The Potential Impact of Climate Change on Hurricane Risk Assessment

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ABSTRACT
This paper presents a framework to assess the potential for increased hurricane risk to residential construction under various wind speed increase scenarios due to climate change. The framework includes a probabilistic hurricane wind field model and a hurricane damage model. A case study of Miami-Dade County, Florida is presented to illustrate the framework. Demographic information, such as median house value and changed house numbers, and distribution of houses on different exposure, are used to estimate the probable damage with or without the increased wind speed. This study finds that climate change may have a substantial impact on the damage and loss estimation in coastal areas.

INTRODUCTION
Rising sea surface temperatures (SST) are accepted as a direct result of the global climate change (IPCC 2007). The increase in sea surface temperature has been found to be approximately 0.5°C per year, based on data from 1970 to 2004. Tropical cyclone/hurricane activities can only occur when sea surface temperatures have reached a temperature of 26°C or more (Webster et al. 2005).

However, whether the rising SST changes hurricane (cyclone) intensity and frequency is still a matter for debate. Studies have suggested a relationship between the rising sea surface temperatures and hurricane intensity (Webster et al. 2005) and Emanuel (2005) related hurricane intensity to the climate change. It was found that every increase in temperature of 1°C could result in an increase of the peak wind speed of a tropical cyclone by 5%. The study found that the destructiveness of hurricanes is increasing in relation to the warming temperatures of the sea. The destructiveness of hurricanes was defined by an index based on the power dissipation of hurricanes which has significantly increased since the 1970’s.

Elsner (2006) showed a direct connection between climate change and hurricane intensity. Due to the increase in sea surface temperature, hurricane frequency may be affected, as indicated in the report by the Intergovernmental Panel on Climate Change (IPCC 2007). However, because of the lack of consistent data available, the global trend in change of frequency for cyclones or hurricanes cannot be verified (Webster et al. 2005). On the other hand, some have suggested that the increased hurricane activities in recent decades is a result of a natural cycle in Atlantic cyclone activity, rather than a long-term trend due to climate change (Landsea et al. 2006, Landsea 2007).

Every year hurricanes cause extensive damage worldwide. From the period 1950-1989, the United States (US) averaged $1.6 billion dollars annually in hurricane damages; this figure has increased dramatically for the period 1989-1995, to $6 billion dollars annually in hurricane
damages (Pielke and Pielke 1997). It is estimated that the damage caused by Atlantic hurricanes in 2004 to 2005 was more than $150 billion dollars (Pielke et al. 2008), mainly due to the devastating effect of Hurricane Katrina in 2005.

The population in hurricane prone areas of the US is increasing steadily; for example, insured coastal property values in Florida have increased by 55% from the year 1988 to 1993, from $566 billion to $872 billion (Stewart et al. 2003). With this steady increase in population and wealth to the coastal areas of the US, there is an evident increase in risk of potential hurricane damage.

With the expected changes in hurricane frequency and severity under enhanced greenhouse conditions, it can be anticipated that hurricane damage to the built environment will increase. Because of this anticipated increase in hurricane activity, it becomes increasingly vital to refine the process of hurricane risk assessment and to identify strategies to efficiently mitigate the increase in economic loss. The economic losses can be determined by convolving the hurricane wind model and the hurricane vulnerability model (Li and Ellingwood 2006).

The purpose of this paper is not to examine whether there is direct relationship between climate change and change patterns of wind hazard or to endorse any specific scenario of climate change. Instead, we aim to illustrate the case of “what if”, which is to investigate the potential impact of various climate change scenarios on hurricane risk assessment. This work follows the risk-based framework proposed by Li and Stewart (2008) for assessment of economic damage risks and costs caused by tropical cyclones due to the increases in wind speeds resulting from climate change in Australia. A recent study by Vickery et al. (2009) indicates that it can be expected that wind speeds may increase by 5-10% in the US for 50 and 100-year return period. This further confirms the necessity to evaluate the consequences of increased hurricane risks. In the current study, an increase of 5-15% in mean annual maximum wind speed over 50 years is considered to investigate the potential impact of climate change.

