**The Impact of Hurricanes Strikes on Tourist Arrivals in the Caribbean**

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We quantify the impact of hurricane strike on the tourism industry in the Caribbean. To this end we first derive a hurricane damages index by using historical 3-hourly hurricane track data within a physically based wind field model which allows one to calculate the actual wind speed experienced at any locality relative to the hurricane eye of a passing or land falling hurricane. We then employ this hurricane destruction index within a cross-country panel data context to estimate its impact on country-level tourist numbers. Our results suggest that an average hurricane strike causes tourism arrivals to be about 2% lower of what it would be if no strike had occurred.

**Key words : Hurricanes, Tourism, Caribbean**

## 1. Introduction

The Caribbean is more dependent on tourism to sustain livelihoods than any other region of the world in that this sector often serves as the primary industry or at least as a major earner of foreign exchange. For example, in terms of output generation, in British Virgin Islands, Antigua and Barbuda, and Anguilla tourism constitutes over 70 % of GDP, while in other islands such as Aruba, Barbados, and Bahamas more than half of GDP is generated through tourism and related receipts (WTTC, 2010). However, at the same time the Caribbean is also a region highly susceptible to damages arising from natural disasters, such as hurricanes. As a matter of fact, hurricanes are famous for potentially wreaking havoc in the Caribbean, inducing substantial physical damages and disruption to normal economic activity, including tourism. For instance, in 2004 Hurricane Ivan is believed to have caused damages in Grenada of around $1.1 billion, while also having resulted in a dramatic reduction in tourism.

Given the apparent rise in the number of hurricanes in the Caribbean, possibly linked to climatic changes, over the last number of years, this potential impact on tourism may tbe regarded as particularly worrisome for the region. However, while there are a number of case studies of the effect of a particular hurricane strike within the Caribbean, such as Benson et al. (2001) who noted how infrastructure destruction due to hurricanes have gone hand in hand with a decline in visitor numbers by around 30 % in Dominca over the 1978-1986 period, there is of date no comprehensive statistical analysis that provides any quantitative estimates of the impact on the tourism industry statistically attributable to hurricanes across the Caribbean. One partial exception is Sahely (2005) who examines tourism demand for three major non-banana producing countries (Anguilla, Antigua and

Barbuda, and St. Kitts and Nevis) and finds no negative effects of hurricanes, although it must be noted that the author only used hurricane incidence dummies and thus abstracted from differences in hurricane strengths and destruction. While there are no other econometric analysis of the impact of hurricanes on tourism even outside the Caribbean region that we are aware of, there are a few studies on other types of disasters. For instance, examining the case of an earthquake in Taiwan, Huang and Min (2002) find that it took the tourism industry at least a year to recover. Also, Hultkrantz and Olsson (1997) found that the Chernobyl unclear accident caused losses of 2.5 billion SEK in revenues from incoming tourism. Moreover, there is also a relatively larger literature of the effects of terrorism attacks on tourism, which can similarly be viewed as an exogenous shock to the industry. Most of these seem to find a significant negative impact; see, for instance, Sloboda (2003) and Pizzam and Fleischer (2002).

In this paper we thus explicitly set out to quantitatively measure the impact of hurricanes on tourism for 26 countries within the Caribbean region over the 2003-2008 period. Moreover, rather than using measurement prone *ex post* loss data or simple incidence dummies as proxies for these disaster events - as is prominent in essentially all of the literature cited above - we here employ *ex ante* data on the nature of the striking hurricanes in conjunction with a physical wind field model to develop a proxy of damages incurred that will arguably provide a much more accurate measure of large exogenous negative shocks to the tourism industry. One may want to note in this regard that this approach of using pre-defined information of a natural disaster event to proxy its Impact has recently not only gained popularity in academic circles[1], but also appears to have generated interest among policy

[1] See, for instance, Strobl (2010a).

makers. For instance, the recently established Caribbean Catastrophe Risk Insurance Facility set up by the World Bank now uses the local maximum wind speed of a hurricane to partially determine the amount of funds to disperse in the case of a hurricane strike for participating countries.

