Wind Speed Maps for the Caribbean for Application with the Wind Load Provisions of ASCE 7

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Definition of Basic Wind Speeds Used in ASCE 7

The purpose of this appendix is to review the process used by ASCE 7 Wind Load Task Committee (WLTC) in the development of the wind speed map given in ASCE 7-98 and beyond that presents a design wind speed map that is defined by wind speed contours that represents the 500 year return period wind speed divided by the square root of the load factor (i.e. $\sqrt{1.5}$). The goal of the WLTC was to develop a wind speed map that yielded approximately risk consistent designs (for wind resistance) in hurricane and non-hurricane prone regions of the United States. To reach this objective the WLTC developed an approach that, while approximate, resulted in a design wind speed map that incorporated a hurricane importance factor into the specification of the design wind speeds. The approach essentially involved equating the return period associated with exceeding the ultimate wind load in both the non-hurricane and hurricane prone regions of the United States. The methodology allowed for the implied hurricane importance factor to vary with location rather than using a single value as had been used in prior editions of the standard. The approach taken by the WLTC is extended here for the case where the wind load factor is equal to 1.6 rather than 1.5, and is further extended to determine the effective return period associated with the ultimate design of Category III and IV structures (as defined in ASCE 7).

Prior to the introduction of ASCE 7-95, the design wind load equations in ASCE 7 included a multiplicative term in the form of a hurricane importance factor. This hurricane importance factor was introduced to take into account the fact that the tails of the wind speed exceedance probability distributions for hurricane winds are longer than those associated with non-hurricane winds. The hurricane importance factor varied from about 1.05 at the coast and decayed linearly to 1.0 at a distance of 100 miles inland. The hurricane importance factor in ASCE 7 and it predecessor (ANSI A58.1) was applied to the 50-year return period wind speed given in the standard, *not* the resulting velocity pressure. Thus, using the ASCE and ANSI provisions, buildings and structures located near the coast were designed using a wind speed that had a longer return period than those located 100 miles or more inland.

In the development of the wind speed map given in ASCE 7-95, the hurricane importance factor was incorporated directly into the wind speed map (i.e. wind speeds along the hurricane prone at the coast were increased by 5% and wind speeds 100 miles inland were left unchanged, and those in between were adjusted through linear interpolation of the hurricane importance factor).

In the development of the design wind speed map used in ASCE 7-98 the WLTC re-visited the hurricane importance factor that had been in use in the US standards since 1982. The primary reasons for re-visiting the hurricane factor was the recognition that the importance factor likely varied with location along the coast and using a constant value of 1.05 was not appropriate.

The approach taken to develop a varying importance factor began with the premise that the nominal wind load computed using the methods given in ASCE 7, when multiplied by the wind load factor, was representative of an "ultimate" load. Furthermore, it was assumed that the variability of the wind speed dominates the calculation of the wind load factor. The ultimate wind load, *W*, is given as

$$W = C_F (VI_H)^2 W_{LF} \qquad \text{B-1}$$

where C_F is a building/component specific coefficient that includes the effects building height, building geometry, terrain, gust factors, etc., as computed using the procedures outlined in ASCE 7, V is the design wind speed, W_{LF} is the wind load factor, and I_H is the hurricane importance factor.

In order to estimate the value of the hurricane importance factor, I_H, the committee required that the annual probability of exceeding the ultimate wind load in the hurricane and non-hurricane regions of the US should be the same. Note that requiring the annual probability of exceeding the ultimate load in the two areas (hurricane vs. non-hurricane) to be the same does not mean that the annual probabilities of failure are the same. Recalling that the nominal design wind speed in the non-hurricane regions of the United States is associated with a return period of 50 years, the WLTC sought to determine the return period associated with the wind speed producing the "ultimate" load in a representative non-hurricane prone region. As defined in ASCE 7-98, over most of the non-hurricane prone coastline of the United States, the wind speed for any return period can be computed from:

$$V_T / V_{50} = [0.36 + 0.1\ln(12T)] \qquad \text{B-2}$$

where T is the return period in years and, V_T is the T year return period wind speed. In the non-hurricane prone regions of the United States, the ultimate wind load occurs when:

$$W_T = C_F V_T^2 = C_F V_{50}^2 W_{LF} \qquad \text{B-3}$$

thus

$$V_T / V_{50} = [0.36 + 0.1\ln(12T)] = \sqrt{W_{LF}} \qquad \text{B-4}$$

and from B-4, the return period T associated with the ultimate wind speed in the non-hurricane prone portion of the United States is:

$$T = 0.00228 \exp(10\sqrt{W_{LF}}) \qquad \text{B-5}$$

Using the wind load factor of 1.6 as is currently specified in ASCE 7-05, from (B-5) we get T = 709 years.

