Wind Hazard Maps for the Caribbean Basin

Prepared by
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CEP International Ltd
Consultant to PAHO/WHO
April 2008

Under a special grant from the Office of Foreign Disaster Assistance of the United States Agency for International Development (OFDA/USAID).

Background:

Previous regional wind hazard studies for engineering design purposes

CP3 Chapter V:Part 2 – 1952

75 mph – 1-minute average
(= 93 mph or 41 m/s 3-second gust)

Pan American Health Organization

South Florida Building Code – 1960s

120 mph – fastest mile
(= 137 mph or 61 m/s 3-second gust)

Pan American Health Organization

The Council of Caribbean Engineering Organisations
(CCEO)
1969

gave a mandate to the
Barbados Association of Professional Engineers
(BAPE)
to prepare a wind load standard

Tony Gibbs, AR Matthews, HC Shellard
"Wind Loads for Structural Design – 1970"

including

HC Shellard
"Extreme Winds in the Commonwealth Caribbean"

Pan American Health Organization
Regional Office of the World Health Organization

Statistical analysis of suitable wind speed records covering periods of 20 years or more is required.

In the Commonwealth Caribbean suitable wind records, in some cases, have been available for quite a number of years.

However, no uniform set of records covering a sufficiently long period could be found.

An alternative procedure had to be used.

HCS Thom – 1967

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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
Palisadocs, 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.

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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

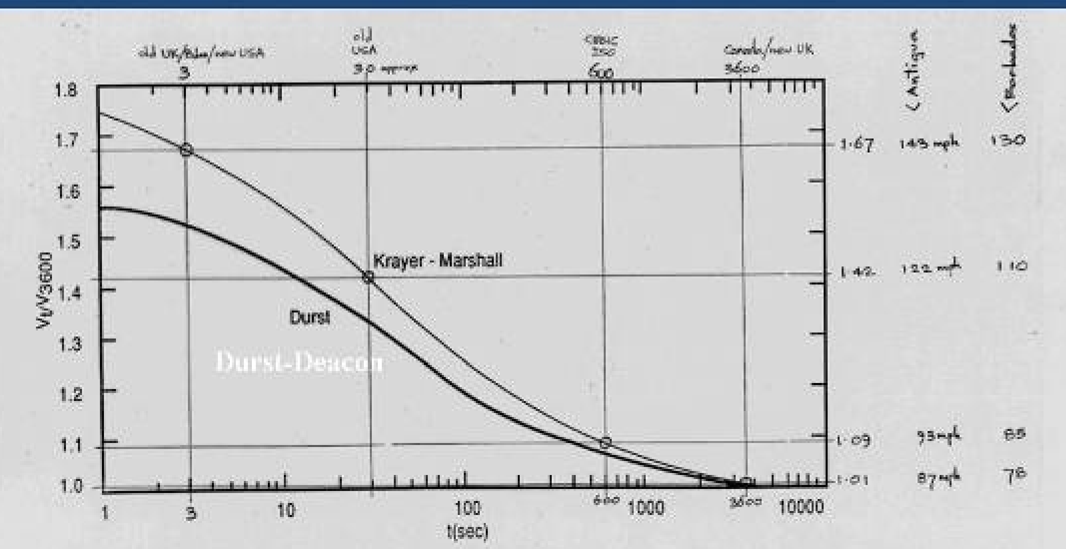

Fig. 2.1 Ratio of Probable Maximum Speed Averaged over *t* Seconds to Hourly Mean Speed

Source: Ref. 4

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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

Suggested Basic Wind Speeds (mph, 3s) 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)

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BA Rocheford (Caribbean Meteorological Institute)
1981 Revision of
"Wind Loads for Structural Design" (3s)
CCEO – BAPE – NCST – OAS
Tony Gibbs – HE Brown – BA Rocheford

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)

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BA Rocheford (Caribbean Meteorological Institute)
1984 Revision of Wind Speeds – 10-minute

Belize – Centre	29.0 m/s	(= 65 mph)
Jamaica – North	37.0 m/s	(= 83 mph)
Jamaica – South	41.0 m/s	(= 92 mph)
St Kitts	44.5 m/s	(= 100 mph)
Antigua	46.0 m/s	(= 103 mph)
Dominica	41.0 m/s	(= 92 mph)
St Lucia	43.0 m/s	(= 96 mph)
Barbados	42.0 m/s	(= 94 mph)
Tobago	31.5 m/s	(= 70 mph)
Trinidad – Central	27.5 m/s	(= 62 mph)

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The Caribbean Uniform Building Code
CUBiC – 1985
The Boundary Layer Wind Tunnel Laboratory
(University of Western Ontario)
Davenport – Surry – Georgiou

Simulation of hurricane wind climate using 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.

Influence of topography on wind speeds

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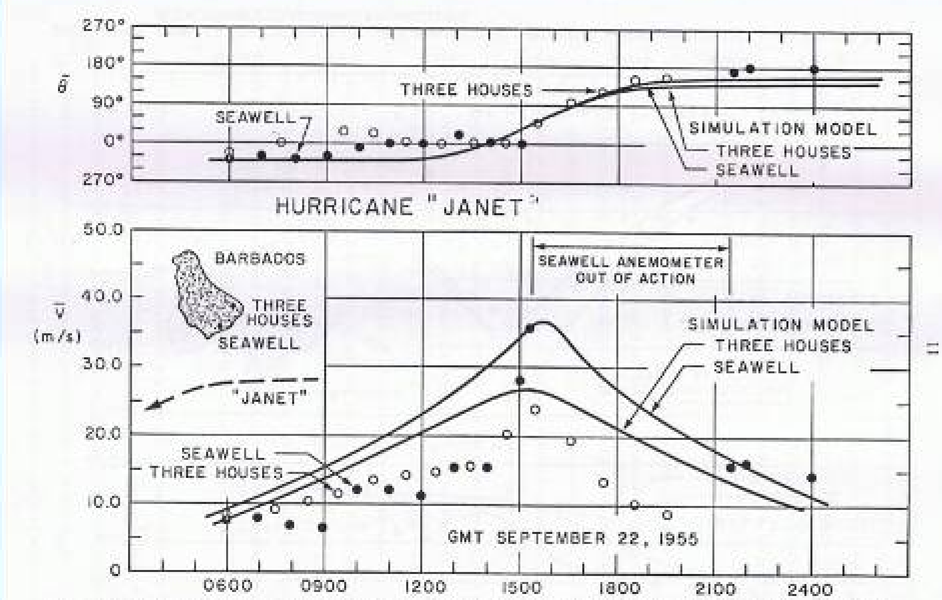

FIGURE 4(a) COMPARISON OF OBSERVED AND SIMULATION WINDFIELD MODEL-PREDICTED WIND SPEEDS AND DIRECTIONS FOR HURRICANE JANET (1955)

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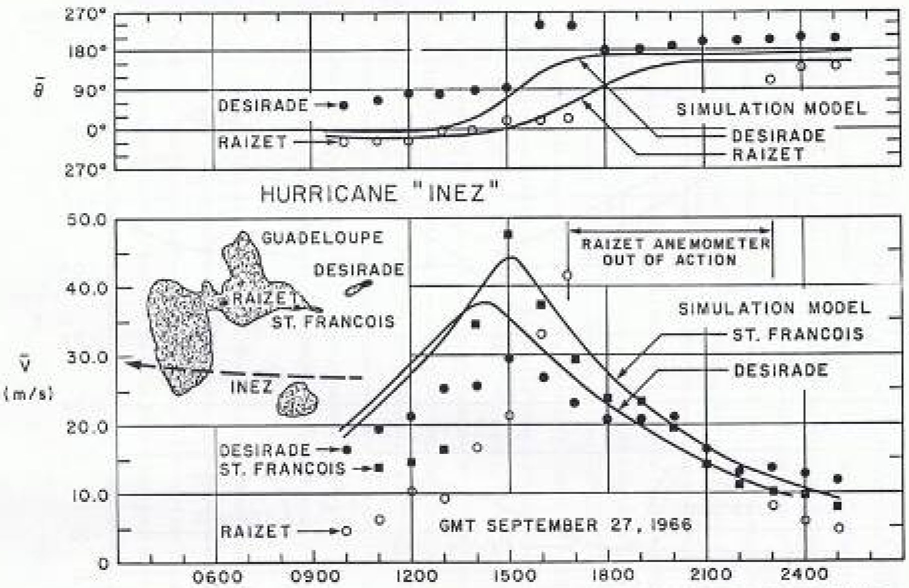

FIGURE 4(b) COMPARISON OF OBSERVED AND SIMULATION WINDFIELD MODEL-PREDICTED WIND SPEEDS AND DIRECTIONS FOR HURRICANE INEZ (1966)

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10-min

TABLE 1

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

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TABLE 2

COMPARISON OF CURRENT SIMULATION EXTREMES WITH ROCHEFORD'S (1984) ESTIMATES

Values refer to mean wind speeds with a recurrence interval of 100 years.

10-min

Location	Windspeeds (m/sec) Simulation*1 Estimates	Rocheford*2 Estimates
Trinidad - Centre	27.5	27.5
Tobago	33.0	31.5
Barbados	39.0	42.0
St. Lucia	39.5	43.0
Dominica	42.0	41.0
Antigua	41.5	46.0
St. Kitts	41.5	44.5
Jamaica - North	41.0	37.0
- South	41.0	41.0
Belize - Centre	37.5	29.0

*1 open-water exposure

*2 over-land exposures relevant to airport station locations for each island.

