Estimating the Vulnerability of U.S. Coastal Areas to Hurricane Damage

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1. Introduction

Although hurricanes can strike most U.S. coastal states and cause damage in noncoastal states as well, some coastal areas are much more likely than others to experience the most costly storms. In the U. S., 40 percent of all major hurricanes have battered Florida, and 83 percent of category 4 or 5 hurricane strikes have pummeled either Florida or Texas (Blake et al., 2007). It is not surprising, therefore, that the Texas and Florida coastlines have experienced much more damage from hurricanes than other southeastern coastal areas. Of the 10 most costly hurricanes, 9 have struck the Texas or Florida coasts (Table 1).

Hurricanes have become much more costly in recent years; 8 of the 10 most damaging hurricanes have occurred since 2004. In total, the seven hurricanes in 2004 and 2005 caused $79.3 billion in insured losses. An increase in hurricane activity may explain some of the increased cost. After a period of infrequent hurricane activity between 1971 and 1994, hurricane activity has increased in recent years. The five most intense consecutive storm seasons on record occurred between 1995 and 2000. In 2004 an unprecedented four hurricanes, viz. Charley, Frances, Ivan and Jeanne, damaged Florida communities. And the 2005 hurricane season was the busiest and most costly in United States history, with 28 named storms, 15 of which were hurricanes, including Katrina (South Carolina Department of Insurance, 2007, 14).

Although a period of increased hurricane activity may have contributed to increased hurricane damage, other factors such as population growth and increased property values have contributed to the higher costs. In order to examine factors that influence hurricane damage we consider eight southeastern states: Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and Texas. We focus on this area because the greatest likelihood of severe damage from hurricanes is along the coastlines of the southeastern Atlantic and Gulf of Mexico states where 112 major hurricanes have struck between 1851 and 2006 (Blake et al., 2007). Understanding more about factors that increase coastal area vulnerability will help mitigate other coastal threats such as northeasters. Northeasters, which are powerful storms that have winds that blow from the northeast, can generate storm surge and waves that cause even greater damage than hurricanes. The Ash Wednesday storm of 1962, which was one of the most damaging northeasters, created waves more than 30 feet high and caused millions of dollars in damage along the mid-Atlantic coast.

In this study, we consider the various factors that increase an area's vulnerability to hurricane damage. We focus on the risk to the built environment not the loss of life from hurricanes, which has been greatly reduced in recent years, generally. However, the

Rank	Date	Area	Name	Dollars when Occurred (millions)	2008 dollars (millions)
1	Aug. 25-29, 2005	LA, MS, Fl	Katrina	$40,600	$45,309
2	Aug. 23-24, 25-26, 1992	SE FL, SELA	Andrew	15,500	23,786
3	Sept. 12-14, 2008	TX, LA	Ike	11,700	11,700
4	Oct. 24, 2005	SE & SW FL	Wilma	10,300	11,355
5	Aug. 13-15, 2004	SW FL	Charley	7,475	8,520
6	Sep. 16-21, 2004	NW FL, AL	Ivan	7,110	8,104
7	Sep. 17-18, 21-22, 1989	SC	Hugo	4,195	7,284
8	Sep. 20-26, 2005	LA, TX, FL	Rita	5,000	6,203
9	Sep. 5, 2004	SE FL	Frances	4,595	5,237
10	Sep. 15-25, 2004	SE FL	Jeanne	3,440	4,166

Table 1. The Ten Costliest U.S. hurricanes

Source: Insurance Information Institute

information we provide can increase the safety of coastal area residents and reduce the disruption to social order. In order to measure the degree of risk to coastal areas we calculate an index value that is composed of factors that affect hurricane damage costs. A better understanding of the factors that increase an area's vulnerability may help create polices that mitigate hurricane damage more effectively. In addition, we consider what effect increased vulnerability may have on insurance premiums for property owners.

2. Vulnerability analysis of coastal areas

Given the risks to which coastal communities are subject, understanding what affects the degree of risk for residents is important. Various authors have considered factors that influence the vulnerability of coastal areas to hurricanes and other threats.