Figure B-1 presents a comparison of $(V_T/V_{50})^2$ (i.e. a surrogate for the wind load factor) plotted vs. return period for a hurricane (in this case Grand Cayman) and a non-hurricane region. The comparison shows that for T=709 years, the wind loads for a structure located in the hurricane prone region is about twice that of the 50 year return period load. In the non-hurricane prone region this difference is only a factor of 1.6 (i.e. the wind load factor). To ensure the annual probability of exceeding the ultimate wind load for the hurricane and non-hurricane prone regions are the same, a load factor of 2 would have to be applied to the 50 year return period design wind speed for a building designed at the hurricane prone location, whereas a load factor of 1.6 is applied to the non-hurricane wind load.

Alternately, from Equations B-1 and B-3, a hurricane importance can be defined as

$$I_H = \sqrt{2/1.6} = 1.12 \qquad \text{B-6}$$

Or more generally,

$$I_H = (V_{709}/V_{50})/\sqrt{W_{LF}} \qquad \text{B-7}$$

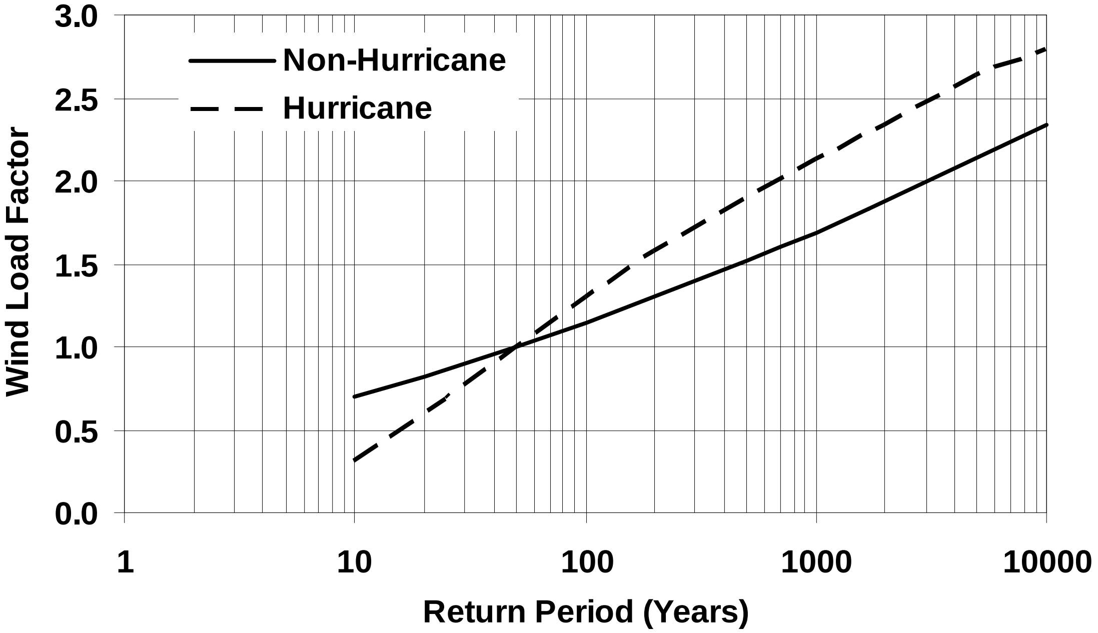

Figure B-1 Wind load factor $(V_T/V_{50})^2$ for Hurricane and Non-Hurricane Wind Speeds plotted vs. return period.

Thus when the 50 year return period wind speed in the hurricane prone region is multiplied by the hurricane importance factor, the annual probability that the ultimate load is exceeded in either location is about the same.

Instead of producing maps of hurricane importance factors to be applied to the nominal 50-year return period wind speed, a design wind speed can be defined as:

$$V_{design} = V_{709}/\sqrt{W_{LF}} \approx V_{700}/\sqrt{W_{LF}} \qquad \text{B-8}$$

Using a wind speed defined as in Equation B-8 eliminates the need to develop a map for both the 50-year return period wind speed and the importance factor. If a basic (design) wind speed associated with a 50 year return period was used in the Caribbean, in order to be consistent with the intent of the ASCE 7 standards, a load factor defined as $(V_{700}/V_{50})^2$ would be used in place of a constant value of 1.6. Figure B-2 presents contours of $(V_{700}/V_{50})^2$ showing the variation of the effective wind load factor over the Caribbean basin, varying from about 1.75 around Puerto Rico to in excess of 6 near Trinidad and Tobago. The very large ratios in the southern portion of the Caribbean occur because of the large number of years where the locations do not experience any hurricanes, and as a result the 50 year return period wind speeds are very low, but these locations experience strong winds from hurricanes associated with rare events.

