Extreme Wind Speed Region in New England and New York

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Abstract

The extreme wind speed region for New York and New England is described in this paper. The wind speed data from the National Climatic Data Center, National Institute of Standards and Technology, and the US National Meteorological Service are analyzed using software from NIST to develop the probability distribution functions. Contours were drawn for extreme wind speeds and their corresponding mean recurrence interval in a map and data for the New York and New England region. Gumbel Type I distribution model is used to predict probability of any unknown wind speed exceeding observed wind speeds. Recommendations are made to use these wind speeds in design of transmission line systems.

1. Introduction

Present National Grid US Transmission (UST) wind speed design standards follow the basic wind speeds denoted by the National Electrical Safety Code (NESC). Wind speed design requirements are most extreme along the sea coast lines and gradually taper off at points more inland. The minimum basic wind speed is 90 mph on a 3 second gust interval (See Figure 1). The area highlighted in red is denoted as a "Special Wind Region" by the NESC. The NESC provides no guidance on wind speeds in this area other than to recommend regional wind studies be performed as part of design.

Some limited wind speed studies have been performed at National Grid by AWS Truewind in 2006 and WSI Corporation 2007, but there has not been a comprehensive study performed to assess the special wind region. Additionally, the WSI study suggested that wind speeds in excess of 90 mph are possible in some areas in New York. Given the unknown status of the NESC special wind region, and the results from other areas, this study was expanded to assess the wind design for the entire National Grid UST territory.

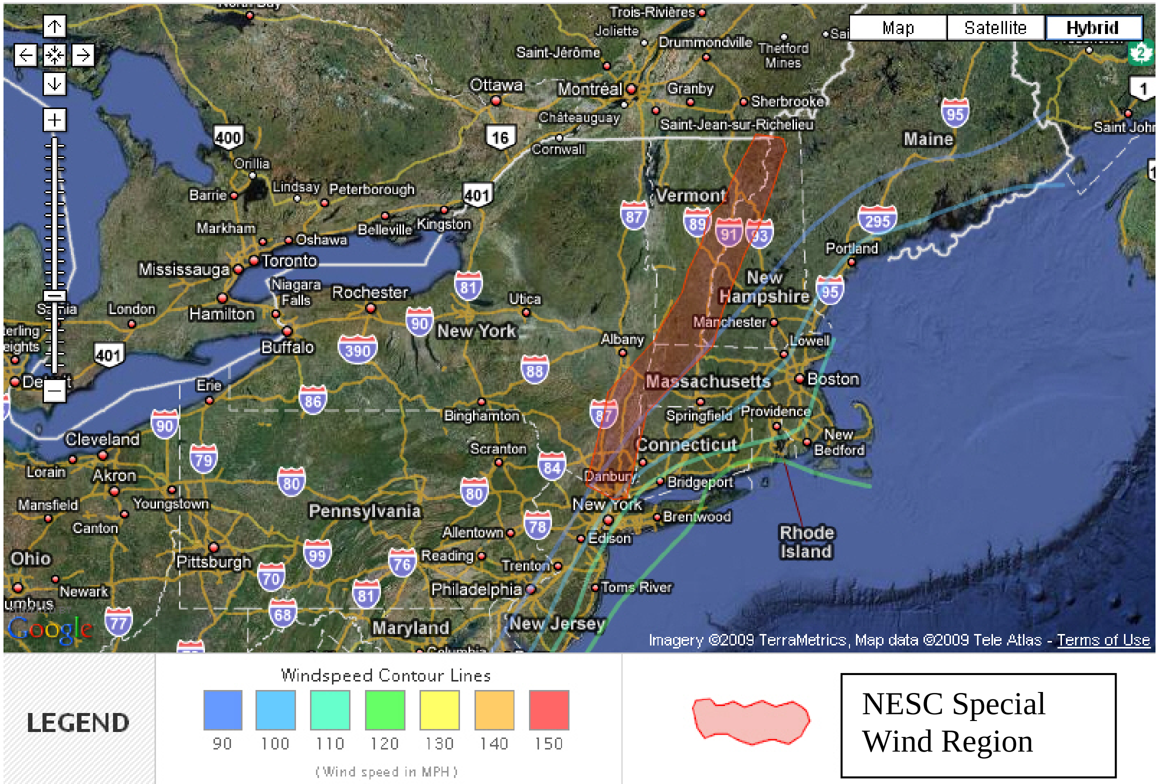

Figure 1. NESC Special wind region and coastal wind contours for New York and New England (map by TerraMetrics).