The remainder of the paper is as follows. In Section 2 we briefly discuss the nature of hurricanes and their likely impact on tourism. Section 3 outlines the construction of our hurricane potential destruction index. Our data sets and some summary statistics are provided in Section 4. Section 5 presents the econometric analysis. Finally, Section 5 concludes.

**Section 2. Hurricanes and the Tourism Industry**

A tropical cyclone is a meteorological term for a storm system which forms almost exclusively in tropical regions of the globe. Tropical storms in the North Atlantic and the North East Pacific region, as we study here, are referred to as hurricanes if they are of sufficient strength[2] and their season can start as early as the end of May and last until the end of November. We provide a sample picture of Hurricane Ivan in 2004, representative of the typical structure of such a storm, in Figure 1. In terms of structure, a hurricane will typically harbor an area of sinking air at the center of circulation, known as the 'eye, where weather in the eye is normally calm and free of clouds, though the sea may be extremely violent.[3] Outside of the eye curved bands of clouds and thunderstorms move away from the

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[2] Generally at least 119 km/hr.

[3] National Weather Service (October 19, 2005). Tropical Cyclone Structure. JetStream - An Online School for Weather. National Oceanic & Atmospheric Administration.

eye wall in a spiral fashion, where these bands are capable of producing heavy bursts of rain, wind, and tornadoes. Hurricane strength tropical cyclones are normally about 483 km wide, although this can vary considerably.

Damages due to hurricanes typically take a number of forms. Firstly, their strong winds may cause considerable structural damage to crops as well as buildings. Secondly, the heavy rainfall can result in extensive flooding and, in sloped areas, landslides. Finally, the high winds pushing on the ocean's surface cause the water near the coast to pile up higher than the ordinary sea level, resulting in storm surges. The flooding inland due storm surges generally occurs as early as 3-5 hours before arrival of hurricane and is often its most damaging aspect, causing severe property damage and destruction and salt contamination of agricultural areas.[4] Such storm surges can also result in considerable coastal erosion. One may also want to note that hurricanes lose their strength as they move over land.

While the extent of potential damages caused by hurricanes may depend on many factors, such as slope of the continental shelf and the shape of the coastline in the landfall region in the case of storm surges, it is typically measured in terms of wind speed. A popular classification has been the Saffir-Simpson (SS) Scale, where values from 1 through 5 correspond to wind speeds of 119-153 km/hr, of 154-177 km/hr, of 178-209 km/hr, of 210-249 km/hr, and 250+ km/hr, respectively. In this regard, it is generally agreed that considerable damages only occur once a hurricane reaches a strength of 3 on the SS scale in approaching the coast and/or making landfall.[5]

[4] See Strobl (2010).

[5] For instance, for the United States Pielke et al (2008) that over 85% of total damages are due to hurricanes of strength 3 and above, although these have only comprised 24 per cent of all U.S. landfalling tropical cyclones.

A priori one should expect the impact to take place on two fronts *a priori*. On the one hand, there will be direct costs like the destruction of infrastructure and coastal degradation, which will make the quality of the location as a tourist destination in question lower, at least in the short run. Related to this, on the other hand, one might anticipate hurricanes strikes increasing the subjective perceived probability of future hurricanes, further discouraging tourists on the margin from choosing the affected country relative to alternatives, as well as reducing future investment in the tourist industry. In this regard, Mahon (2006) noted that *"a healthy tourist economy cannot thrive and grow unless prospective tourists perceive the islands as a safe place in which to visit and vacation. A hurricane or earthquake with tremendous damage, destruction or loss of life may create a long lasting image that Caribbean SIDS are a dangerous and risky vacation setting".* Even if tourist industry is not affected in terms of direct damages or perceived probability or reoccurrence, if a hurricane affects other sectors of the economy, such as agriculture or manufacturing, then there may nevertheless be spill over effects through increased prices. As a consequence, wage rises could further reduce the profit margin of tourist enterprises.