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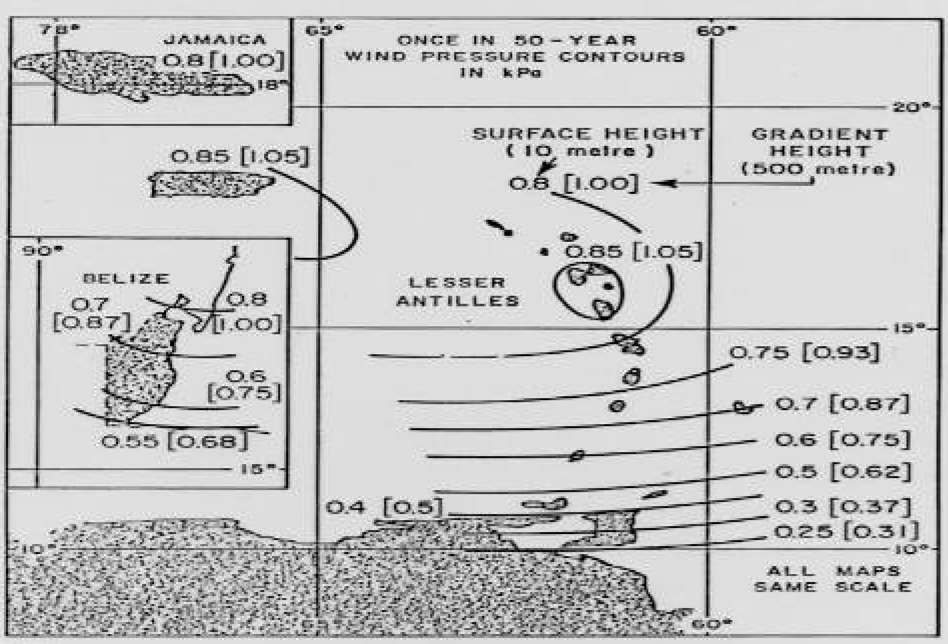

Figure A200.1 Map of Region of Application

CUBiC

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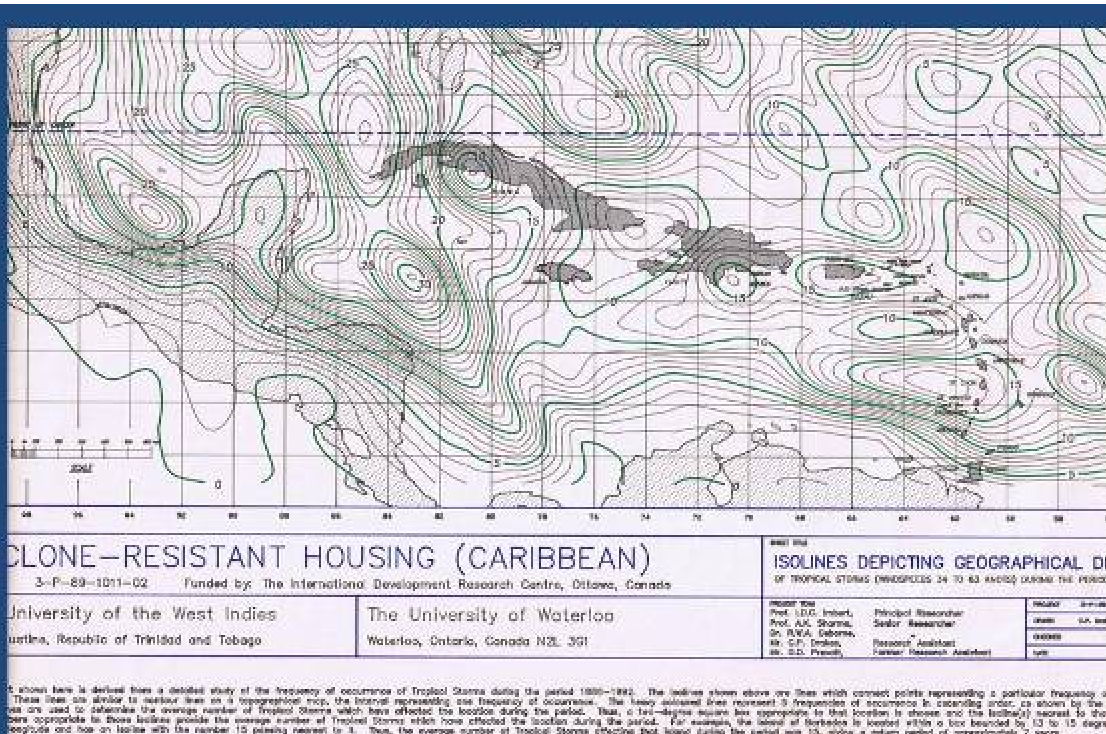
Photo: UWO-BLWTL



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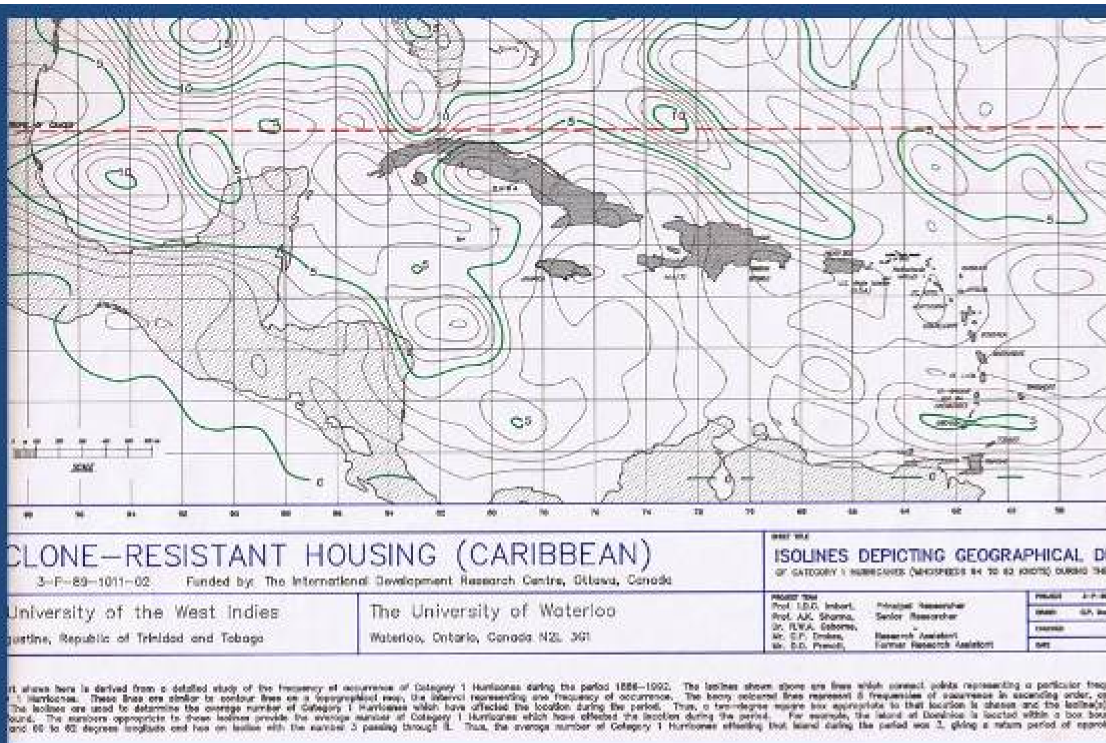

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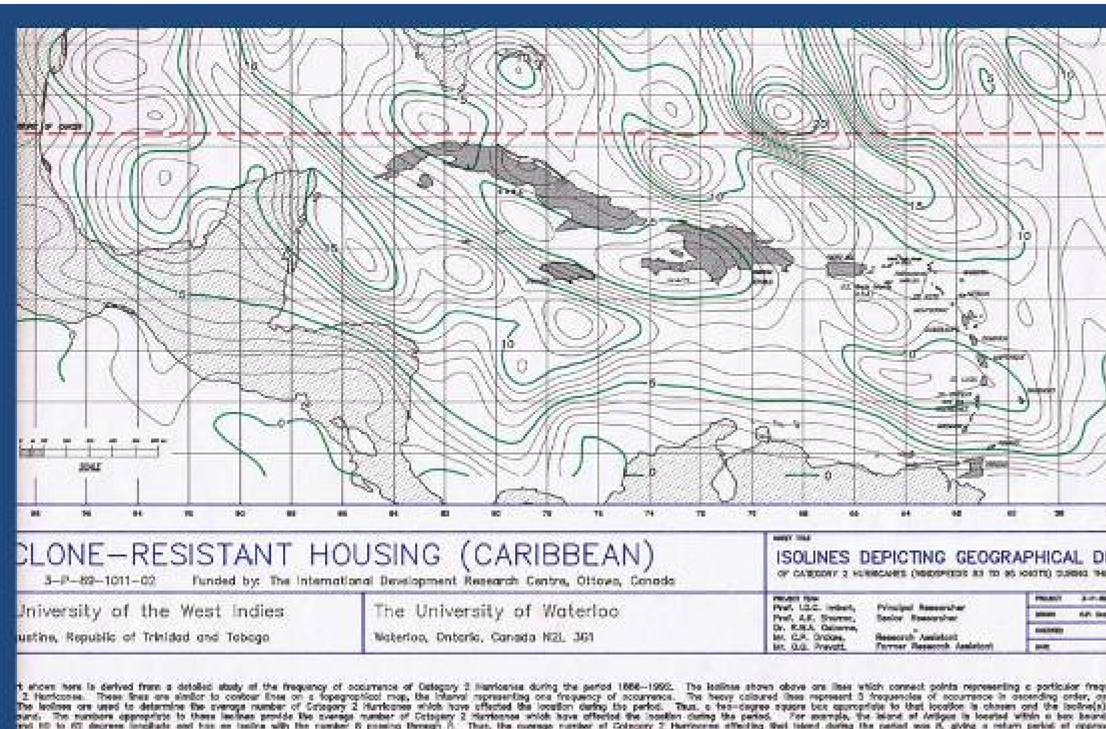

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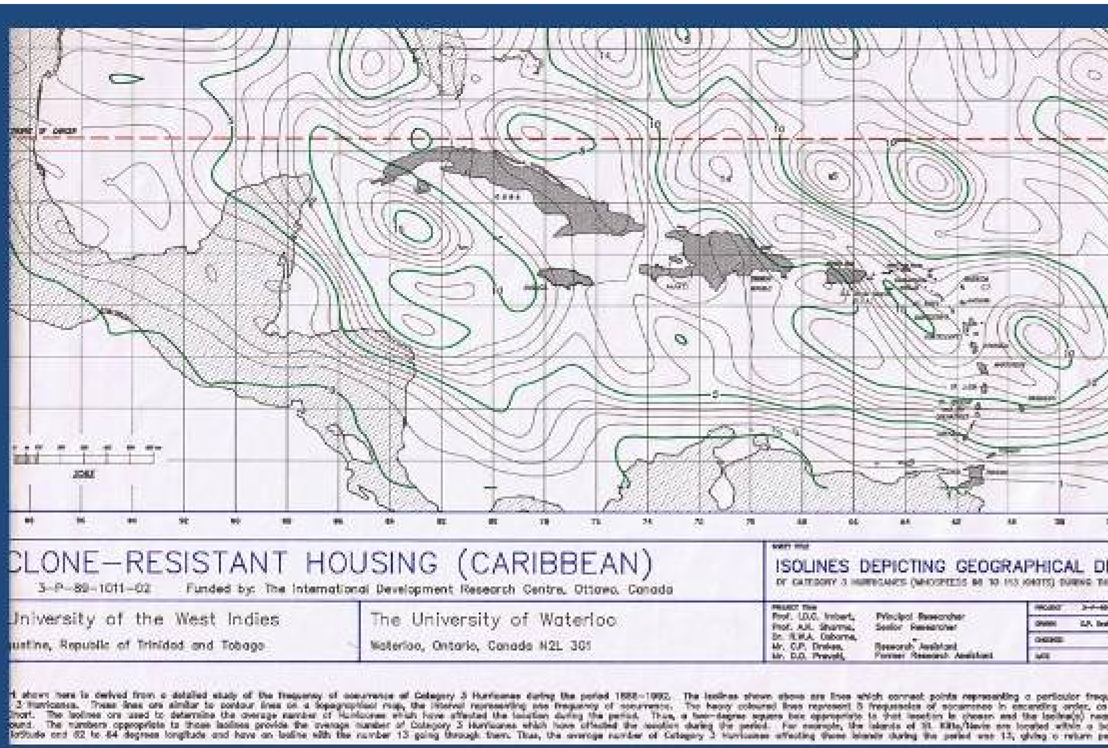