**HURRICANE WIND FIELD MODEL**

Various hurricane wind field models have been developed in the last three decades (Batts, 1980; Georgiou, 1985; Vickery et al. 1995 and 2009). The Weibull distribution is an appropriate model of annual hurricane wind speed in the US (Li and Ellingwood 2006). Miami-Dade County, Florida is the eighth largest county in the US, with a population of 2.4 million, making it the most populous county in Florida. It was chosen to illustrate the potential impact of enhanced greenhouse gases. In this study, wind contour maps from Vickery et al. (2000) were used to calculate the parameters of the Weibull distribution. The wind speeds are 59 m/s and 81 m/s with a return period of 50 and 1,000 years, respectively. The parameters were found to be $u=27.304$ and $\alpha=1.77$, corresponding to a mean maximum annual wind speed of 24.3 m/s, which is assumed to be the stationary wind speed if there is no climate change. The coefficient of variation (COV) is 0.584.

As there is no projection on how the increase of wind speed will occur. It was assumed that the wind speed over a 50 year time period increases linearly regardless of climate change scenario. The Weibull parameters and the maximum annual wind speed for each year in the time period can be determined accordingly.

The Weibull distribution is used to model the 3-sec gust wind speed, at a height of 10m on open terrain for hurricanes. The cumulative distribution function (CDF) and probability density function (PDF) are:
\[ F_v(v) = 1 - \exp\left[ -\left(\frac{v}{u}\right)^\alpha \right] \]  \hspace{1cm} (1)

\[ f_v(v) = \frac{\alpha}{u} \left(\frac{v}{u}\right)^{\alpha - 1} \exp\left[ -\left(\frac{v}{u}\right)^\alpha \right] \]  \hspace{1cm} (2)

where \( v \) is the 3-sec gust wind speed, \( \alpha \) and \( u \) are the parameters for the Weibull distribution.

Wind speed increase between 5-15% in 50 years due to different climate change scenarios were explored in this study.

**Vulnerability Models**

A hurricane vulnerability model estimates the damage caused by hurricanes; hurricane vulnerability is the damage expected to a region. Various vulnerability models have been developed (Leicester et al., 1979; Sparks et al., 1994; Khanduri and Morrow, 2003).

Huang et al. (2001) developed a damage model using Southeastern US insurance data from Hurricanes Hugo and Andrew. This particular model is based on two ratios; the claim ratio which is the total number of claims versus the total number of policies, and the damage ratio which is the total amount paid by the insurer versus the total insured value. To develop the vulnerability model, these two ratios are related to the recorded average mean surface speed of the hurricane.

Huang’s damage ratio model is:

\[ F_D(v) = \exp(0.252 \cdot v - 5.823) \quad v \leq 41.4 \frac{m}{s} \] \hspace{1cm} (3)

\[ F_D(v) = 100 \quad v \geq 41.1 \frac{m}{s} \] \hspace{1cm} (4)

where \( v \) is the mean surface wind speed.

Huang’s damage model (2001) was used in this study, along with the Weibull distribution of maximum annual wind speeds, to calculate the annual insured damage risk caused by wind hazards. The purpose of this paper is to illustrate the framework of estimating the potential damage hurricanes can cause under enhanced greenhouse conditions. Huang’s model is relatively simple; however, when more sophisticated vulnerability models becoming available, they can be incorporated into the framework developed herein to update loss estimates.

**Annual and Cumulative Damage**

The annual damage can be determined by convolving the vulnerability function and the PDF of wind field model (Li and Ellingwood 2006).

\[ D(v) = \int F_D(v) \cdot f_v(v) dv \] \hspace{1cm} (5)

To take into account the effects of exposure on wind speed, the location of houses was identified within this study. Huang et al. (2001) identified three exposure categories: Foreshore (within 1 km from coast) with an exposure factor of 0.90, Locations within 10 km inland, with an exposure factor of 0.80, and all other locations farther inland, with an exposure factor of 0.72. These factors were accounted for in the damage model herein.
The model in Huang et al. (2001) was developed based on the mean surface wind speed, which is a 10-min duration. The wind contour maps in ASCE-7 are for 3-sec gust and a conversion factor of 0.7 was used to adjust the 3-sec gust stipulated in wind speed maps to surface wind speed for all the exposure categories, according to ASCE-7 (2006).

