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AIRCURRENTS: EXPLORING THE IMPACT OF VULNERABILITY ON CARIBBEAN TROPICAL CYCLONE RISK

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EDITOR'S NOTE: *In this article, Dr. Apoorv Dabral and Matt Maddalo discuss the Caribbean's diversity in building types, construction mixes, building codes, and building practices. In the AIR Tropical Cyclone Model for the Caribbean, the amalgamation of all these factors shapes an island or territory's vulnerability—and tropical cyclone risk.*

THE ARTICLE: Overviews the myriad of factors that must be considered when evaluating a region's risk.

HIGHLIGHTS: Under harsh hurricane conditions, a building's performance is strongly dictated by the structure's materials, design, and construction methods. It is crucial for a catastrophe model to fully capture variability in building vulnerability in order to provide a realistic view of damage and risk.

INTRODUCTION

In the Caribbean, two neighboring territories—in fact, two territories sharing the same island—can be characterized by dramatically different tropical cyclone risk. How is it possible? Tropical cyclone risk is generally strongly influenced by hazard, and in the case of neighboring territories, hazard conditions are usually similar. So, if not hazard, the main driver of these large differences must be vulnerability.

Every Caribbean territory has a unique assemblage of vulnerability risk drivers: construction materials, building types, building codes, and code enforcement practices. These factors influence how well a building withstands intense winds and heavy rain. For example, a house made of reinforced concrete will outperform a wood frame house. Likewise, a commercial building in a country with strict building codes and practices will generally better withstand tropical cyclone conditions than a similar structure in a country with similar building code requirements, but lower code enforcement.

This article explores the general impact of vulnerability on tropical cyclone risk in the Caribbean, with a focus on the unique role vulnerability plays in explaining differences in risk between neighboring territories.

EXPOSURE'S INFLUENCE ON VULNERABILITY, RISK

One of the key drivers of Caribbean vulnerability risk is the mix of exposure, or building inventory. Generally, all the islands use similar types of construction materials for residential, commercial, and industrial building types, namely wood frame, unreinforced masonry, reinforced masonry, reinforced concrete, and steel. Certain construction materials perform better under hurricane conditions than others. In general, the ordering of building materials from least to most vulnerable is as follows: reinforced concrete, steel, reinforced masonry, unreinforced masonry, and wood frame. It is the distribution of these construction materials for a given occupancy that can differ significantly between territories (Figure 1 and Figure 2), and thus seriously impact risk.

The construction material distributions of single family homes for select Caribbean territories are shown in Figure 1. Similarly, the construction material distributions of commercial buildings for certain Caribbean territories are displayed in Figure 2.

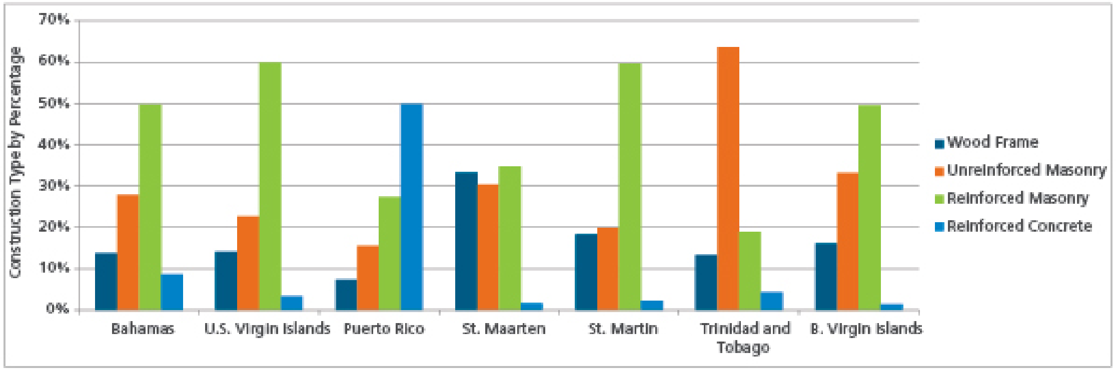

Figure 1. Distribution of construction material for single family homes for seven Caribbean territories (Source: AIR)