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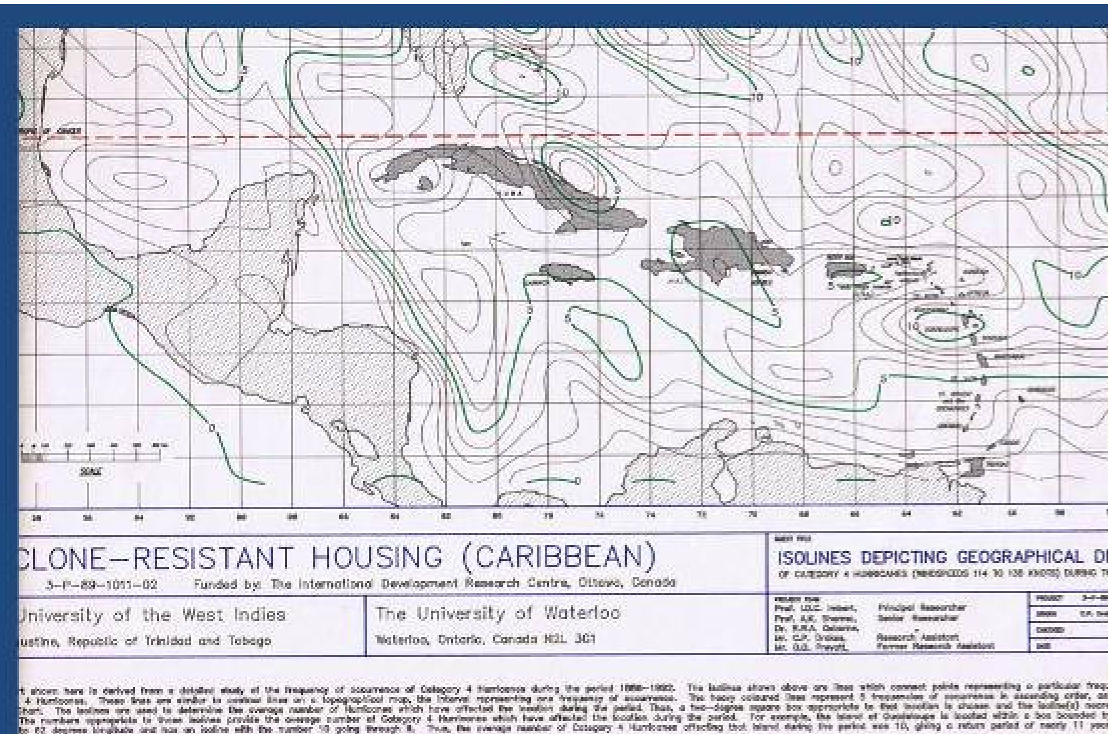

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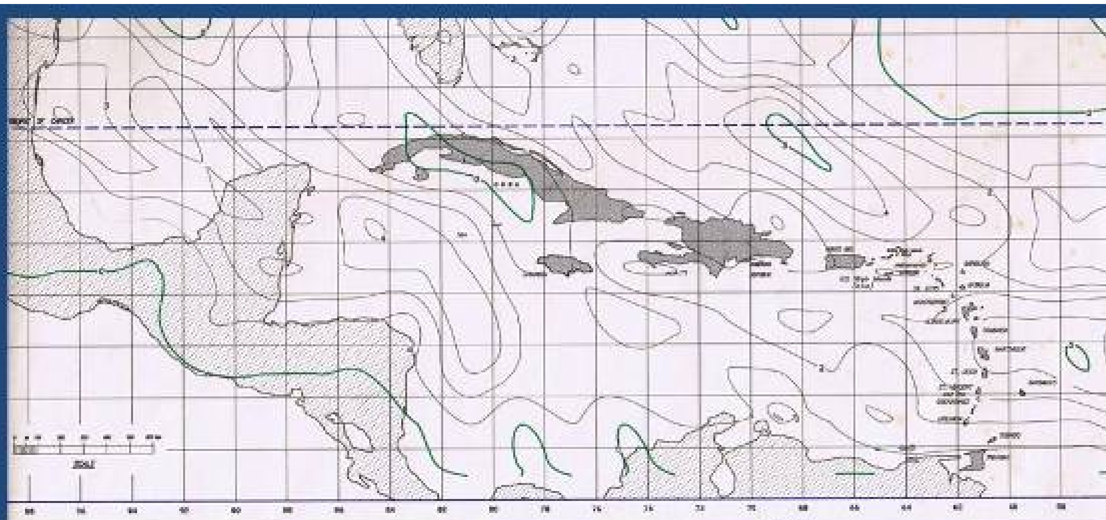

CLONE–RESISTANT HOUSING (CARIBBEAN)

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)

Prof. I.D.C. Imbert, Principal Researcher
Prof. A.K. Sharma, Senior Researcher
Dr. R.N.A. Osborne,
Mr. C.P. Drakes, Research Assistant
Mr. D.D. Prescott, Former Research Assistant

rt shown here is derived from a detailed study of the frequency of occurrence of Category 5 Hurricanes during the period 1886–1992. The isolines shown above are lines which connect points representing a particular freq… 5 Hurricanes. These lines are similar to contour lines on a topographical map, the interval representing one frequency of occurrence. The heavy coloured lines represent 5 frequencies of occurrence in ascending order… Chart. The isolines are used to determine the average number of Hurricanes which have affected the location during the period. Thus, a two-degree square box appropriate to that location is chosen and the isoline(s) nea… found. The numbers appropriate to these isolines provide the average number of Category 5 Hurricanes which have affected the location during the period. For example, the island of St. Lucia is located within a box boun… and 60 to 62 degrees longitude and has an isoline with the number 4 passing nearest to it. Thus, the average number of Category 5 Hurricanes affecting that island during the period was 4, giving a return period of app…

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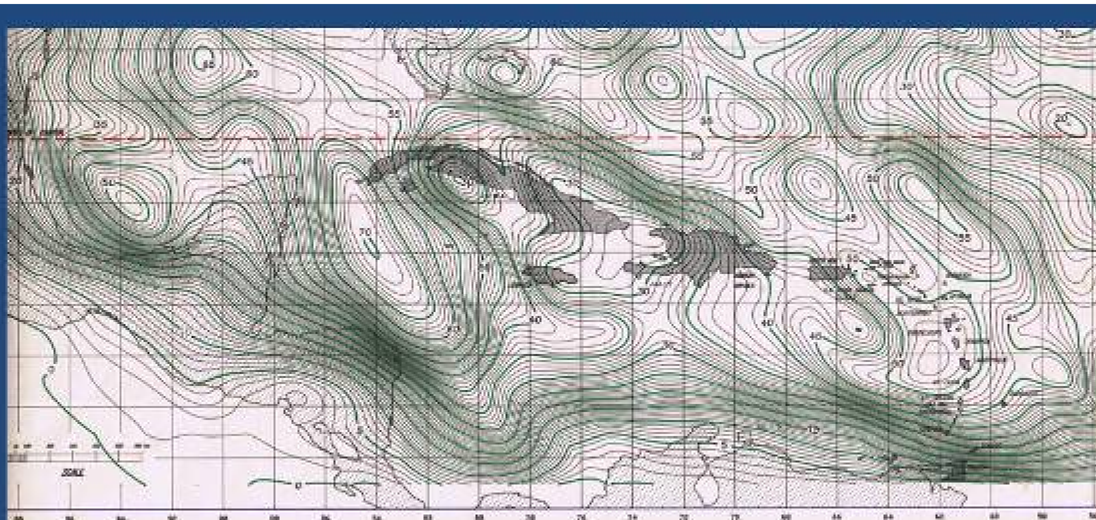

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ISOLINES DEPICTING GEOGRAPHICAL DIS

OF TROPICAL STORMS & HURRICANES (WINDSPEEDS GREATER THAN 34 KNOTS)

Prof. I.D.C. Imbert, Principal Researcher
Prof. A.K. Sharma, Senior Researcher
Dr. R.N.A. Osborne,
Mr. C.P. Drakes, Research Assistant
Mr. D.D. Prescott, Former Research Assistant

shown here is derived from a detailed study of the frequency of occurrence of Tropical Storms & Hurricanes during the period 1886–1992. The isolines shown above are lines which connect points representing a particular… are similar to contour lines on a topographical map, the interval representing one frequency of occurrence. The heavy coloured lines represent 8 frequencies of occurrence in ascending order, as shown by the numbering… are used to determine the average number of Tropical Storms and Hurricanes which have affected the location during the period. Thus, a two-degree square box appropriate to that location is chosen and the isoline(s)… and. The numbers appropriate to these isolines provide the average number which have affected the location during the period. For example, the island of Jamaica is located within a box bounded by 17 to 19 degrees lat… and has isolines with the numbers 33 to 38 passing through it. Thus, the average number of Tropical Storms and Hurricanes affecting that island during the period ranged from 33 to 38, giving return periods of 3 to 4 ye…

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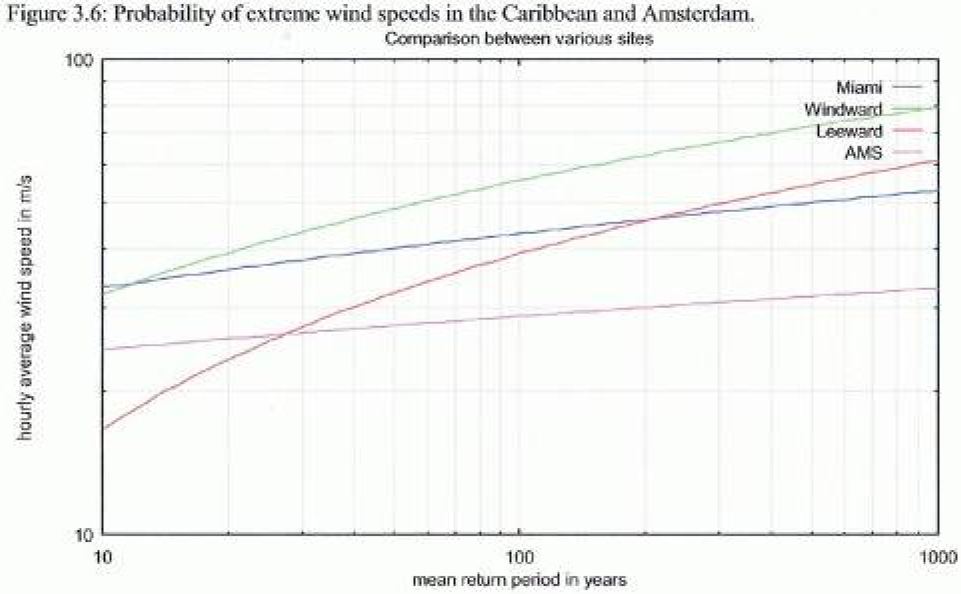
Ir P C van Staalduinen
and
Dr Ir C P W Geurts
TNO

"Hurricane Hazard in the Netherlands Antilles …."

