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Housing damage, loss, and shelter need estimations using an ensemble of return period consistent tropical storms

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SUMMARY:

This study develops a methodology to select an ensemble of return period consistent hurricane tracks based on wind speed. First, a stochastic hurricane simulation program is used to generate a database of 100,000 years of simulated hurricane tracks. Second, a hurricane wind hazard curve defined in terms of hurricane induced wind speed versus return period is produced for a site of interest. Using the hazard curve, an ensemble of storm tracks with approximately the same return period is selected. The ensemble of storm tracks may be used to quantify the storm-to-storm uncertainty and in turn the uncertainty in impacts (e.g. monetary losses, downtime and shelter needs) in a loss estimation framework. As an illustrative example, an ensemble of simulated hurricane tracks having the same return period as the 1989 Hurricane Hugo which made landfall in Charleston region of South Carolina is selected. Using the ensemble of selected Hugo-like storm tracks, the range of potential losses to residential buildings in Charleston County are analyzed using the building fragility curves obtained from the FEMA (Federal Emergency Management Agency) HAZUS-MH program. The estimated losses and damages to residential housing serve as inputs for a two-stage stochastic programming model to make short-term logistics plans for temporary housing and emergency shelter needs.

Keywords: return period, storm tracks, fragility curve, simulated storms, Charleston County, Emergency acquisition, Hurricane Hugo, relief logistics network design, disaster housing

1. INTRODUCTION

Hurricane Hugo was a powerful Category 4 storm that struck the United States in 1989 causing widespread damage and destruction in South Carolina, particularly in the Charleston area with estimated maximum sustained winds of 135-140 mph and a minimum central pressure of 934 mb (NOAA, 2014). Hugo caused at least $7 to $10 billion in damage [unadjusted 1989 dollars] (US Department of Commerce, 2014). FEMA provided housing assistance to the victims of the hurricane in South Carolina at a total cost of over $31 million. FEMA received over 42,000 requests for temporary housing assistance from South Carolina residents and determined that nearly 30,000 residents, or about 70 percent who applied, were eligible for some type of temporary housing assistance (United States General Accounting Office, 1991). Between 15,000 and 20,000 people were left homeless in Charleston County (United States General Accounting Office, 1991). The impacts or damages caused by a hurricane to the built environment are highly variable from storm-to-storm. Factors such as proximity of a storm to the population center, heading direction at landfall, forward speed etc. may affect the overall losses and damages of a study domain. If a hurricane similar to that of the 1989 Hugo was to make landfall again in Charleston area, the actual impacts of various Hugo-like storms could vary significantly. The objective of this study is (1) to develop a methodology to select an ensemble of return period consistent storm tracks, and (2) to quantify the variability of impacts (monetary losses, damage, downtime etc.) due to storm-to-storm uncertainty.

2. METHODOLOGY

Study Domain: For this research, Charleston County is selected as the study domain to demonstrate the proposed storm tracks selection methodology. The geographical size of the region is 965.05 square miles and contains 98 US Census Tracts. Currently, there are over 173,000 households in the region having a total population of 407,722 (FEMA, 2022).

Hurricane Tracks Catalog: This study uses a stochastic simulation framework to simulate hurricanes (Fig. 1a), which consists of several modules including a hurricane formation model, tracking model, intensity model, central pressure filling rate model, and wind field model. More details of the simulation program may be found in Liu (2014). For this study, a database of 10,000 years of simulated storms has been generated using the stochastic hurricane simulation program. The mean annual spawn rate of the Atlantic Basin hurricanes from 1966 to 2021 (16.82 storms/year) is used in the simulation program, resulting in approximately 168,000 simulated storm tracks over 10,000 simulation years.