Davidson and Lambert (2001) develop a Hurricane Disaster Risk Index in which they use factors such as hurricane frequency and emergency evacuation routes to examine the relative risk of economic and life loss in coastal counties. Jain et al. (2005) produce a case study of two North Carolina counties in which they find that building inventory changes affect losses significantly. Zandberger (2009), who examined the historic record of hurricanes for the period 1851 to 2003, finds that the top 10 counties in terms of cumulative exposure are in coastal Florida (6), North Carolina (3), and Louisiana (1). The factors that describe the exposure to hurricanes include distance to coast, latitude, longitude, size, and shape of the counties.

Thieler and Hammer-Klose (1999) create a physical vulnerability index to examine the vulnerability of U.S. coastal areas to sea level rise using mean tidal range, coastal slope, rate of relative sea level rise, shoreline erosion and accretion rates, mean wave height, and erodability. They find that sections of the mid-Atlantic coast – from Maryland south to North Carolina and northern Florida - are some of the most vulnerable areas to sea level rise. The most vulnerable areas generally are high-energy coastlines where the regional coastal slope is low and where the major landform type is a barrier island. Although they consider an areas vulnerability to sea level rise, similar physical conditions may contribute to increased flood damage from hurricanes. Boruff et al. (2005) use socioeconomic and

physical characteristics to examine the vulnerability of coastal area residents to erosion. They find that physical characteristics (such as coastal slope, sea level rise, and mean wave height) determine Atlantic and Pacific Ocean vulnerability and social characteristics (such as persons age 65 and over) determine Gulf of Mexico vulnerability.

3. Factors that influence hurricane damage costs

Most damage from hurricanes is caused by high winds and storm surge, which is the water that a hurricane's wind pushes toward shore. A major hurricane, which would be a category 3, 4, or 5 on the Saffir/Sampson Hurricane Scale, has winds that exceed 110 miles per hour. A storm surge of up to twenty-eight feet above average sea level was recorded in Mississippi during Katrina (Masters, 2010). If the storm surge is accompanied with high tide, the damage is even greater.

Three interacting elements contribute to the amount of damage caused by a hurricane: the amount and type of property at risk, the degree of vulnerability of the property, and the likelihood of the natural disaster. We examine the contribution of the three elements to property damage for the coastal counties of the eight southeastern states. We use only the coastal counties because hurricane damage is greatest, generally, in coastal areas where the damage from wind and storm surge is most severe. We define a coastal county as one that has some land area exposed to the Atlantic Ocean or Gulf of Mexico, which is the definition used by the United States Geological Survey. There are 99 coastal counties in the southeastern U.S. states that meet this criterion.

Population growth and increased property values in coastal areas are major contributors to the increased damage costs from hurricanes. Although the 10 most costly hurricanes have occurred since 1989, earlier hurricanes could be more damaging but not as costly because population and development was much less. Pielke et al. (2008) normalize hurricane damage by adjusting for inflation, wealth, and changes in population and housing units. After adjustments they find that the decade with the greatest cumulative damage was 1926 to 1935, and the most damaging single storm was the 1926 Great Miami storm, which caused $140 to $157 billion of normalized damage.

Coastal population has increased much more rapidly than the nation's population. Population in the U.S. and southeastern coastal counties has increased by 27 and 40 percent, respectively, from 1970 to 2000. In addition, population density is much higher in coastal areas. In 2000, average population density in the U.S. and southeastern counties was 80 and 290 people per square mile, respectively (Table 2). In many coastal areas housing growth has exceeded population growth as property owners have built second homes and rental properties. The number of houses in southeastern coastal counties has increased by 51.9 percent from 1970 to 2000. The density of houses in coastal counties was 72.3 houses per square mile in 2000 which was an increase of 59.3 percent from 1970 (National Oceanic Economics Program, 2009).