Note that when the wind speed maps were being developed for ASCE 7-98, the wind load factor at the time was equal to 1.53, which the wind load task committee rounded down to 1.5 and computed an ultimate load return period of 475 years, which subsequently rounded up to 500 years. The final wind speed map used in ASCE 7-98 was developed using $V_{design} = V_{500}/\sqrt{1.5}$. During the same time period when the wind load map was being developed, the ASCE 7 committee examining load factors increased the load factor from a value of 1.53 to 1.6. Thus when ASCE 7-98 was published there was a disconnection between the load factor used to develop the map and the load factor used in the wind loading equations.

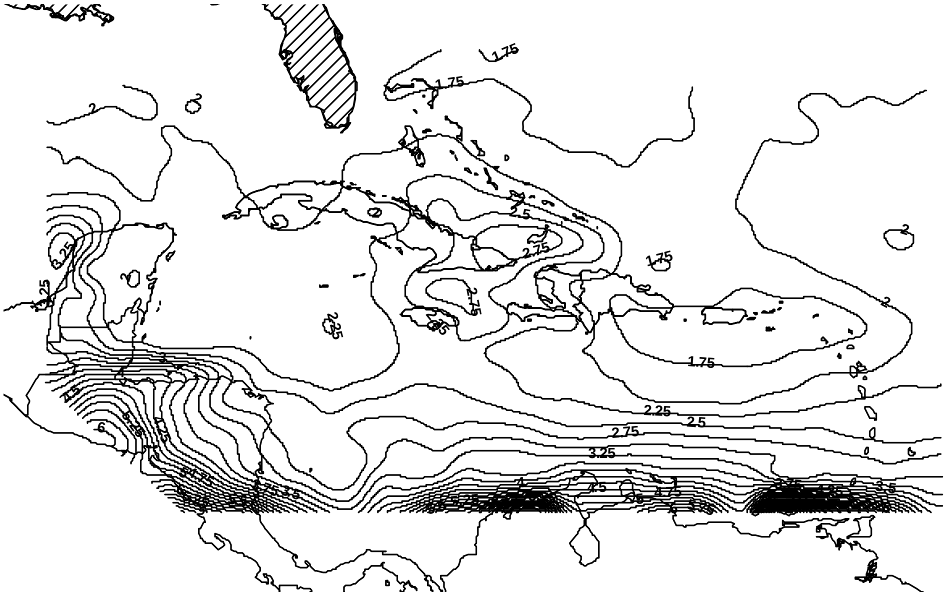

Figure B-2 Contour plots of (V_{700}/V_{50})^2

As indicated above, when the correct load factor of 1.6 is used, a design wind speed defined as $V_{design} = V_{700}/\sqrt{1.6}$ is appropriate. This design wind speed is equivalent to designing a structure using the 700 year return period wind speed and a load factor of unity.

The importance factor used in ASCE 7 for the computation of wind loads for the design of category III and IV structures is defined so that the nominal 50-year return period non-hurricane wind speed is increased to be representative of a 100-year return period value. This importance factor *is not* the hurricane importance factor, $I_{H,}$ but rather a factor used to increase the wind loads based on an occupancy classification. The importance factor is applied to the design of all category III and IV buildings whether or not they are located in a hurricane prone region. Following the approach used above to estimate the resulting ultimate load return period associated with the 100 year design wind speed in the non-hurricane prone regions we find that:

$$T = 0.00228 \exp[10(V_{100} / V_{50})\sqrt{W_{LF}}\,] \qquad \text{B-9}$$

where for V_{100} / V_{50} computed from B-4 and W_{LF} = 1.6, we find that T=1,697 years. In the development of Equation B-9, the term $(V_{100} / V_{50})\sqrt{W_{LF}}$ replaces the $\sqrt{W_{LF}}$ used in Equation B-5, effectively resulting in a higher load factor for category III and IV structures equal to $W_{LF}\,(V_{100} / V_{50})^2$. Thus for Category III and IV structures, a design wind speed of $V_{1700} / \sqrt{1.6}$ is appropriate.

In the versions of ASCE 7 since 1993 (i.e., ASCE 7-95 and beyond), the importance factor has been applied to the velocity pressure, *not*, the wind velocity as was the case in prior editions. The design pressure in ASCE 7-95 and later is

$$q_z = 0.00256 K_z K_{zt} K_d V^2 I \qquad \text{B-10}$$

where the importance factor I is equal to 1.15 for category III and IV structures. For consistency in the hurricane prone regions, the importance factor should be defined as:

$$I = (V_{1700} / V_{700})^2 \qquad \text{B-11}$$

Figure B-3 presents contour plots of $I = (V_{1700} / V_{700})^2$ where a large gradient of I from north to south is evident, but over most of the region, I, is consistent with the 1.15 value given in ASCE 7. In the case of the Category II buildings where a 700 year return period wind speed represents an ultimate design wind speed for these Category II buildings, we find that for Category III and IV buildings a 1,700 year return period wind speed is representative of the ultimate wind load. Both approaches inherently include the variation in the hurricane importance factor in hurricane prone regions, but are tied back to a wind load factor equal to 1.6 as applied to the non-hurricane prone region of the United States.

