The Impact of Climate Change on

Design Wind Speeds

in Saint Lucia

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Acknowledgements:

Glossary

ASCE 7: American Society of Civil Engineers (ASCE)'s standard that provides minimum design loads for buildings and other structures.

Basic Wind Speed: It is the 700-year wind speed divided by the square root of 1.6, at a height of 10 m (33 ft) in flat, open terrain.

Best Track Wind Speeds: A subjectively smoothed representation of a tropical cyclone's location and intensity over its lifetime. The best track contains the cyclone's latitude, longitude, maximum sustained surface winds, and minimum sea-level pressure at six hourly intervals. Best track positions and intensities, which are based on a post-storm assessment of all available data, may differ from values contained in storm advisories. They also generally will not reflect the erratic motion implied by connecting individual center fix positions. National Hurricane Center (NHC).

Climate Change: A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. Intergovernmental Panel on Climate Change (IPCC).

Gust Wind Speed: The maximum wind speed averaged over a duration of 3 seconds. The 3-second gust wind speed forms the basis of the design wind loading standard in the United States.

Hurricane: A severe tropical cyclone that develops over the warm North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, and Eastern North Pacific having one sustained (1-minute average) wind speed at the surface of at least 74 mph. The maximum wind speeds are normally located in the front right quadrant of the hurricane. The size is highly variable with the diameter of the eye ranging from 6 miles to as much as 60 miles. The overall size of the hurricane is also highly variable. Narendra Taly, *Loads and Load Paths in Buildings: Principles of Structural Design*. ICC Publications, 2003.

Heading: Direction of motion of a hurricane measured clockwise from north.

Hurricane Hazard Curve: A plot or graph, showing the annual probability of exceeding (or return period associated with) a given wind speed.

HURDAT: is the official record of tropical storms and hurricanes for the Atlantic Ocean, Gulf of Mexico and Caribbean Sea, including those that

have made landfall in the United States. This database is utilized for a wide variety of purposes: setting of appropriate building codes for coastal zones, risk assessment for emergency managers, analysis of potential losses for insurance and business interests, intensity forecasting techniques, verification of official and model predictions of track and intensity, seasonal forecasting, and climatic change studies.

Intensity: Strength of a hurricane defined using either pressure or wind speed. Higher wind speeds and lower pressures equate to more intense hurricanes.

Landfall: The intersection of the surface center of a tropical cyclone with a coastline. Because the strongest winds in a tropical cyclone are not located precisely at the center, it is possible for a cyclone's strongest winds to be experienced over land even if landfall does not occur. Similarly, it is possible for a tropical cyclone to make landfall and have its strongest winds remain over the water. Compare direct hit, indirect hit, and strike. National Hurricane Center (NHC).

Load Factor: Factors by which the nominal (anticipated working or service) loads are multiplied to determine the design ultimate loads. Narendra Taly, *Loads and Load Paths in Buildings: Principles of Structural Design*. ICC Publications, 2003.

Wind: The movement of free air caused by thermal currents in the first 10-mile zone above the earth's surface. For engineering purposes, the term "wind" is used to describe the movement of air parallel to ground surface. Narendra Taly, *Loads and Load Paths in Buildings: Principles of Structural Design*. ICC Publications. 2003.

Wind Pressure: Pressure exerted on an object by wind. Narendra Taly, Loads and Load Paths in Buildings: Principles of Structural Design. ICC Publications, 2003.

Peak Wind Speed: The maximum instantaneous value of the wind speed within some fixed time intervals of measurement. Narendra Taly, *Loads and Load Paths in Buildings: Principles of Structural Design*. ICC Publications, 2003.

Pressure Profile Parameter: Defines the rate of change of pressure with distance from the center of a hurricane. Larger values of the profile parameter yield higher rates of change of pressure, and consequently, higher wind speeds.

Radius of Maximum Winds: The distance from the center of a tropical cyclone to the location of the cyclone's maximum winds. In well-developed hurricanes, the radius of maximum winds is generally found at the inner edge of the eyewall. National Hurricane Center (NHC).

Saffir-Simpson Scale: This scale was developed in an effort to estimate the possible damage a hurricane's sustained winds and storm surge could do to a coastal area. The scale of numbers is based on actual conditions at some time during the life of the storm. As the hurricane intensifies or weakens, the scale number is reassessed accordingly. National Hurricane Center (NHC). Wind speeds are 1-minute average values at a height of 10m in unobstructed terrain, usually over water. The following table shows the scale broken down by central pressure, winds, and storm surge:

Category	Central Pressure (mb)	Wind Speed (mph)	Storm Surge (ft.)	Damage
1	980 or >	74 - 95	4 - 5	Minimal
2	965 - 979	96 - 110	6 - 8	Moderate
3	945 - 964	111 - 130	9 - 12	Extensive
4	920 - 944	131 - 155	13 - 18	Extreme
5	< 920	> 155	> 18	Catastrophic

Source: NHC

Translation speed: Rate of movement of the center of a hurricane often computed as the distance the center of the hurricane moves in a 6-hour period divided by 6 hours.

Executive Summary

The objective of this study is to develop a methodology to estimate the change in the wind speeds used for the design of structures in Saint Lucia associated with a potential increase in hurricane intensity and frequency brought about by climate change. The methodology makes use of a recently completed study used to develop hurricane hazard maps for the Caribbean. Information on the potential increase in hurricane frequency is given in Curry et al. (2008).

The design wind speeds in Saint Lucia are shown to be governed by Category 4 and 5 hurricanes passing near the Island; thus, the effect of climate change on the frequency of future Category 4 and 5 hurricanes controls the changes in the wind speeds used to design buildings and other structures. Using hurricane hazard curves previously developed for Saint Lucia, coupled with a statistical weighting technique, curves were developed presenting the percentage change in the design wind speeds associated with a percentage increase in the number of Category 4 and 5 hurricanes. Since only Category 4 and 5 hurricanes control the design wind speeds in Saint Lucia, we are only interested in the increase in frequency of these hurricanes. Figure 1 presents the curves for Category II (ordinary buildings) and Category III and IV buildings (important buildings such as hospitals, emergency operation centers, etc.).
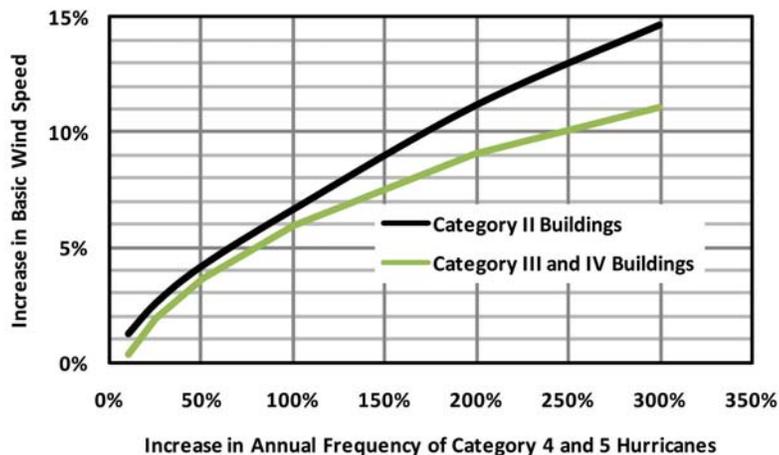
Figure 1. Percentage Increase in Basic Wind Speed in St. Lucia vs. Percentage Increase in Annual Rates of Category 4 and 5 Hurricanes.