**Section 3. Hurricane Destruction Index**

Our hurricane wind damage index is based on being able to estimate local wind speeds at any particular locality where a hurricane strength tropical storm directly passes over or nearby. To do so we rely on the meteorological wind field model developed by Boose et al (2004)[6], which provides estimates of wind field velocity at any point relative to

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Similarly Vickery et al (2008) show using the loss functions of the HAZUS-MH model that the loss ratio is minimal for wind speeds below 177 km/hr.

[6] This wind field model was, for instance, verified by Boose et al (2004) on data for Puerto Rico.

the 'eye' of the hurricane. This model, based on Holland's well known equation for cyclostrophic wind and sustained wind velocity[7], estimates wind speed at any point *P* to be:

$$V = GF\left[V_m - S(1-\sin(T))\frac{V_h}{2}\right]\left[\left(\frac{R_m}{R}\right)^B \exp\left(1-\left[\frac{R_m}{F}\right]^B\right)\right]^{\frac{1}{2}} \quad (1)$$

where $V_m$ is the maximum sustained wind velocity anywhere in the hurricane , *T* is the clockwise angle between the forward path of the hurricane and a radial line from the hurricane center to the point of interest, *P*, $V_h$ is the forward velocity of the hurricane, $R_m$ is the radius of maximum winds, *R* is the radial distance from the center of the hurricane to point *P*, and *G* is the gust wind factor. The relationship between these parameters and *P* are depicted in Figure 2. The remaining ingredients, *F, S,* and *B*, are scaling parameter for surface friction, asymmetry due to the forward motion of the storm, and the shape of the wind profile curve, respectively.

If we take as a given that the power dissipation, and hence subsequent damage, of a hurricane is intrinsically related to its wind speed, then we can propose the following index, *HURR*, of total destruction due of a storm *r* over its life time τ in any country *i* at time *t*:[8]

$$HURR_{i,r,t} = \left(\sum_{j=1}^{J} \int_0^{\tau} V_{jt}^{\lambda} w_{i,j,r,t} dr\right) \quad \text{if } V_{jt}>177 \text{ km/hr (SS}\geq 3\text{) and zero otherwise} \quad (2)$$

Where V are estimates of local wind speed at localities *j*, *J* is the set of localities *j* within country *i*, *w* are weights assigned according to characteristics of the locality to capture the 'potential' damage there, and λ is a parameter that relates local wind speed to the local level

[7] See Holland (1980).

[8] In essence this is a modified version of Emanuel's (2005) proposed destruction index.

of damage. In terms of the weights *w* we use the time varying share of population of each individual locality *j* at *t-1*, where the underlying argument is that, even if severely damaged by hurricane winds, sparsely populated areas are unlikely to play a significant role in the overall impact of a hurricane for a country in any year. In this regard, it has been noted by McGranaham et al (2007) that in developing countries a significant share of the population tends to live in coastal areas, especially in small island countries, which are of course more vulnerable to tropical storm incidence. One should note that in (2) we focus only on wind speeds that cause significant damages, i.e., on those that that are of least strength 3 on the SS scale, as discussed above.

An important input variable to (2) is λ, i.e., the parameter that links wind speed to its level of destruction. In this regard Emanuel (2005) noted that both the monetary losses as well as the power dissipation of hurricanes tend to increase as the cube of the maximum observed wind speed rises, and hence argues that the destructiveness of a hurricane can roughly be measured by the cubic value of its maximum observed wind speed.[9] We thus assume λ to take on the value of 3 here as well.

## Section 4. Data and Summary Statistics

*Hurricane Data*

For data on hurricanes in the CAC region[10] we rely on two data sources, the North Atlantic Hurricane database (HURDAT). The HURDAT database consists of six-hourly

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[9] Strobl (2010) estimates a similar parameter for the US and finds that this is around 3.14.