Figure B-3 Contour plots of importance factor for ASCE category III and IV structures defined by $I=(V_{1700}/V_{700})^2$

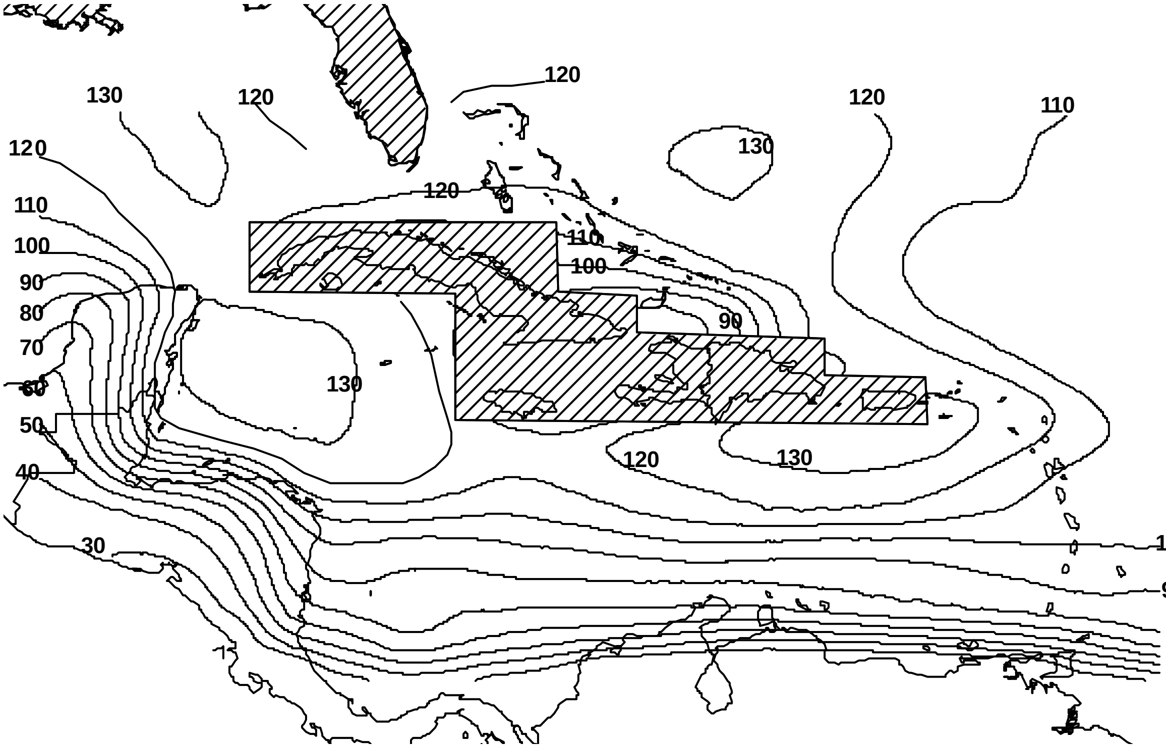

Figure 3-1. Contours or predicted 50 year return period peak gust wind speeds (mph) at a height of 10m in flat open terrain.

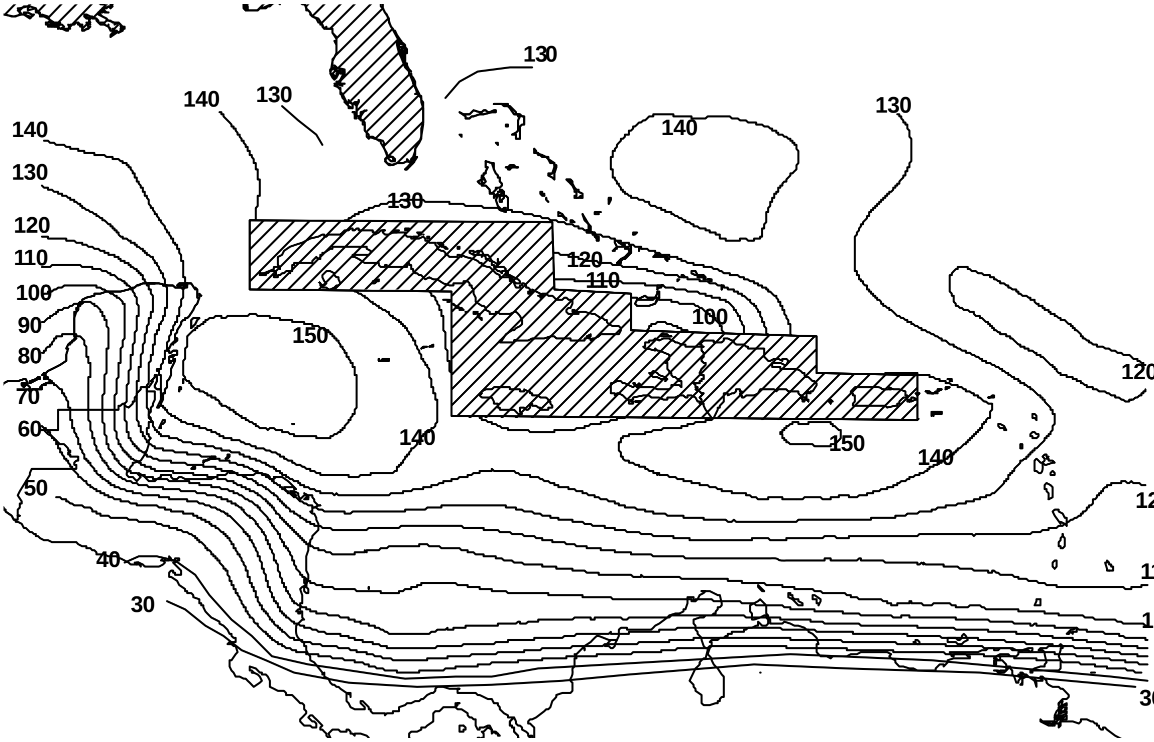

Figure 3-2. Contours or predicted 100 year return period peak gust wind speeds (mph) at a height of 10m in flat open terrain.

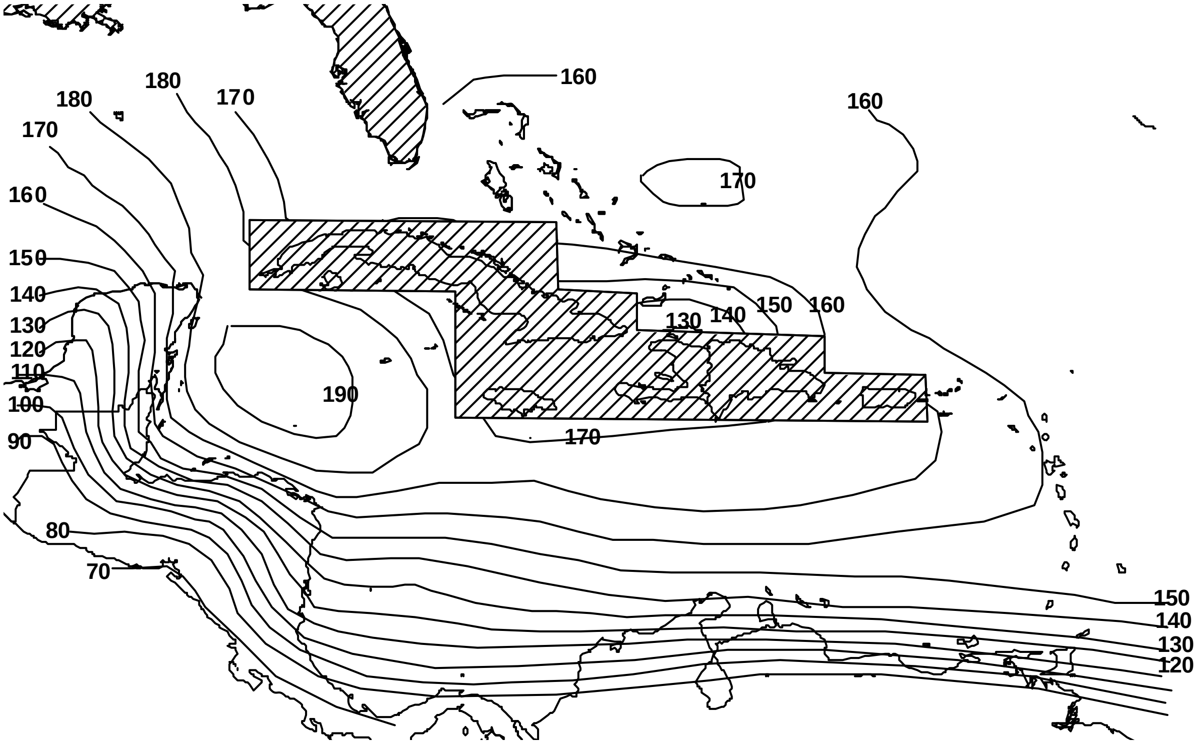

Figure 3-3. Contours or predicted 700 year return period peak gust wind speeds (mph) at a height of 10m in flat open terrain.

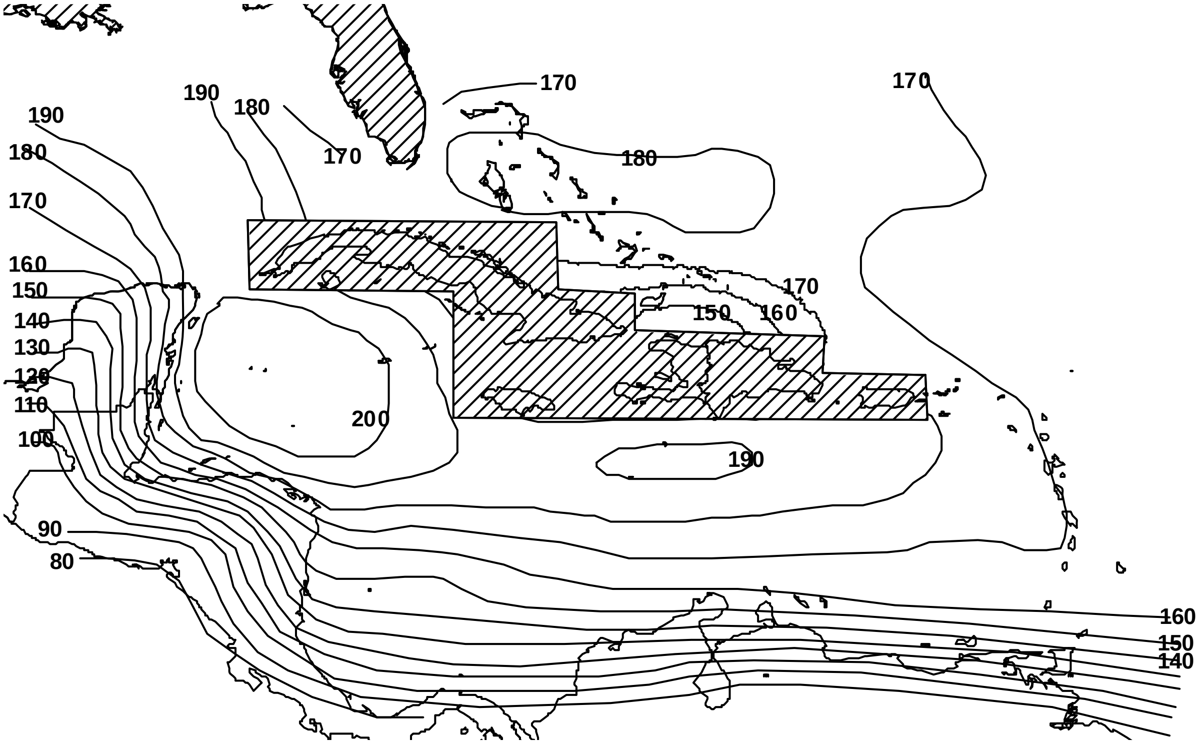

Figure 3-4. Contours or predicted 1,700 year return period peak gust wind speeds (mph) at a height of 10m in flat open terrain.

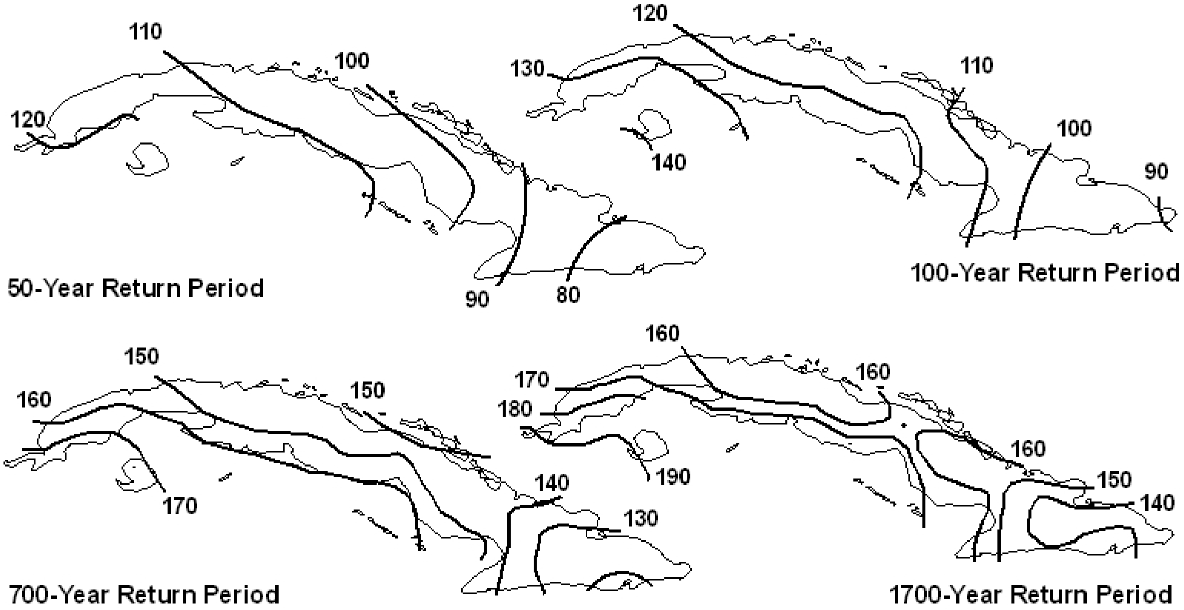

Figure 3-5. **Contours of period peak gust wind speeds (mph) at a height of 10m in flat open terrain for various return periods for Cuba.**