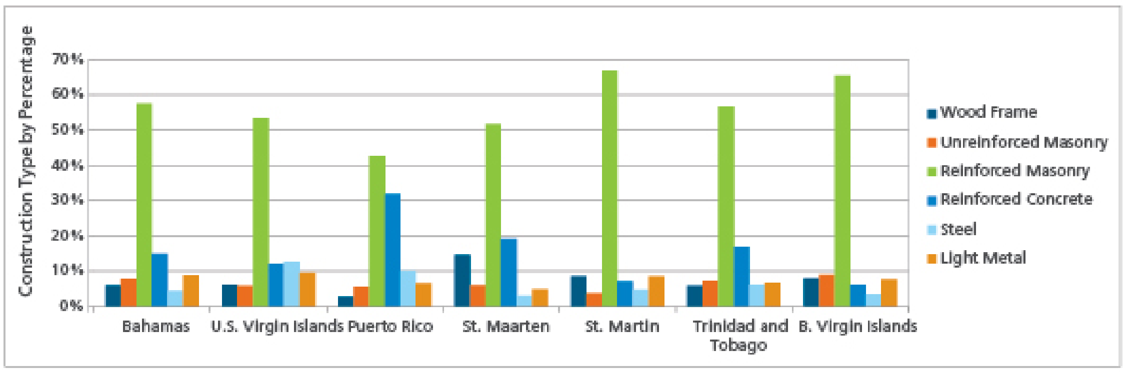

Figure 2. Distribution of construction material for commercial properties for seven Caribbean territories (Source: AIR)

Of the territories illustrated in Figures 1 and 2, Puerto Rico's building material distributions most clearly correlate to the island's level of overall vulnerability. Puerto Rico has a low vulnerability, attributable in large part because the island has high percentages of reinforced concrete for both single family homes and commercial structures—indeed the highest percentage of concrete single family homes in the Caribbean. This anomalously high utilization of concrete is realized in the form of the island's distinctive "bunker style" construction (see the sidebar for more information).

In Trinidad and Tobago, the picture becomes more complex: there is a relatively weak residential construction mix, but a strong commercial building inventory. Which line of business, residential or commercial, is the dominant indicator of risk? In order to truly decipher the island's tropical cyclone risk, all vulnerability risk drivers need to be considered.

DEBUNKING PUERTO RICO'S BUNKER STYLE

In 1989, Puerto Rico was struck by the intense Hurricane Hugo. Winds of Saffir Simpson Category 3 damaged 25% of homes in Puerto Rico and left approximately 75% of the island without power. Yet buildings made in the bunker style impressively weathered the storm with minimal damage. Following Hugo, Puerto Rico adopted better engineering practices and this included an increase in bunker style construction.

Predominantly a residential building style, bunker construction single family homes and apartment buildings are built of reinforced concrete walls (sometimes combined with reinforced or unreinforced masonry), and concrete slab floor and ceilings. Bunker buildings often have "Miami" style windows or other highly wind-resistant windows. This building type is generally one to four stories in height, and the building vulnerability does not vary significantly with height. Damage functions have been developed in the AIR Tropical Cyclone Model for the Caribbean that can account for the bunker construction in single family homes, apartments, and government buildings.

BUILDING CODE AND PRACTICES

Simply having high percentages of strong building types is not enough to substantially decrease an island's risk if other vulnerability factors, such as building codes and building practices, are also not strong.

Across the Caribbean, there is a wide range in building code type, utilization, and enforcement. The Caribbean Uniform Building Code (CUBiC) was approved by the Caribbean Community (CARICOM) Council of Ministers of Health in 1986; it provides a common standard for buildings within the region for members of CARICOM. Specifically, it provides reference velocity pressures—that is, the wind load exerted on buildings by wind at standard roughness, height, and topography—for the 50-year return period. If not used directly, many regional and country codes are at least partially based on CUBiC. Other codes and standards used throughout the modeled region include ASCE, Eurocode, British Standards, and the International Building Code. It is also common practice, depending on the country, for different engineers to apply different codes within the same island.

Not all codes are of the same caliber. Some regulations are much more thorough than others. An example of a comprehensive code includes the Bahamas Building Code, which was initially based on the rigid South Florida Building Code and has since been updated to follow the ASCE 7 standards. Moreover the Bahamas Building Code accounts for wind loading up to 150 mph on various engineered structure; this code is strictly enforced.

A rigorous building code is important for lowering a country's tropical cyclone vulnerability, but the code means nothing if it is not enforced. Strict building code enforcement plays a large role in reducing a region's building vulnerability. Returning to the example of Trinidad and Tobago, as was mentioned before, the island has a weak residential construction mix, but a strong commercial one. Using this information alone, it is impossible to determine the island's vulnerability, as well as overall risk.

Let's now consider building code and code enforcement. Trinidad and Tobago developed a building code for small residential and commercial structures based on the CUBiC code in 2002. This code has still not been formally put into regulation nor is it routinely enforced. Based on this information, it becomes clear that Trinidad and Tobago has a high vulnerability relative to the Bahamas, and this greatly contributes to the island's overall tropical cyclone risk.