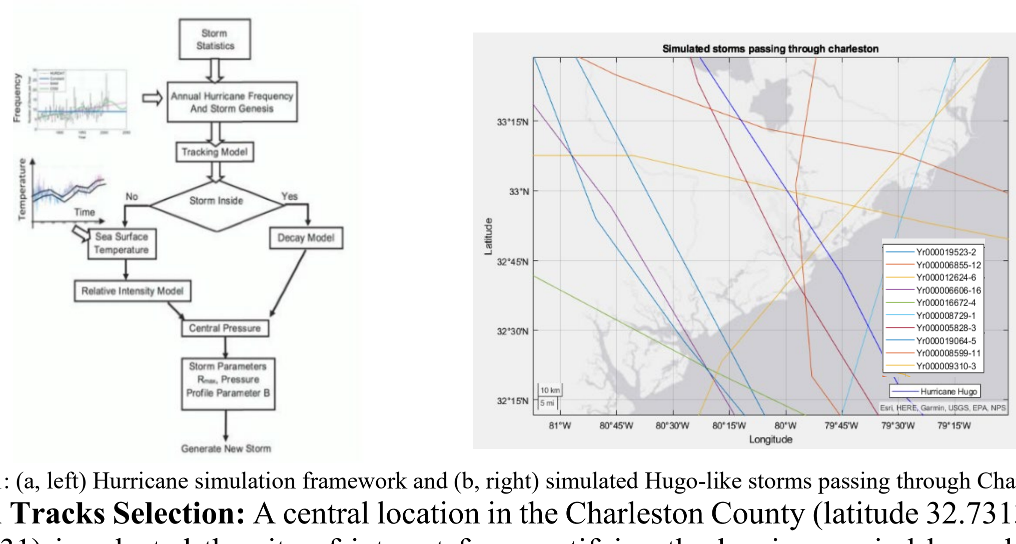

Figure 1: (a, left) Hurricane simulation framework and (b, right) simulated Hugo-like storms passing through Charleston, SC

Storm Tracks Selection: A central location in the Charleston County (latitude 32.7313, longitude -80.0631) is selected the site of interest for quantifying the hurricane wind hazard. To reduce computational time in calculating wind speeds, all storms that pass within 250 km from the site of interest are pre-selected (23,744 storms). The Georgiou (1985) wind field model is used to compute the peak wind speed at the site of interest for each of the 23,744 pre-selected storm tracks. **Fig. 2** shows the hurricane wind hazard curve of the site. Also shown in the figure is the ASCE 7-16 wind speeds for various return periods at the site of interest (square markers). The peak wind speed of the 1989 Hurricane Hugo at the site is estimated as 120 mph (3s gust, 10m elevation, open terrain). According to the wind hazard curve, the mean return interval (MRI) or return period of Hurricane Hugo is approximately 125 years. Note that the hazard curve shown in **Fig. 2** represents the peak wind speeds of 23,744 storms. To select an ensemble of 10 Hugo-like storms, the 10 storms having the return period closest to 125 years are identified. These tracks are plotted in **Fig. 1b**.

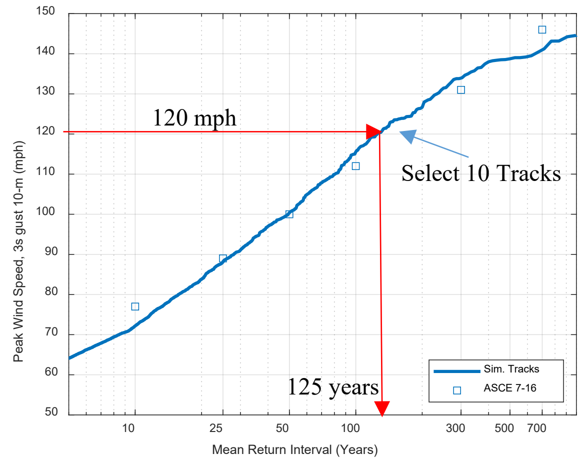

Figure 2: Peak wind speed (3s gust at 10m elevation, open terrain) versus mean return interval

Loss Estimation: A framework for estimating the damage condition, monetary loss, and shelter requirements for residential buildings affected by hurricanes is developed using fragility and loss functions (**Fig. 3**). Fragility functions relate a specific intensity measure (IM) (e.g. wind speed) to the probability of exceeding a specific damage state (e.g. minor damage). Similarly, loss functions relate a specific IM to the loss ratio of specific building types. In this study, the damage fragility curves and loss functions of the FEMA HAZUS-MH 6.0 program are utilized to estimate losses to residential buildings in the study domain (Charleston County).