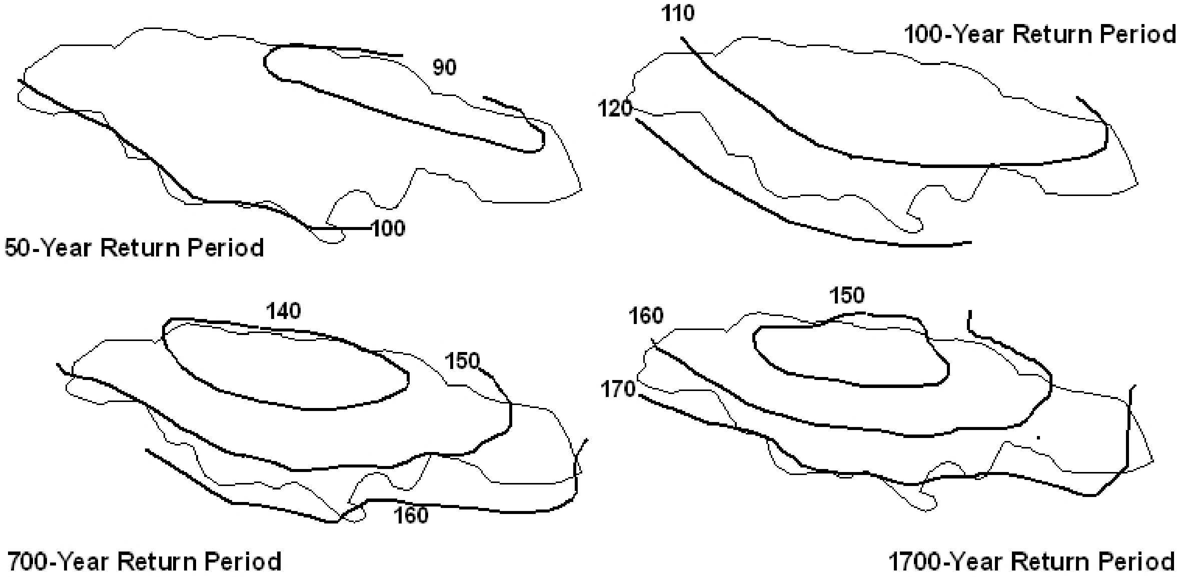

Figure 3-6. **Contours of period peak gust wind speeds (mph) at a height of 10m in flat open terrain for various return periods for Jamaica.**

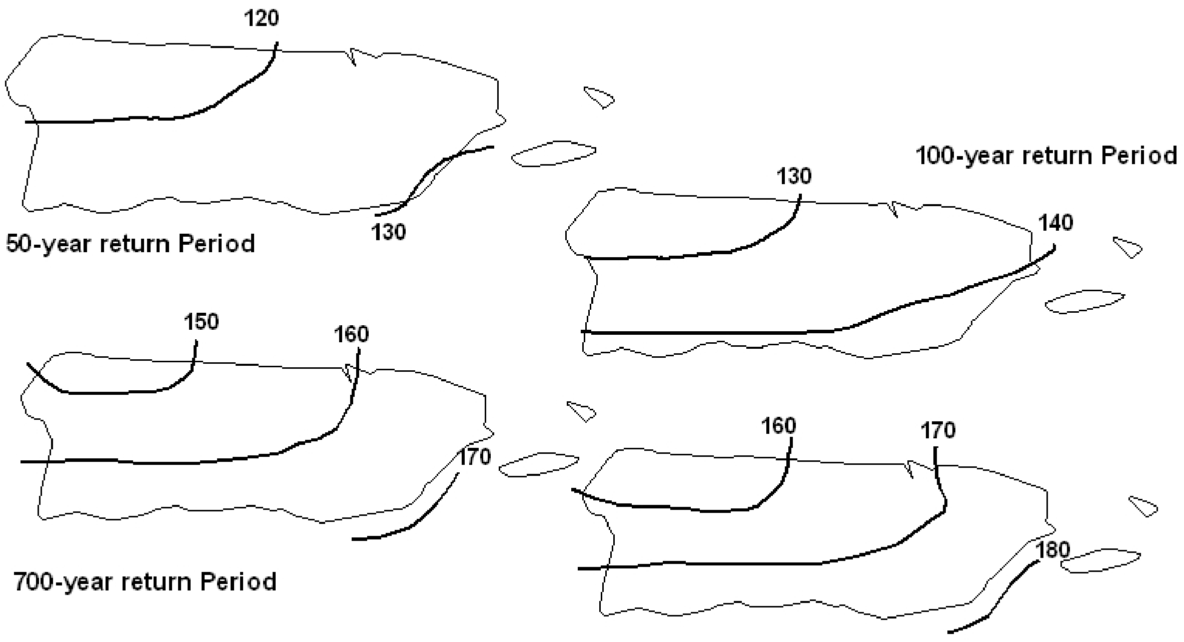

Figure 3-7. **Contours of period peak gust wind speeds (mph) at a height of 10m in flat open terrain for various return periods for Puerto Rico.**