The results given in Figure 1 can be used with any assumed increase in hurricane activity, encompassing a range of no change through a 300-percent increase in the annual rate of occurrence of Category 4 and 5 hurricanes.

1. Overview

On October 3, 2006 a Grant Agreement (GEF Trust Fund Grant Number TF056744) for $2.1 million United States dollars (USD) was signed between the World Bank, acting as the implementing agency for the Global Environment Fund (GEF), and the Caribbean Community Climate Change Centre (CCCCC), acting as the executing agency, for the implementation of the Implementation of Adaptation Measures (SPACC) Project. The main objective of the project is to support efforts by Dominica, Saint Lucia and St. Vincent and the Grenadines to implement specific (integrated) pilot adaptation measures addressing the impacts of climate change on the natural resource base of the region, focused on biodiversity and land degradation along coastal and near-coastal areas.

In Saint Lucia, one of the pilot adaptation measures identified seeks to demonstrate the design and implementation of appropriate interventions to reinforce critical infrastructure to the effects of climate change in the Castries area. The project's objective is to develop a technical translation of existing hurricane information into useful engineering guidelines which can be applied in Saint Lucia and elsewhere in the Caribbean. The project includes the presentation of this report and a training workshop on engineering guidelines for selected technical staff in Saint Lucia.

The objective of this study is to develop a methodology to estimate the change in the basic wind speeds used for the design of structures on the Island of Saint Lucia (Figure 2) associated with a potential increase in hurricane frequency brought about by climate change. The basic wind speed is defined as a 3-second peak gust wind speed at a height of 10 m in flat, open terrain. The methodology makes use of a recently completed study (Vickery and Wadhera, 2008a) in which a hurricane simulation model was used to develop hurricane hazard maps for the Caribbean. The hurricane simulation model used to develop the hazard maps was developed using hurricane data encompassing the period of 1900 through 2007, although the pressure data used in the model development is biased towards the 1970 to 2007 time period. The details of the simulation model are given in Vickery and Wadhera (2008a). Information on the potential increase in hurricane frequency is given in Curry et al. (2008).
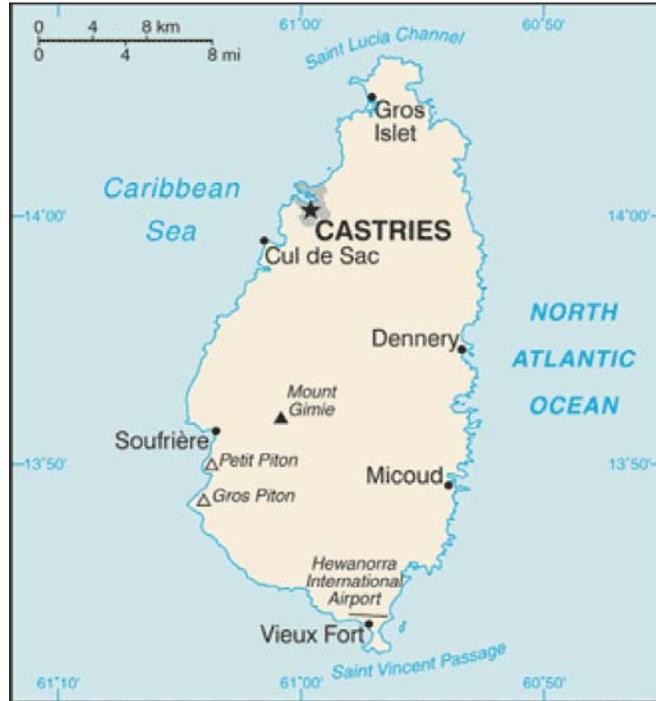
Figure 2. Map of St. Lucia.

2. Estimation of Hurricane Hazard—Current Climate

The hurricane simulation methodology used to develop the hazard maps for the Caribbean is outlined in Figure 3 and can be summarized in four basic steps. In the first step, a model storm is initialized by sampling a starting position, date, heading, translation speed, intensity, storm size as defined by the radius to maximum winds (*RMW*), and pressure profile parameter, *B*. In the second step, which is repeated multiple times during the simulated life of the hurricane, the hurricane is moved forward and new values of translation speed, heading, intensity and size are computed as described in Vickery et al. (2000), Vickery et al. (2008a) and Vickery and Wadhera (2008a). The model hurricane is moved forward in 6-hour increments. Each 6-hour position along the model track is associated with a date and time, latitude, longitude, central pressure, *B* value, *RMW* and maximum sustained wind speed over water. If the model storm makes landfall (Step three), then it is weakened (i.e., central pressure increases) using the filling model described in Vickery (2005). In Step four, the wind speeds at a study site are computed if the model hurricane passes within 250 km of the study site, in this case, Saint Lucia. Wind speeds are computed every 15 minutes while the storm is within 250 km of the site and the largest value, greater than 20 mph, is retained for use in the computation of the hurricane hazard curve. Wind speeds are com-

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puted using the hurricane wind field model described in Vickery et al. (2008b). The entire simulation process is repeated for the next sampled hurricane within a sample year, and then repeated again for a subsequent year. In the case of the Saint Lucia study, a 100,000-year simulation was performed.
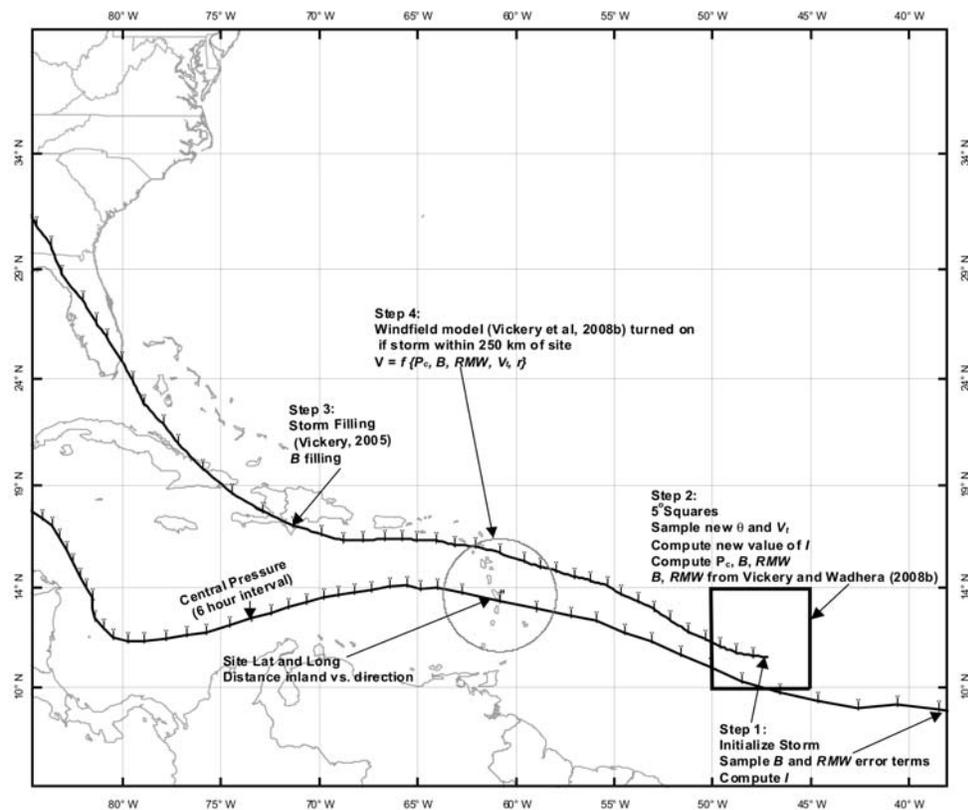
Figure 3. Overview of Hurricane Simulation Methodology.