2. Wind Speed Design History

Wind speeds can vary greatly depending upon terrain roughness and geographic features. The American Society of Civil Engineers (ASCE, 1991a) defines 4 major terrain roughness exposure categories. Exposure B is classified as urban and suburban areas and wooded areas. Exposure C is flat open country such as farms and grasslands. This type of terrain is typical of airports where most wind speed data is captured and is the exposure that the NESC basic wind speed is based upon. Exposure D is unobstructed coastlines and open sea. Exposure A is city landscape that is not applicable for transmission line design. It is allowable by ASCE to modify basic wind speeds by using a terrain factor, Zv. For example, if the NESC basic wind speed of 90 mph is given for a transmission tower 70 feet in height located in a suburban setting (Exposure B), the design speed can be adjusted to 90 x 0.82 = 73.8 mph (See Table 1).

Table 1. ACSE terrain factors. (ASCE, 1991b)

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TABLE 2.4-1. Terrain Factor, Z_v

Height above ground level, z (ft) (1)	Exposure B (2)	Exposure C (3)	Exposure D (4)
0–33	0.72	1.00	1.18
40	0.75	1.03	1.21
50	0.79	1.06	1.23
60	0.82	1.09	1.26
70	0.85	1.11	1.28
80	0.88	1.14	1.29
90	0.91	1.16	1.31
100	0.93	1.17	1.32
120	0.96	1.20	1.35
140	0.99	1.23	1.37
160	1.02	1.26	1.39
180	1.05	1.28	1.40
200	1.08	1.30	1.42

Wind speeds can also be affected by local topography (ASCE, 1991c). Increased wind speeds can occur due to funneling affects and wind flows through mountain passes. Wind blowing normal to mountains can see velocity increases on both the windward and leeward faces. Wind flows over mountains can create higher velocities in valley regions sometimes at locations several miles from the mountain ridge.

The NESC underwent a major change in the wind speed design requirements in 2002. Prior to 2002, the NESC based basic wind speed criteria on fastest mile wind (the amount of time it takes for 1 mile of wind to pass by an anemometer) with a 50 year mean return period. Special wind regions were also designated along the southeastern coast of Lake Erie and from southeastern New York extending north easterly through western Massachusetts and the Vermont – New Hampshire borders (See Figure 2).