[10] The CAC region consists of 31 countries/territories. We list these in Table 1.

positions and corresponding intensity estimates in terms of maximum wind speed of tropical cyclones in the North Atlantic Basin over the period 1851-2008 and is the most complete and reliable source of North Atlantic hurricanes.[11] We linearly interpolated the positions and wind speeds between the six hourly data to obtain three hourly track data since hurricanes can move considerable distance in just a few hours.[12]

We depict the total number of tropical storms over the period in Figure 3, where darker shading indicates when these obtained maximum speeds of SS scale of 3. As can be seen, while there are many tropical storms only a few of these, and then only for parts of their track, translate into potentially damaging hurricanes.

In terms of applying our wind field model to obtain local wind intensity estimates for the Caribbean region, we followed each tropical cyclone over each point of the interpolated track and calculated the wind intensity relative to the center of each grid cells in the schemata provided by the population data as long as these fell within 500 km of the hurricane's location. This provided us with a complete set of estimates of wind fields experienced by all spatially relevant localities relative to each position of each tropical cyclone. We were then able to calculate local destruction according to our index of (2).

As a demonstration of how our HD index translates into estimates of local destruction for individual hurricane occurrences we next calculated and plotted its value over all affected localities for Hurricanes Dennis, which struck the Caribbean in 2005, in

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[11] While due to differences in data collection methods for periods prior to the 1960s some weak tropical storms may be missed, in terms of cyclones that reached hurricane density the data set can be considered essentially to be exhaustive. For a detailed description see Jagger and Elsner (2004).

[12] One should note that interpolating the track data to obtain more frequent observations of the tropical cyclone is standard in the literature; see, for instance, Jagger and Elsner (2006).

Figure 4, where shading moving from yellow to red indicates the rising scale of damages (measured in terms of their contribution on a national scale because of the population weights). One may want to note that Hurricane Dennis was an early-forming major hurricane in the Caribbean and Gulf of Mexico during the very active 2005 Atlantic hurricane season. Dennis was the fourth named storm, second hurricane, and first major hurricane of the season. In July, the hurricane set several records for early season hurricane activity, becoming both the earliest formation of a fourth tropical cyclone and the strongest Atlantic hurricane ever to form before August. Dennis hit Cuba twice as a Category 4 hurricane on the Saffir-Simpson Hurricane Scale. Dennis is believed to have caused at least 89 deaths (42 direct) and caused approximately $2.23 billion (2005 US dollars) in damages in the Caribbean, primarily on Cuba.

As can be seen from Figure 4, Hurricane Dennis only made landfall at hurricane strength in Cuba, causing damages throughout the island. Noteworthy in this regard is that the extent of damages differed widely. One may also want to take note that while no other islands were directly struck in terms of landfall, Hurricane Dennis' winds were strong enough to affect Haiti, Jamaica and small parts of the Bahamas.

In Table 1 we depict the total sum of our HURR index for the 26 countries in our sample. As can be seen, the distribution of hurricane destruction experienced over our sample period differs widely across countries. More precisely, while there are many countries that were not affected by hurricanes, others such as Cuba and Jamaica have suffered large potential destruction.

*Tourism Data*

Our source for tourism demand is the monthly tourism data for the period 2003-2008 available online from www.onecaribbean.org, which is the official tourism business website of the Caribbean Tourism Organisation. The data consists of information on tourism arrivals for 26 countries/territories in the Caribbean. These are Anguilla, Antigua & Barbuda, Aruba, Bahamas, Barbados P, Belize P, Bermuda, Bonaire, British Virgin Is., Cayman Islands, Cuba, Dominica, Dominican Republic, Grenada, Guyana, Jamaica, Martinique P, Montserrat, Puerto Rico, Saba, St Lucia, St. Eustatius, St. Kitts & Nevis P, St. Vincent & the Grenadines, Suriname, Trinidad & Tobago, US Virgin Islands. One should note that while for most countries we have observations on all months over our sample period, for a few there are some missing, and thus our data set consists of an unbalanced panel.

We depict our sample's average monthly tourist arrival numbers in Table 1. As can be seen, the Dominican Republic is by far the receiver of most Caribbean tourists within our sample, averaging around 250,000 a month. Other popular tourist destinations include Cuba, Jamaica, Bahamas, and Puerto Rico, while countries such as Montserrat, Anguilla, and St. Vincent have in absolute numbers few tourists per month. One may want to note that two of the primary destinations, Jamaica and Cuba, are also those that were those that over our sample period experienced relatively large potential hurricane destruction.

**Section 5. Econometric Analysis**

Our task is to econometrically determine the extent to which hurricane strikes affected the extent of monthly tourism arrivals across Caribbean countries/territories over our sample period, 2003-2008. Given that our dependent variable consists simple of the count of tourists in any month, we thus need to employ a count data model. Popular choices in this regard are the Poisson and Negative Binomial models, where the latter is normally preferred where the data may be characterized by a significant number of outliers. Given that outliers did not appear to be a problem in the tourism arrival data, we thus use the Poisson specification. More specifically, we estimate the following:

$$Arrivals_{it} = \alpha + \beta HURR_{it} + \gamma YD_t + \delta M_t + \mu_i + \varepsilon \quad (3)$$

where i is a country subscript, t is a time subscript, HURR is our hurricane destruction index, YD are a set of year dummies, M are a set of monthly dummies, μ is a time invariant unobservable country specific effect, and ε is an i.i.d error term. Importantly one should note that arguably hurricane shocks are of an exogenous nature. Thus, although we in this preliminary analysis do not include any other explanatory variables, one can be reasonable confident this should not result in a biased estimate of β. One possibility violating this assumption may be that although hurricanes are not strictly predictable, there are clearly spatial patterns to likelihood. As a matter of fact, a large climatological literature is devoted to estimating their spatial return probabilities. If potential tourists have some, even imperfect, information as to what the return probabilities are, then some destinations may be relatively less visited because of such a return probability. Moreover, there may be other country specific factors, such as geographical or climatic ones, that affect both the attractiveness of a location and its likelihood of being subjecting to a hurricane strike. It seems reasonable in this regard to assume that such factors would be time invariant over our relatively short sample period and hence we run a (country) fixed effects version of the Poisson specification above, thus purging the μ's from the equation.

Our results of running such a fixed effects Poisson regression are shown in the first column of Table 2, where we simply include current values of our HURR index in addition to the year and month dummies as regressors. As can be seen, the coefficient on HURR is negative and highly significant. As a matter of fact the coefficient suggests that an average hurricane strike causes tourism arrivals to be about 0.98 of what it would be if not strike occurred. The largest value of HURR over our sample period, which was for Jamaica in 2004 as a result of Hurricane Ivan, in contrast reduced tourist arrivals by 20 per cent.

We also experimented with allowing for more longer term effects on tourist numbers by including up to 6 lags of HURR, as shown the second column of Table 2. However, all of these are statistically insignificant, and the coefficient on the current values is only marginally changed. Although not reported here, we also included up to 24 lags of the hurricane destruction index, but results were similar, with only an immediate effect appearing. Thus our results indicate that hurricane strikes have a potentially large negative impact but this lasts no longer than the actual month of the strike. One should note that our index implicitly assumes that only wind speeds above the SS scale are destructive enough to matter. To verify this we recalculated our destruction index but included all local measured speeds that were of any strength above SS scale of1. As can be seen from the last two columns, this results in producing a statistically insignificant coefficient on HURR, as well as its lagged values.

**Section 6. Conclusion**

In this paper we estimated the impact of hurricanes on monthly tourist arrivals in the Caribbean. To this end we first derived a hurricane damages index by using actual hurricane track data and a physical wind model. Regressing monthly arrivals on this index showed that hurricanes have indeed had a statistically significant impact on the tourism industry in the region. Quantitatively this effect translates into a 2 per cent loss in arrivals for the average destruction due to hurricanes, while in contrast the very largest event caused a up to 20 per cent reduction.