Upon completion of the 100,000-year simulation, the wind speed data are rank ordered and then used to define the wind speed probability distribution, *P(v>V)*, conditional on a storm having passed within 250 km of the site and producing a peak gust wind speed at ground level in open terrain of at least 20 mph. In developing the wind speed hazard curve, we do not attempt to fit the wind speed data to an analytic distribution, such as a Weibull or Lognormal distribution, but rather interpolate from the rank ordered data to determine a wind speed associated with a given probability level. The probability that the tropical cyclone wind speed (independent of direction) is exceeded during a time period, *t,* is

$$P_t(v > V) = 1 - \sum_{x=0}^{\infty} P(v < V \mid x) p_t(x)$$

Equation (1)

where $P(v < V \mid x)$ is the probability that velocity, v, is less than V given that x storms occur, and $p_t(x)$ is the probability of x storms occurring during time period t. From Equation 1, with $p_t(x)$ defined as Poisson and defining t as one year, the annual probability of exceeding a given wind speed is

$$P_a(v > V) = 1 - \exp\left[-\upsilon P(v > V)\right] \qquad \text{Equation (2)}$$

where υ represents the average annual number of storms approaching within 250 km of the site and producing a minimum 20 mph peak gust wind speed (i.e., the annual occurrence rate). Each simulated hurricane used to develop the conditional probability distribution, $P(v < V \mid x)$, has a probability of $1/N$, where N is the total number of hurricanes producing a wind speed of 20 mph or more during the 100,000-year simulation.

3. Estimation of Hurricane Hazard—Future Climate

As will be discussed later in this report, **the basic gust wind speeds in Saint Lucia are dominated by Category 4 and 5 hurricanes.** Research by Curry et al. (2007) indicates that **because of changing climatic conditions (i.e., global warming) it is likely that the frequency of future Category 4 and 5 hurricanes will increase in comparison to their frequency during the past 100 years.** In order to take this potential increase in hurricane frequency and intensity into account, we define a "climate conditioning" region around Saint Lucia where we compute the modeled and historical annual rates of hurricanes by category. The climate conditioning region for Saint Lucia is defined as a 10-degree square bounded by 10ºN to the south and 20ºN to the north and 55ºW to the east and 65ºW to the west. The hurricane category is defined as the maximum intensity of the hurricane (modeled or historical) while the hurricane is in the climate conditioning region. We also associate the maximum wind speed produced by a simulated hurricane in Saint Lucia with the maximum intensity of the simulated hurricane while in the climate conditioning box. The combined wind speed-intensity information provides a means to modify the statistical weight, or likelihood, of an event occurring given an increase in the future number of Category 4 or 5 hurricanes. For example, if in a future climate scenario we expect that the annual frequency of Category 5 hurricanes will increase by a factor of 2, then the statistical weight of all model peak gust wind speeds greater than 20 mph that are produced by a simulated hurricane reaching Category 5 status while within the climate conditioning region will be doubled. Figure 4 presents the climate conditioning box.
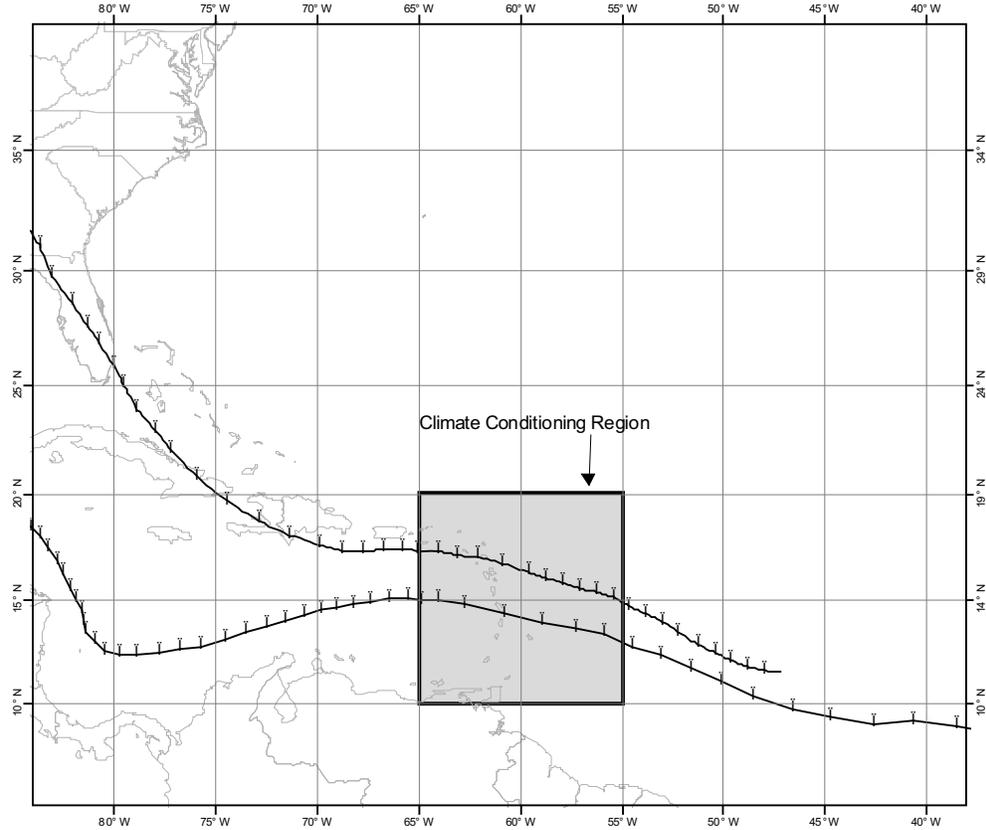
Figure 4. Climate Conditioning Region for Saint Lucia.

Using the peak gust wind speeds at the site produced by the weighted events (hurricanes), the probability distribution, $P(v < V)$ is computed as

$$P(v < V) = \frac{1}{W} \sum_{i=1}^{v(i)<V} w_i \qquad \text{Equation (3)}$$

where $W = \sum_{i=1}^{N} w_i$, is simply the sum of all the individual weights. In the example noted above, the weights, w_i, for all Category 5 hurricanes will be 2 and for all other hurricanes the weight will be 1. In Equation 2, the annual occurrence rate is defined as $W/100,000$ instead of $N/100,000$. Thus, using Equation 2 coupled with the climate conditioned occurrence rates and conditional probability distributions, we can determine the impact of various climate change scenarios on the nominal "basic" wind speeds.