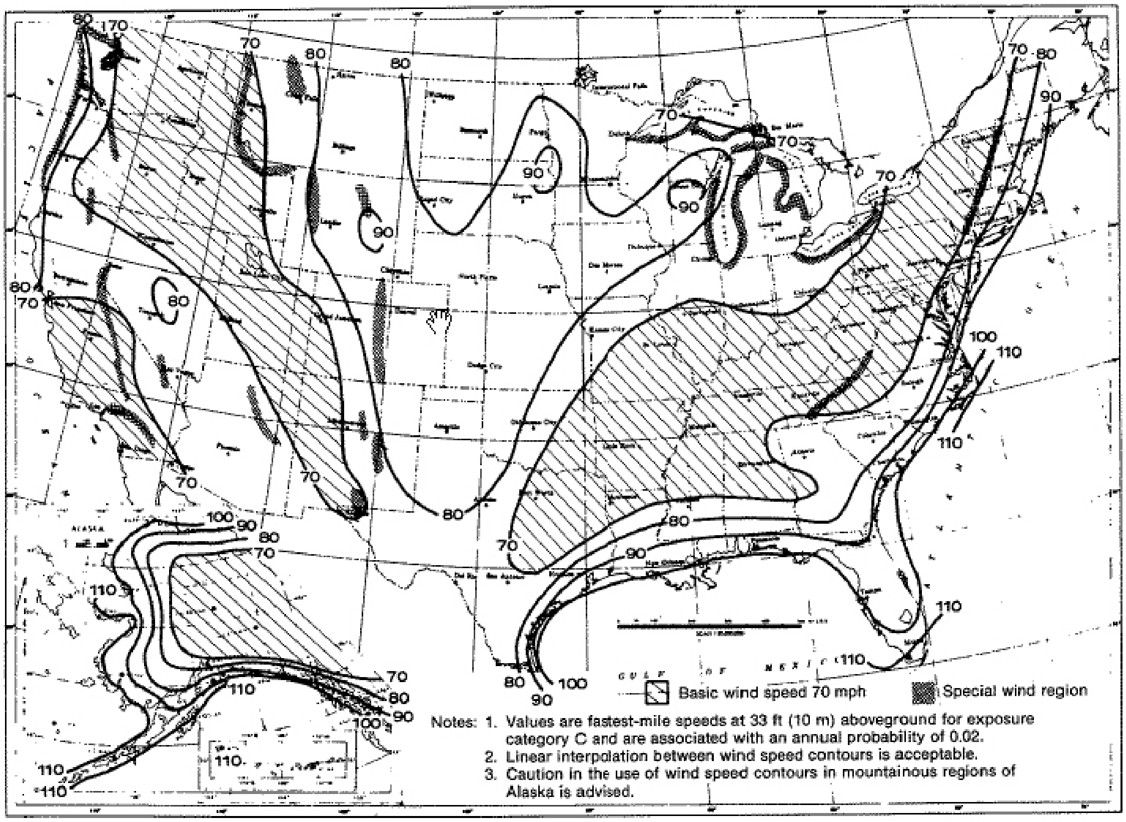


Figure 2. Basic wind speed design chart from NESC 1997. Special wind regions are dentoed by the darkened areas (NESC 1997).

In 2002, the NESC changed the basic wind speed design criteria from fastest mile to 3-second gust interval. Since the velocity of the 3-second gust is greater than the fastest mile wind, the basic wind speed design requirements for all locations were increased by roughly 20 mph. However, the introduction of a gust response factor somewhat compensates for this increase. The other notable change was the elimination of the special wind region on the southwest coast of Lake Erie and the widening of the special wind region in the north east (See Figure 3).