Differences in relative code enforcement across several Caribbean territories are shown in Figure 4.

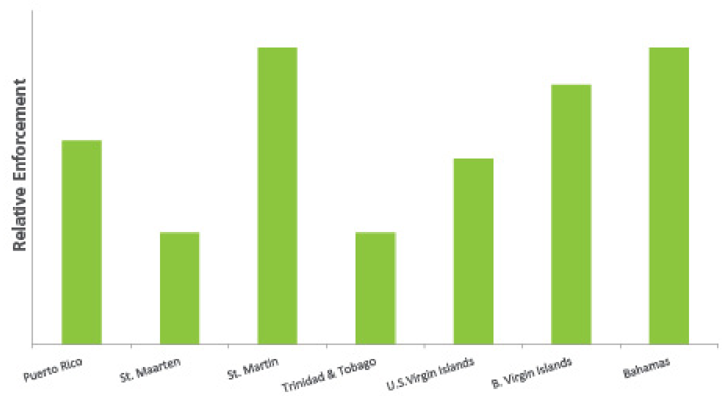

Figure 3. Comparison of relative building code enforcement for select territories (Source: AIR)

CARIBBEAN VULNERABILITY CASE STUDY: SAINT MARTIN VS. SINT MAARTEN

There is no better example to illustrate the influence of vulnerability on risk than the French Saint Martin (St. Martin) and Dutch Sint Maarten (St. Maarten). These two territories are as physically close as neighboring countries can be—they share the same small island—and yet, their vulnerability characteristics are strikingly different. St. Martin has a strong overall construction mix and building code, matched with strict code enforcement. St. Maarten, in comparison, has a weak residential construction mix, but a reasonable commercial building inventory. The Dutch territory also has a weak building code and less strict code enforcement. The impacts of exposure mix, building code, and code enforcement on St. Martin and St. Maarten's overall vulnerabilities and tropical cyclone risks are explored below using vulnerability ratios and simulated event loss calculations.

The main differences in residential and commercial exposure mix distributions between the Dutch and French territories are displayed in Figure 1 and Figure 2, respectively. In the bar graphs below, however, vulnerability ratios are compared to highlight differences in the actual construction materials used by the two countries, as well as emphasize the aggregated effect of construction material differences on the total exposure's vulnerability. For example, Figure 5 displays the ratio of residential wood frame construction vulnerability for St. Martin over that of St. Maarten. These ratios were created for select construction types (wood frame(WF), unreinforced masonry(URM), reinforced masonry(RM), and reinforced concrete(RC)), as well as the exposure weighted construction, i.e., an averaged construction that is weighted in terms of relative percentage of different construction types. All vulnerability ratio values were averaged over the wind speed range 80-120 mph.

Within this wind speed range, the vulnerabilities of all residential construction types, but especially for reinforced masonry buildings, are higher for St. Maarten (Figure 5). Moreover, the residential exposure-weighted ratio is greater than any particular residential construction ratio, emphasizing the effect of the construction mix contribution on overall vulnerability differences between St. Martin and St. Maarten. The greatest commercial exposure vulnerability ratio is for reinforced concrete construction (Figure 6). This occurs because reinforced concrete structures are more engineered than other buildings, and the most vulnerable components for these buildings are claddings and openings. If these components are not built to code and are not attached properly, the building's vulnerability can increase dramatically. This is consistent with the fact that St. Martin has a strict building code and code enforcement, as compared to St. Maarten.

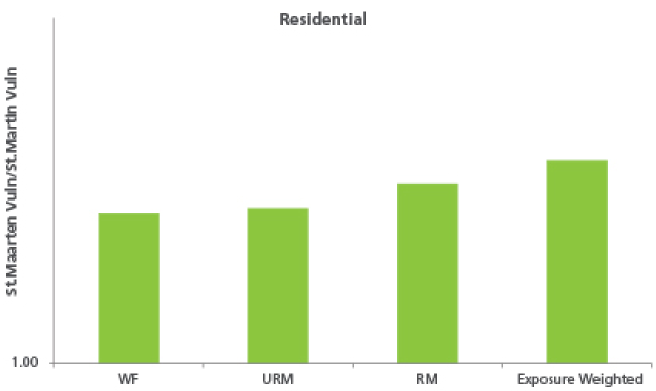

Figure 4. Ratio of average residential St. Maarten and St. Martin vulnerabilities compared by construction type (Source: AIR)

