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Journal of Wind Engineering
and Industrial Aerodynamics 90 (2002) 1657–1669

JOURNAL OF wind engineering AND industrial aerodynamics

www.elsevier.com/locate/jweia

Generalized extreme gust wind speeds distributions

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Abstract

Since summer 1996, the US wind engineers are using the extreme gust (or 3-s gust) as the basic wind speed to quantify the destruction of extreme winds. In order to better understand these destructive wind forces, it is important to know the appropriate representations of these extreme gust wind speeds. Therefore, the purpose of this study is to determine the most suitable extreme value distributions for the annual extreme gust wind speeds recorded in large selected areas. To achieve this objective, we are using the generalized Pareto distribution as the diagnostic tool for determining the types of extreme gust wind speed distributions. The three-parameter generalized extreme value distribution function is, thus, reduced to either Type I Gumbel, Type II Frechet or Type III reverse Weibull distribution function for the annual extreme gust wind speeds recorded at a specific site.

With the considerations of the quality and homogeneity of gust wind data collected at more than 750 weather stations throughout the United States, annual extreme gust wind speeds at selected 143 stations in the contiguous United States were used in the study.

Keywords: Gust winds; General pareto distribution; Generalized extreme value distribution; Cumulative mean exceedance method; Gumbel and reverse Weibull distributions

1. Introduction

In the United States, ASCE 7-93 [1] was the last version of wind load standards using the fastest-mile wind data, which statistically reduced extreme value distributions by using the Fisher–Tippet Type I function. The current ASCE 7-98

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0167-6105/02/$ - see front matter
PII: S0167-6105(02)00277-5

[2] uses the 3-s extreme gust wind speeds for estimating wind loads on structures. Recognizing that extreme wind speeds are physically bounded, researchers have used Weibull and reverse Weibull distributions in their analyses of extreme winds [3–7]. Results from these studies have indicated that annual fastest-mile wind speeds (excluding tornado and hurricane winds) are better described by the reverse Weibull distribution in most, if not all cases. Our recent study on annual extreme gust winds suggests that a two-parameter generalized Pareto distribution (GPD) may be used to analyze the extreme gust wind speeds instead of the current practice of assuming that the parent extreme winds (regardless of location) are all Type I distributed. The solution range of the tail-length parameter c of GPD may serve as an indicator that the extreme events under consideration may be represented by either Type I Gumbel (for c value approaching zero), Type II Frechet (for $c > 0$) or Type III reverse Weibull (for $c < 0$) extreme value functions.

2. Strategy

Consider $W(t)$ as the wind speed time series at a specific site, and V as the extreme gusts associated with $W(t)$, in general, the parent distribution of V is unknown. However, V may be identified by estimating its tail quantile probability of a proposed conditional cumulative distribution function (CDF) $F(v)$

$$\mathrm{Prob}(V \leqslant v) = F(v) = 1 - (1 + cv/d)^{-1/c} \tag{1}$$

for $d > 0$ and $(1 + cv/d) > 0$, in which, $V = W(t) - u$, where u is a sufficiently large threshold value of $W(t)$, v is a conditional realization of V, c and d are the shape (or tail-length) and scale parameters, respectively. Eq. (1) is the well-known GPD, which may be considered as the basis for extreme gust representation. The element $(1 + cv/d)^{-1/c}$ on the right-hand side of Eq. (1) is known as the generalized Pareto tail.

Using the GPD for extreme gust wind representation is an approach departing from the current practice of assuming the parent extreme wind distributions. The solution ranges of the GPD's shape (or tail-length) parameter c will distinguish the extreme event as either Type I, Type II or Type III distributed [8,9]. The GPD has been used by researchers in generating fastest-mile wind speeds annual series as well as in Monte Carlo simulations [5–7,10].

3. Generalized extreme value distribution

One of the important properties of GPD is that the extreme gust wind variate v in Eq. (1) has, essentially, a generalized extreme value (GEV) distribution. This is true if the occurrences of the variate v, which exceed sufficiently high thresholds, are rare events and the occurrences can be represented by a Poisson process [8]. The CDF of GEV distribution may be expressed as

$$G(v) = \exp\{-[1 + c(v - a)/b]^{-1/c}\} \tag{2}$$

for $c \neq 0$, where a, b and c are the threshold (or location), scale and tail-length (or shape) parameters, respectively. It is noteworthy that the tail-length parameters, c, of the GPD (Eq. (1)) and the GEV (Eq. (2)) are exactly identical [8,9]. From Eq. (2), three types of extreme value distributions for maxima may be realized by examining the range of tail-length parameter [11,12].