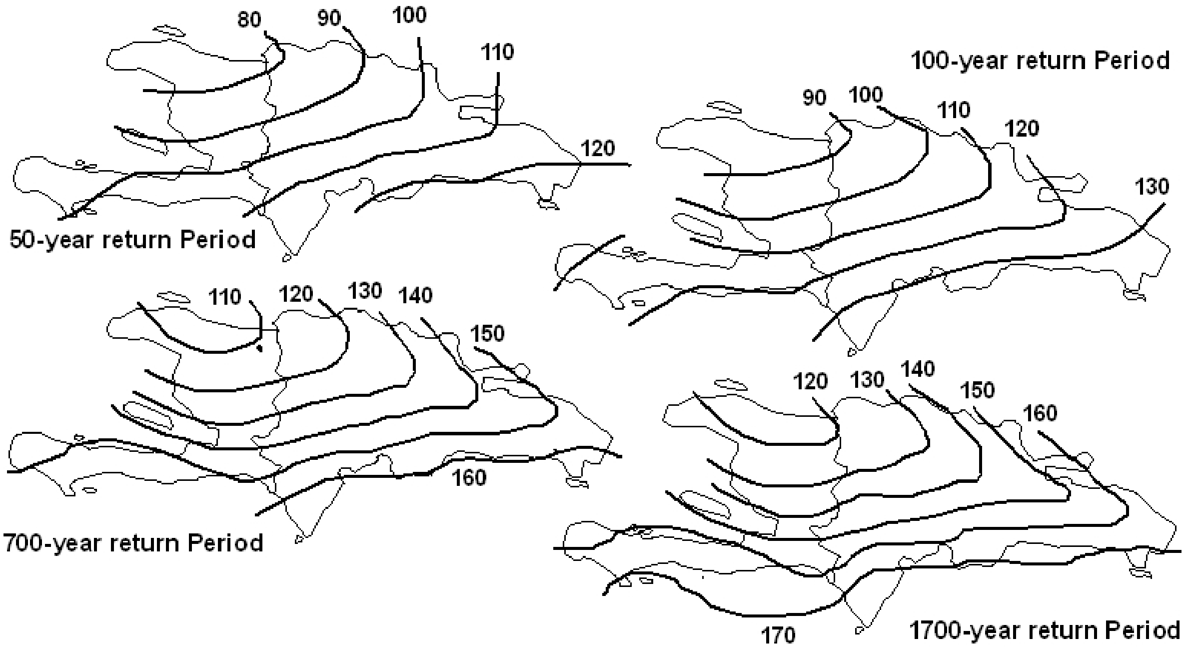

Figure 3-8. **Contours of period peak gust wind speeds (mph) at a height of 10m in flat open terrain for various return periods for the island of Hispaniola.**

Table 3-1 Peak gust wind speeds (mph) in flat open terrain (ASCE 7 Exposure C) as a function of return period for selected locations in the Caribbean

Location	Lat	Long	Return Period (years)			
			50	100	700	1700
Trinidad (S)	10.08	-61.33	21	35	87	110
Trinidad (N)	10.80	-61.33	45	71	128	147
Isla Margarita	11.00	-63.96	43	68	133	152
Grenada	12.12	-61.67	85	107	154	168
Bonaire	12.25	-68.28	77	101	149	156
Curacao	12.17	-69.00	73	97	149	165
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	-62.19	119	132	161	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	18.06	-63.05	127	140	167	175
Anguilla	18.22	-63.05	127	140	165	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	19.30	-81.38	128	147	187	198
Little Cayman/Cayman Brac	19.72	-79.82	118	136	178	197
Belize	17.25	-88.76	98	117	150	161
Turks & Caicos (Grand Turk)	21.47	71.13	105	120	150	162
Turks & Caicos (Providenciales)	21.77	72.27	110	124	155	170
Eleuthera	24.96	76.45	122	135	165	180
Andros	24.29	77.68	120	132	162	180
New Providence (Nassau)	25.04	77.46	121	132	163	180
Great Abaco	26.45	77.30	121	133	162	178
Grand Bahama (Freeport)	26.55	78.70	120	132	161	175