1997

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



Wind Hazard Maps for the Caribbean Basin (3-second mph at 33ft) Overall region and individual islands April 2008

Principal researcher – Applied Research Associates (Peter Vickery)
Regional coordinator – Tony Gibbs (CEP International Ltd)
Executing agency – Pan American Health Organization (Dana van Alphen)
Funding agency – United States Agency for International Development

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Regional Office of the World Health Organization

Why do we need a new Caribbean Wind Hazard Map?

1 The only pan-Caribbean wind hazard maps ever produced for application in the design of structures were:

1969 (Caribbean Meteorological Institute – H C Shellard)
1981 (Caribbean Meteorological Institute – B Rocheford)
1985 (UWO Boundary Layer Wind Tunnel Laboratory – Davenport, Surry, Georgiou)

2 Since 1985 the region has collected another 20 years of relatively reliable data. The incorporation of these data would serve to improve the quality of currently-available wind hazard information.

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Why do we need a new Caribbean Wind Hazard Map?

3 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).

4 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.

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Why do we need a new Caribbean Wind Hazard Map?

5 This questioning, 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 some Caribbean countries.

6 The present project envisages the inclusion of the Caribbean coastlines of South and Central American countries. In several of these cases there is no presently available wind hazard guidance for structural design purposes. The present project will plug that gap.

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What use will be made of the results of the proposed project?

1 The new edition of the Caribbean Uniform Building Code (CUBiC) is presently in preparation. That project does not include any new wind hazard mapping for the target region. The results of this Caribbean Basin Wind Hazard Map (**CBWHM)** Project could be plugged directly into the new CUBiC.

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What use will be made of the results of the proposed project?

2 Those Caribbean countries which, for whatever reason, are developing their own standards and not participating in the CUBiC project will also require wind hazard information. This **CBWHM** Project will provide wind hazard information in forms specifically designed to fit directly into standards documents with different approaches. (Technical standards in the Caribbean are best dealt with regionally and not in a country-by-country manner.)

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What use will be made of the results of the proposed project?

3 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.

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What use will be made of the results of the proposed project?

4 Clients sometimes wish to specify the levels of safety of their facilities.

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What use will be made of the results of the proposed project?

5 Insurance providers sometimes wish to know the risks they underwrite. This depends critically on the quality of hazard information.

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What use will be made of the results of the proposed project?

6 Financing institutions sometimes wish to specify wind design criteria for their projects.

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What use will be made of the results of the proposed project?

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.

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Caribbean Basin Wind Hazard Maps (CBWHM)

The present **CBWHM** 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.

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An interim, information meeting was held at PAHO on 01 October 2007. Meteorologists, engineers, architects, emergency managers, standards personnel and funding agency personnel from the wider Caribbean were invited to attend.

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The principal researcher, Dr Peter Vickery of Applied Research Associates (ARA):

- o described the methodology for developing the maps;
- o presented the interim results available at the time of the meeting;
- o received comments from participants and answered their questions;
- o discussed what systems need to be put in place to improve knowledge of the wind hazard in the Caribbean region;
- o outlined the further work to finalise the present mapping exercise.

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The trend for Caribbean standards is to adopt and adapt the ASCE-7 approach

(Dominican Republic, new CUBiC, Cayman, Bahamas)

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The Neutral Wind:

"The basic wind speed is the 3-second gust speed estimated to be exceeded on the average only once in 50 years ..... at a height of 10 m (33 ft) above the ground in an open situation ....."

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Comparative table with different ways of reporting wind velocity

Averaging time	Wind Velocity (mph)			
1 Hour	120	113	91	79
10 minutes	127	120	96	84
Fastest mile	158	149	120	105
3 second gust	181	171	137	120

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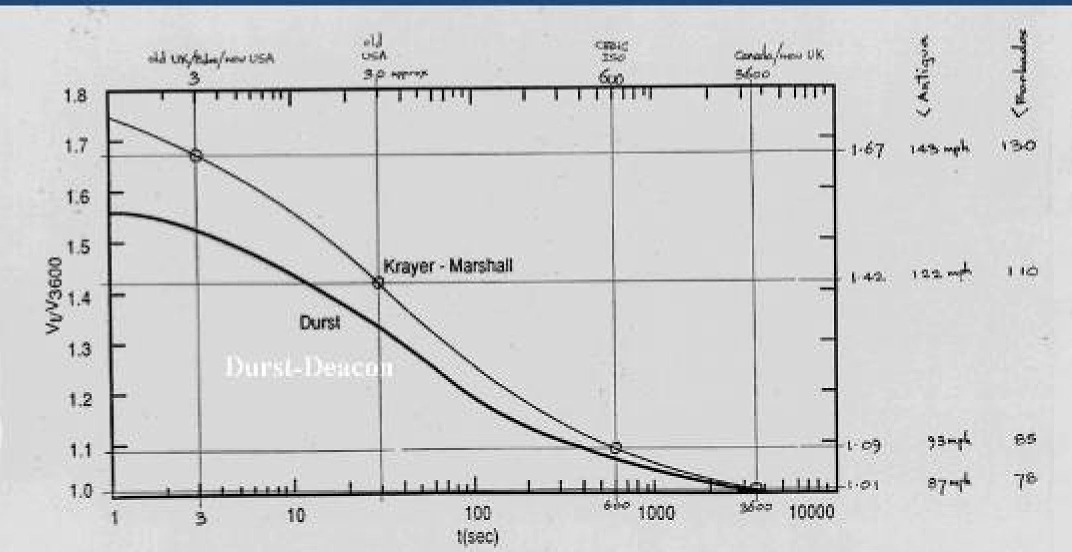

Fig. 2.1 Ratio of Probable Maximum Speed Averaged over *t* Seconds to Hourly Mean Speed

Source: Ref. 4

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Contour plots of observed minimum central pressures (mbar) 50 year return period pressures. Contours represent the minimum pressure *anywhere* within 250 km of a point.

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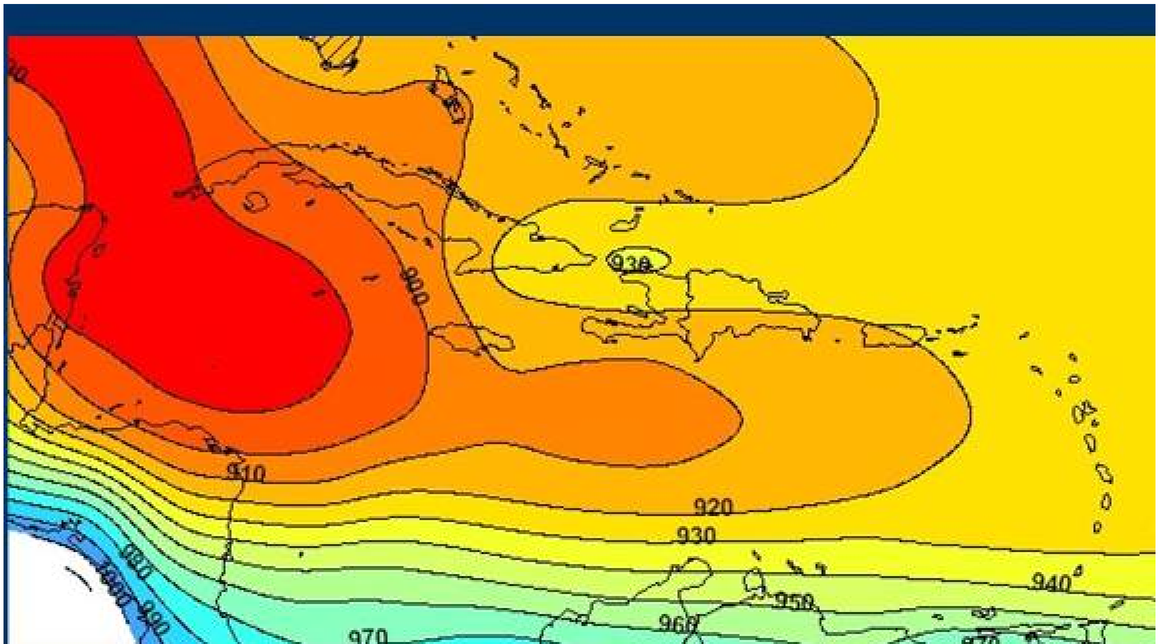

Contour plots of modeled minimum central pressures (mbar) 50 year return period. Contours represent the minimum pressure *anywhere* within 250 km of a point

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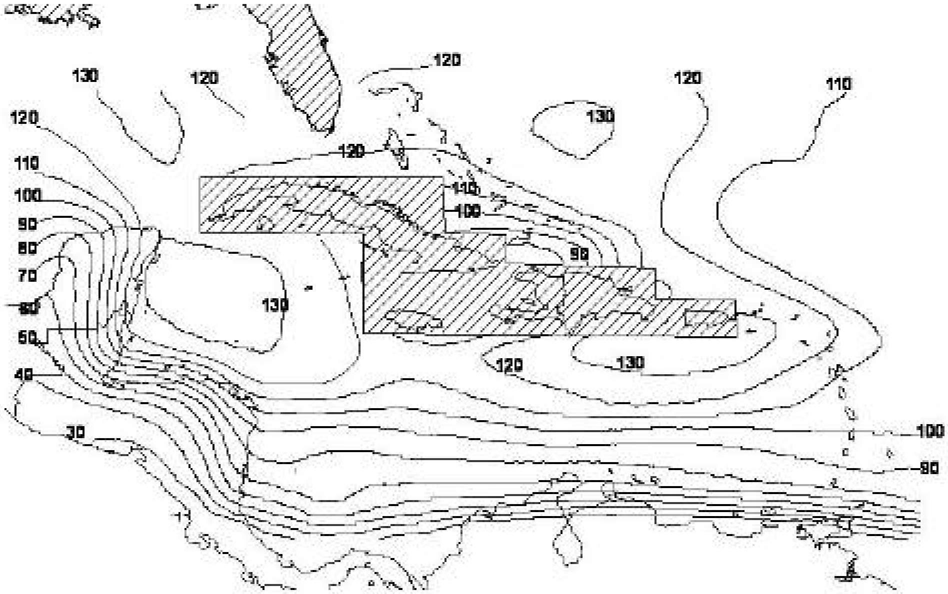
50 Year Wind Speeds for Caribbean



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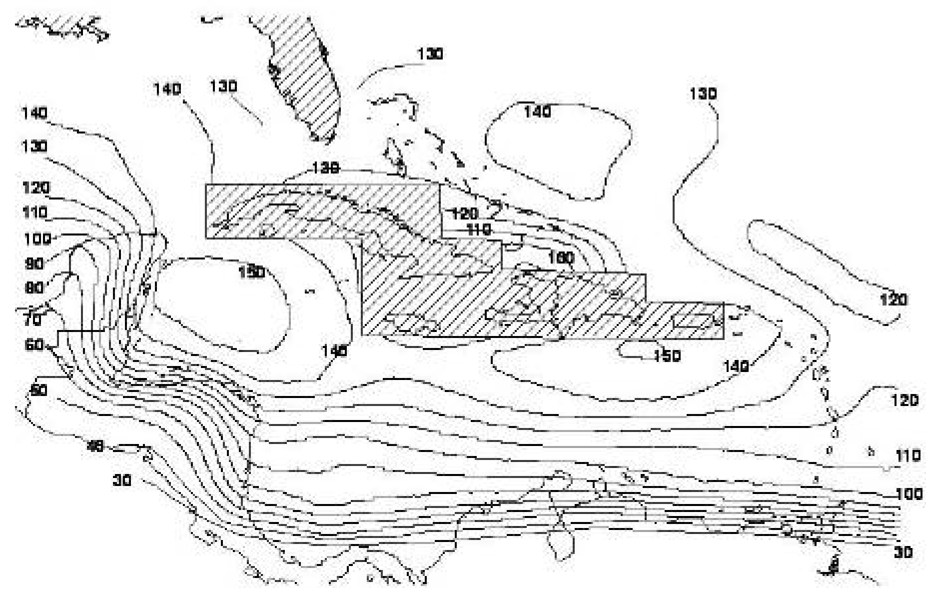
100 Year Wind Speeds for Caribbean



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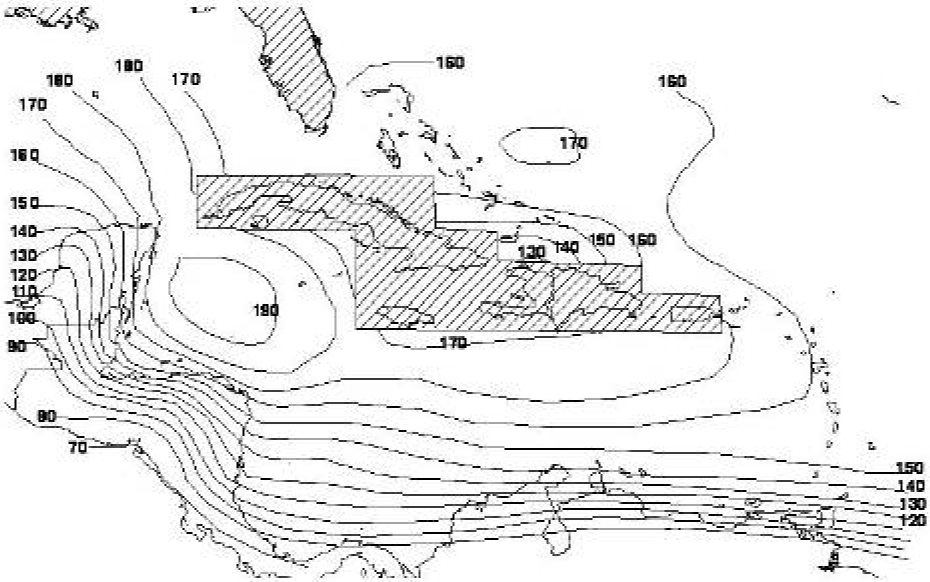
700 Year Wind Speeds for Caribbean



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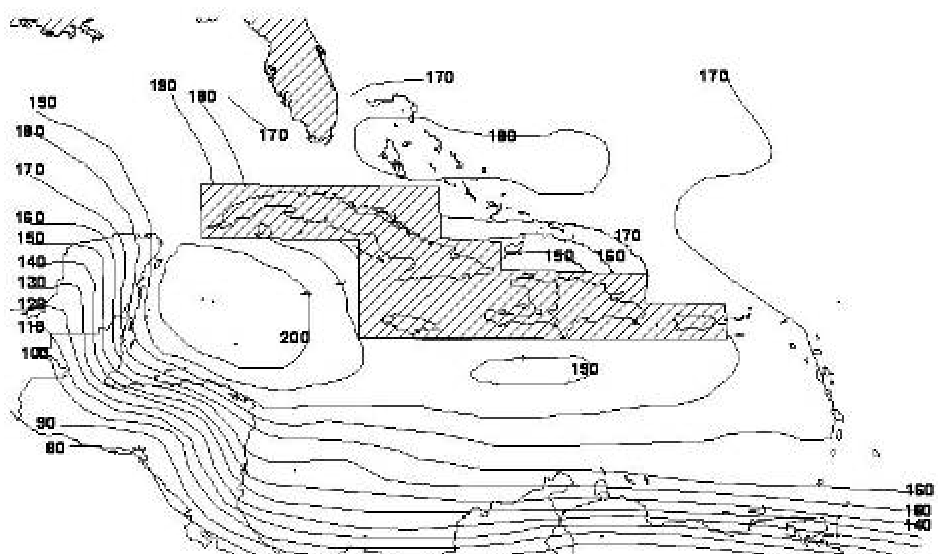
1700 Year Wind Speeds for Caribbean



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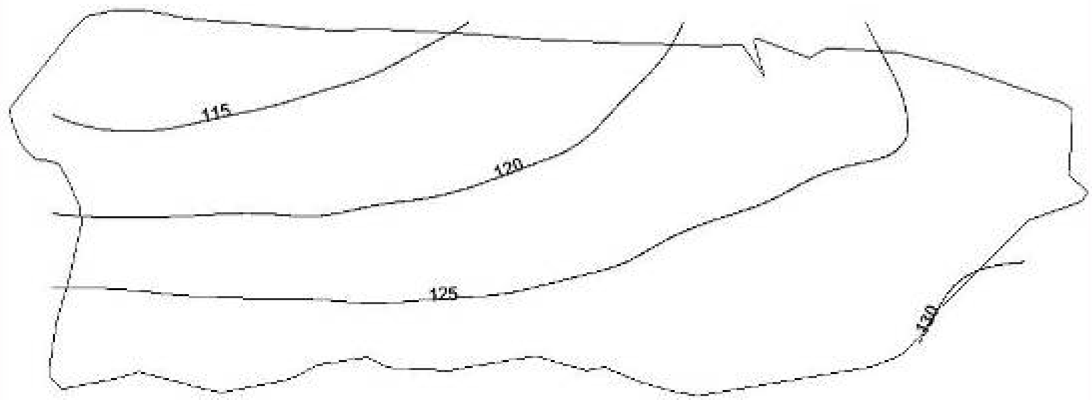
50 year Return Period Wind Speeds for Puerto Rico



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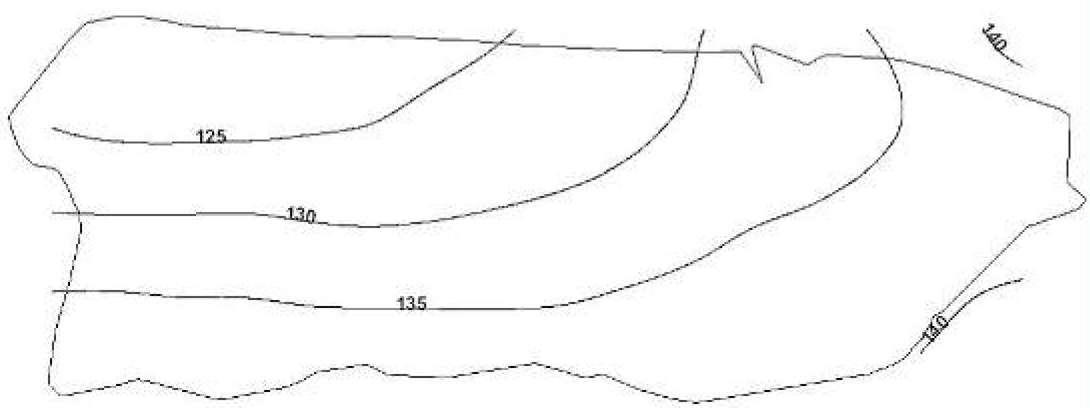
100 year Return Period Wind Speeds for Puerto Rico



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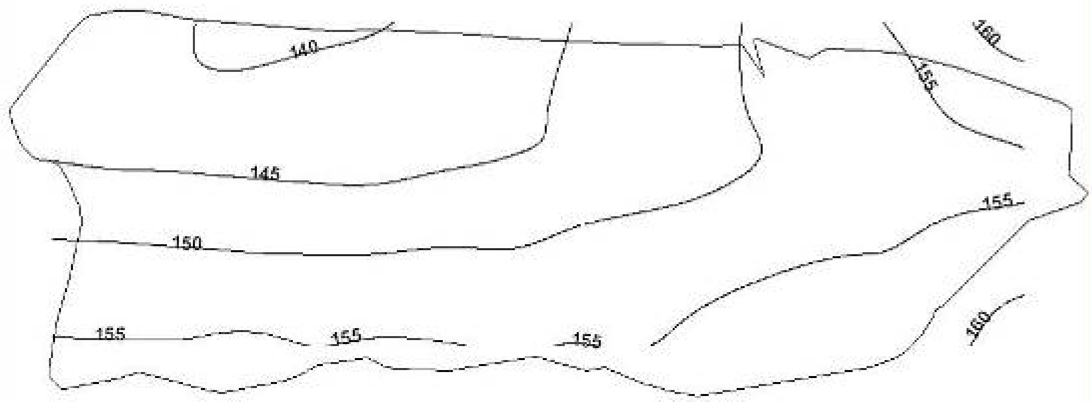
700 year Return Period Wind Speeds for Puerto Rico



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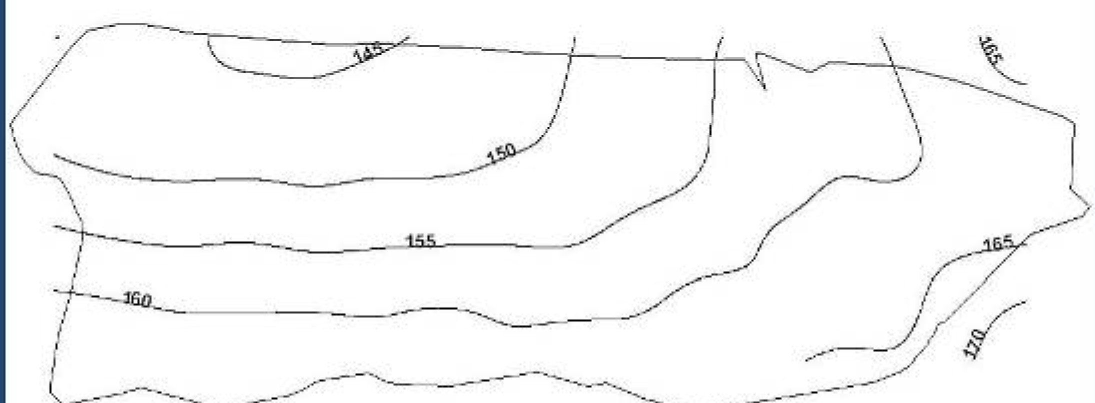
1700 year Return Period Wind Speeds for Puerto Rico