Following the approach given in American Society of Civil Engineers Standard 7 (ASCE 7) for selecting basic wind speeds, we define the basic wind speed for Category II buildings as the 700-year return period wind speed divided by the square root of 1.6 (the wind load factor). The wind speed for the design of Category III and IV structures is the 1700-year return period wind speed divided by the square root of 1.6. With these basic wind speeds in mind, we are concerned with the effect of climate change on the 700- and 1700-year return period wind speeds in Saint Lucia.

Figure 5 presents the building category classification system as given in ASCE 7, which maps a building size and intended use to a building category.

4. Evaluation of Best Track Wind Speeds

The potential impact of climate change on hurricane activity as described in Curry et al. (2008), as well as others such as Webster et al. (2005) and Emanuel (2005), relies on estimates of hurricane intensity or hurricane wind speeds as given in HURDAT (HURricane DATabase), or Best Track data. In engineering design, the hurricane classification is not considered, but in this study, which uses estimates of future hurricane activity in terms of annual frequencies of hurricane intensity or HURDAT wind speeds, it is important to determine whether or not there are any differences between HURDAT wind speeds and wind speeds derived using other methods.

Although poorly documented in the peer reviewed literature, many experienced civil and ocean engineers working with hurricane winds believe that the estimates of the maximum wind speeds in hurricanes provided by the National Hurricane Center (NHC) are biased towards overstating the maximum surface level winds. In this study, we will be using NHC estimates to define the potential future increase in hurricane activity as a function of storm category and, therefore, it is important to attempt to quantify the magnitude of any bias in the NHC estimates of wind speeds. To quantify the bias in the NHC wind speeds, we shall use comparisons of the wind speed estimates derived from H*Wind [Powell et al. (1998) and Powell and Houston (1998)] and those derived by the NHC. The wind speed estimates produced by H*Wind represent the only independent peer reviewed estimates of the maximum surface level wind speeds in recent hurricanes. Two different approaches for comparing the NHC and H*Wind estimates of wind speeds were performed. The first approach compares 6-hour wind speeds along the tracks of hurricanes occurring since 2004. The second approach compares estimated wind speeds at landfall using the H*Wind derived wind speeds as reported in Powell and Aberson (2000) and Powell and Reinhold (2007) to

those provided by NHC. In addition to performing comparisons of H*Wind and NHC wind speeds, comparisons between the maximum wind speeds obtained in post storm analyses described in Vickery et al. (2008b) and the NHC estimates are also presented.

Figure 6 presents an example of a comparison of H*Wind and NHC Best Track (HURDAT) wind speeds for Hurricane Ivan (2004). The H*Wind wind speed data are available at http://www.aoml.noaa.gov/hrd/data_sub/wind.html. In the case of Hurricane Ivan, the H*Wind data consist of the real time analyses provided at 3- and 6-hour intervals at times usually 1 $^1/_2$ hours prior to the times associated with the Best Track wind speeds. In some instances the H*Wind data have been reanalyzed and these wind speeds are given at the same times as the Best Track data. When required, the H*Wind wind speeds have been interpolated to the Best Track times to enable point-by-point comparisons of the two sets of wind speeds. As indicated in the scatter plot shown in Figure 6, the H*Wind estimates of the wind speeds in Hurricane Ivan are 7- to 8-percent lower than the Best Track wind speeds. Figures 7 and 8 present examples for Hurricane Felix (2007) and Hurricane Rita (2005).

Minimum Design Loads for Buildings and Other Structures

Table 1-1. Classification of Buildings and Other Structures for Flood, Wind, Snow and Earthquake Loads

Nature of Occupancy	Category
Buildings and other structures that represent a low hazard to human life in the event of failure including, but not limited to: • Agricultural facilities • Certain temporary facilities • Minor storage facilities	I
All buildings and other structures except those listed in Categories I, III and IV	II
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with day-care facilities with capacity greater than 150 • Buildings and other structures with elementary or secondary school facilities with capacity greater than 250 • Buildings and other structures with capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients but not having surgery or emergency treatment facilities • Jails and detention facilities • Power generating stations and other public utility facilities not included in Category IV Buildings and other structures containing sufficient quantities of toxic, explosive other hazardous substances to be dangerous to the public if released including, but not limited to: • Petrochemical facilities • Fuel storage facilities • Manufacturing or storage facilities for hazardous chemicals • Manufacturing or storage facilities for explosives Buildings and other structures that are equipped with secondary containment of toxic or explosive or other hazardous substances (including, but not limited to double wall tank, dike of sufficient size to contain a spill, or other means to contain a spill or a blast within the property boundary of the facility and prevent release of harmful quantities of contaminants to the air, soil, ground water or surface water) or atmosphere (where appropriate) shall be eligible for classification as a Category II structure. This reduced classification shall not be permitted for seismic loads. In hurricane prone regions, buildings and other structures that contain toxic, explosive, or other hazardous substances and do not qualify as Category IV structures shall be eligible for classification as Category II structures for wind loads if these structures are operated in accordance with mandatory procedures that are acceptable to the authority having jurisdiction and which effectively diminish the effects of wind on critical structural elements or which alternatively protect against harmful releases during and after hurricanes.	III
Buildings and other structures designated as essential facilities including, but not limited to: • Hospitals and other health care facilities having surgery or emergency treatment facilities • Fire, rescue and police stations and emergency vehicle garages • Designated earthquake, hurricane, or other emergency shelters • Communications centers and other facilities required for emergency response • Power generating stations and other public utility facilities required in an emergency • Ancillary structures (including, but not limited to communications towers, fuel storage tanks, cooling towers, electrical substation structures, fire water storage tanks or other structures housing or supporting water or other fire-suppression material or equipment) required for operation of Category IV structures during an emergency • Aviation control towers, air traffic control centers and emergency aircraft hangars • Water storage facilities and pump structures required to maintain water pressure for fire suppression • Buildings and other structures having critical national defense functions	IV

**Figure 5. Classification of Building and Structure Occupancy/Usage Category as Defined in ASCE 7.
Source: ASCE 7-05[1].**