The annual damage, $D(t)$, for a climate change scenario of a 10% increase in wind speed was calculated with Eq. (5) for all exposure categories over a 50 year time period. For a 10% increase, the annual damage for a foreshore location is 2.7% in year 0, which is consistent with the 2-3% predicted by Huang et al. (2001). The annual damage remains constant for each of the locations when no increase in wind speed is assumed.

Figure 1 shows the cumulative damage for a climate change scenario of a 10% increase in wind speed compared to the case of no climate change. The cumulative damage was calculated for all three exposure categories over a 50 year time period. For an increase in wind speed of 10%, the cumulative damage increases to 132.3% for foreshore in year 50, to 68.5% for locations within 10 km of the shore in year 50, and to 35.7% for locations farther than 10 km inland. This figure clearly illustrates the significant effect different exposure categories have on the total regional loss. For comparison, the cumulative damage reaches 97.5% for foreshore locations for no increase in wind speed, and 48.5% and 24.6% for locations within 10 inland and locations farther than 10 km inland, respectively. The cumulative damage increases by 35.7% for the foreshore locations under an increase of 10% in wind speed.

**Figure 1**: Cumulative damage at each location, assuming an increase of 0% and 10% in wind speed over 50 years
REGIONAL LOSS ESTIMATION AND EFFECTS OF CLIMATE CHANGE SCENARO

The cumulative regional loss estimation \((L(0,t))\) is found by summing the annual regional loss estimation \((D_{\text{annual}})\) over a time period, which is 50 years in this case. The insured value of a house \((C)\) can be used to estimate the expected damage costs \((L_c(0,t))\) in monetary units.

The US Census Bureau estimates that there are approximately 971,600 residential housing units located in Miami-Dade County, in 2007; 53% of these housing units are single-family units according to a 2008 report by the Greater Miami Chamber of Commerce. Reports have stated that the majority of hurricane damage occurs to single-family units (NAHB, 1993). Therefore, within this study, damage is calculated for single-family units within each exposure category.

The annual house growth rate is calculated from information from the US Census Bureau for years 2000 and 2006. The annual growth rate was found to be 1.97%, or approximately 2%. Therefore, the number of single-family units will increase from approximately 451,700 in 2000 to 1,215,800 units by the year 2050, if the annual growth rate is assumed to be constant. These assumptions are used to perform a comparative risk analysis.

The approximate median value of a single-family unit is $195,500 in Miami-Dade County (The Miami Herald 2009). The land price is assumed to be approximately 50% of the median value (Zigomanis 2007). Therefore, the replacement house value is $97,800. Huang et al. (2001) found that because homeowners often hold contents insurance, the insured value of a household is 50% greater than the house replacement value. Therefore, it is assumed that the insured value is 150% that of the replacement value, so the median insured value is \(C = \$146,600\).

Figure 2 shows the cumulative regional damage costs for single-family units \(L_c(0,t)\) for Miami-Dade County, for wind speed increase scenarios ranging from 0-15%. If there is no climate change it can be estimated that damage costs in Miami-Dade County will be $58 billion over 50 years. This value increases to $71 billion for an increase in wind speed of 5%, $86 billion of an increase of 10% in wind speed, and $103 billion if wind speeds increase by 15%. Total damage losses over 50 years will increase by 22% for a 5% increase in wind speed, by 48% for a 10% increase in wind speed, and by 78% for a 15% increase in wind speed. The potential economic effects of climate change are clearly significant. Figure 2 also shows that total regional damages accelerate over time.
CONCLUSIONS

An increase of 10% in wind speed due to climate change could potentially increase the cumulative damage cost to single-family units in Miami-Dade County in 50 years by 48%, compared to the case of no climate change. In monetary terms, the increase in annual regional damage to housing units is up to $1 billion per year if wind speeds increase by 15% over 50 years. To manage the potential higher hurricane damage risks as a result of the enhanced greenhouse effect, it is necessary to recommend economically viable mitigation strategies to strengthen or retrofit construction in hurricane-prone zones.

Figure 2: Cumulative damage cost to single-family units in Miami-Dade County under different climate change scenarios
REFERENCES:


