Engineering Guidelines for Incorporating Climate Change into the Determination of Wind Forces on Buildings and Other Structures

by **Tony Gibbs** BSc DCT(Leeds) FICE FIStructE FASCE FconsE FRSA FRICS

October 2008

1 History of Wind Hazard Studies for Engineering Design in the Caribbean

Prior to the 1950s the design and construction of buildings and other structures in the Caribbean were based on traditional practice and observation of successes and failures in previous hurricane events. The formal calculation of wind forces can be said to have started in the latter half of the 1950s, coincident with the growth of the private-sector, consulting-engineering profession.

At that time, in the Commonwealth Caribbean, engineering practice followed closely the British traditions. Thus the first wind-loading code of practice to find its way onto design desks was the British Standard CP3:Chapter V:Part 2. That document, dated 1952, gave a wind speed of 72 miles per hour (1-minute average) for severe exposures. The equivalent 3-second gust would be 89 miles per hour. Throughout this document, with one exception, the Durst-Deacon relationships are used to convert wind speeds from one averaging period to another. The exception is noted when it occurs. The Dust-Deacon curve can be seen in Appendix Page-2 top[1] (App-2-T)[2]. This was almost equivalent to a minimum hurricane.

Very soon consulting engineers recognised the inappropriateness of CP3:Chapter V:Part 2:1952 for the Caribbean with its exposure to severe hurricanes. Guidance was sought from the neighbouring USA and, in particular, the state of Florida. The South Florida Building Code became a frequently-quoted reference document in the Caribbean in the 1960s. It also became the formal base document for the Bahamas Building Code which was first published towards the end of that decade. Typically, designs based on the South Florida Building Code in those days used a "fastest-mile" wind speed of 120 miles per hour. At that speed the averaging period is 30 seconds and the equivalent 3-second gust would be 139 miles per hour.

About that time the British Standards Institution was undertaking a major rewriting of their wind

---

[1] The chart also shows the Krayer-Marshall relationship which was used briefly in the 1990s for tropical cyclone regions.

[2] Please note that the various illustrations in the Appendix are taken from other documents and bear the table numbers, *etc*, of the original documents.

loads standard[3]. The early drafts of the proposed standard became available to engineers in the Caribbean who welcomed the more rational, first-principles approach as contrasted with that of the South Florida Building Code which tended to be quasi-prescriptive. The recently formed Council of Caribbean Engineering Organisations (CCEO) commissioned its constituent member, the Barbados Association of Professional Engineers (BAPE), to prepare a wind-loading standard for the Caribbean. A draft document "Wind Loads for Structural Design" was published in 1970. This draft document was based on the new (draft) British Standard which was eventually published in 1972. The draft document contained an appendix on the derivation of basic wind speeds for the various parts of the Caribbean. This was the first comprehensive, regional, meteorological study to be carried out aimed directly at wind-engineering applications in the Caribbean. The authors of the 1970 document were engineer A R Matthews, meteorologist H C Shellard and Tony Gibbs (as Chairman).

Harold Shellard employed statistical analyses requiring suitable wind speed records covering periods of 20 years or more for his studies. In the Commonwealth Caribbean suitable wind records, in some cases, had been available for quite a number of years. However, no uniform set of records covering a sufficiently long period could be found. (See App-1-T.) An alternative procedure had to be used. This alternative procedure followed the 1967 work of USA researcher H C S Thom. Appendix Page-1 bottom (App-1-B) shows the derived fastest-mile wind speeds for various return periods for selected locations. App-2-B shows the equivalent 3-second gust speeds for those locations. The wind speeds which were adopted for the 1970 standard are in the table below:

Suggested Basic Wind Speeds (miles per hour, 3-second)
for Some Commonwealth Caribbean Countries
1970

Jamaica	120	(= 54 m/s)
BVI	120	(= 54 m/s)
Leeward Islands	120	(= 54 m/s)
St Lucia, St Vincent	120	(= 54 m/s)
Barbados	120	(= 54 m/s)
Grenada, Tobago	100	(= 45 m/s)
Trinidad	90	(= 40 m/s)
Guyana	50	(= 22 m/s)

By the start of the 1980s the need to revise the 1970 "Wind Loads for Structural Design" was evident. The meteorological section was reviewed and revised taking into account another decade of relatively reliable data. This revised document was published in 1981. (This revised

[3] This was triggered by the judicial enquiry into the Ronan Point disaster of 1968.

document is known as the OAS/NCST[4]/BAPE "Wind Loads for Structural Design". It is also a Barbados standard BNS CP28.) The authors of the 1981 revision were engineer H E Browne, meteorologist B A Rocheford and Tony Gibbs (as Chairman). The wind speeds which were adopted for the 1981 standard are given in the table below:

B A Rocheford (Caribbean Meteorological Institute)[5]
1981 Revision of "Wind Loads for Structural Design" (3-second)

Jamaica	56 m/s (= 125 mph)
BVI	64 m/s (= 143 mph)
Leeward Islands	64 m/s (= 143 mph)
St Lucia, Dominica	58 m/s (= 130 mph)
Barbados, St Vincent	58 m/s (= 130 mph)
Grenada, Tobago	50 m/s (= 112 mph)
Trinidad	45 m/s (= 101 mph)
Guyana	22 m/s (= 49 mph)

Also of interest in the 1981 edition of the standard was the recognition that the relationships of long-return-period wind speeds to short-return-period wind speeds were different in the Caribbean when compared with the United Kingdom. The graph in the App-3-T shows the UK relationships as straight lines and the Caribbean relationships as curves. This information was provided in 1971 by Norris Helliwell of the UK Meteorological Office. This characteristic was confirmed in subsequent independent investigations.

Three years later Rocheford revisited his work and produced the revised figures shown in the table below:

B A Rocheford (Caribbean Meteorological Institute)
Revision of Wind Speeds – 10-minute averages
1984

Belize – Centre	29.0 m/s	(= 65 mph)	[= 93 mph 3s]
Jamaica – N	37.0 m/s	(= 83 mph)	[= 119 mph 3s]
Jamaica – S	41.0 m/s	(= 92 mph)	[= 132 mph 3s]
St Kitts	44.5 m/s	(= 100 mph)	[= 143 mph 3s]
Antigua	46.0 m/s	(= 103 mph)	[= 147 mph 3s]
Dominica	41.0 m/s	(= 92 mph)	[= 132 mph 3s]
St Lucia	43.0 m/s	(= 96 mph)	[= 137 mph 3s]
Barbados	42.0 m/s	(= 94 mph)	[= 134 mph 3s]

[4]OAS = Organisation of American States
NCST = National Council for Science and Technology (of Barbados)

[5]now the Caribbean Institute for Meteorology and Hydrology

Tobago	31.5 m/s	(= 70 mph)	[= 100 mph 3s]
Trinidad – Central	27.5 m/s	(= 62 mph)	[= 89 mph 3s]

In 1984/85, as part of the Caribbean Uniform Building Code (CUBiC) project, a new wind-loading standard was prepared by Professor Alan Davenport of the Boundary Layer Wind Tunnel Laboratory of the University of Western Ontario. This followed closely the form of the document of the International Organisation for Standardisation (ISO)[6] which was also being worked on contemporaneously by Prof Davenport. (The ISO document was eventually published in 1998.) As part of the CUBiC exercise the wind hazard regime was revisited, leading to revised wind speeds for various parts of the Caribbean. The CUBiC document uses reference pressures, rather than basic wind speeds, as the starting point for calculation. The reference pressures are based on wind speeds averaged over 10 minutes.

The wind hazard studies were undertaken by Prof Alan Davenport assisted by Dave Surry and Peter Georgiou. They employed the simulation of the hurricane wind climate using the drop in barometric pressure, radius of the ring to maximum wind speeds, the translation speed, the angle of its track and the position of the point of interest relative to the centre of the storm. The wind speeds derived from these studies are shown in App-3-B. The equivalent 3-second gust values of the 10-minute averages which informed the reference pressures in CUBiC are given in the table below. In this case the 3-second gust equivalents were provided by UWO-BLWTL and may not be the same as would be obtained from the Durst-Deacon relationship.

CUBiC 1985
UWO-BLWTL
Wind Speeds – 3-second – 50-year return

Belize – North	54 m/s	(= 121 mph)
Belize – South	45 m/s	(= 101 mph)
Jamaica	55 m/s	(= 123 mph)
St Kitts – Nevis	59 m/s	(= 132 mph)
Montserrat	59 m/s	(= 132 mph)
Antigua	56 m/s	(= 125 mph)
Dominica	57 m/s	(= 128 mph)
St Lucia	57 m/s	(= 128 mph)
St Vincent	56 m/s	(= 125 mph)
Barbados	51 m/s	(= 114 mph)
Grenada	47 m/s	(= 105 mph)
Tobago	42 m/s	(= 94 mph)
Trinidad – North	39 m/s	(= 87 mph)
Trinidad – South	30 m/s	(= 67 mph)

[6] ISO 4354

In the first half of the 1990s The University of the West Indies[7] prepared Caribbean basin maps showing isolines of tropical storm and hurricane events over the period 1886-1992. The maps for Category-4[8] and Category-5 events are in App-4-T&B.

In the second half of the 1990s, as part of the USAID[9]-funded, OAS-executed Caribbean Disaster Mitigation Project, Charles Watson prepared the pictorial representation of the variation of wind speed across the Caribbean which is shown in App-5-T.

In 1997 Ir P C van Staalduinen and Dr Ir C P W Geurts of the Netherlands research organisation TNO[10] published their study "Hurricane Hazard in the Netherlands Antilles" which included the graph shown in App-5-B. That graph tells a similar story to that earlier in App-3-T – the ratio of long-return-period wind speeds to short-return-period wind speeds increases as one moves closer to the equator in the North Atlantic.

The App-3-T and App-5-B graphs are combined with the similar Vickery graph in App-6-T.

2 The New Caribbean Basin Wind Hazard Maps

Why were new wind hazard maps prepared? Here are some of the reasons:

- The only pan-Caribbean wind hazard maps ever produced for application in the design of structures were in 1969 (Caribbean Meteorological Institute – H C Shellard), 1981&1984 Caribbean Meteorological Institute – B Rocheford), 1985 (University of Western Ontario Boundary Layer Wind Tunnel Laboratory – Davenport, Surry, Georgiou).
- Since 1985 the region has collected another 23 years of relatively reliable data. The incorporation of these data should serve to improve the quality of currently-available wind hazard information.
- There have been developments in the science and technology related to the long-term forecasting of hurricane activity in the North Atlantic (including the Caribbean).
- The past 13 years of higher-than-normal hurricane activity in the North Atlantic has led to the questioning of wind design criteria incorporated in the present standards in the Caribbean.
- This, in turn, has led to uninformed and unreasonable and counterproductive decisions on appropriate basic (and therefore design) wind speeds for some Caribbean projects and in

---

[7] in collaboration with the University of Waterloo, Canada

[8] Saffir-Simpson Scale

[9] United States Agency for International Development

[10] TNO - Netherlands Organisation for Applied Scientific Research
Building and Construction Research

some Caribbean countries.

- The subject project includes the Caribbean coastlines of South and Central American countries. In several of these cases there were no previously available wind hazard guidance for structural design purposes. The new maps plug those gaps.
- The phenomenon of hurricane activity in the Caribbean is best dealt with regionally and not in a country-by-country manner.

What use will be made of the results of the proposed project? Here are some answers:

- New regional standards are currently being prepared in a project funded by the Caribbean Development Bank (CDB) and executed by the Caribbean Regional Organisation for Standards and Quality (CROSQ). These will replace the Caribbean Uniform Building Code (CUBiC). The CDB-CROSQ project does not include new wind hazard maps for the target region. These new Caribbean Basin maps have been prepared to be consistent with the CDB-CROSQ intension to base the new standards project on the USA "International" codes which reference the wind load provisions of the American Society of Civil Engineers (ASCE 7 Chapters 2 and 6). Thus the results of this wind hazard mapping project could be plugged directly into the new CDB-CROSQ standards.
- Those Caribbean countries which, for whatever reason, are developing their own standards and not participating in the CDB-CROSQ project will also require wind hazard information. This wind hazard mapping project will provide wind hazard information which could readily be represented in forms designed to fit directly into standards documents with different approaches.
- Engineers in all Caribbean countries are designing projects every day which must resist the wind. Confidence in the wind hazard information is important to designers. Clients sometimes wish to specify the levels of safety of their facilities. Insurance providers sometimes wish to know the risks they underwrite. This depends critically on the quality of hazard information. Financing institutions sometimes wish to specify wind design criteria for their projects. There is, in summary, an immediate and palpable need for wind hazard information based on up-to-date meteorological records and methodologies recognised by consensus in the scientific community.

The agencies and main personnel responsible for the new maps are:

- Principal researcher – Applied Research Associates (Peter Vickery)
- Regional coordinator – Tony Gibbs (CEP International Ltd)
- Executing agency – Pan American Health Organisation (PAHO) (Dana van Alphen)
- Funding agency – United States Agency for International Development (Tim Callaghan and Julie Leonard)

The open process adopted in his project is exemplified by:

- The Caribbean Basin Wind Hazard Maps project has prepared a series of overall, regional, wind-hazard maps using uniform, state-of-the-art approaches covering all of the

Caribbean islands and the Caribbean coastal areas of South and Central America. The project was executed in consultation with interest groups throughout the target region.

- An interim, information meeting was held at PAHO in Barbados on 01 October 2007. Meteorologists, engineers, architects, emergency managers, standards personnel and funding agency personnel from the wider Caribbean were invited (and were funded) to attend.
- At that meeting the principal researcher, Dr Peter Vickery of Applied Research Associates (ARA) described the methodology for developing the maps; presented the interim results available at the time of the meeting; received comments from participants and answered their questions; discussed what systems need to be put in place to improve knowledge of the wind hazard in the Caribbean region and outlined the further work to finalise the mapping exercise.

There are web sites presenting the results of the project including:

http://www.paho.org/english/dd/ped/caribbeanwindhazardmaps.htm
and
http://www.istructe.org/BRANCH/CARIBBEAN/news/article.asp?NID=370&Name=CARIBBEAN&BID=30

The sites contain:

- the 20 wind hazard maps;
- Peter Vickery's paper describing the methodology;
- Tony Gibbs's presentation of the CBWHM project to recent conferences;
- Peter Vickery's presentation of the CBWHM project to the 2008 National Hurricane Conference.

3 Guidelines for the Use of Peter Vickery's Wind Speed Results as Adjusted for Climate Change

Vickery's study has developed a methodology to estimate the change in the wind speeds used for the design of structures in St. Lucia as affected by climate change. The climate change information was obtained from a recently-completed study on the potential increase in hurricane frequency by J A Curry *et al* of the Georgia Institute of Technology Climate Forecast Applications Network.

The ASCE 7 Wind Loads standard assumes a level of safety comparable with failure occurring at a wind speed with a 700-year return period for standard (Category II) buildings and a 1,700-year return period for more important (Categories III&IV) buildings. Vickery assumes that the same level of safety (or probability of failure) would apply when climate change is taken into account.

The equivalent wind speed (for comparison with the St Lucia Code) in the PAHO-USAID maps, before allowing for climate change, would be 123 miles per hour. If an increase of 13% is allowed for climate change (standard buildings – Category II) the new value would be about 8%

higher than envisaged in the St Lucia Building Code.

The Curry *et al* estimate of the hurricane activity *circa* 2020 to 2025 which was used by Vickery means that 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. Since all new Category II, III and IV buildings are likely to have lifespans beyond 2025, the wind speed adjustments for climate change will simply be an additional 12 to 14 percent for Category II buildings in St. Lucia and 10 percent for Category III and IV buildings. Thus the wind speeds ajusted for climate change would be:

175 mph ("ultimate" or 700-year wind speed) – Category II buildings
189 mph ("ultimate" or 1,700-year wind speed) – Categories III & IV buildings

In implementing these wind speeds while using ASCE 7-05 Chapters 2 and 6, the following Load Combinations should be used as factored loads in strength design. Combinations **3a**, **4a** and **6a** will replace combinations 3, 4 and 6. The combinations relate to Category II buildings. For Category III and IV buildings W_{700} should be replaced by W_{1700}.

1: $1.4(D + F)$
2: $1.2(D + F + T) + 1.6(L + H) + 0.5(Lr \text{ or } R)$
3: $1.2D + 1.6(Lr \text{ or } R) + (L \text{ or } 0.8W)$
3a: $\mathbf{1.2D + 1.6(Lr \text{ or } R) + (L \text{ or } 0.8W_{700}/1.6)}$
4: $1.2D + 1.6W + L + 0.5(Lr \text{ or } R)$
4a: $\mathbf{1.2D + 1.0W_{700} + L + 0.5(Lr \text{ or } R)}$
5: $1.2D + 1.0E + L$
6: $0.9D + 1.6W + 1.6H$
6a: $\mathbf{0.9D + 1.0W_{700} + 1.6H}$
7: $0.9D + 1.0E + 1.6H$

The symbols are:

D = dead load
E = earthquake load
F = load due to fluids with well-defined pressures and maximum heights
Fa = flood load
H = load due to lateral earth pressure, ground water pressure, or pressure of bulk materials
L = live load
Lr = roof live load
R = rain load
T = self-straining force
W = wind load

Alternatively, the following Load Combinations should be used as nominal loads in allowable stress design. Combinations **5a**, **6a** and **7a** will replace combinations 5, 6 and 7. The combinations relate to Category II buildings. For Category III and IV buildings W_{700} should be replaced by W_{1700}.

1: $D + F$
2: $D + H + F + L + T$
3: $D + H + F + (Lr \text{ or } R)$
4: $D + H + F + 0.75(L + T) + 0.75(Lr \text{ or } R)$
5: $D + H + F + (W \text{ or } 0.7E)$
5a: $\boldsymbol{D + H + F + (W_{700}/1.6 \text{ or } 0.7E)}$
6: $D+H+F+0.75(W \text{ or } 0.7E)+0.75L+0.75(Lr \text{ or } R)$
6a: $\boldsymbol{D+H+F+0.75(W_{700}/1.6 \text{ or } 0.7E)+0.75L+0.75(Lr \text{ or } R)}$
7: $0.6D + W + H$
7a: $\boldsymbol{0.6D + W_{700}/1.6 + H}$
8: $0.6D + 0.7E + H$

The present St Lucia Building Code adopts by reference CUBiC:Part-2:Section-2:Wind Load. The CUBiC reference pressures are stated as 50-year return period, 10-minute averages. St Lucia is allocated a reference pressure which equates to a 3-second gust of 128 miles per hour.

The loads obtained from the CUBiC standard are “working” loads, not failure or “ultimate”loads. The failure loads would be obtained by multiplying the working loads by load factors.

The engineering guidelines to allow for climate change are quite simple. However, there will be the need for a significant amount of familiarisation of interested persons (owners, financiers, insurers) and training of designers (engineers, architects) in the use of ASCE 7 Wind Loads incorporating the new wind hazard maps enhanced by climate change considerations and modified by the Caribbean Application Document (under preparation) for ASCE 7 (Chapters 2 and 6).

Appendix

TABLE I – Data Required for Estimation of Extreme Wind Distributions for Caribbean Stations

Station	v_m mile/h	Period	β	f	p_T
San Juan, Puerto Rico	12·9	1940–55	50·5	1·2	0·27
Palisadoes, Jamaica	13·4	1950–62	51·7	1·1	0·22
Coolidge, Antigua	15·0*	1941–48	55·4	1·2	0·27
Seawell, Barbados	16·5	1954–60	58·7	0·9	0·13
Pearls, Grenada	13·0	1954–60	50·7	0·8	0·10
Piarco, Trinidad	8·1	1954–60	37·5	0·7	0·08
East coast, Trinidad	12·0*		48·3	0·7	0·08
Crown Point, Tobago	13·0*		50·7	0·7	0·08

In three cases the values of v_m were estimated. The only average wind speed data readily available for Coolidge, Antigua was an annual average of 13.4 mph over the years 1941-1948, and 15.0 mph is therefore a conservative estimate of the average speed in the windiest month. The mean speed

* Estimated.

TABLE III – Fastest Mile Speeds (mph) for return Periods of 10, 20, 25, 50, 100 and 200 Years

	10	20	25	50	100	200 Yrs.
San Juan	72(65)	80	83(80)	94(95)	105(110)	118
Palisadoes	71	79	83	93	105	117
Coolidge	78	88	91	102	113	126
Seawell	79	88	91	100	110	121
Pearls	67	74	77	85	94	104
Piarco	48	54	56	63	69	77
Trinidad (E. Coast)	63	69	73	78	86	93
Crown Point	67	74	77	85	93	103

4

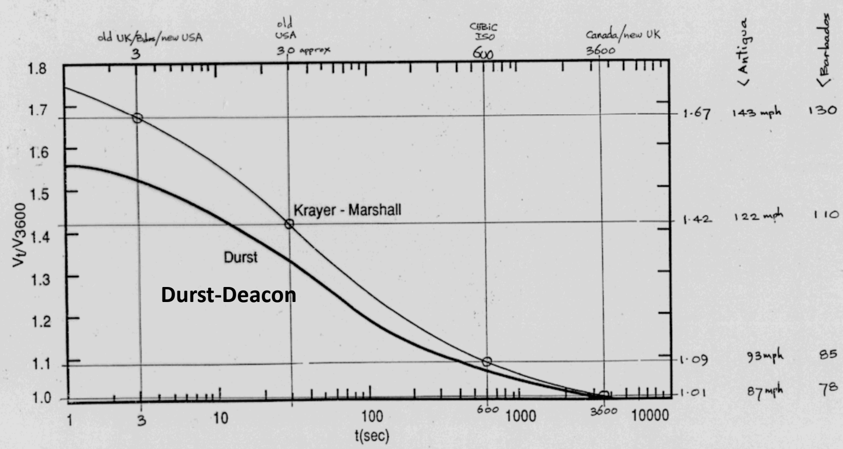
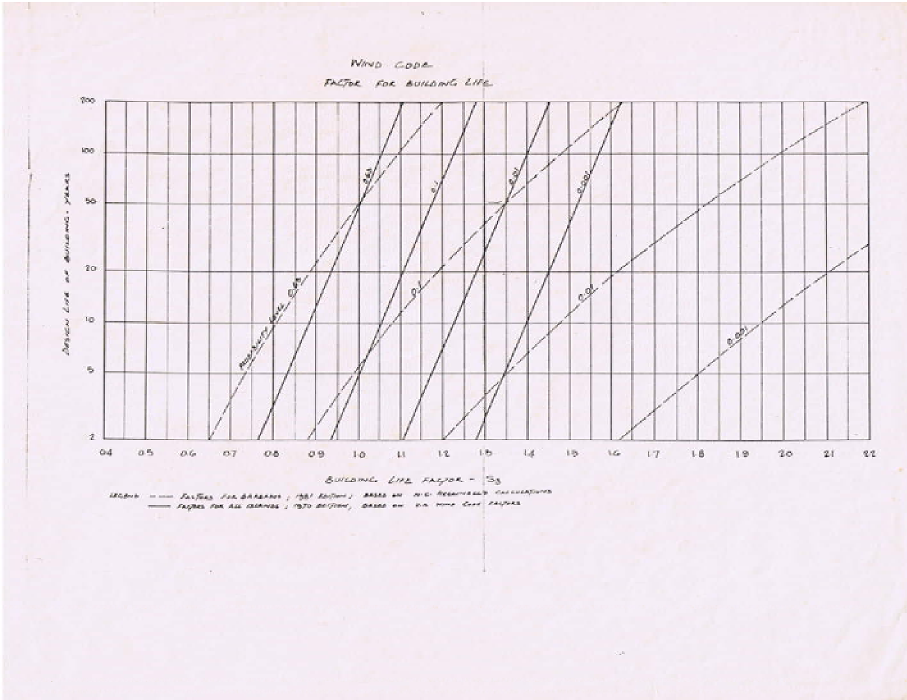


Fig. 2.1 Ratio of Probable Maximum Speed Averaged over *t* Seconds to Hourly Mean Speed

Source: Ref. 4

TABLE IV – Maximum Gust Speeds (mph) for return Periods of 10, 20, 50 and 100 Years

	10	20	50	100
San Juan, P.R.	87	95	111	123
Palisadoes, Jamaica	85	94	110	123
Coolidge, Antigua	93	104	120	132
Seawell, Barbados	94	104	117	128
Pearls, Grenada	81	89	101	111
Piarco, Trinidad	60	67	76	83
E. Coast, Trinidad	76	83	93	102
Crown Point, Tobago	81	89	101	110

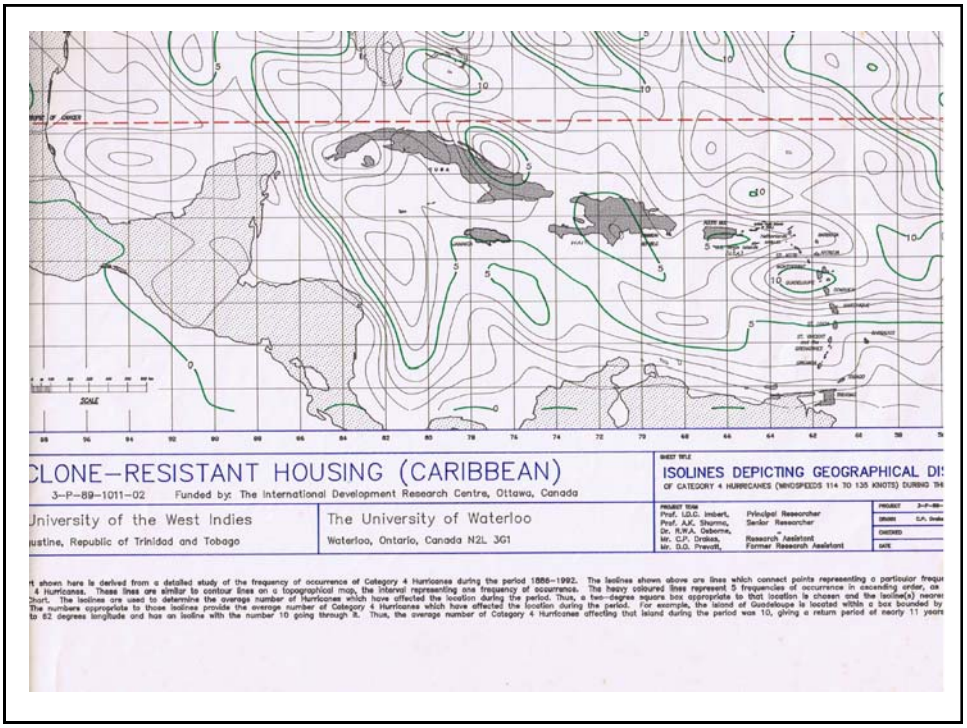


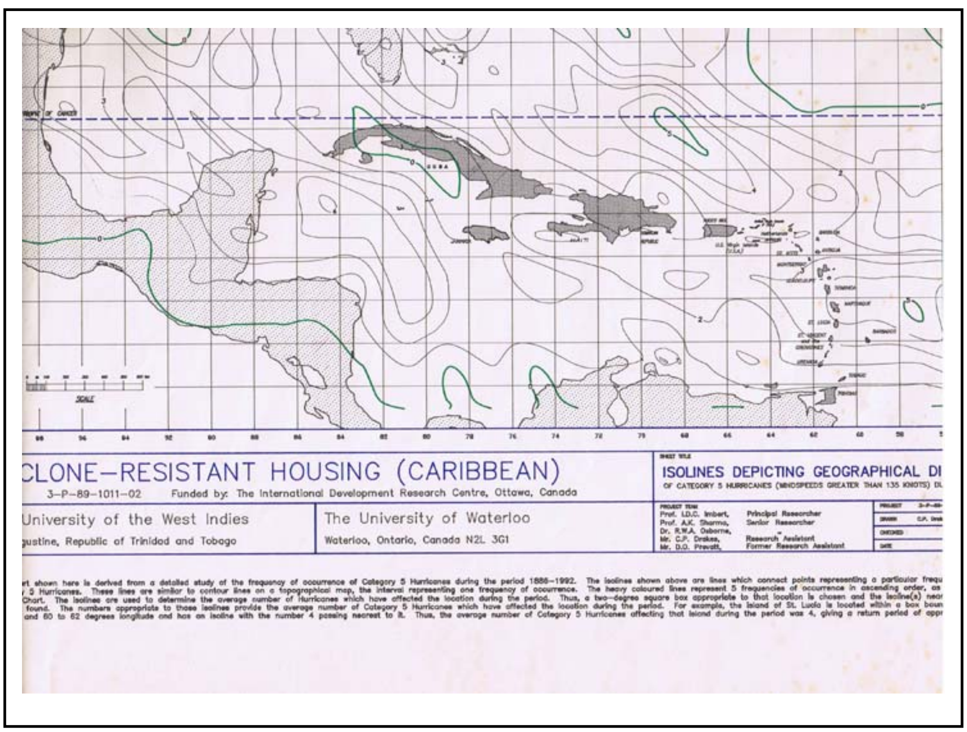
10-min

EXTREME WIND SPEEDS IN HURRICANES FOR THE EASTERN CARIBBEAN, JAMAICA AND BELIZE

Values refer to mean windspeeds at a height of 10m over open water.

Location	Windspeed (m/sec) Once in 10 years	Once in 100 years
Trinidad - South	9.0	25.0
- North	12.0	30.0
Tobago	15.0	33.0
Grenada	20.0	35.0
Barbados	23.5	39.0
St. Vincent	24.0	39.5
St. Lucia	24.0	39.5
Martinique	25.0	40.0
Dominica	26.0	42.0
Guadeloupe	26.0	42.0
Montserrat	25.5	41.5
Antigua	25.5	41.5
St. Kitts-Nevis	25.5	41.5
St. Martin	25.0	41.5
Puerto Rico	24.5	43.0
Jamaica	25.0	41.0
Belize - North	25.0	40.0
- South	21.0	35.0


CLONE–RESISTANT HOUSING (CARIBBEAN)
3–P–89–1011–02 Funded by: The International Development Research Centre, Ottawa, Canada
University of the West Indies
ustine, Republic of Trinidad and Tobago
The University of Waterloo
Waterloo, Ontario, Canada N2L 3G1
ISOLINES DEPICTING GEOGRAPHICAL DI
OF CATEGORY 4 HURRICANES (WINDSPEEDS 114 TO 135 KNOTS) DURING TH
Prof. I.D.C. Imbert, Principal Researcher
Prof. A.K. Sharma, Senior Researcher
Dr. R.W.A. Osborne,
Mr. C.P. Drakes, Research Assistant
Mr. D.O. Prevatt, Former Research Assistant


CLONE–RESISTANT HOUSING (CARIBBEAN)
3–P–89–1011–02 Funded by: The International Development Research Centre, Ottawa, Canada
University of the West Indies
gustine, Republic of Trinidad and Tobago
The University of Waterloo
Waterloo, Ontario, Canada N2L 3G1
ISOLINES DEPICTING GEOGRAPHICAL DI
OF CATEGORY 5 HURRICANES (WINDSPEEDS GREATER THAN 135 KNOTS) DU
Prof. I.D.C. Imbert, Principal Researcher
Prof. A.K. Sharma, Senior Researcher
Dr. R.W.A. Osborne,
Mr. C.P. Drakes, Research Assistant
Mr. D.O. Prevatt, Former Research Assistant

Maximum Wind Speeds (50-year return)