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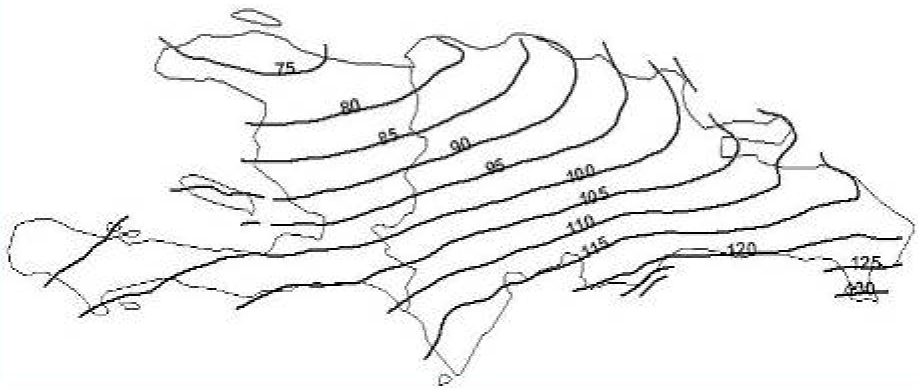
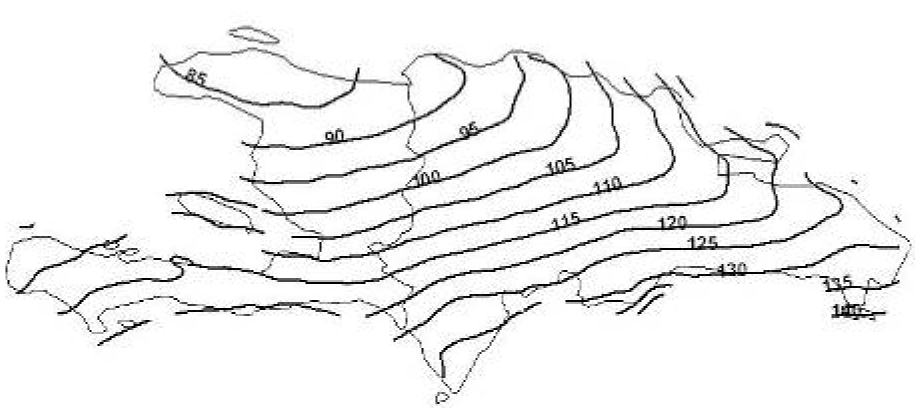
50 Year Return Period Wind Speeds for the Island of Hispaniola



100 Year Return Period Wind Speeds for the Island of Hispaniola



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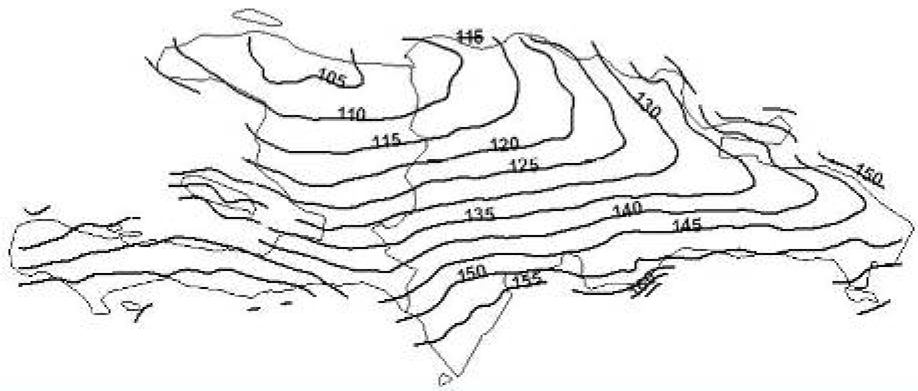
700 Year Return Period Wind Speeds for the Island of Hispaniola



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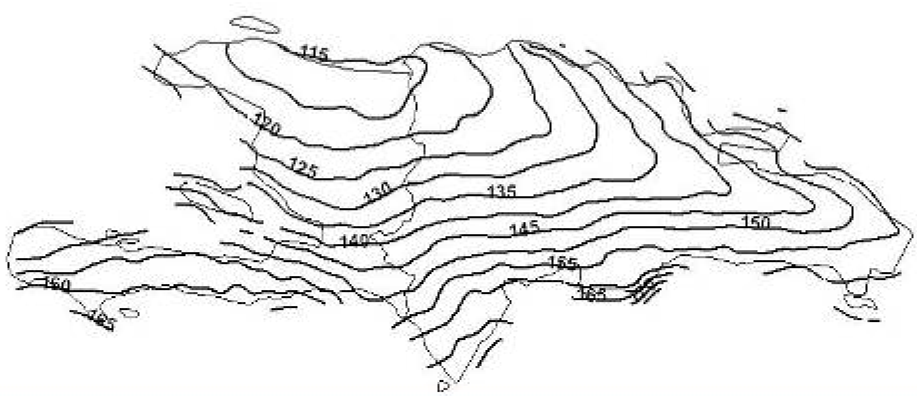
1700 Year Return Period Wind Speeds for the Island of Hispaniola



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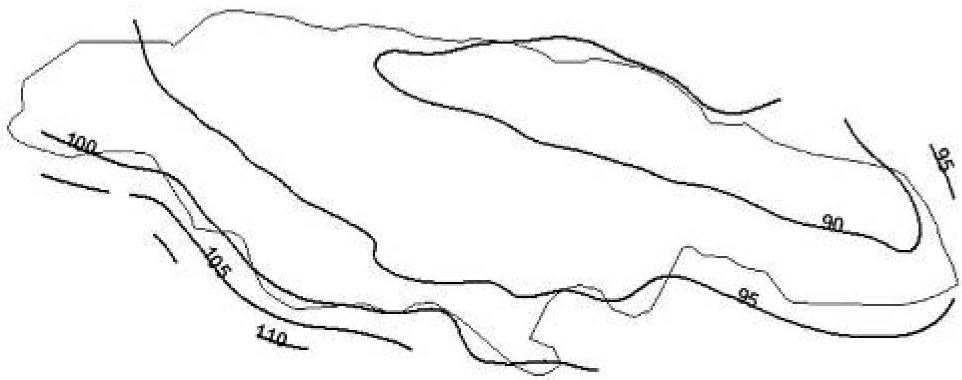
50 year Return Period Wind Speeds for Jamaica



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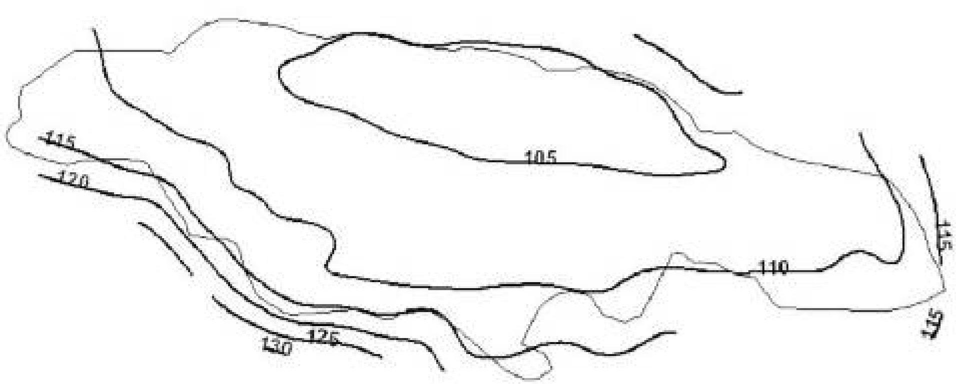
100 year Return Period Wind Speeds for Jamaica



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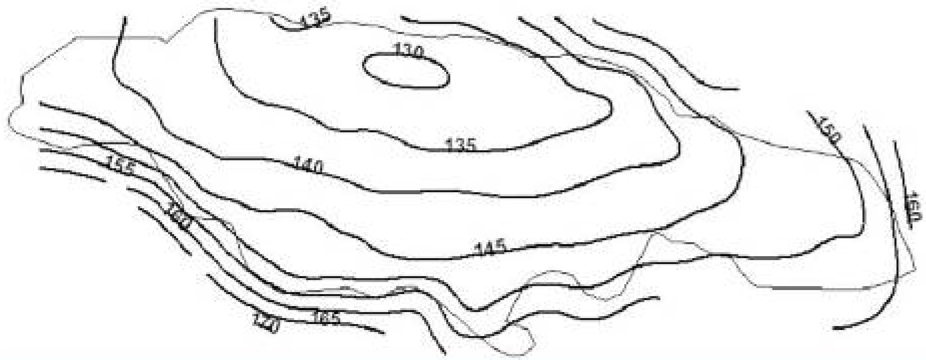
700 year Return Period Wind Speeds for Jamaica



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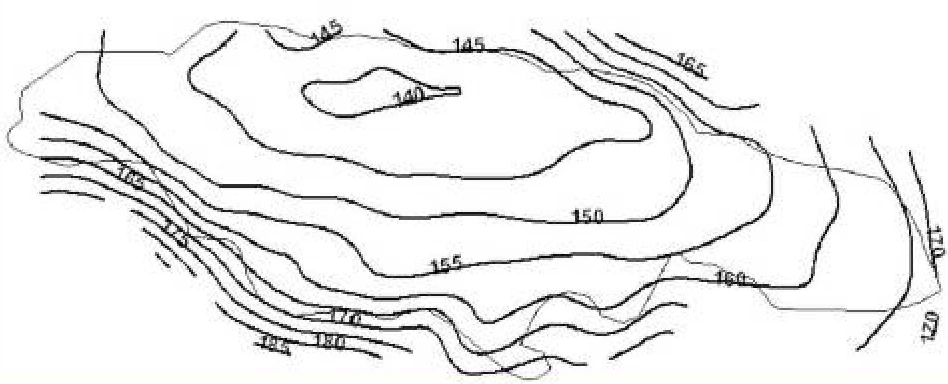
1700 year Return Period Wind Speeds for Jamaica