For $c = 0$, that is the limit of c approaching zero, Eq. (2) becomes

$$G_{\mathrm{I}}(v) = \exp\{-\exp[-(v-a)/b]\}. \tag{3}$$

For $c > 0$, then $c = 1/q$ and Eq. (2) becomes

$$G_{\mathrm{II}}(v) = \exp\{-[(v-a)/b]^{-q}\}. \tag{4}$$

For $c < 0$, then $c = -1/q$ and Eq. (2) becomes

$$G_{\mathrm{III}}(v) = \exp\{-[(a-v)/b]^{q}\}. \tag{5}$$

Eqs. (3)–(5) are the Type I (Gumbel), Type II (Frechet) and Type III (reverse Weibull) extreme value distributions, respectively. Mathematically, the difference between Types II and III distributions is only a sign conversion.

Since the tail-length parameter c of the three-parameter GEV and the two-parameter GPD are exactly identical, we are using the two-parameter GPD as the diagnostic tool for determining the types of extreme gust wind speed distributions.

The tail-length parameter c and scale parameter d of GPD can be estimated by means of the straightforward method of moments if excessive biased results associated with c and d are not of primary concern. However, we prefer the more accurate threshold method of evaluating c and d. Consider v and w as the realizations of V and W, respectively. We may state that $v = w - u$ (where u is a sufficiently large threshold of w). Consequently, Eq. (1) may be expressed as

$$F(v) = \mathrm{Prob}(V \leqslant v) = 1 - [1 + c(w-u)/d]^{-1/c} \tag{6}$$

for $d > 0, w > u$ and $[1 + c(w-u)/d] > 0$; and $[1 + c(w-u)/d]^{-1/c}$ is the generalized Pareto tail.

Now consider the exceedance conditional mean of V [9,11]

$$E[V|V > 0] = (d + cu)/(1 - c). \tag{7}$$

For $c < 1, u > 0$ and $(d + cu) > 0$.

For a given sample set, the observed mean excess data over the threshold u (as the ordinate) can be plotted against various levels of selected u (as the abscissa). If the GPD assumption is correct, then the cumulative mean exceedance (CME) plot, in a general sense, should follow a straight line. The slope of the straight line $c/(1-c)$ and its intercept $d/(1-c)$ can be easily quantified. Thus, c and d are determined. This is also known as the CME method. Since the tail-length parameter c is known, the solutions of the threshold and scale parameters a and b associated with the Gumbel, Frechet or the reverse Weibull distributions i.e., Eqs. (3), (4) or (5), respectively, can be found in many standard texts.

4. Data preparation

The gust wind speed data used in this study were obtained from the US National Climatic Center database [13]. This database consists of more than 750 weather stations throughout the United States. Of the 750 plus stations, about 525 stations have data ranged from 5 to 45 years (1946–1990).

A minimum record length of 15 years was chosen to allow an adequate amount of wind data to be analyzed in this study. Because of climatic characteristics, a smaller sample may not adequately represent all possible wind patterns. Therefore, stations with less than 15 years of record were removed from the database. As a result, 350 stations remained. However, only 270 out of the 350 stations have anemometer elevation records. For the sake of homogeneity, the Pacific Island stations also were removed. The number of available stations then was reduced to 184. For further homogeneity consideration, stations affected by hurricanes and tornadoes were therefore excluded from the study. We felt that hurricane and tornado winds deserve separate attention. Furthermore, stations with non-continuous records also were excluded. Finally, 143 weather stations in the contiguous United States were selected for the analysis.

For the selected 143 stations, it was necessary to convert all gust wind speeds at all stations to a common elevation. As required in the ASCE Minimum Load Standards [2], all gust wind speed data at the 143 stations were converted to a common 10 m above ground level using the logarithmic law with peak gust effective roughness lengths [14, 15]. The longitudes and latitudes of the 143 stations were entered to a Geographic Information System software [16] to generate Fig. 1.

Fig. 1. The 143 stations in the contiguous United States used in the study.

5. Illustration

The GPDs tail-length and scale parameters, c and d, for the annual extreme gust wind speeds at all 143 stations were quantified by means of the described CME method in Section 3 and presented in Column (7) of Table 1.

It is noteworthy that the selection of an appropriate threshold value reduces the bias since it conforms best with the asymptotic assumption on which the GPD is based; however, because it results in less data, therefore, it will increase the sampling error [5]. On the other hand, excessive lowering of the threshold value would increase the availability of extreme values and it would introduce correlation among the data. This correlation would violate the basic assumptions of the GPD used in this study, which assumes the exceedances of the extreme events to be independently and identically distributed. Since the threshold value is site-dependent, the annual series' median wind speed, V_{med}, was found to provide satisfactory results [5]. The V_{med}, was also chosen to be the threshold value for all the 143 stations used in this study. Obviously, the occurrence of V_{med} is rare in a sense. Therefore, it is reasonable to assume that successive extreme events arrive according to a Poisson process and have independent magnitudes. In addition, we found out that by choosing V_{med} as the threshold value can indeed reduce the nonlinearity of the CME plots. Therefore, the tail-length parameter c values obtained have better accuracy. This finding is generally in agreement with the results obtained by other researchers [17,18]. As indicated in Column (7) of Table 1, the values of parameter c varied from 0.82 to -3.20 for all the 143 stations considered.