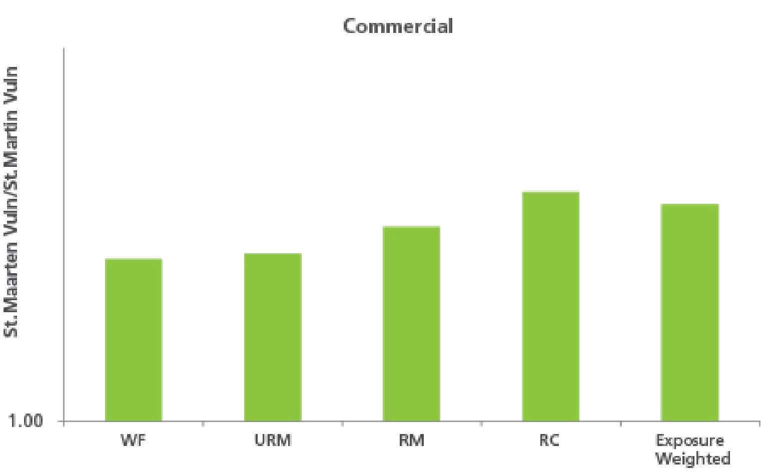

Figure 5. Ratio of average commercial St. Maarten and St. Martin vulnerabilities compared by construction type (Source: AIR)

The differences in vulnerabilities and risk of these two islands is further explored below using a simulated event (Event ID: 20839) from the 10,000-year catalog of the AIR Tropical Cyclone Model for the Caribbean. The differences in vulnerability between St. Martin and St. Maarten become apparent, even when hazard conditions are similar between the territories.

The simulated wind footprint over St. Martin and St. Maarten is shown in Figure 7. Although the distribution of winds is not uniform because of variations in elevation and land use/land cover within the island, both countries experience similar ranges of wind speeds, with winds up to Category 3 strength (between 110–130 mph). East-central St. Martin experiences the highest wind speeds across the two regions; the area of lowest wind speeds—in St. Maarten—delineates a forested area.

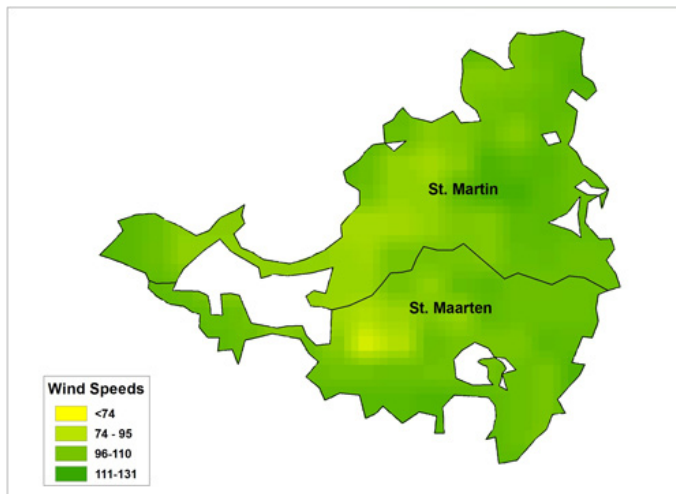

Figure 6. Simulated event wind footprint (Source: AIR)

Despite St. Martin experiencing slightly higher wind speeds, St. Maarten suffers greater residential and commercial damage from this event. To highlight damage differences, a contrived exposure representing specific construction-occupancy combinations was uniformly distributed across the entire island. The damage levels, or damage ratios, of the two territories for single family homes of reinforced masonry are shown in Figure 8. Similarly, the damage levels for St. Martin and St. Maarten for general commercial structures of reinforced masonry is shown in Figure 9. Across lines of business, the highest levels of damage are consistently observed in St. Maarten—and indeed there is a clear and discrete change in damage ratios at the border of the two countries.

The county-specific damage patterns highlight the previously noted differences in building codes and practices. St. Martin has relatively strict code enforcement: construction must comply with French "norms," and building designs and constructions must be inspected by the bureaux de contrôle, an independent firm licensed by the state. St. Marteen, however, has less severe code enforcement and inspections are conducted only by the in-house staff of the Dutch Public Works Department.