In addition to the increased number of houses, property values in coastal areas have increased in recent decades. The AIR Worldwide Corporation (2008) estimates that insured property value in the coastal U.S. was $8,891 billion in 2007. The insured value of coastal area properties grew at a compound annual growth rate of just over 7 percent from 2004 to 2007; that growth rate will lead to a doubling of the total value every decade (AIR 2008). Several factors such as inflation, higher building costs, and larger homes cause higher housing prices. In the U.S. the average size of a single family house has increased from 983 to 2434 square feet between 1950 and 2005 (National Home Builders Association, 2007). In

Coastal Counties	Population 1970	Population 2000	Population Growth Rate	Average Population Density (per square mile of land)
Alabama	376,690	540,258	43.42%	206
Florida	5,388,655	12,285,697	127.99%	410
Georgia	281,157	439,154	56.20%	159
Louisiana	1,415,649	1,658,507	17.16%	431
Mississippi	239,944	363,988	51.70%	199
North Carolina	477,404	792,902	66.09%	112
South Carolina	497,984	884,925	77.70%	140
Texas	2,830,354	5,041,960	78.14%	262
United States (Total)	203,211,926	281,421,906	38.49%	80

Table 2. Population Growth in Southeastern Coastal Counties

Source: U.S. Census (author's calculations)

coastal areas, homes as large as 5000 square feet are not uncommon and rental homes as large as 10,000 square feet with 16 bedrooms have been built. Large oceanfront homes that provide seasonal rentals have replaced smaller single-family cottages that were once a popular form of accommodation for visitors.

Strengthening buildings with hurricane resistant construction reduces damage costs. Fronstin and Holtman (1994) found that Hurricane Andrew, which struck Florida in 1992, caused less damage in subdivisions with higher average home prices. Although houses were more expensive in higher income areas, because the houses were more storm-resistant, nearby houses suffered less damage from wind-blown debris. States enforce building codes that have been designed to create more hurricane resistant housing. However, agencies may not do an adequate job of enforcement. Areas with a larger number of older houses, which are less hurricane resistant, generally, may suffer greater damage costs.

Although it is not possible to predict where or when hurricanes will strike, the likelihood of a major hurricane striking an area can be estimated using climatology data. The climatological probability of a major hurricane strike in the southeastern states is highest in Florida (21 percent) and lowest in Georgia (1 percent) (U.S. Landfalling Hurricane Probability Project, 2010). In addition, the past history of hurricane strikes provides some indication of which areas are likely to be struck by a hurricane. The highest and lowest expected return period of a major hurricane is 9 and 34 years for Miami-Dade County (Florida) and Chatham County (Georgia), respectively (Blake et al., 2007).

The geology of a coastal area may increase the likelihood of hurricane damage. For example, storm surge may be more damaging if the shoreline has a shallow beach slope or a bay that funnels storm surge. The rate of shoreline erosion (which averages two to three feet per year along the Atlantic coast and six feet per year on the Gulf coasts) may affect hurricane damage because beaches absorb and dissipate wave force. The force of waves causes much of the storm related damage in coastal areas. Mean wave height and sea level rise are two other physical factors that may impact hurricane damage.

4. The hurricane vulnerability index

In order to rank the susceptibility of coastal areas to hurricane damage we calculate a Hurricane Vulnerability Index (HVI) which is a composite of the elements that contribute to hurricane damage. Three elements contribute to the degree to which communities

experience hurricane damage: (1) the level of exposure, (2) physical susceptibility to the hurricane, and (3) the hurricane's frequency and intensity. Each element is comprised of several indicators that represent characteristics of risk. The seven indicators that we employ are: population, number of housing units, house value, probability of hurricane strike, building code effectiveness, building age, and vulnerability to sea-level rise.[1] The rationale for choosing these indicators was discussed in the previous section.

We use multiattribute utility theory to formulate the HVI (Keeney and Raiffa 1976). We standardize the indicators using a range from 1 to 10 because the indicators are measured in different units (dollars and percentage, e.g.). The value 1 is equal to the minimum risk and 10 is the maximum risk. The formula used to standardize the indicators is:

$$R_{ij} = (x_{ij} - min_i) * 10 / (max_i - min_i) \qquad (1)$$

where R_{ij} and x_{ij} are the scaled and unscaled value of risk indicator i for county j; and min_i and max_i are the minimum and maximum values for the ith indicator, respectively.