Further in Table 1, of the 143 stations studied, only one station (Station #23050-Albuquerque, NM) yielded a positive tail-length value (indicating Type II distribution for that station), three stations (Station # 13729-Elkins, WV; #13733-Lynchburg, VA; and #24127-Salt Lake City, UT) with values approaching zero (i.e., Type I distributions), and the rest were all negative values (i.e., Type III distributions).

The observed extreme gust winds v at all 143 sites were plotted against a reduced variate W calculated for the Type I distribution. The observed data were then fitted graphically by both the Gumbel and reverse Weibull distributions which were converted into reduced variate forms, as illustrated in Figs. 2–4.

As indicated in Column (7) of Table 1, the Type III reverse Weibull distributions are most suitable for delineating the annual extreme gust wind speeds at the 139 stations; therefore, the reverse Weibull distribution is the basic representative probability function for those 139 stations. This result is in agreement with the conclusions suggested by other studies for fastest-mile winds [5,7]. However, a simple statistical analysis revealed the opposite results (Columns (9) and (12) of Table 1). As indicated in Columns (9) and (12) of Table 1, for the great majority of the stations considered, the Type I Gumbel distribution yielded higher accuracy than the Type III distribution for gust winds with greater recurrence intervals. This result is further verified by fitting the wind data at the 139 stations by both Type I and Type III distributions. Few examples are presented in Figs. 2–4.

Table 1
Estimated annual gust wind speeds at 143 stations in contiguous United States

								Reverse Weibull			Gumbel		
	Sta. No. (1)	Sta. Abv. (2)	N (yrs) (3)	Mean (m/s) (4)	SD (m/s) (5)	V_{max} (m/s) (6)	CME C_{med} (7)	V_{RN} (m/s) (8)	R_1 (%) (9)	V_{50} (m/s) (10)	V_{GN} (m/s) (11)	R_2 (%) (12)	V_{50} (m/s) (13)
1	3812	AVL	16	24.40	2.03	28.50	−1.77	25.46	0.107	25.46	27.92	0.020	29.66
2	3813	MCN	18	26.29	3.57	40.37	−0.55	34.59	0.143	35.36	36.71	0.091	40.22
3	3820	AGS	18	25.60	3.32	32.26	−0.76	29.42	0.088	29.69	31.66	0.019	34.21
4	3822	SAV	26	26.53	3.82	37.64	−1.21	29.62	0.213	29.65	34.56	0.082	36.42
5	3860	HTS	16	23.96	3.04	29.03	−2.14	25.19	0.132	25.20	29.24	0.007	31.85
6	3870	GSP	15	26.13	4.00	32.93	−1.04	29.76	0.096	29.91	32.89	0.001	36.51
7	3872	BKW	16	24.78	2.70	30.29	−1.47	26.55	0.123	26.56	29.47	0.027	31.78
8	3927	DFW	32	28.14	4.10	38.17	−0.58	33.98	0.110	34.20	37.44	0.019	38.78
9	3940	JAN	18	26.67	2.91	31.72	−0.25	31.51	0.007	32.71	31.98	0.008	34.21
10	3945	COL	21	30.44	4.71	44.63	−0.58	36.84	0.174	37.41	39.59	0.113	42.65
11	3947	MCI	18	28.18	4.53	37.64	−0.30	35.52	0.056	37.16	36.44	0.032	39.92
12	4725	BGM	16	26.52	2.72	32.23	−1.13	28.82	0.106	28.88	31.24	0.031	33.57
13	12921	SAT	19	26.36	3.90	35.59	−1.46	28.94	0.187	28.96	33.64	0.055	36.48
14	13722	RDU	15	24.66	2.63	29.03	−1.13	26.87	0.074	26.95	29.09	0.002	31.47
15	13723	GSO	16	25.54	6.14	45.70	−1.80	28.69	0.372	28.70	36.20	0.208	41.46
16	13729	EKN	15	24.23	2.67	29.57	−0.06	28.72	0.029	30.86	28.73	0.028	31.15
17	13733	LYH	16	23.98	3.36	33.55	−0.02	29.81	0.112	32.56	29.82	0.111	32.70
18	13739	PHL	17	26.69	3.27	32.26	−1.00	29.78	0.077	29.90	32.52	0.008	35.17
19	13741	ROA	16	27.87	4.50	36.33	−0.42	34.42	0.053	35.70	35.68	0.018	39.54
20	13743	DCA	38	28.03	4.36	45.40	−1.03	32.18	0.291	32.19	38.49	0.152	39.35
21	13748	ILM	19	27.38	4.42	35.00	−0.83	32.21	0.080	32.48	35.62	0.018	38.83
22	13781	WIL	16	28.36	3.16	33.33	−0.68	39.20	0.176	32.60	33.85	0.016	36.56
23	13865	MEI	20	24.56	3.70	32.26	−0.57	29.61	0.082	30.12	31.62	0.020	34.16
24	13866	CRW	16	26.02	3.68	34.06	−0.76	30.21	0.113	30.56	32.41	0.048	35.57
25	13874	ATL	21	28.01	4.24	36.02	−1.55	30.63	0.150	30.64	36.24	0.006	39.00
26	13877	BRI	18	26.55	4.54	40.86	−1.36	29.77	0.271	29.81	34.84	0.147	38.32
27	13880	CHS	22	26.61	2.94	33.33	−1.84	28.08	0.157	28.09	32.44	0.027	34.25

28	13882	CHA	19	25.02	4.75	34.95	−1.24	28.73	0.178	28.79	33.89	0.030	37.34
29	13891	TYS	18	25.50	3.29	31.99	−2.11	26.86	0.160	26.86	31.52	0.015	34.04
30	13893	MEM	15	28.51	3.75	37.33	−1.09	31.79	0.148	31.91	34.84	0.066	38.24
31	13895	MGM	15	24.86	3.81	30.81	−0.51	30.01	0.026	30.89	31.29	0.016	34.74
32	13897	BNA	21	26.68	4.82	43.24	−0.29	34.85	0.194	36.33	36.05	0.166	39.19
33	13957	SHV	38	27.74	4.47	40.86	−0.67	33.67	0.176	33.77	38.44	0.059	39.32
34	13962	ABI	18	28.08	3.86	36.41	−0.87	32.14	0.117	32.36	35.13	0.035	38.09
35	13966	SPS	27	29.33	3.90	37.48	−0.60	34.70	0.074	34.99	37.64	0.004	39.43
36	13967	OKC	21	29.98	4.30	43.01	−0.85	34.65	0.194	34.85	38.34	0.109	41.14
37	13968	TUL	21	26.99	3.52	31.87	−1.49	29.26	0.082	29.27	33.83	0.062	36.12
38	13970	BTR	19	23.37	3.23	33.87	−1.30	25.78	0.239	25.81	29.40	0.132	31.75
39	13985	DDC	19	29.34	3.01	35.00	−1.19	31.78	0.092	31.83	34.95	0.001	37.14
40	13994	STL	21	27.70	4.13	38.72	−0.48	33.79	0.127	34.50	35.72	0.077	38.41
41	13995	SGF	19	25.35	2.80	31.72	−3.09	25.96	0.182	25.96	30.57	0.036	32.60
42	13996	TOP	21	30.01	4.19	38.17	−0.73	35.02	0.082	35.33	38.15	0.001	40.88
43	14732	LGA	16	29.27	2.97	35.49	−0.86	32.39	0.087	32.60	34.43	0.030	36.97
44	14734	EWR	17	28.97	3.42	38.71	−0.80	32.76	0.154	33.02	35.06	0.094	37.83
45	14735	ALB	17	27.17	2.75	31.18	−0.93	29.92	0.041	30.05	32.07	0.028	34.30
46	14737	ABE	16	30.81	4.51	43.01	−0.67	36.30	0.156	36.88	38.65	0.102	42.51
47	14739	BOS	26	29.70	3.13	36.79	−1.05	32.57	0.115	32.62	36.28	0.014	37.80
48	14740	BDL	15	28.13	5.40	39.64	−1.23	32.38	0.183	32.48	37.25	0.060	42.15
49	14742	BTV	16	24.60	3.38	33.33	−0.37	29.70	0.109	30.84	30.46	0.086	33.35
50	14745	CON	16	22.46	2.06	25.96	−2.09	23.33	0.101	23.33	26.04	0.003	27.81
51	14777	AVP	16	25.44	2.37	30.52	−1.50	26.95	0.117	26.96	29.55	0.032	31.58
52	14820	CLE	19	29.43	3.87	38.17	−0.42	35.26	0.076	36.16	36.65	0.040	39.46
53	14821	CMH	22	27.84	4.31	36.56	−0.64	33.41	0.086	33.80	36.36	0.006	39.01
54	14826	FNT	15	27.48	4.07	33.73	−0.41	33.37	0.011	34.65	34.35	0.018	38.04
55	14827	FWA	17	28.31	1.65	32.26	−0.15	31.14	0.035	32.08	31.24	0.032	32.57
56	14836	LAN	19	27.53	3.07	32.80	−0.43	32.15	0.020	32.86	33.27	0.014	35.50
57	14837	MSN	19	28.92	5.70	47.11	−1.29	33.22	0.295	33.28	39.55	0.160	43.69
58	14839	MKE	17	29.95	3.47	37.64	−0.10	36.03	0.043	38.31	36.14	0.040	38.97
59	14842	PIA	16	28.60	4.40	39.79	−0.79	33.48	0.159	33.85	36.24	0.089	40.02
60	14847	CIU	16	26.51	2.56	33.33	−2.27	27.46	0.176	27.46	30.95	0.071	33.15
61	14852	YNG	15	28.42	3.99	36.56	−0.51	33.85	0.074	34.79	35.15	0.039	38.76
62	14860	ERI	15	29.43	3.29	35.56	−0.91	32.73	0.080	32.93	34.98	0.016	37.97
63	14891	MFD	15	29.14	3.37	37.64	−1.85	30.81	0.181	30.81	34.82	0.075	37.87