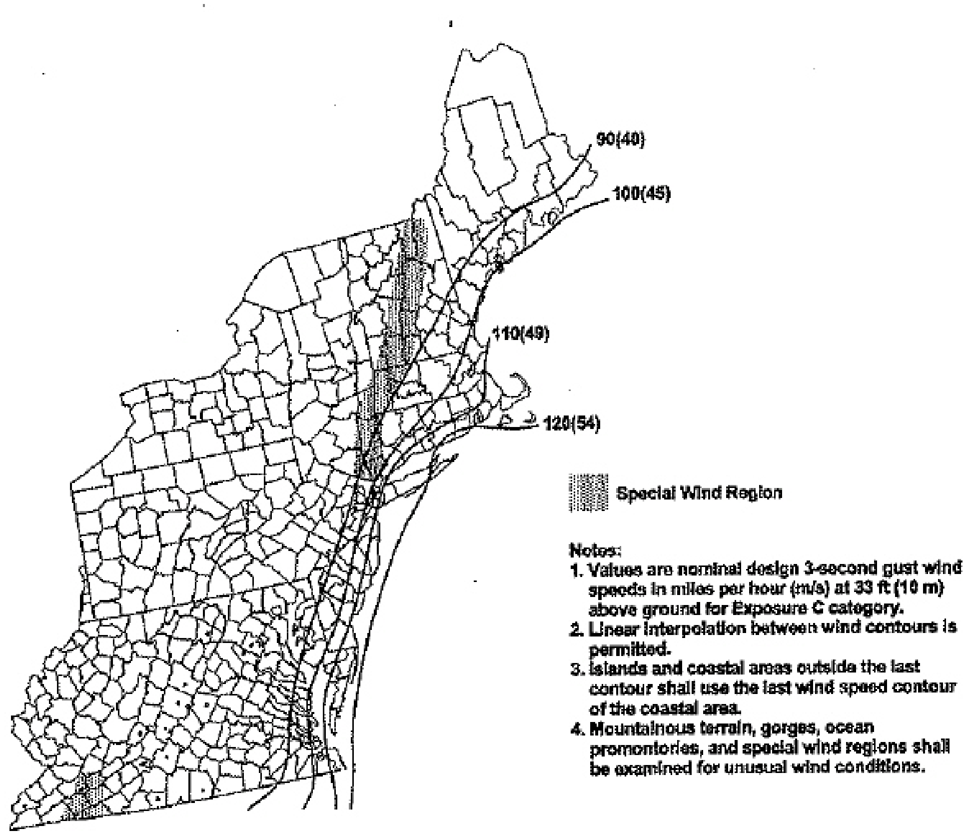


Figure 3. Basic wind speed design chart from NESC 2002 and NESC 2007 (NESC 2007). Note the elimination of the special wind region along the southwest coast of Lake Erie and the widening of the special wind region in the northeast as compared to NESC 1997, Figure 2.

3. Extreme Wind Data in New York and New England

In order to evaluate extreme wind speeds in the UST territory, wind data from weather stations had to be gathered and analyzed statistically. Weather station data was selected following the guidelines of ASCE Standard 7-88 (ASCE, 1991) which sets forth the following criteria:

1. Acceptable extreme-value statistical analysis procedures have been employed in reducing the data.
2. Consideration is given to the length of record, averaging time, anemometer height, data quality, and terrain exposure.
3. The basic wind speed used is not less than 90 mph.

The extreme-value statistical analysis procedure used was Extreme Type I Gumbel distribution method. ASCE has stated that this is a practice well accepted by other investigators including Simiu et al. The procedure determines the probability density and probability distribution functions where Probability P[V(t) < or = X] for any wind velocity V(t) less than or equal to a specified value X, for an averaging time, t. The Return Period R of this velocity V(t), being exceeded by X, is determined from 1/[1-P(v)]. This defines the Mean Recurrence Interval R of any wind velocity V(t) being exceeded by a value X, or equal to it. X is any value of wind speed, greater than or equal to V(t). The resulting output from this model was verified by mathematical equations developed by Simiu et al (2). The output desired from the NIST model is a 3-second gust interval at a 50 year return period which is consistent with the NESC requirements.

Data was gathered from the National Climatic Data Center (NCDC, 2008) Global Summary of the Day database. A total of 53 weather stations spread throughout the UST service territory were selected. At least 14 years of weather station wind data was used. All stations were consistent in the data provided. Wind speeds were in terms of knots at hourly, 10 minute, and 5 second averaging times. The 10 minute average was determined to be the most robust data and is also a World Meteorological Organization (WMO) standard, so this was the data used for analysis. All stations used a standard WMO anemometer height of 33 ft, and all terrain at station locations was Exposure C, flat open country. The wind speeds entered into the Extreme Type I Gumbel model had to be in terms the fastest speed in miles per hour recorded for each year over a 3-second averaging time. To convert the wind speeds from 10 minute to 3 second averaging times, the wind data was multiplied by a factor of 1.43 as determined by the chart developed by Durst (Simiu et al, 1978) and presented by Simiu and Scanlan (2), shown in Appendix A.

Because weather is extreme at the Mount Washington station in New Hampshire, it was left out of the analysis. (The 50 year, 3 second gust winds from the Mount Washington, N.H, and observatory was calculated at 166.1 mph.)

4. Statistical Data Analysis

The results of the Extreme Gumbel Type I distribution model for each weather station examined are shown in Table 2.

Table 2. Weather station locations and final wind speed results.