The HVI is calculated with the following equation:

$$HVI = (E)(S)(H) \qquad (2)$$

where E and S are the exposure and susceptibility to the hurricane, and H is likelihood of the hazard. We use a multiplicative model because risk is a product of exposure, susceptibility, and hazard. We weight the scaled values in order to adjust for the relative importance of the indicators. We use Saaty's (1980) analytic hierarchy process, which creates a pair wise comparison of the indicators, to guide in the selection of the appropriate weights. The three elements are calculated with the following equations:

$$E = w_{E1}R_{E1} + w_{E2}R_{E2} + w_{E3}R_{E3} \qquad (3)$$

$$S = w_{S1}R_{S1} + w_{S2}R_{S2} + w_{S3}R_{S3} \qquad (4)$$

$$H = w_{H1}R_{H1} \qquad (5)$$

where R_{E1}, R_{E2}, and R_{E3} are population, housing units, and housing value; R_{S1}, R_{S2}, and R_{S3} are building code effectiveness, average building age, and vulnerability to sea-level rise ; R_{H1} is hurricane probability; and w is the appropriate weight for each indicator

5. Case study

We estimate the HVI for a sample of southeastern counties in order to demonstrate the estimation process and method to interpret the results. This sample of counties provides at least one county from each of the eight states; we chose two counties from three states (Texas, Florida, and North Carolina) that have large coastlines and a high probability of hurricane strikes. The 11 counties are: Cameron (TX), Galveston (TX), Orleans (LA), Harrison (MS), Mobile (AL), Miami-Dade (FL), Bay (FL), Chatham (GA), Charleston (SC), New Hanover (NC), and Dare (NC). The indicator definitions, and minimum and maximum values, are listed in Table 3. There is significant variation between the indicators for the

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[1] We do not include indicators for non-residential construction but assume that it would be proportional to residential construction.

sample counties. Most of these coastal areas have experienced rapid population growth and development growth in recent decades despite the risk of hurricane damage.

Indicator	Minimum Risk	Maximum Risk
Resident Population	0	2253362
Number of Housing Units	0	852278
Median value of owner-occupied housing	0	137200
Climatological probability of hurricane strike (percent)	0	100
Average Building Code Enforcement Grade	1	10
Percentage of homes built after 1990	0	100
Vulnerability to sea-level rise	1	4

Table 3. Hurricane Vulnerability Index Indicators

We use values for population and housing data from the 2000 U.S. Census to estimate the four demographic HVI indicators. We use the coastal vulnerability index from Thieler and Hammer-Klose (1999) for a measure of the physical shoreline characteristics that increase the susceptibility to hurricane damage. We use the Insurance Services Office (ISO) rating on building code enforcement. The ISO's Building Code Effectiveness Grading Schedule evaluates the effectiveness of a municipality's enforcement of building codes. For the climatological probability, we use U.S. Landfalling Hurricane Probability Project estimations of the likelihood that a hurricane will strike a particular county.

The HVI value for the 11 sample counties is presented in Table 4. A higher HVI value indicates a county that where the risk of hurricane damage is greater. The maximum and minimum risk possible would be indicated by a value of 10 and 0, respectively. The most and least vulnerable county to hurricane damage from our sample is Miami (5.52) and Chatham (0.11), respectively, based on the HVI values. Examining the individual indicators can explain much of the ranking for a particular county. For example, of the 11 sample counties, Miami is the most at risk for three of the indicators – population, number of houses, and probability of a strike – and among the most risky for the other four indicators. Chatham County is the least at risk for two variables – probability and vulnerability – and near the lowest risk for two variables – population and the number of houses.