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## Table 1: Summary Statistics

| COUNTRY | HURR | TOURIST ARRIVALS |
|---|---|---|
| ANGUILLA | 574 | 5302 |
| ANTIGUA | 0 | 20781 |
| ARUBA | 1821 | 61052 |
| BAHAMAS | 2771 | 123265 |
| BARBADOS | 0 | 46268 |
| BELIZE | 2156 | 19888 |
| BERMUDA | 0 | 23137 |
| BRITISH VIRGIN ISLANDS | 0 | 28159 |
| CAYMAN ISLANDS | 4486 | 21984 |
| CUBA | 210913 | 180330 |
| DOMINICA | 0 | 63978 |
| DOMINICAN REPUBLIC | 234 | 255905 |
| GRENADA | 1446 | 10358 |
| GUYANA | 0 | 9914 |
| HAITI | 0 | 8661 |
| JAMAICA | 186164 | 130426 |
| MARTINIQUE | 542 | 39937 |
| MONTSERRAT | 0 | 712 |
| PUERTO RICO | 12 | 116277 |
| SAINT KITTS AND NEVIS | 20 | 9803 |
| SAINT LUCIA | 102 | 24708 |
| SAINT VINCENT AND THE GRENADINES | 13 | 7386 |
| SURINAM | 0 | 12808 |
| TRINIDAD AND TOBAGO | 982 | 36558 |
| TURKS AND CAICOS ISLANDS | 551 | 14025 |
| UNITED STATES VIRGIN ISLANDS | 496 | 55805 |

## Table 2: Poisson Model of Tourism Arrivals

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| $HURR_t$ | -1.751*** | -1.667*** | -0.777 | -0.602 |
| | (0.655) | (0.639) | (0.549) | (0.553) |
| $HURR_{t-1}$ | | -0.513 | | -0.286 |
| | | (0.562) | | (0.582) |
| $HURR_{t-2}$ | | 0.165 | | -0.135 |
| | | (1.078) | | (0.800) |
| $HURR_{t-3}$ | | 0.424 | | -0.318 |
| | | (0.748) | | (0.776) |
| $HURR_{t-4}$ | | 0.660 | | 0.216 |
| | | (1.156) | | (0.489) |
| $HURR_{t-5}$ | | 0.035 | | 0.086 |
| | | (0.945) | | (0.747) |
| $HURR_{t-6}$ | | 0.815 | | 0.281 |
| | | (0.964) | | (0.692) |
| Obs. | 1671 | 1671 | 1671 | 1671 |
| Countries | 26 | 26 | 26 | 26 |
| Pseudo – R-squared | 0.837 | 0.837 | 0.837 | 0.837 |

Notes: (1) standard errors in parentheses, (2) ***, **, and * indicate 1, 5, and 10 per cent significance levels.