[1]Minimum Design Loads for Buildings and Other Structures, ASCE/SEI 7-05; 2006, *American Society of Civil Engineers*
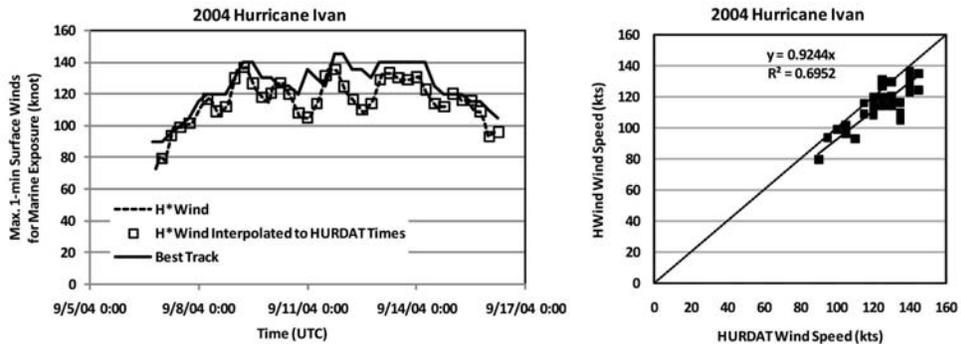
Figure 6. Comparison of H*Wind and Best Track Wind Speeds for Hurricane Ivan (2004).
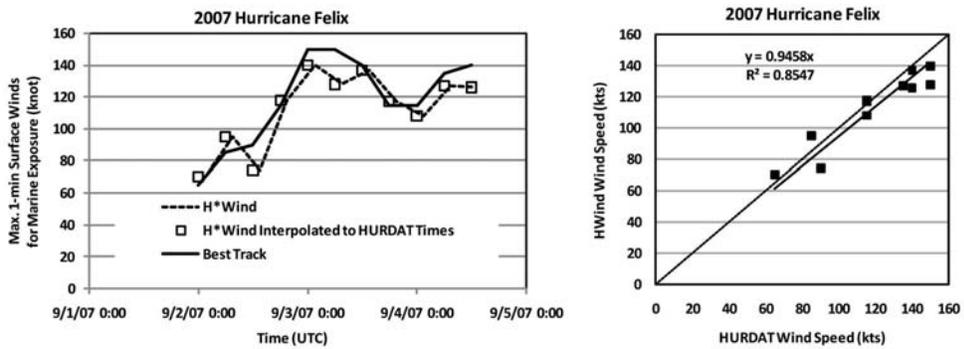
Figure 7. Comparison of H*Wind and Best Track Wind Speeds for Hurricane Felix (2007).
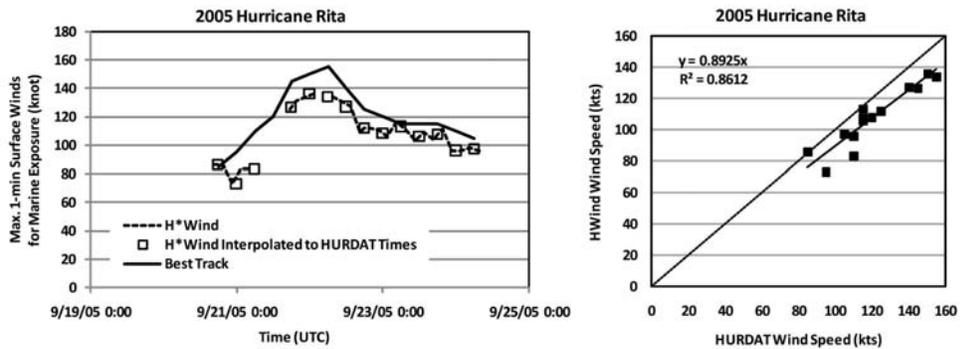
Figure 8. Comparison of H*Wind and Best Track Wind Speeds for Hurricane Rita (2005).

In the case of Hurricanes Felix (2007) and Rita (2005), the H*Wind wind speeds are about 5 percent and 11 percent lower than the Best Track wind speeds, respectively.

Figure 9 presents a summary comparison of Best Track and H*Wind wind speeds for all hurricanes affecting the US and Caribbean during the period of 2004 through 2007, where it is seen that on average, the H*Wind wind speeds are about $7^{1}/_{2}$ percent less than the Best Track wind speeds.
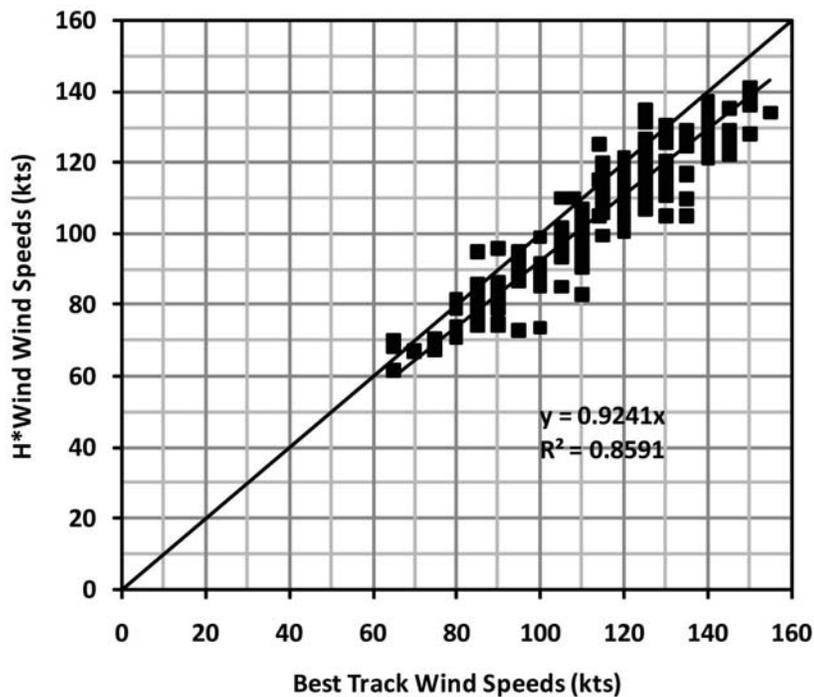
Figure 9. Summary Comparison of H*Wind and Best Track Wind Speeds for Hurricanes Impacting the US and Caribbean between 2004 and 2007.

In addition to comparing H*Wind and Best Track winds at 6-hour positions along the track of hurricanes occurring during the 2004 through 2007 seasons, we also compare the estimated wind speeds at landfall. The landfall estimates of wind speeds are developed from more data than those along the track of the hurricane. The additional wind speed data associated with the landfall estimates of wind speeds are usually obtained from land-based measurements of wind speeds that are adjusted to be equivalent to conditions over water. Figure 10 presents a comparison of the Best Track and H*Wind estimated wind speeds at the time of landfall. H*Wind wind speeds were obtained from Powell and Aberson (2001) and Powell and Reinhold (2007). In cases where wind speeds given in Powell and Aberson (2001) and Powell and Reinhold (2007) differed, wind speeds given in the more recent paper

were used. As indicated in Figure 10, the H*Wind estimates of the maximum wind speeds in US landfalling hurricanes are about 8 percent less than those given in the Best Track data.