Table 1 (*Continued*)

								Reverse Weibull			Gumbel		
	Sta. No. (1)	Sta. Abv. (2)	N (yrs) (3)	Mean (m/s) (4)	SD (m/s) (5)	V_{max} (m/s) (6)	CME C_{med} (7)	V_{RN} (m/s) (8)	R_1 (%) (9)	V_{50} (m/s) (10)	V_{GN} (m/s) (11)	R_2 (%) (12)	V_{50} (m/s) (13)
64	14898	GRB	16	26.66	4.83	37.64	−1.00	31.20	0.171	31.40	35.04	0.069	39.18
65	14913	DLH	24	26.52	3.50	33.19	−0.90	30.18	0.091	30.28	33.68	0.015	35.60
66	14914	FAR	21	25.12	3.14	33.15	−1.76	26.78	0.192	26.79	31.22	0.058	33.27
67	14918	INL	16	25.44	2.86	29.57	−1.81	26.90	0.090	26.90	30.40	0.028	32.85
68	14922	MSP	18	26.85	2.80	31.91	−0.75	30.09	0.057	30.32	31.96	0.001	34.11
69	14923	MLI	18	30.32	3.54	36.91	−1.05	33.55	0.091	33.65	36.79	0.003	39.50
70	14925	RST	19	32.10	3.82	40.48	−1.19	35.21	0.130	35.27	39.22	0.031	41.99
71	14933	DSM	21	29.01	3.11	35.49	−0.38	33.93	0.044	34.65	35.04	0.013	37.06
72	14936	HUR	16	29.84	3.16	35.49	−0.55	34.04	0.041	34.64	35.33	0.004	38.03
73	14939	LNK	18	28.79	4.12	39.25	−0.60	34.18	0.129	34.75	36.32	0.075	39.49
74	14943	SUX	19	29.75	2.90	34.93	−2.02	31.02	0.112	31.02	35.15	0.007	37.26
75	14944	FSD	19	30.14	3.94	38.72	−1.65	32.39	0.163	32.40	37.49	0.032	40.36
76	23034	SJT	19	31.49	4.60	43.55	−0.53	37.92	0.129	38.69	40.08	0.080	43.42
77	23042	LBB	18	30.64	4.21	39.02	−1.74	32.90	0.157	32.91	38.34	0.018	41.57
78	23044	ELP	21	28.41	4.76	39.25	−1.72	31.00	0.210	31.01	37.66	0.041	40.75
79	23047	AMA	21	30.86	2.87	37.18	−1.71	32.43	0.128	32.44	36.43	0.020	38.30
80	23050	ABQ	18	29.83	1.58	33.46	0.82	32.02	0.043	32.30	32.72	0.022	33.93
81	23061	ALS	16	27.11	2.93	32.18	−0.49	31.19	0.031	31.86	32.20	0.001	34.72
82	23062	DEN	35	25.54	1.96	29.34	−1.63	26.68	0.091	26.68	30.10	0.026	30.61
83	23065	GLD	16	31.40	2.60	36.02	−1.36	33.24	0.077	33.27	35.91	0.003	38.13
84	23066	GJT	16	29.06	3.53	36.26	−1.05	32.26	0.110	32.38	35.19	0.029	38.22
85	23154	ELY	15	27.42	1.60	30.11	−1.40	28.52	0.053	28.54	30.12	0.000	31.57
86	23155	BFL	20	21.23	3.00	26.88	−1.94	22.63	0.158	22.63	26.95	0.003	29.02
87	23157	BIH	16	27.82	3.41	32.90	−2.32	29.05	0.117	29.05	33.75	0.026	36.67
88	23160	TUS	21	27.80	4.13	37.64	−0.36	34.46	0.084	35.49	35.83	0.048	38.52
89	23169	LAS	20	30.35	4.83	41.94	−0.86	35.50	0.153	35.73	39.56	0.057	42.88
90	23174	LAX	40	21.85	2.85	30.34	−1.41	23.83	0.215	23.83	28.79	0.051	29.24
91	23185	RNO	21	31.65	4.16	40.48	−1.19	35.24	0.130	35.31	39.72	0.019	42.42