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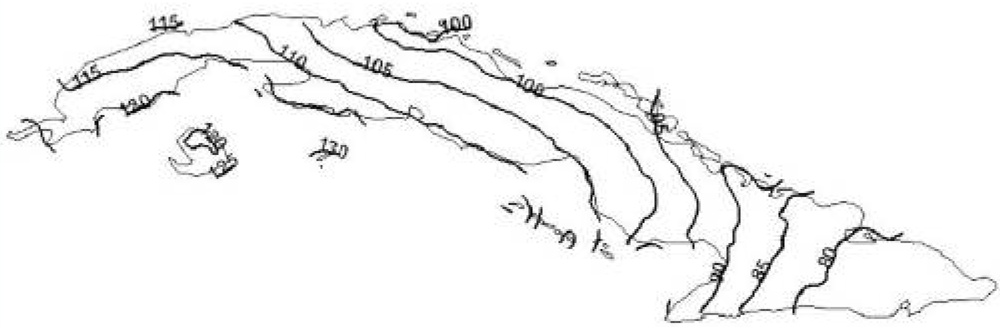
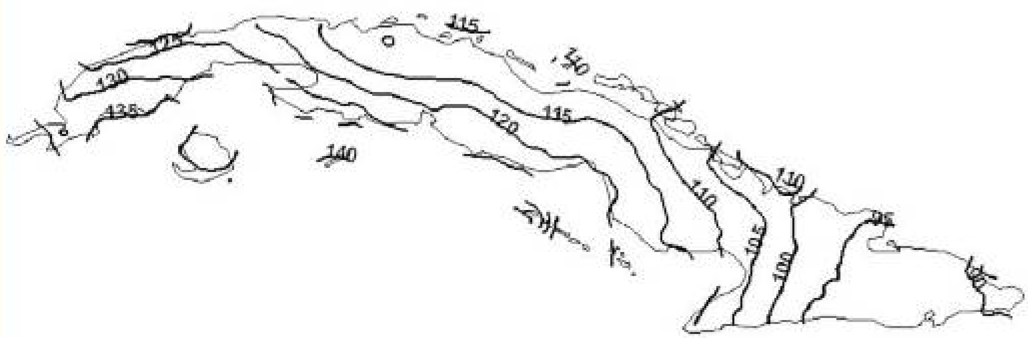
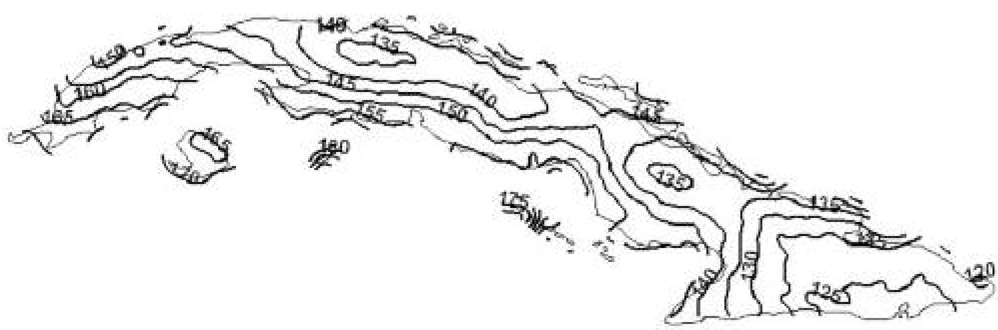
50 Year Return Period Wind Speeds for Cuba



100 Year Return Period Wind Speeds for Cuba



700 Year Return Period Wind Speeds for Cuba



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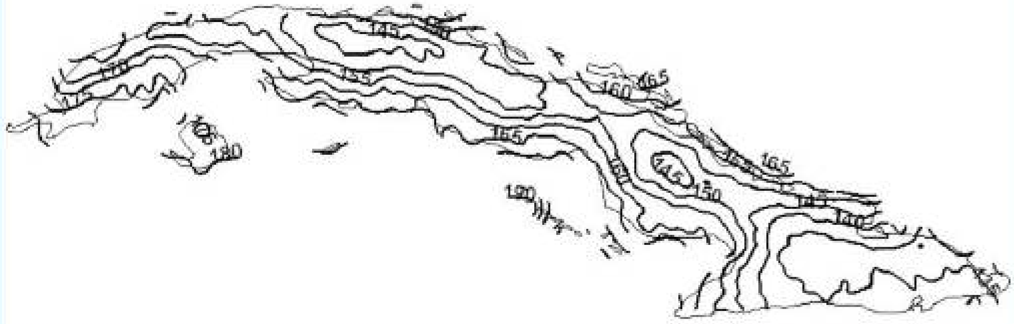
1700 Year Return Period Wind Speeds for Cuba



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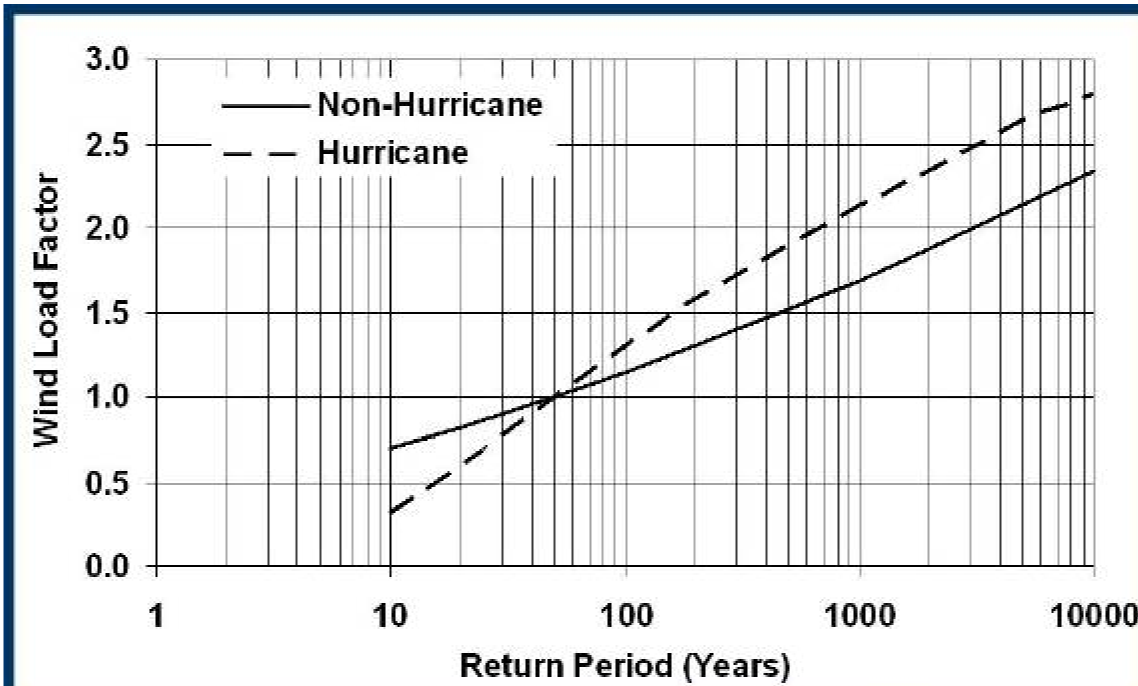
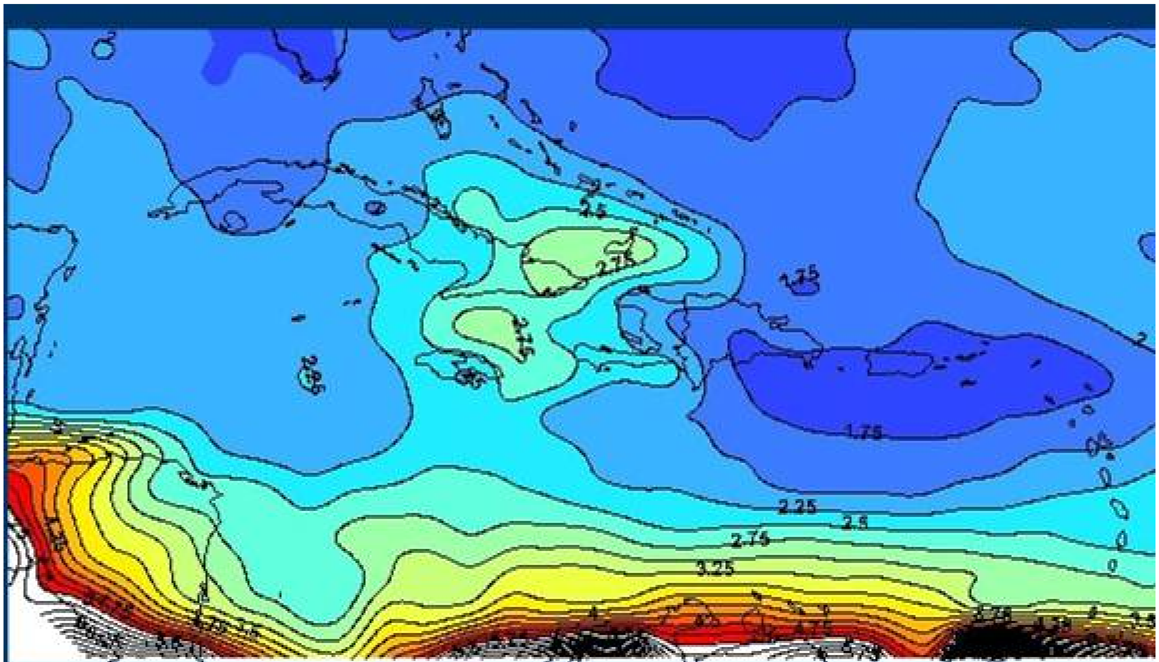
Peak gust wind speeds (mph) in flat open terrain as a function of return period for selected locations in the Caribbean

Location	Lat	Long	Return Period (years)			
			50	100	700	1700
Trinidad (S)	10.03	61.33	19	33	82	102
Trinidad (N)	11.20	61.33	61	85	136	156
Isla Margarita	10.50	64.17	24	42	100	128
Granada	12.13	61.67	85	107	154	168
Bonaire	12.25	68.28	77	101	149	156
Curacao	12.17	69.55	73	96	147	168
Aruba	12.53	70.03	77	100	146	162
Barbados	13.08	59.50	92	112	152	169
Saint Vincent	13.17	61.17	93	111	155	171
Saint Lucia	14.03	60.97	101	119	155	172
Martinique	14.60	61.03	104	121	159	171
Dominica	15.42	61.33	106	124	159	172
Guadeloupe	16.00	61.73	110	126	157	168
Montserrat	16.75	62.70	120	135	164	172
St. Kitts and Nevis	17.33	62.75	125	138	163	170
Antigua and Barbuda	17.33	61.80	121	134	160	168
Saint Martin/Sint Maarten	17.98	63.17	129	141	168	178
Anguilla	18.25	63.17	127	140	166	176
US Virgin Islands	18.35	64.93	130	143	167	176
British Virgin Islands	18.45	64.62	128	141	169	180
Grand Cayman	19.33	81.40	128	147	187	200
Little Cayman/Cayman Brac	19.72	79.82	118	136	178	197



Wind load factor $(V_T/V_{50})^2$ for Hurricane and Non-Hurricane Wind Speeds plotted vs return period



Contour plots of $(V_{700}/V_{50})^2$

Contour plots of importance factor for ASCE category III and IV structures defined by $I=(V_{1700}/V_{700})^2$

Basic Wind Speed

adjusted for:

1 topography
2 ground roughness
3 height above ground
4 size of structure
5 desired level of safety