**Figure 1: Satellite Image of Hurricane Ivan (2004)**

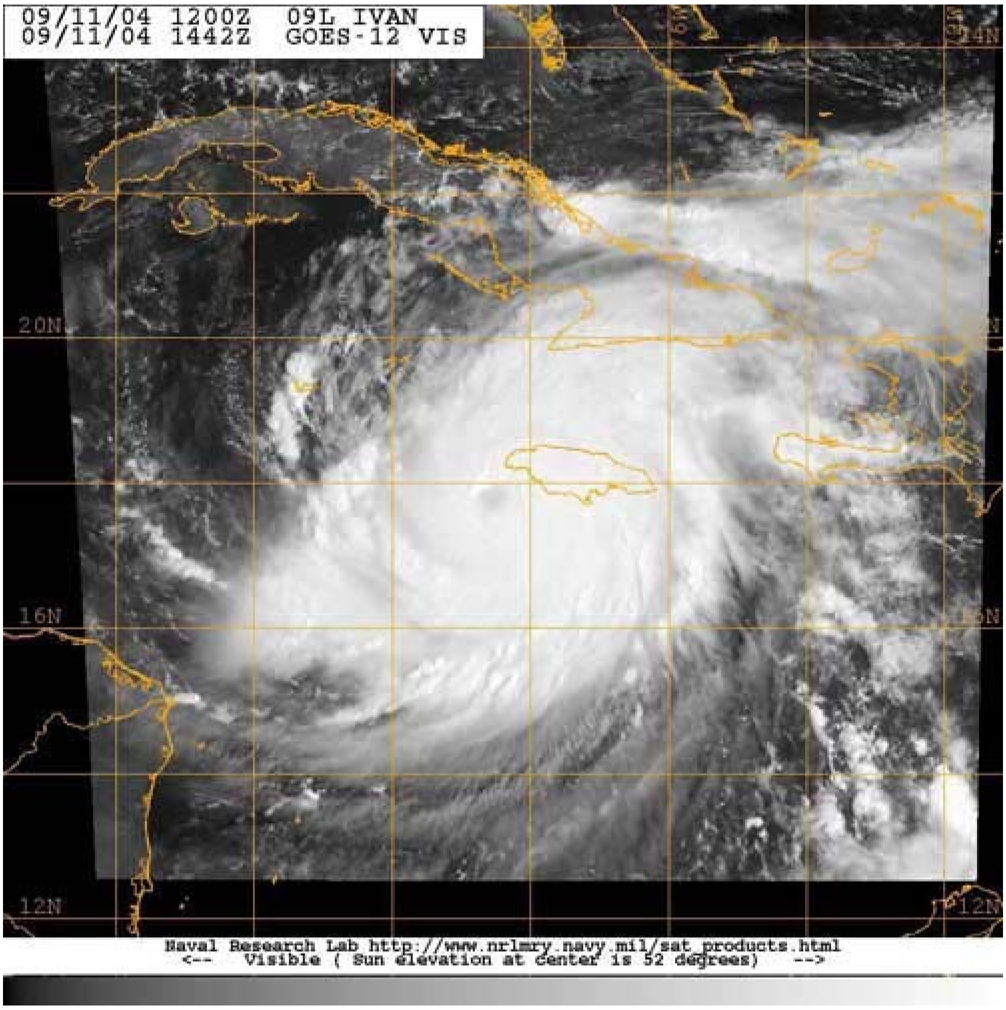
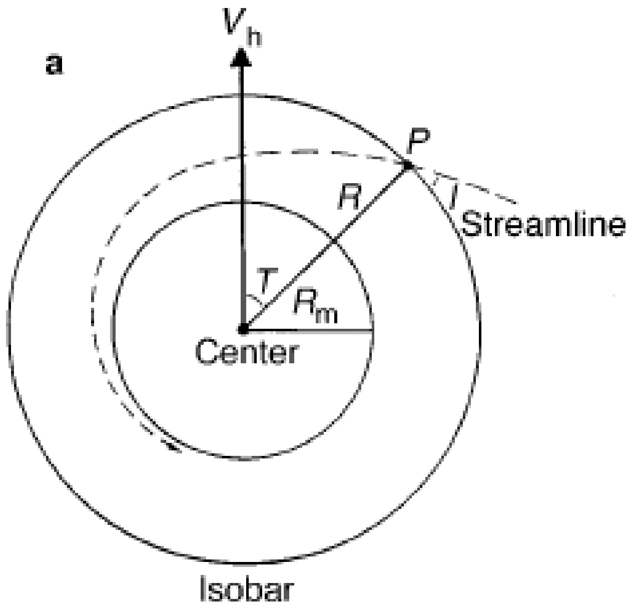


**Figure 2: Wind Field Model Structure**




Source: Boose et al (2004)

**Figure 3: All Tropical Cyclone Activity Since 2003**

Notes: The darker portion of the tracks constitute the segments of tropical storm tracks that reached at least hurricane intensity.

**Figure 4: Hurricane Dennis' (2005) Destruction Path**

Notes: The degree of destruction increases as the colour scheme turns darker.