92	23188	SAN	21	20.46	3.24	30.11	−0.48	25.22	0.162	25.77	26.75	0.111	28.86
93	23234	SFO	40	28.62	5.35	47.30	−0.84	34.67	0.267	34.72	41.66	0.119	42.50
94	24011	BIS	21	27.57	3.38	36.72	−0.48	32.52	0.114	33.09	34.13	0.071	36.33
95	24029	SHR	16	29.67	1.99	33.33	−1.05	31.46	0.056	31.53	33.12	0.006	34.82
96	24033	BIL	21	28.88	2.75	33.75	−2.43	29.80	0.117	29.80	34.21	0.014	36.00
97	24089	CPR	15	29.82	1.77	32.26	−3.20	30.18	0.065	30.18	32.81	0.017	34.41
98	24090	RAP	17	31.71	2.45	38.55	−0.52	35.08	0.090	35.56	36.08	0.064	38.07
99	24127	SLC	36	29.29	4.11	44.09	−0.02	31.90	0.276	31.91	38.79	0.120	39.95
100	24128	WIN	17	27.51	4.57	39.79	−0.53	33.78	0.151	34.67	35.66	0.104	39.37
101	24131	BOI	21	25.60	3.10	33.33	−0.94	28.70	0.139	28.80	31.62	0.052	33.63
102	24144	HLN	17	27.55	3.01	37.64	−0.34	32.24	0.143	33.27	32.91	0.126	35.35
103	24146	FCA	17	25.11	3.31	32.26	−0.92	28.43	0.119	28.60	31.02	0.039	33.70
104	24149	LWS	16	25.57	2.78	33.33	−0.77	28.71	0.139	28.97	30.39	0.088	32.77
105	24153	MSO	17	26.14	3.19	34.06	−0.99	29.18	0.143	29.29	32.09	0.058	34.41
106	24155	PEN	21	28.29	3.25	35.49	−1.52	30.34	0.145	30.35	34.60	0.025	36.71
107	24156	PIH	21	29.39	3.59	38.17	−0.36	35.20	0.078	36.10	36.37	0.047	38.71
108	24157	GEG	21	25.88	2.32	31.18	−1.48	27.39	0.122	27.40	30.39	0.025	31.90
109	24221	EUG	19	23.97	3.07	30.65	−0.36	28.83	0.059	29.71	29.70	0.031	31.93
110	24225	MFR	21	23.09	2.87	29.03	−0.86	26.18	0.098	26.31	28.68	0.012	30.54
111	24227	OLY	16	22.55	3.28	30.11	−0.81	26.12	0.133	26.38	28.24	0.062	31.04
112	24229	PDX	32	26.96	5.10	40.60	−0.70	33.46	0.176	33.63	38.52	0.051	40.19
113	24232	SAE	19	24.53	3.49	33.33	−0.78	28.49	0.145	28.73	31.04	0.069	33.57
114	24233	SEA	18	22.73	3.06	29.86	−0.52	26.99	0.096	27.55	28.33	0.051	30.68
115	24243	YKM	21	25.91	2.90	32.26	−0.63	29.69	0.080	29.99	31.54	0.022	33.43
116	93193	FAT	21	20.01	2.62	25.81	−0.60	23.50	0.089	23.80	25.09	0.028	26.79
117	93730	ATC	32	28.46	3.97	37.64	−0.57	34.16	0.092	34.38	37.45	0.005	38.76
118	93738	IAD	16	27.72	3.88	36.56	−0.59	32.73	0.105	33.38	34.46	0.057	37.79
119	93805	TLH	19	24.48	6.17	37.97	−0.34	34.38	0.095	36.25	35.99	0.052	40.48
120	93814	CVG	17	28.78	4.18	38.71	−0.90	33.05	0.146	33.27	36.23	0.064	39.63
121	93817	EVV	17	27.17	3.95	35.49	−1.41	29.86	0.158	29.89	34.20	0.036	37.40
122	93819	IND	23	31.00	8.13	55.92	−0.37	44.25	0.209	45.96	47.36	0.153	52.08
123	93820	LEX	18	25.35	3.25	36.12	−1.10	28.18	0.220	28.25	31.29	0.134	33.78
124	93821	SDF	20	28.25	5.39	39.25	−1.04	33.22	0.154	33.36	38.52	0.018	42.23
125	93822	SPI	19	27.11	3.18	35.49	−3.06	27.81	0.216	27.81	33.04	0.069	35.35
126	93842	CSG	18	27.11	6.02	44.64	−1.07	32.48	0.272	32.63	38.09	0.147	42.70
127	94008	GGW	21	29.65	3.89	40.32	−0.10	36.98	0.083	38.97	37.21	0.077	39.74

Table 1 (*Continued*)

	Sta. No. (1)	Sta. Abv. (2)	N (yrs) (3)	Mean (m/s) (4)	SD (m/s) (5)	V_{max} (m/s) (6)	CME C_{med} (7)	Reverse Weibull V_{RN} (m/s) (8)	Reverse Weibull R_1 (%) (9)	Reverse Weibull V_{50} (m/s) (10)	Gumbel V_{GN} (m/s) (11)	Gumbel R_2 (%) (12)	Gumbel V_{50} (m/s) (13)
128	94014	ISN	16	27.31	2.70	32.77	−0.75	30.39	0.072	30.66	32.00	0.024	34.31
129	94224	AST	20	31.67	3.54	37.10	−1.36	34.20	0.078	34.22	38.41	0.035	40.85
130	94702	BDR	15	26.29	3.16	31.93	−0.90	29.48	0.077	29.67	31.62	0.010	34.48
131	94746	WOR	21	28.82	2.51	31.99	−0.80	31.65	0.011	31.79	33.69	0.053	35.33
132	94789	JFK	15	27.71	2.58	33.33	−2.04	28.82	0.135	28.83	32.06	0.038	34.39
133	94814	HTL	16	23.49	2.33	26.81	−1.78	24.70	0.079	24.70	26.31	0.019	29.53
134	94822	RFD	19	28.21	3.88	37.64	−1.37	30.96	0.177	30.99	35.45	0.058	38.27
135	94830	TOL	16	26.54	2.73	33.74	−0.95	29.20	0.135	29.33	31.27	0.073	33.61
136	94846	ORD	24	27.22	3.99	35.49	−0.34	33.91	0.044	34.76	35.37	0.003	37.55
137	94847	DTW	24	25.49	3.33	37.95	−1.43	27.75	0.269	27.76	32.31	0.149	34.14
138	94849	APN	16	23.63	2.45	27.73	−1.86	24.83	0.104	24.83	27.87	0.005	29.97
139	94860	GRR	21	28.09	3.66	36.56	−0.98	31.65	0.134	31.75	35.19	0.037	37.57
140	12912	VCT	17	23.22	2.399	28.61	−0.43	24.17	0.155	24.17	27.49	0.039	29.44
141	24143	GTF	17	27.30	3.22	34.14	−0.51	31.75	0.070	32.40	33.03	0.033	35.63
142	93721	BWI	16	27.22	3.37	36.02	−0.72	31.16	0.135	31.53	33.06	0.082	35.95
143	93729	HSE	15	27.84	4.10	39.23	−1.33	30.81	0.214	30.87	34.75	0.114	38.47

N, V_{max}: Sample size, maximum observed gust wind speed with specified N-yr data.
Mean, SD: Mean and standard deviation of observed gust wind speed with specified N-yr data.
Col. 1: US National Weather Service station number.
Col. 7: C_{med}: Estimated c based on CME method at median gust wind speed with specified N-yr data.
Col. 8,10: V_{RN} and V_{50} are estimated N- and 50-yr gust wind speed based on Reverse Weibull distribution, respectively.
Col. 9: $R_1 = [\text{Col. (6)–Col. (8)}]/\text{Col. (6)}$.
Col. 11, 13: V_{GN} and V_{50} are estimated N- and 50-yr gust wind speed based on Gumbel distribution, respectively.
Col. 12: $R_2 = [\text{Col. (6)–Col. (11)}]/\text{Col. (6)}$.

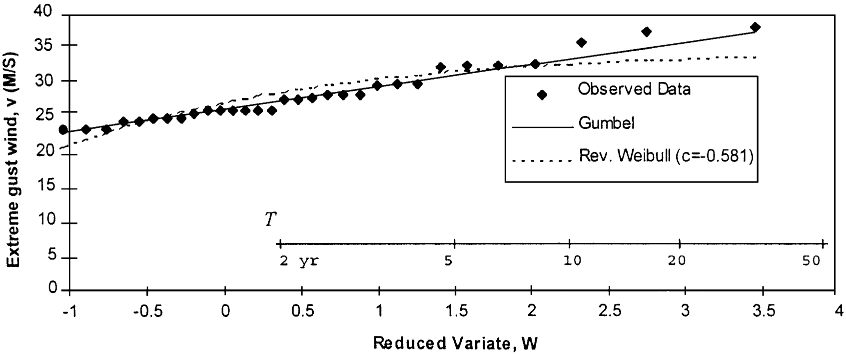

Fig. 2. Gumbel and reverse Weibull distributions applied to the annual extreme gust wind speeds (1954–1985) at Dallas/Fort Worth, Texas station.