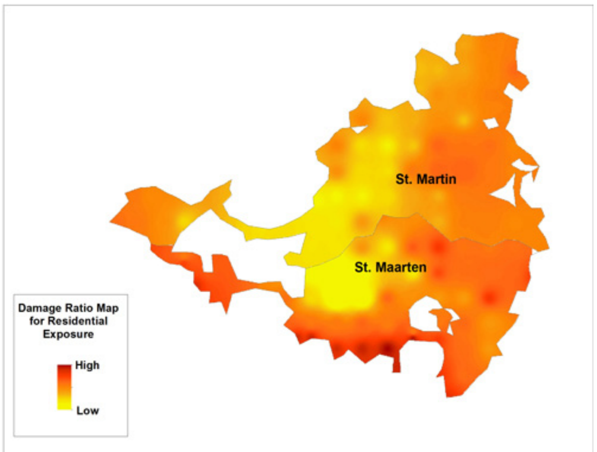

Figure 7. Damage ratio map for St. Martin and St. Maarten of single family homes of reinforced masonry construction (Source: AIR)

CONCLUSION

In the AIR Tropical Cyclone Model for the Caribbean, differences in vulnerability strongly contribute to differences in relative risk between islands. The major vulnerability drivers include construction distributions, building codes, and code enforcement. It is important to stress that any one driver may not be a clear indicator of risk. Instead, it is how all the driver's work together. The island with the lowest vulnerability will have not only strong building construction, but also robust building codes and stringent code enforcement.

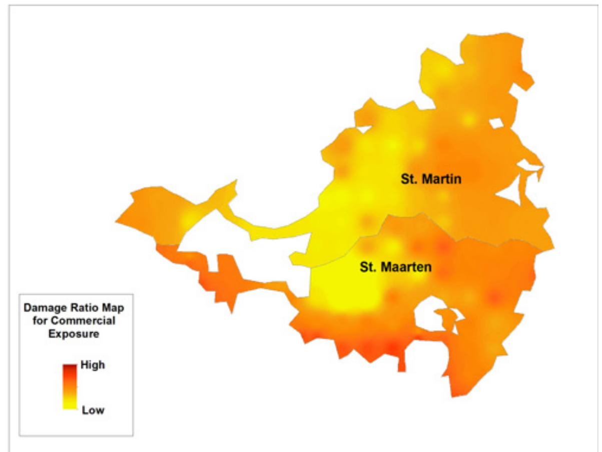

Figure 8. Damage ratio map for St. Martin and St. Maarten of commercial buildings of reinforced masonry construction (Source: AIR)

A WORD ON HAZARD

Of course, tropical cyclone risk is determined by more than just building vulnerability. Indeed the primary drivers of insured loss in the Caribbean are hazard characteristics, including storm size, intensity, duration, and frequency.

The hazard component of the AIR Tropical Cyclone Model for the Caribbean was built using high resolution hazard data, over 100 years of historical storm information, and scientific expertise. The model features a large stochastic catalog of simulated events that appropriately captures the behavior of Atlantic basin tropical cyclones, as well as the observed correlation of risk between countries—an important criteria for companies that insure properties across the region.

Both wind and precipitation-induced flood (accumulated runoff) perils are major drivers of tropical cyclone loss, and these perils are both captured in the model. Using the latest satellite-derived, high-resolution land use/land cover and elevation data from the United States Geological Survey (USGS), AIR's wind modeling captures the effects of surface friction based on the direction of the wind at each location, as well as the effects of coastal and inland terrain on wind speeds.

Unlike tropical cyclone winds, which generally decrease as a storm moves inland, precipitation intensity and the related flood hazard can actually increase as the system moves inland. The AIR Tropical Cyclone Model for the Caribbean incorporates a flood module that estimates the probability and severity of a flooding event and its associated damage. Based on storm size, intensity and rainfall characteristics, as well as terrain and land use, the model captures an hourly precipitation footprint at each location over the entire duration of the storm. The total accumulation is then redistributed based on the porosity of the soil, land use and slope.

Almost every major hurricane (Category 3 or higher) that has caused damage in the United States or Central America has passed through the Caribbean first—examples include Okeechobee, Hugo, Andrew, and Dean. In fact, many severe Atlantic basin storms have reached their peak intensity in the Caribbean. Of all the landmasses at risk of tropical cyclones in the North Atlantic, the Caribbean islands experience the greatest number of tropical cyclones, especially more intense storms. Correspondingly, this contributes to the Caribbean's relatively high regional tropical cyclone risk.

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AIR Worldwide (AIR) is the scientific leader and most respected provider of risk modeling software and consulting services. AIR founded the catastrophe modeling industry in 1987 and today models the risk from natural catastrophes and terrorism in more than 90 countries. More than 400 insurance, reinsurance, financial, corporate, and government clients rely on AIR software and services for catastrophe risk management, insurance-linked securities, detailed site-specific wind and seismic engineering analyses, agricultural risk management, and property replacement-cost valuation. AIR is a member of the Verisk Insurance Solutions group at Verisk Analytics (Nasdaq:VRSK) and is headquartered in Boston with additional offices in North America, Europe, and Asia. For more information, please visit **www.air-worldwide.com**.