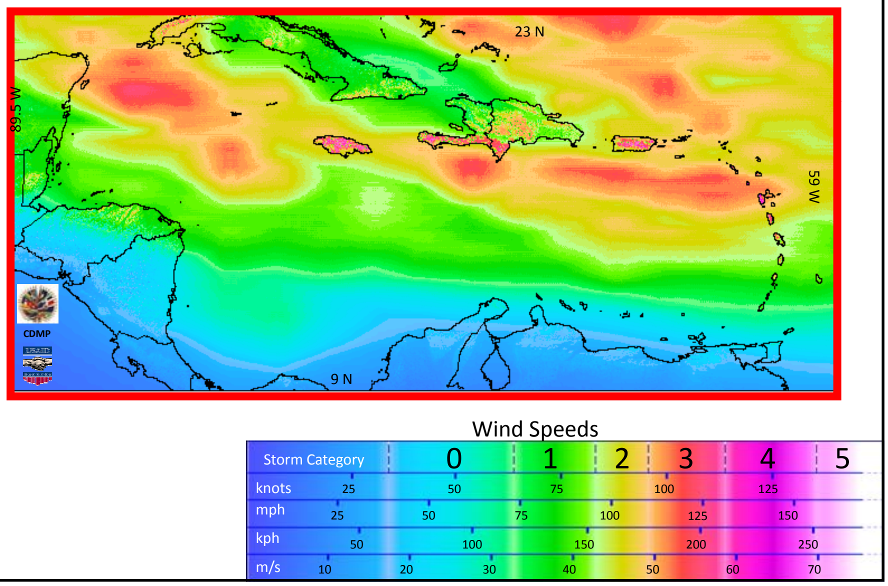
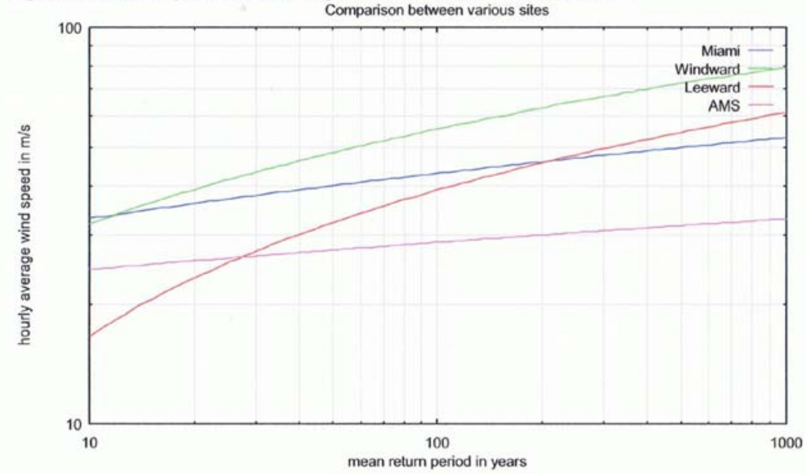
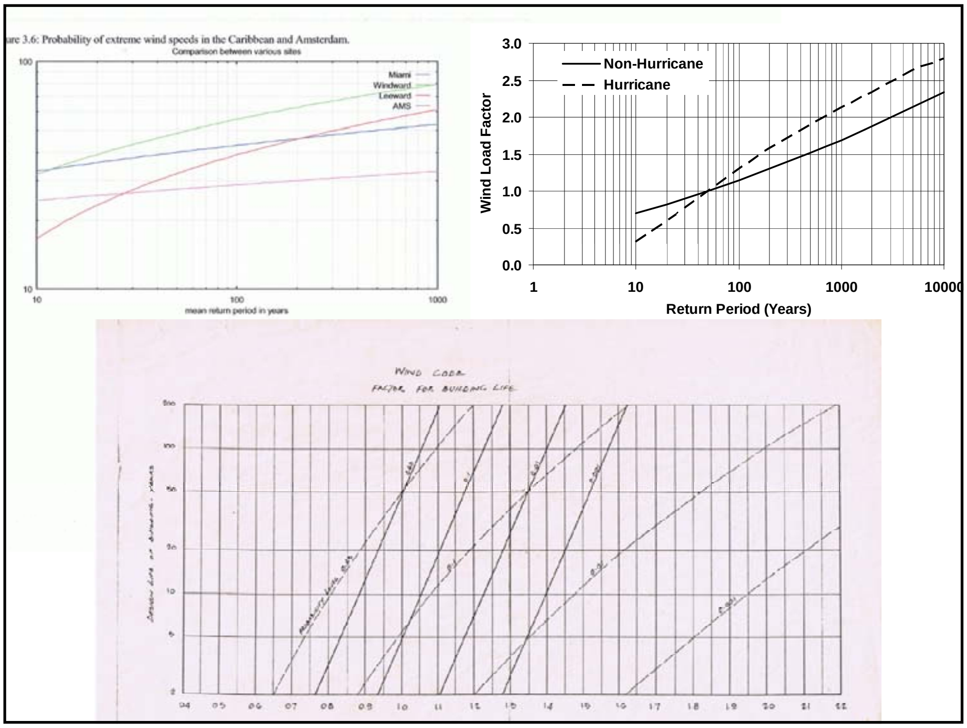


Figure 3.6: Probability of extreme wind speeds in the Caribbean and Amsterdam.




Probability of extreme wind speeds in the Caribbean and Amsterdam.
Comparison between various sites
Miami
Windward
Leeward
AMS
mean return period in years
Non-Hurricane
Hurricane
Wind Load Factor
Return Period (Years)