Estimates of the maximum wind speeds for landfalling US hurricanes using a combination of measured surface level wind speeds and pressures and the wind field model described in Vickery et al. (2008b) provide an additional viewpoint on the magnitude of the maximum wind speeds produced by landfalling hurricanes. As indicated in Vickery et al. (2008b), the hurricane wind field model used in the analysis of landfalling hurricanes provides an unbiased estimate of the hurricane wind speeds. Figure 11 shows the comparison of the estimated maximum sustained wind speeds derived by Applied Research Associates (ARA) (Vickery et al., 2008b) and the Best Track values. On average, it is seen that the ARA estimated wind speeds are about 13 percent lower than the Best Track values.
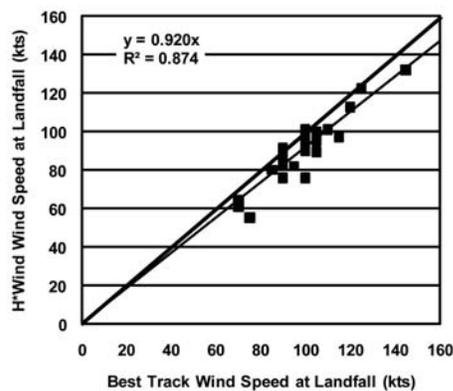
Figure 10. Summary Comparison of H*Wind and Best Track US Landfall Wind Speeds.
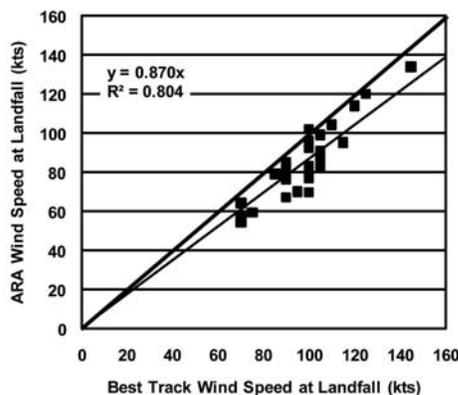
Figure 11. Summary Comparison of ARA and Best Track US Landfall Wind Speeds.

Figure 12 shows a comparison of both the H*Wind and ARA estimates (at landfall) versus the Best Track landfall values, considering only hurricanes with Best Track wind speeds exceeding 100 knots, where it is seen that the difference between the Best Track and ARA estimates reduces a little, with the ARA and H*Wind wind speeds being about 11 percent and 8 percent less than the Best Track wind speeds, respectively.
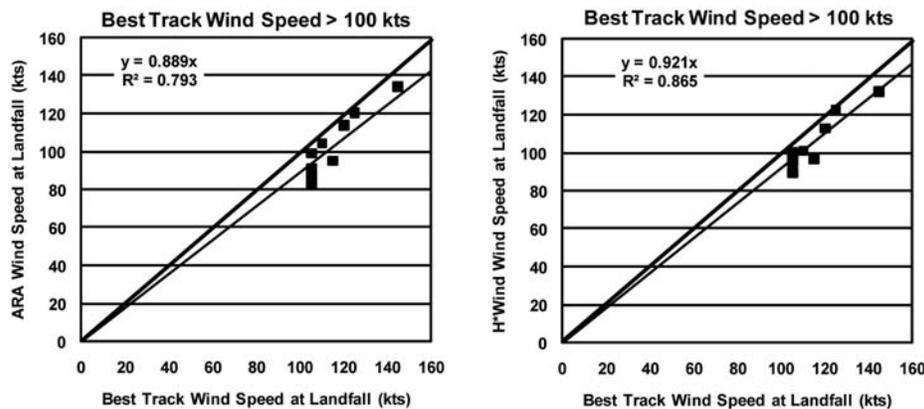
Figure 12. Summary Comparison of ARA (left) and H*Wind (right) and Best Track Estimated US Landfall Wind Speeds for Best Track Winds Greater than 100 kts.

In order to categorize the model hurricanes used to develop the hurricane hazard curve for Saint Lucia into their appropriate Saffir-Simpson categories, the modeled wind speeds are increased by 10 percent to account for the apparent bias in the Best Track wind speeds.

5. Regional Analysis

In order to define the hurricane climate in the region of Saint Lucia, a box is defined encompassing the region 10 degrees north to 20 degrees north and 55 degrees west to 65 degrees west. Each modeled or historical (Best Track) hurricane that enters the box is assigned a Saffir-Simpson category based on the highest sustained wind speed produced by the hurricane while within the box. For categorization purposes, the maximum wind speeds associated with the modeled hurricane are increased by 10 percent to account for the observed bias in the NHC Best Track wind speeds. Figure 13 presents a comparison of the maximum intensities of the Best Track and model hurricanes within the box. The period of record for the historical hurricanes includes the period of 1900 through 2007. Figure 14 presents a comparison of the modeled and historical hurricane intensities within the box where the historical period of record is 1970 through 2007 (the satellite era). Chi square tests of

the histograms show that the statistical distribution of the model results are equivalent to the distributions derived from the historical data using either the 1900 through 2007 data or the 1970 through 2007 data. **It is also clear that the annual frequency of Category 4 and 5 hurricanes was higher during the 1970 through 2007 period as compared to the 1900 through 2007 period.** It can be seen that the annual frequency of Category 4 and 5 hurricanes derived from the model agrees more closely with the 1970 though 2007 period than with the 1900 through 2007 period.
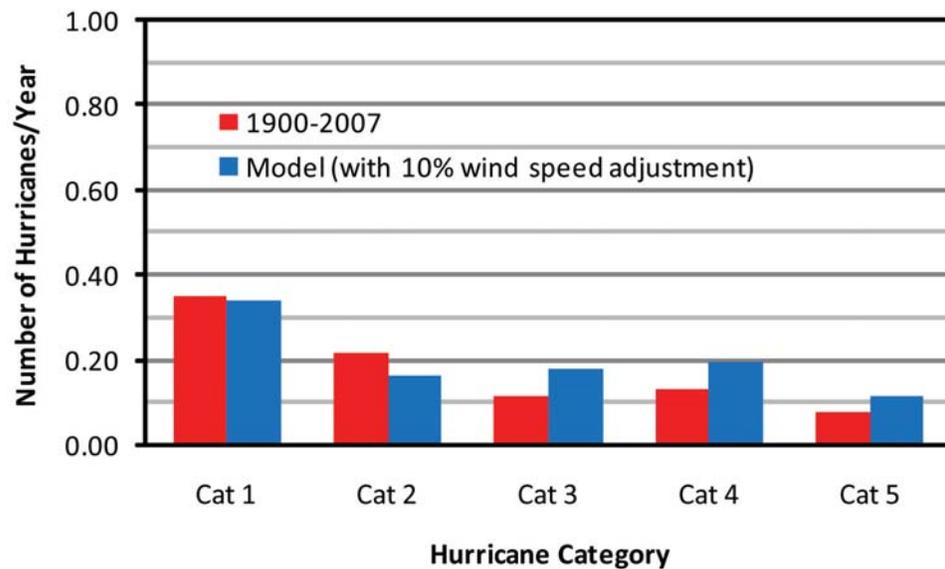
Figure 13. Comparison of Model and Historical Hurricane Frequencies by Category in the St. Lucia Area. Historical Data Encompasses the Period of 1900 through 2007.