County	HVI Value
Miami-Dade, FL	5.52
Dare, NC	1.10
Charleston, SC	1.34
New Hanover, NC	0.42
Bay, FL	0.19
Harrison, MS	0.69
Galveston, TX	0.71
Orleans, LA	0.78
Cameron, TX	0.68
Chatham, GA	0.11
Mobile, AL	0.65

Table 4. HVI for sample counties

The hurricane return period, probability of a strike, and hurricane damage cost for each sample county is listed in Table 5. Comparing the HVI value to the historical hurricane damage cost provides some validation of the HVI values. The county with the most and least cumulative damage is Miami-Dade and Chatham, respectively. The two counties have the highest and lowest HVI, respectively. Between 1851 and 2006, the greatest number of major hurricane strikes occurred in Florida (37), and the fewest strikes occurred in Georgia (3) (Blake et al., 2007). Coastal areas that are predicted to have a higher probability of a hurricane strike – Miami-Dade, Charleston, Cameron, and Dare. - have the highest HVIs, generally. Although Cameron County has the third highest strike probability, its HVI is ranked sixth. This is partially the result of Cameron having the lowest housing values of the sample.

Examining individual indicators can indicate which factors contribute the most to risk for a particular county, and therefore which factors should receive the most attention. For example, Bay County's HVI is slightly higher than Chatham County's HVI. The principle difference between the indicators for the two counties is that Bay County has a much higher vulnerability indicator than Chatham. This difference may account for some of the higher historical damage costs for Bay County. The higher vulnerability for Bay County would suggest that hurricane mitigation efforts and resources should be focused on creating less vulnerable communities in Bay County. Building hurricane-resistant housing or protecting shorelines would be productive activities.

Counties	Return Period Hurricane (years)	Hurricane Strike Probability[1] (climatological)	Hurricane Damage Costs(1950-2008) (2008 $)
Cameron, TX	25	2.7	47,301,684
Galveston, TX	18	1.9	869,886,903
Orleans, LA	19	1.7	988,065,664
Harrison, MS	18	1.9	1,322,042,826
Mobile, AL	23	1.9	622,166,867
Bay, FL	17	0.5	164,097,087
Miami-Dade, FL	9	5.0	3,523,941,209
Chatham, GA	34	0.4	3,596,486
Charleston, SC	15	2.9	878,583,973
New Hanover, NC	16	1.1	399,547,814
Dare, NC	11	2.4	88,484,892

[1]Probability of intense hurricane striking the county

Sources: Blake et al., 2007; U.S. Landfalling Hurricane Probability Project; Hazards & Vulnerability Research Institute

Table 5. Hurricane Statistics for Sample Counties

The HVI can be helpful in creating equitable rates for property insurance. With the recent frequency of storms and hurricanes, insurance companies and state agencies have reassessed their insurance policies in coastal markets. Insurance companies began changing their coastal policy writing practices shortly after 1992's Hurricane Andrew, which struck south Florida and caused an estimated $32 billion in property damages. Insurers immediately attempted to limit coverage and raise rates where coverage was provided in areas subject to hurricane impacts. Additional, heavy losses in the years following Andrew have caused coastal insurance for wind and hail to become much more expensive and even difficult to obtain in many areas as insurance companies attempt to reduce risk. For

example, following the 2004 hurricane season, premiums doubled for windstorm insurance in many parts of the Florida with owners of 1,500 square foot homes facing premiums of $10,000 for wind damage alone with total insurance costs of $13,000 and deductibles of up to $18,000 (Mortgage News Daily 2007).

As insurance companies have reduced coverage and raised rates, consumers have become increasingly concerned and groups such as the real estate industry have called for increased government intervention. State insurance agencies, which provide oversight of insurance rates, can use the HVI in order to more accurately regulate insurance companies. For example, Miami-Dade's HVI value of 5.52 is much higher than Charleston County's of 1.34, which is the second highest HVI. This indicates that the risk of damage, and therefore insurance rates should be much higher in Miami-Dade County. However, examining individual indicators is important in order to assess rates correctly. Dare County's HVI, for example, is ranked third; this is due in part to the modest population and housing totals. Other indicators, such as hurricane probability and vulnerability are very high for Dare, which would suggest that rates should be adjusted accordingly.

In addition, the HVI can be used to inform residents about areas of greater risk. Property owners moving to counties with high HVI values can be informed of the potential risk. Although we provide an illustration of the HVI calculation using a sample of coastal counties, expanding the analysis to include all counties from the southeastern U.S. or adding other indicators would follow this methodology.