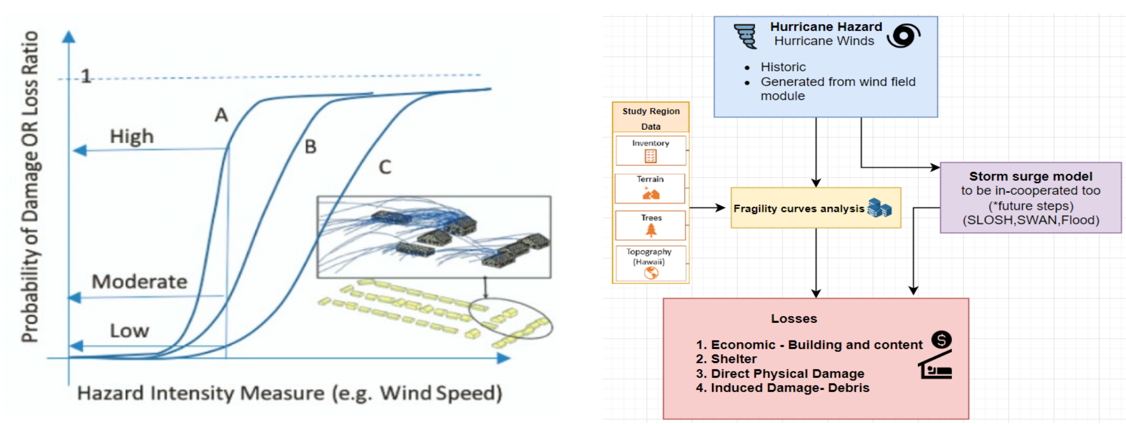

Figure 3: (a- left) Damage fragility curves for typical residential building, (b- right) framework for loss and damage estimations.

The study region data is taken from the FEMA inventory which uses 2020 US Census data and Nationwide Structure Inventory (NSI 2022). The general building stock consists of square footage data, building count, dollar exposure, general building type mapping, specific building type mapping, and wind building characteristics distribution.(FEMA, 2022) According to US census, buildings are grouped by Specific Occupancy Type for which exposure values (x$1000) are provided by the census reports. Wind Engineers have further classified buildings which are grouped into 39 Specific Building Type (SBT) for which exposure values (x$1000) are also provided by the census reports. These 39 SBT has further been divided into 6116 wind building types according to building characteristics affecting wind performance (e.g. roof shape). Various fragility curves and loss functions were used for the damage and loss computation according to these wind building types.

3.PRELIMINARY RESULTS

The estimated total economic loss of residential homes in Charleston County is $5.4 billion (building economic loss is $4.15 billion, and content economic loss is $1.25 billion) if Hurricane Hugo were to re-occur at present day using the current building stock, i.e. 2020 US Census database (**Fig. 4**). The estimated shelter needs for short term is 2,668 units and displaced household shelter needs is estimated to be 5,779 units. Based on the 10 Hugo-like simulated storms having a return period of 125 years, the mean of losses of the 10 simulations was found to be $8.8 billion with a standard deviation of $5.24 billion. From **Fig 4b**, it can be seen that if a 125-year return period storm were to hit the region, there is an approximately 80% chance that the total economic loss would exceed that of the 1989 Hurricane Hugo. This information can be used to inform emergency management and disaster response efforts and guide infrastructure projects to make them more resilient to natural hazards.

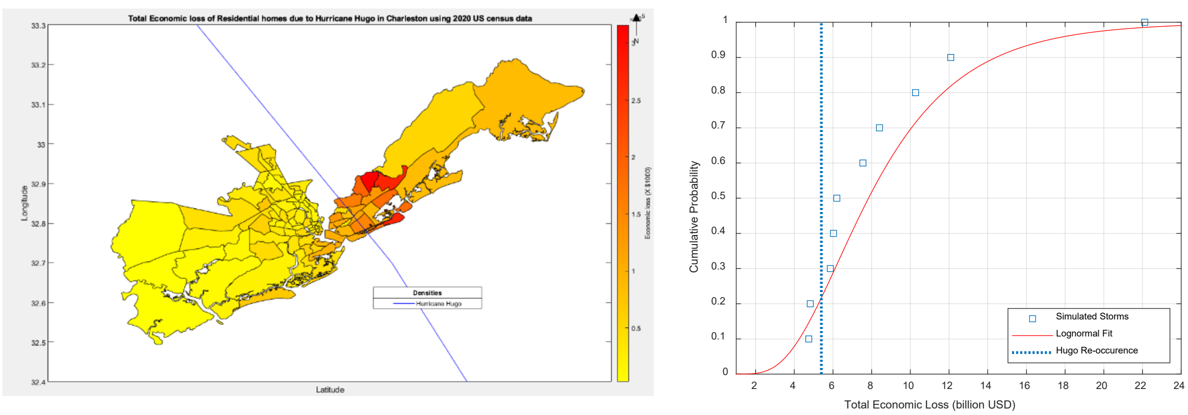

Figure 4: (a-left) Study domain with 1989 Hugo track, (b-right) total economic loss of Hugo-like storms.

4. CONCLUDING REMARKS

The use of an ensemble of hurricane tracks in loss estimation allows one to quantify the storm-to-storm uncertainty. Based on the analysis results, the 1989 Hurricane Hugo appears to be a “below average” event in terms of economic losses among the 125-year MRI storms. The presented study is part of a bigger project in which the estimated losses and shelter needs will be used in a logistics planning model for hurricane disaster relief. Select details of the logistic planning model will be discussed during the conference.

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