleo	13
13	1985	Elena	9
14	1955	Connie	8
15	1957	Audrey	8
16	1985	Gloria	7
17	1975	Eloise	6
18	1954	Edna	5
19	1967	Beulah	4
20	1979	David	3

Figure 7. Normalization component of the study done in 1987 by D. G. Friedman.
Data: Storms from 1949 to 1986 in classes 1 through 5

A second study was presented in 1992 at the 14th Annual National Hurricane Conference in Norfolk, VA (Sheets, 1992.) In this work, the authors used changes in coastal populations, property value changes, and inflation to adjust past hurricanes. Initial indications in the paper were that a South Florida hurricane could result in damage of $35 billion, a number the author at the time deemed to be "unreasonably high." Little did he know that four months later, a class 4 hurricane (Andrew) would cause nearly that very amount, calling into question how conservative the numbers were.

The results of this study appear below in figure 8.

Sheets Study - 1992

Rank	Year	Name	L_B^i
1	1989	Hugo	111
2	1965	Betsy	100
3	1972	Agnes	99
4	1969	Camille	81
5	1955	Diane	65
6	1938	1938-NE	56
7	1979	Frederic	54
8	1983	Alicia	37
9	1954	Carol	37
10	1961	Carla	30
11	1960	Donna	28
12	1985	Juan	26
13	1970	Celia	24
14	1991	Bob	23
15	1954	Hazel	22
16	1985	Elena	22
17	1926	1926-FL	20
18	1964	Dora	18
19	1975	Eloise	17
20	1985	Gloria	16

Figure 8. Normalization component of the study done in 1992 by R. C. Sheets.
Data: Storms from 1901 to 1990 in classes 1 through 5

One of the first post-Andrew papers to include normalization amounts was done as part of a book that appeared three years after the hurricane (Kamford, 1995.) In this work, the author adjusted reported losses for inflation using the Boeckh Construction Costs Index as well as a "Demographic Shift Factor" based on US Census population data. His focus included earthquakes, fires, and winter storms and those results have been excluded from the table of his work that appears below in figure 9.

Kamford Study – 1995

Rank	Year	Name	L_B^i
1	1992	Andrew	361
2	1950	King	147
3	1989	Hugo	109
4	1965	Betsy	100
5	1964	Hazel	64
6	1954	Carol	62
7	1970	Celia	47
8	1960	Donna	40
9	1961	Carla	36
10	1979	Frederick	33
11	1950	Easy	33
12	1964	Cleo	27

Figure 9. Normalization component of the study done in 1995 by P. L. Kamford.
Data: Storms from 1949 to 1994 causing at least $1B in damage

Last year, two authors took the methodology a bit further (Pielke and Landsea, 1998.) In this work, the starting point was again the actual reported historical loss for the hurricane, but the normalization method included a price adjustment using the Gross National Product deflator, a wealth indicator reflecting per capita wealth relative to the base year, and a relative population factor. The time period of the study was also the most extensive yet, covering the period 1900 to 1994.

Their results appear below in figure 10.

Pielke / Landsea Study – 1998

Rank	Year	Name	L_B^i
1	1926	1926-FL/AL	581
2	1992	Andrew	266
3	1900	Galveston	214
4	1915	Galveston	182
5	1944	SW Florida	136
6	1938	New England	134
7	1928	SE Florida	111
8	1965	Betsy	100
9	1960	Donna	97
10	1969	Camille	88
11	1972	Agnes	86
12	1955	Diane	82
13	1989	Hugo	75
14	1954	Carol	73
15	1947	SE FL/LA/AL	67
16	1961	Carla	57
17	1954	Hazel	57
18	1944	1944-NE	53
19	1945	1945-FL	51
20	1979	Frederic	51

Figure 10. Normalization component of the study done in 1998 by Pielke and Landsea.
Data: Storms from 1901 to 1995 in classes 1 through 5

Finally, the work done in section 2 needs to be restated for the L_B^i normalization method. Taking the simulated damage from the actual historical storm set within the EQE software and presenting the results in L_B^i format, the storms with the worst damage appear below in figure 11.