Given the overall uncertainty in the demonstrated bias in the Best Track wind speeds and the general uncertainty in the estimation of hurricane wind speeds, and hence hurricane categories, the comparisons of model and observed hurricanes by category indicate that the hurricane simulation model replicates the current climatology when the climatology is defined by the Saffir-Simpson wind speed category of a hurricane.
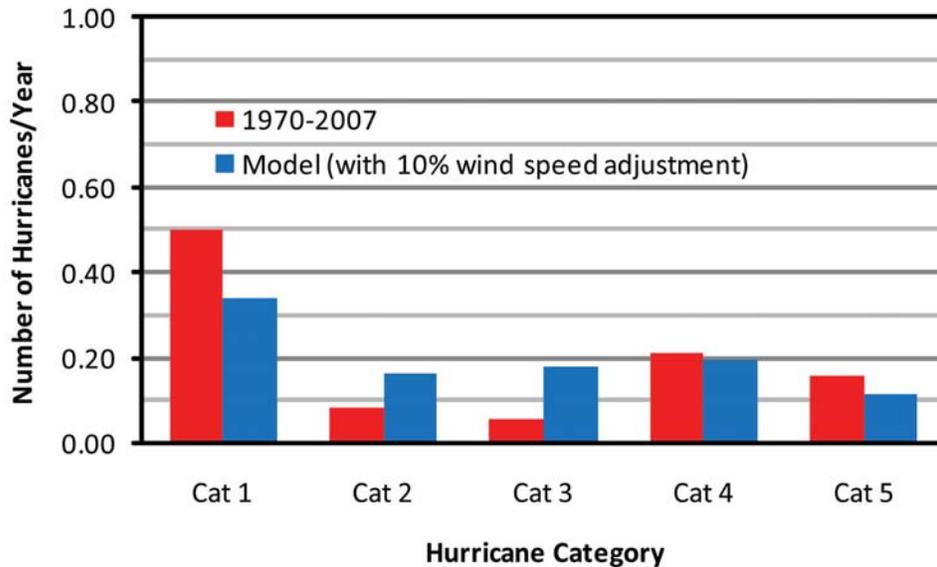
Figure 14. Comparison of Model and Historical Hurricane Frequencies by Category in the St. Lucia Area. Historical Data Encompasses the Period of 1970 through 2007.

6. Contribution of Hurricane Categories to the St. Lucia Hurricane Hazard Curve

Figure 15 presents the hurricane hazard curve for Saint Lucia based on the current climate model as given in Vickery and Wadhera (2008a), along with two other hazard curves derived with zero weight given to Category 3 and lower storms in one case, and zero weight applied to Category 4 and lower storms in the other case. In the case where the frequencies of Category 0 (tropical storms), and Category 1, 2, 3 and 4 hurricanes have been multiplied by zero we are left with only hurricanes that reach Category 5 status somewhere within the climate conditioning region.

Recall that for categorizing the storms, the maximum sustained wind speed within a modeled storm is increased by 10 percent in order to perform the categorization. Effectively, this means that a simulated hurricane is classified as a Category 5 hurricane if the maximum sustained marine wind speed in the model hurricane exceeds 141 mph. As indicated in Figure 15, hurricanes reaching categories less than 4 somewhere within the Saint Lucia area climate conditioning region have little effect on the hurricane hazard curve in Saint Lucia for return periods of 100 years or more. Only Category 5 hurricanes contribute to the hurricane wind speed hazard for return periods

of approximately 500 years or longer. **The fact that only Category 4 and 5 storms contribute to the wind speeds considered for design in Saint Lucia** means that we do not need to consider the effect of climate change on the frequencies of Category 3 and lesser hurricanes.

The impact of Category 1, 2 and 3 hurricanes on the hurricane hazard becomes more important for lower return periods and may contribute significantly to the average annual losses on the Island, but not to the basic wind speeds.
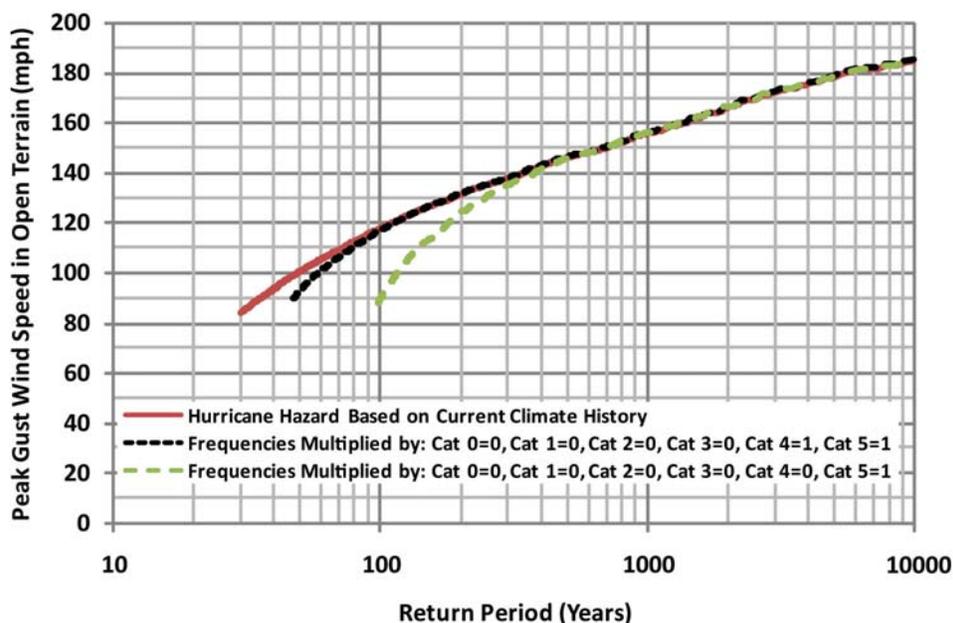
Figure 15. Effect of Category 4 and 5 Hurricanes on Basic Wind Speeds in St. Lucia.

Figure 16 shows the effect of increasing the annual frequency of Category 4 and 5 hurricanes by factors of 2 and 3 (100 percent and 200 percent increase in frequency) on the hurricane hazard curve for Saint Lucia. A 100-percent increase in the frequency of Category 4 and 5 storms results in the 700-year return period wind speed (3-second gust wind speed 10 m above flat, open terrain) increasing from 150 mph to 160 mph, or approximately 7 percent. This 7-percent increase in wind speed results in an increase in the design wind pressure of 14 percent for rigid structures. In the case of Category III and IV buildings, the 100-percent increase in the frequency of Category 4 and 5 hurricanes yields an approximate 6-percent increase in the