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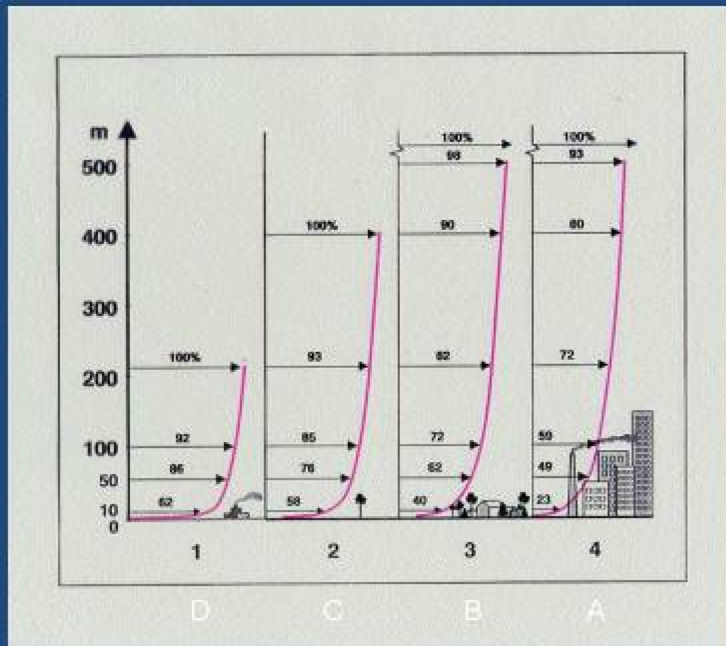
Photo: UWO-BLWTL



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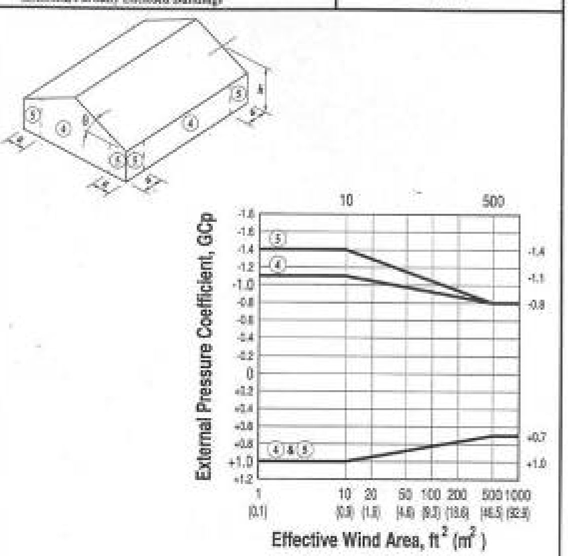
Components and Cladding – Method 2		h ≤ 60 ft.
Figure 6-11A	External Pressure Coefficients, GC_p	Walls
Enclosed, Partially Enclosed Buildings		



Notes:

1. Vertical scale denotes GC_p to be used with q_h.
2. Horizontal scale denotes effective wind area, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Each component shall be designed for maximum positive and negative pressures.
5. Values of GC_p for walls shall be reduced by 10% when $\theta \le 10°$.
6. Notation:
   - a: 10 percent of least horizontal dimension or 0.4h, whichever is smaller, but not less than either 4% of least horizontal dimension or 3 ft (0.9 m).
   - h: Mean roof height, in feet (meters), except that eave height shall be used for $\theta \le 10°$.
   - θ: Angle of plane of roof from horizontal, in degrees.

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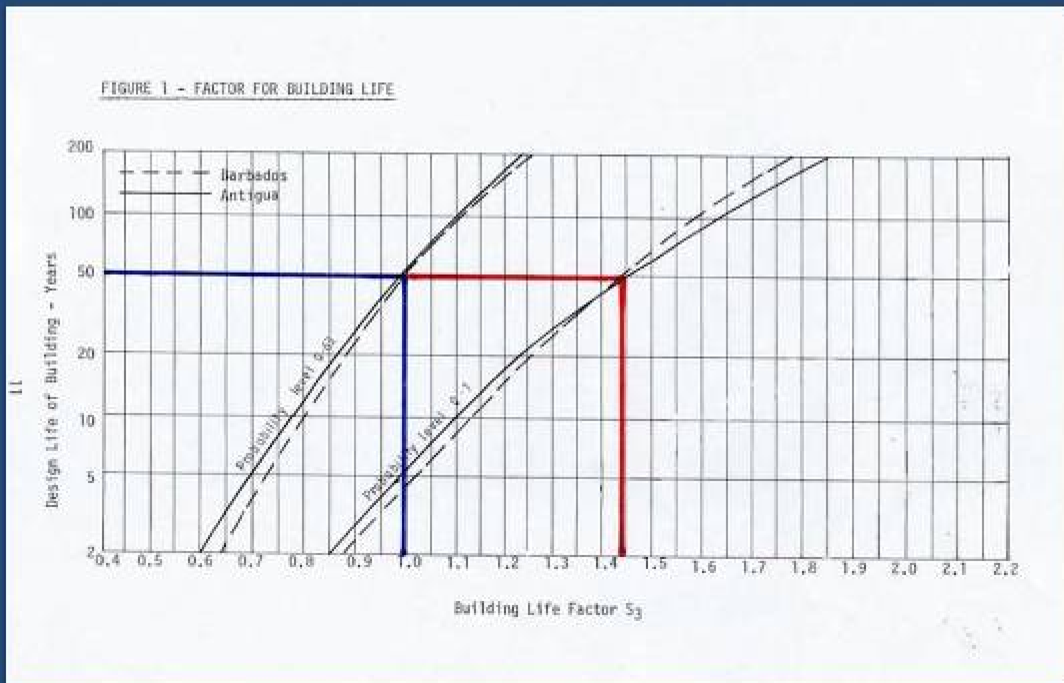

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Wind basic pressure

Dynamic part of Bernoulli's basic equation

$$q = \frac{1}{2}\rho V^2$$

Constant = 0.00256

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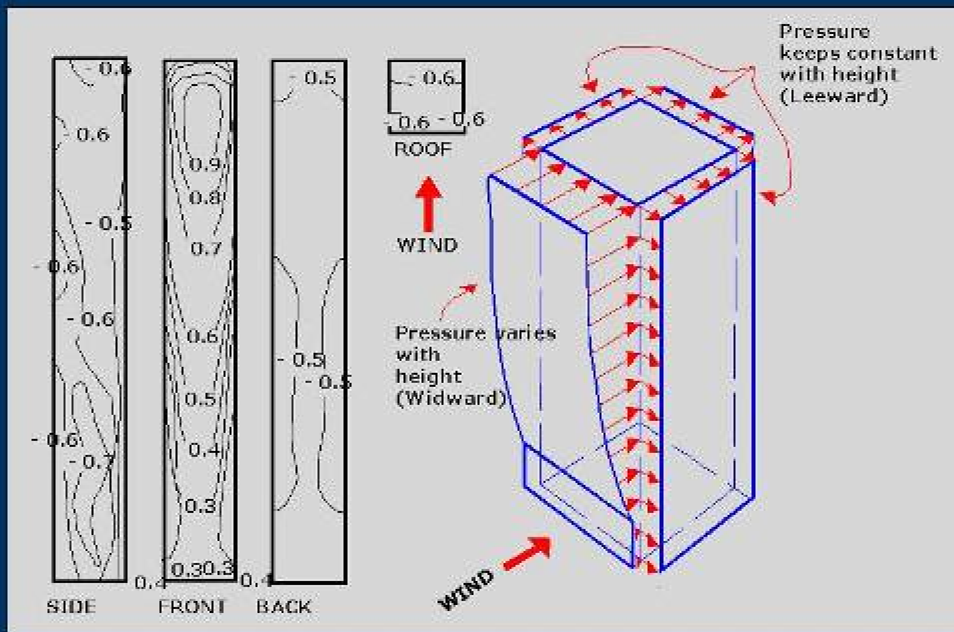
Pressure coefficients on high rise buildings



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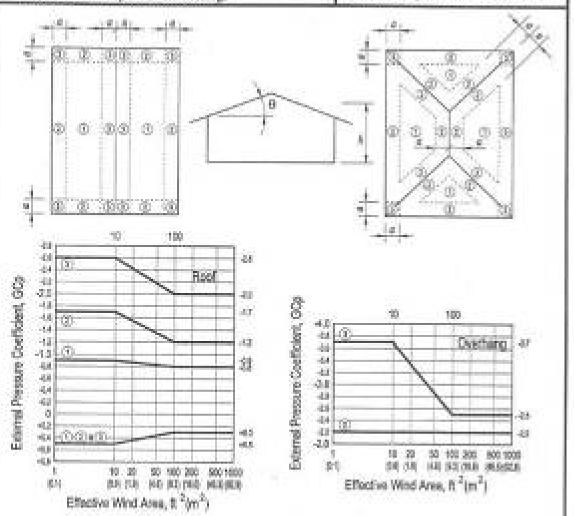
Components and Cladding – Method 2		h ≤ 60 ft.
Figure 6-11C	External Pressure Coefficients, GC_p	Gable/Hip Roofs 7° < θ ≤ 27°
Enclosed, Partially Enclosed Buildings		



Notes:

1. Vertical scale denotes GC_p to be used with q_h.
2. Horizontal scale denotes effective wind area, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Each component shall be designed for maximum positive and negative pressures.
5. Values of GC_p for roof overhangs include pressure contributions from both upper and lower surfaces.
6. For hip roofs with 7° < θ ≤ 27°, edge/ridge strips and pressure coefficients for ridges of gabled roofs shall apply on each hip.
7. For hip roofs with θ ≤ 25°, Zone 3 shall be treated as Zone 2.
8. Notation:
   - a: 10 percent of least horizontal dimension or 0.4h, whichever is smaller, but not less than either 4% of least horizontal dimension or 3 ft (0.9 m).
   - h: Mean roof height, in feet (meters), except that eave height shall be used for θ ≤ 10°.
   - θ: Angle of plane of roof from horizontal, in degrees.

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Gust Effect Factor G_f

MWFRS for flexible buildings and other structures

$$G_f = 0.925\left[\frac{1+1.7I_{\bar{z}}\sqrt{g_Q^2Q^2g_R^2R^2}}{1+1.7g_vI_{\bar{z}}}\right]$$

g_Q = peak factor for background response
g_R = peak factor for resonant response
R = resonant response factor
$I_{\bar{z}}$ = intensity of turbulence
Q = background response factor
g_v = peak factor for wind response

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Saffir-Simpson Hurricane Scale					
Category	Damage	Minimum wind speed	Maximum wind speed	Surge (USA coasts)	Pressure
		1-minute mph	1-minute mph	feet	mb
HC1	Minimal	74	95	4-5	>980
HC2	Moderate	96	110	6-7	965-980
HC3	Extensive	111	130	9-12	945-965
HC4	Extreme	131	155	13-18	920-945
HC5	Catastrophic	156		>18	<920

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Photo: Billy Wagner

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