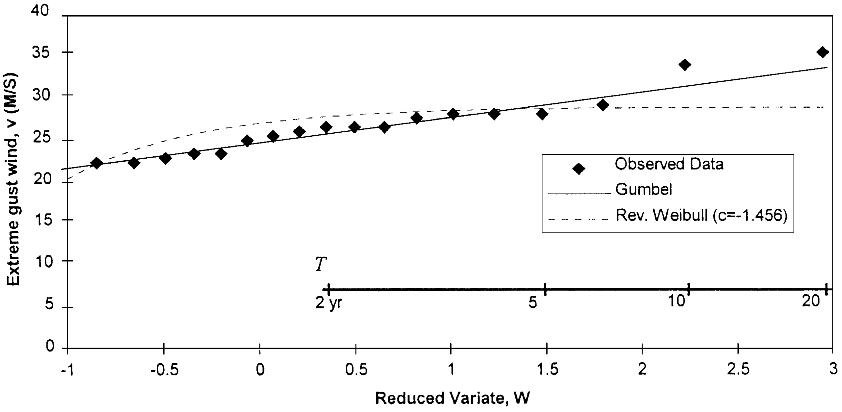

Fig. 3. Gumbel and reverse Weibull distributions applied to the annual extreme gust wind speeds (1970–1988) at San Antonio, Texas station.

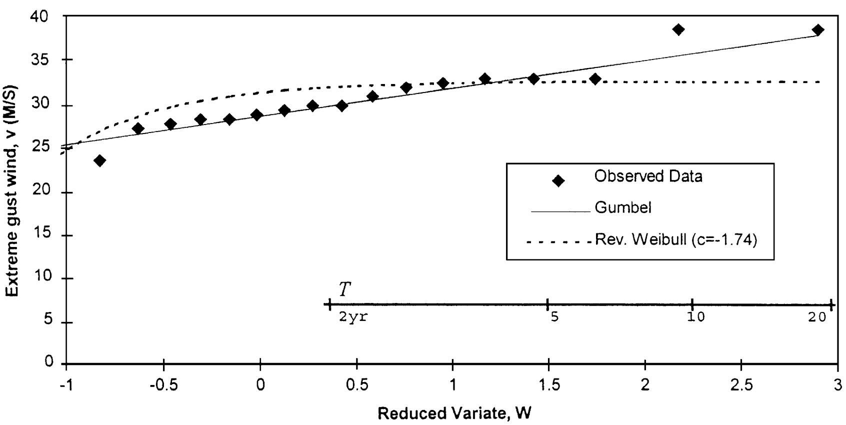

Fig. 4. Gumbel and reverse Weibull distributions applied to the annual extreme gust wind speeds (1973–1990) at Lubbock, Texas station.

6. Conclusions

Preliminary annual extreme gust wind speed distributions at the selected 143 stations in the contiguous United States were investigated. The CME method based calculation indicated that the annual extreme gust wind speeds at 139 out of the 143 stations are reverse Weibull function distributed (i.e., Type III). However, the results obtained from a simple statistical analysis and a graphic curve fitting approach revealed that instead, the Type I Gumbel extreme value function is a better model for the great majority of the stations studied.

With the contradictory results obtained from the CME and graphic curve fitting methods, a number of questions could be raised. Could it be that the sample sizes at the stations are too small, since the length of the annual series varied from 15 to 40 years? Could it be that the samples contained mixed populations? For example, gust wind records may be developed from different storm types [18]. The linear results obtained from our CME plots suggest that the annual extreme gust winds are homogeneous sets. Nevertheless, the homogeneity of the data sets should be further examined?

It is understandable that the probabilistic model should reflect the physical limitation of gust wind. Type I Gumbel distribution has an infinite upper tail that may be unrealistic to delineate the physically bounded nature of the peak gust wind. For a greater recurrence interval, wind speed predicted by the Gumbel distribution may be unrealistically high. However, only 50-year recurrence intervals were used in this study. For the limited length of records available at the selected 143 stations (maximum 40 years of data), Type I extreme value function indeed offers better accuracy in modeling the annual extreme gust wind speeds at the 139 stations studied.

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