basic winds speed and, consequently, a 12-percent increase in the design pressure for rigid structures.
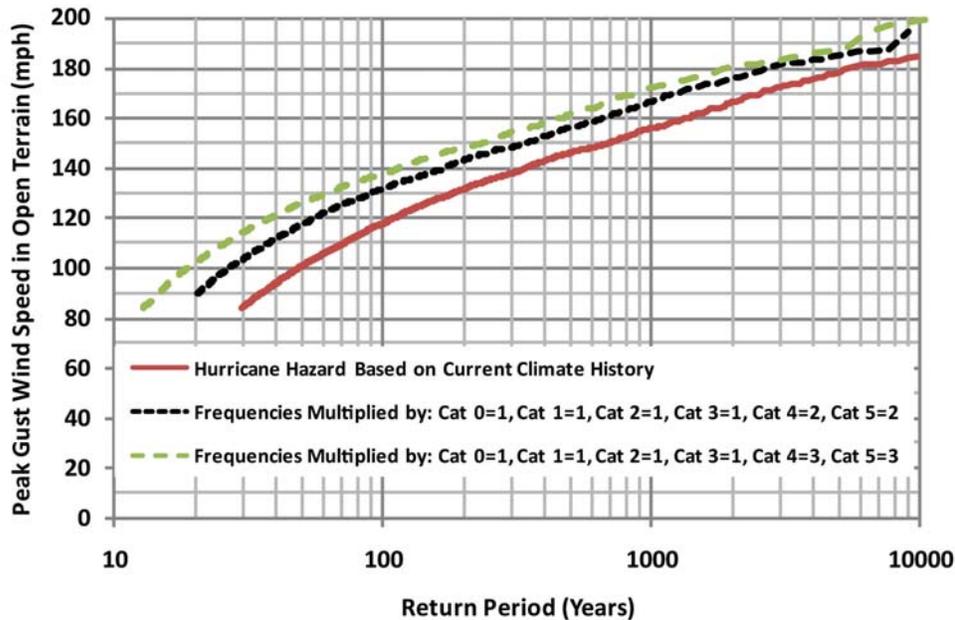
Figure 16. Effect of Increasing Annual Frequencies of Category 4 and 5 Hurricanes on Peak Gust Wind Speeds Hazard Curve.

Because in the case of Saint Lucia, the basic wind speeds are influenced only by Category 4 and 5 hurricanes, the effect on increasing the frequency of Category 4 and 5 hurricanes in a future climate scenario has the effect of shifting the wind speed hazard curve to the left. For example, a doubling of the frequency of Category 4 and 5 hurricanes shifts the wind speed associated with an annual occurrence rate of 100 years in the current climate to a wind speed having an annual occurrence of 50 years in this future climate scenario. The change in basic wind speed as a function of the change in hurricane frequency is thus dependent on the slope of the wind speed versus the return period curve centered on the return period of interest. **Generally, the higher the return period of interest, the lower the slope of the wind speed versus the return period curve, and as a result, increases in hurricane frequency yield lower percentage increases in the basic wind speeds.** Figure 17 presents the change in the basic wind speed (expressed as a percentage) versus the percentage increase in the number of Category 4 and 5 hurricanes affecting Saint Lucia.
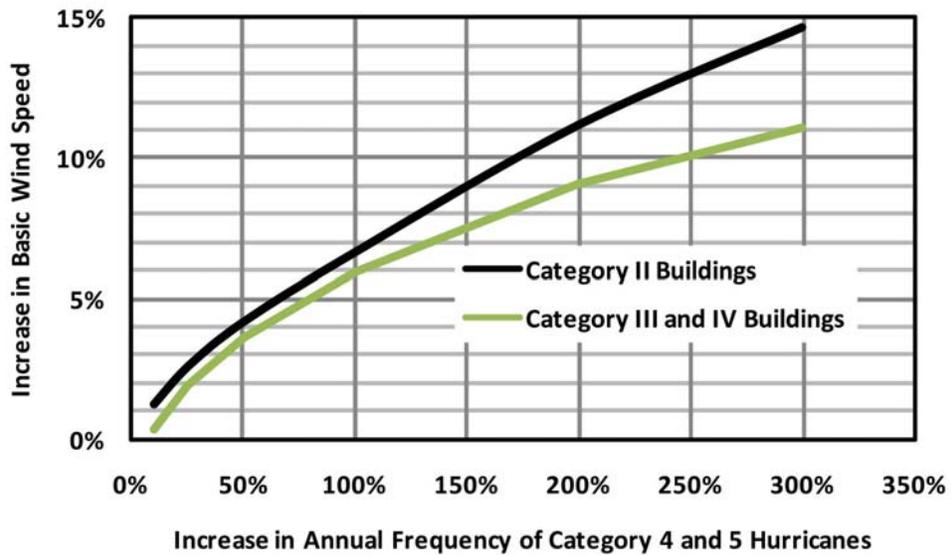
Figure 17. Percentage Increase in Basic Wind Speed in St. Lucia vs. Percentage Increase in Annual Rates of Category 4 and 5 Hurricanes.

% Increase in Annual Frequency of Category 4 and 5 Hurricanes	% Increase in Basic Wind Speed for Category II Buildings	% Increase in Basic Wind Speed for Category III and IV Buildings
10%	1.3%	0.4%
25%	2.6%	2.0%
50%	4.2%	3.6%
100%	6.7%	5.9%
200%	11.2%	9.0%
300%	14.7%	11.0%

Table 1. Increase in Basic Wind Speed in St. Lucia vs. Percentage Increase in Annual Rates of Category 4 and 5 Hurricanes.

According to Curry et al. (2007), **there could be an average of three to four Category 4 and 5 hurricanes per year by 2025 in the Atlantic Basin**. This represents a 210- to 280-percent increase in the number of Category 4 and 5 hurricanes compared to the long-term (1944-2007) average of 1.4 Category 4 and 5 hurricanes per year. If this were the case, the basic wind speeds for Category II buildings in Saint Lucia should be increased by about 12 to 14 percent, and the basic wind speeds for Category III and IV buildings should be increased by about 10 percent. Note that the increases in the basic

wind speeds assume that the hurricane hazard remains elevated for the expected life of the building. The Curry et al. (2007) estimate of the hurricane activity circa 2020 to 2025 does not suggest that the activity will continue at the predicted rate of three to four Category 4 and 5 hurricanes per year. **The estimate is a combination of an assumed 1ºF increase in the tropical sea surface temperature due to global warming and that around 2020-2025 we will be at a peak of the warm phase of the Atlantic Multidecadal Oscillation (AMO). Thus the estimate of a future Atlantic Ocean climate with three to four Category 4 and 5 hurricanes per year is a likely upper-bound estimate of a future hurricane climate. This upper-bound analysis also assumes that an increase in basinwide hurricane activity will be reflected equivalently in the Saint Lucia area.**

7. Conclusions

The basic wind speeds (including the effect of the load factor) used for the design of buildings in the Saint Lucia area are dominated by Category 4 and 5 hurricanes passing near the Island. Using this result, an approach has been developed to assess the impact of increased hurricane activity on basic wind speeds in the Saint Lucia area. The methodology can be applied using any estimates regarding the increased rate of Category 4 and 5 hurricanes in the future. The methodology assumes that the relative level of risk to be accepted by a designer remains constant. **Specifically, if a designer designs a building with an annual probability of exceeding the design wind load in today's climate of 0.0017 ($^{1}/_{700}$), then the methodology assumes that the same level of risk will be the target in a future climate.** In other words, it is assumed that the increased design wind speeds compensate for an increase in the hurricane hazard expected in the future, so the target reliability of the new designs is achieved even though the frequency of hurricanes may be increasing. The methodology developed here can be readily applied to other islands in the Caribbean and elsewhere. Following this final report, a technical one-day workshop will take place in Saint Lucia to present the results and provide a short training program on **engineering guidelines** for local engineers, architects and planners.

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