6. Mitigating hurricane risk

The HVI provides a guide to areas that are the most vulnerable coastal communities. Although hurricane risk cannot be eliminated, various actions can help to minimize the damage to communities. For example, natural systems can provide some protection against storm damage. Protecting coastal wetlands, which buffer shorelines against erosion and absorb floodwaters from storms will reduce storm damage. Costanza et al., (1989) estimated that coastal Louisiana wetlands provided $452/acre/year (in 2009 dollars) in storm reduction benefits. Although the Mississippi deltaic plain bordering Louisiana provides valuable storm-damage reduction benefits, numerous human activities have destroyed large areas of the coastal marshes. Since 1900, about 4900 km^2 of wetlands in coastal Louisiana have been lost at rates as high as 100 km^2/year, most of the loss is the result of human activities. A large-scale effort is now considering ways to protect and enhance these coastal areas.

Engineering solutions such as levees to protect against flooding may provide some protection from hurricane damage. The British and Dutch have built large, expensive barriers that provide some protection against North Sea storm surge. However, engineering solutions may fail as was the case with New Orleans. An independent study by the American Society of Civil Engineers (2007) explains that engineering and planning failures caused much of the catastrophic flooding from Katrina. Two engineering failures were responsible for the levee breaches in New Orleans: (1) the I-walls were poorly designed, which caused their collapse and (2) overtopping resulted because the levees were not protected from erosion. In addition, the existing pump stations, which should have removed the water during and after the storm, were inoperable.

Storm resistant construction as defined by the International Building and Residential Codes (IBRC) can effectively reduce hurricane damage. In order for homes built along the coast to withstand winds of 130 to 150 miles per hour (the guideline set by the IRBC), it is necessary

to use more steel and concrete, hurricane–resistant windows, metal strapping from the foundation to the roof, and plywood to wrap around the house (McLeister, 2007). Recent changes in state building codes require such construction. Following Katrina, state agencies in Louisiana, Mississippi, and Alabama, recognizing the importance of hurricane resistant construction, adopted better building standards.Unfortunately, building codes are not always enforced. Building codes were poorly enforced at the time of the Gulf coast hurricanes in 2005 for the states of Alabama, Louisiana, Mississippi, and Texas (Burby, 2006). Insurance companies offer lower insurance rates for actions such as storm resistant construction. Lower insurance rates could encourage property owners to pay the added cost for the construction.

As shown earlier, in recent decades population and housing growth in coastal areas has escalated; this has been a major contributor to the increased damage from hurricanes. Ensuring that those who choose to live in high risk areas bear the cost of potential damage will decrease development and help to lower damage costs. Market signals, such as higher property insurance rates in high hazard areas, may discourage development in areas that are most susceptible to storm damage. Following the increase in hurricane damage in recent years, property insurance rates in coastal areas have increased, in some cases dramatically. Hairston (2007) reported on the waves of transplants from Florida coastal communities that relocated to Atlanta because of increased property insurance costs.

Government can direct development away from hazardous areas which would limit the potential damage from storms. However, government efforts to discourage development of hazardous areas through the National Flood Insurance Program (NFIP) have been ineffective. The NFIP, begun in 1968, was to guide development away from flood-prone areas and to enforce building standards, in exchange for subsidized flood insurance for property owners. Due to the influence of special interest groups such as land developers, the policy has not been effective. Burby (2001) found that more than a third of the 6.6 million buildings located in the 100-year floodplains of participating communities were built after the start of the NFIP floodplain management plan.

Communities in certain high-risk areas, which are included in the 1982 Coastal Barrier Resource Act (CBRA), are restricted from receiving NFIP insurance. CBRA prohibits federal financial assistance, post-storm reconstruction, and erosion control in undeveloped areas of barrier islands designated by the Department of Interior. Barrier islands parallel mainland areas thus providing a buffer against storms and offering a valuable habitat for fish and wildlife. The goal of CBRA, which was amended by the Coastal Improvement Act in 1990, is to protect barrier island ecosystems by not encouraging development with federal subsidies. The original 186 CBRA locations were expanded to 590 in 1990 (Pasternick 1998, 146).