Kelly / Zeng Study - 1999

Rank	Year	Name	L_B^i
1	1926	1926-FL	273
2	1938	1938-NE	252
3	1960	Donna	173
4	1954	Hazel	168
5	1947	1947-FL	150
6	1954	Carol	147
7	1992	Andrew	138
8	1965	Betsy	100
9	1928	1928-FL	82
10	1921	1921-FL	72
11	1935	1935-FL	61
12	1945	1945-FL	61
13	1985	Gloria	60
14	1950	King	58
15	1944	1944-NE	58
16	1933	1933-NC	55
17	1949	1949-FL	54
18	1950	Easy	52
19	1900	1900-TX	48
20	1919	1919-FL/TX	46

Figure 11. Normalization component of the study in section 2, restated for normalization against Hurricane Betsy of 1965 instead of Hurricane Andrew of 1992. Data was all hurricanes from 1900 to 1996 in classes 3, 4, and 5.

3.3 Comparing the Studies

Admittedly, it is still difficult to compare the results, even with the normalization of the authors work done with L_B^i. This is because the authors did their works at different points in time and also choose different timeframes and different selection criteria. To make this comparison as easy as possible, the studies are shown side by side and the results of the L_B^i numbers are displayed in ranking terms. These results are in figure 12 below.

Multi-Study Ranking Comparison

		1999	1998	1995	1992	1987
Year	Hurricane	Kelly/Zeng	Pielke/Landsea	Kamford	Sheets	Friedman
1926	1926-FL	1	1	ni	17	ni
1938	1938-NE	2	6	ni	6	ni
1960	Donna	3	9	8	11	5
1954	Hazel	4	17	5	15	2
1947	1947-FL	5	15	ni	23	ni
1954	Carol	6	14	6	9	3
1992	Andrew	7	2	1	ni	ni
1965	Betsy	8	8	4	2	1
1928	1928-FL	9	7	ni	over 20th	ni
1921	1921-FL	10	over 20th	ni	over 20th	ni
1935	1935-FL	11	over 20th	ni	over 20th	ni
1945	1945-FL	12	19	ni	over 20th	ni
1985	Gloria	13	over 20th	ni	20	16
1950	King	14	over 20th	2	over 20th	8
1944	1944-FL	15	5	ni	21	ni
1933	1933-NC	16	over 20th	ni	over 20th	ni
1949	1949-FL	17	21	ni	over 20th	10
1950	Easy	18	over 20th	11	over 20th	over 20th
1900	1900-TX	19	3	ni	23	ni
1919	1919-FL/TX	20	over 20th	ni	over 20th	ni
1989	Hugo	over 20th	11	3	1	ni
1972	Agnes	over 20th	9	ni	3	over 20th

Figure 12. A comparison of the normalizations done by the five studies.
"ni" indicates the storm was not included in the study
"over 20th" indicates the storm did not rank in the top 20 storms for the study

What conclusions can be drawn from figures 7 through 12? Despite the differences in methodology discussed in section 1.1, there are a number of striking similarities. First, of all the hurricanes that have occurred during the last century, the storm that should be termed most severe in terms of normalized damages is probably not Hurricane Andrew. This can be seen most clearly in figures 10 and 11 where studies done with the most data indicate Andrew pales in comparison to the hurricane of 1926 in Southern Florida.

Secondly, the differences in methodology may account for much of the differences in ranking. For instance, our methodology used in section 2 relies on residential data for density of values and probably uses too simplistic a methodology of values placement to account for the resolution needed for the analysis. The methodology employed by most of the other studies starts with reported losses which implicitly assumes that the reported loss mechanism has been relatively constant and remains in constant proportion to underlying damage. This is probably not so since hurricanes have significant differences in the ratio of commercial to residential property losses and in unreported losses.

Further work should be done in this area to reconcile the differences in these two methodologies. Whatever the outcome of that research is, however, the undeniable fact remains that the Eastern Coast of the United States is severely exposed to unprecedented hurricane damage because of a period of coastal property growth that coincided with unusually low hurricane activity. As the dual effects of growth and hurricane patterns are adjusted to impose the historical pattern of hurricanes upon the properties of today, the conclusion (regardless of the methodology) is a sobering one for regulators, planners, and the insurance industry alike -- we are a country and an industry with a disaster waiting to happen.

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