Unfortunately, the NFIP and other government policies have encouraged development in high hazard areas. Lowering the risk of damage costs to property owners increases coastal development and the damage costs from hurricanes. State wind pools, for example, provide wind insurance at below market prices in some high risk areas. The Florida state government, for example, has created the Citizens Property Insurance Corporation (CPIC) which is a state-run insurance company. The CPIC, which was intended to be an insurer of last resort, is a tax-exempt entity that charges premiums, issues policies, and pays claims, just as a private insurance company does. The CPIC competes with private companies and has the advantage of financing its deficits by levying a surcharge on its competitors. Limiting policies that lower costs of development in coastal areas will be more equitable and will reduce hurricane damage costs.

7. Conclusion

Coastal areas can be hazardous locations in which to reside and additional challenges may increase the risk of damage to coastal communities. For example, land subsidence and melting polar ice caps are causing sea levels to increase, which will cause coastal flooding. Geologists have concluded that large portions of North Carolina's Outer Banks could disappear within the next several decades if sea level continues to increase at the current level or if one or more major hurricanes directly hit the barrier islands (Riggs et al., 2008).

Some project that climate change will cause an increase in global temperatures that could melt enough ice cover in Greenland and Antarctica to increase sea level by 2 to 3 feet in the current century. Because coastal processes occur over so narrow a range (all wave and current energy that affects the shore occurs within a vertical range of 65 feet on the shoreline), small changes in sea level can have significant impacts. The increased flooding caused by sea level rise will exacerbate hurricane damage. In addition, some evidence suggests that climate change may also increase hurricane activity and intensity.

Hurricane strikes will continue to put coastal community residents and their property in harms way. Although we focused on property damage in this study, the information provided here can aid in the protection of individuals and help create communities that can better adapt to the threats from natural disasters such as hurricanes. Despite this risk of severe property damage from hurricanes and other events, all evidence suggests that increasing numbers of people will choose to live in coastal areas. The HVI formulated here can better inform the public about areas that are located in high hazard locations. If individuals are given accurate information about risk, they should be willing to accept the cost of the potential damage.

The HVI can provide valuable information to the insurance industry, which is important to coastal area residents because insurance helps to minimize the financial risk of living in hazardous area. For insurance policies to be feasible, risks must be estimable and manageable for the company, and the rates must be affordable to consumers. A better understanding of the factors that affect hurricane damage can create more equitable rates for policyholders and decrease uncertainty for insurance companies. Better information on the areas that are most likely to suffer from damaging storms can guide policy-makers in creating plans that mitigate storm risk. The factors that contribute most to risk can be addressed and funds can be allocated to the most vulnerable areas.

Although we cannot control the path of a hurricane we can undertake actions to minimize the risks to coastal communities. Improving our understanding of the factors that increase those risks will lead to adaptation and avoidance practices that can help make coastal communities less vulnerable to the vagaries of nature.

8. Acknowledgements

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This book represents recent research on tropical cyclones and their impact, and a wide range of topics are covered. An updated global climatology is presented, including the global occurrence of tropical cyclones and the terrestrial factors that may contribute to the variability and long-term trends in their occurrence. Research also examines long term trends in tropical cyclone occurrences and intensity as related to solar activity, while other research discusses the impact climate change may have on these storms. The dynamics and structure of tropical cyclones are studied, with traditional diagnostics employed to examine these as well as more modern approaches in examining their thermodynamics. The book aptly demonstrates how new research into short-range forecasting of tropical cyclone tracks and intensities using satellite information has led to significant improvements. In looking at societal and ecological risks, and damage assessment, authors investigate the use of technology for anticipating, and later evaluating, the amount of damage that is done to human society, watersheds, and forests by land-falling storms. The economic and ecological vulnerability of coastal regions are also studied and are supported by case studies which examine the potential hazards related to the evacuation of populated areas, including medical facilities. These studies provide decision makers with a potential basis for developing improved evacuation techniques.

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