Station Call Sign	Station Name	State	Latitude	Longitude	Elevation, meters	Data Points, years	Extreme Wind Speed, 50 Yr 3-sec Gust, mph
KBDL	HARTFORD BRADLEY INTL AP	CT	41.938º N	72.683º W	54.60	64	83.7
KHVN	NEW HAVEN TWEED AIRPORT	CT	41.264º N	72.887º W	0.40	53	91.3
KHYA	BARNSTABLE MUNI BOA	MA	41.667º N	70.267º W	1.70	36	92
KBED	BEDFORD HANSCOM FIELD	MA	42.47º N	71.289º W	4.10	37	82.5
KBOS	BOSTON LOGAN INT'L ARPT	MA	42.361º N	71.011º W	0.90	66	94
BUZM3	BUZZARDS BAY (Buoy Station)	MA	41.383º N	71.033º W	1.70	25	130.6
KCQX	CHATHAM MUNI ARPT	MA	41.683º N	70º W	1.90	31	95.8
KCEF	CHICOPEE FALLS WESTO	MA	42.198º N	72.534º W	7.50	65	77.3
KMVY	MARTHAS VINEYARD	MA	41.393º N	70.615º W	2.10	36	90.2
KACK	NANTUCKET MEMORIAL	MA	41.25º N	70.067º W	1.40	60	108.3
KEWB	NEW BEDFORD RGNL	MA	41.667º N	70.95º W	2.50	35	83.1
KFMH	OTIS ANGB	MA	41.65º N	70.517º W	4.00	57	91.2
KTAN	TAUNTON MUNI ARPT	MA	41.867º N	71.017º W	1.30	38	95.7
KBAF	WESTFIELD BARNES MUNI AP	MA	42.158º N	72.716º W	82.60	35	95.2

KORH	WORCESTER MUNICIPAL ARPT	MA	42.267º N	71.876º W	31.00	60	86.8
KAUG	AUGUSTA AIRPORT	ME	44.321º N	69.797º W	11.00	43	93.9
KPWM	PORTLAND INTL JETPORT	ME	43.642º N	70.304º W	1.90	61	77.9
KRUM	RUMFORD	ME	44.533º N	70.533º W	20.50	27	79.7
KCON	CONCORD MUNICIPAL ARPT	NH	43.195º N	71.501º W	10.60	61	77.5
KEEN	DILLANT HOPKINS	NH	42.9º N	72.267º W	15.30	35	62.6
KMHT	MANCHESTER AIRPORT	NH	42.933º N	71.438º W	7.10	47	86.9
KMWN	MOUNT WASHINGTON	NH	44.267º N	71.3º W	191.00	36	166.1
KPSM	PEASE INTL TRADEPOR	NH	43.083º N	70.817º W	3.10	53	70.5
KSLK	ADIRONDACK RGNL	NY	44.385º N	74.207º W	50.70	36	86
KALB	ALBANY COUNTY AP	NY	42.748º N	73.803º W	89.00	56	78.2
KBGM	BINGHAMTON BROOME COUNTY ARPT	NY	42.208º N	75.981º W	49.90	61	76.7
KBUF	BUFFALO BUFFALO ARPT	NY	42.941º N	78.736º W	21.50	65	94.9
DBLN6	DUNKIRK (Buoy Station)	NY	42.483º N	79.35º W	19.70	24	137.3
KDKK	DUNKIRK CHAUTAUQUA CO AP	NY	42.493º N	79.272º W	21.10	16	100.3
KELM	ELMIRA AIRPORT	NY	42.159º N	76.892º W	29.10	42	81.3
KGTB	FORT DRUM/WHEELER-S	NY	44.05º N	75.733º W	20.70	50	86.1
KRME	GRIFFISS AFB	NY	43.233º N	75.4º W	158.20	57	72.5
KJHW	JAMESTOWN (AWOS)	NY	42.15º N	79.267º W	52.50	33	95
KMSS	MASSENA AP	NY	44.936º N	74.846º W	6.50	60	88.9
K13G	NIAGARA (CGS)	NY	43.267º N	79.067º W	82.00	20	93.7
KIAG	NIAGARA FALLS AF	NY	43.107º N	78.945º W	17.90	50	83.3
KOGS	OGDENSBURG INTL	NY	44.683º N	75.467º W	9.10	25	91.2
K28G	OSWEGO (CGS) (Buoy Station)	NY	43.467º N	76.517º W	78.00	20	113.7
PBG	PLATTSBURGH AFB	NY	44.65º N	73.467º W	7.20	40	64.4
KPOU	POUGHKEEPSIE	NY	41.633º N	73.883º W	47.20	31	91.6
K26G	ROCHESTER (CGLS)	NY	43.25º N	77.6º W	82.00	20	91.9
KROC	ROCHESTER GREATER ROCHESTER I	NY	43.117º N	77.677º W	16.90	61	90.9
KSYR	SYRACUSE HANCOCK INT'L ARPT	NY	43.109º N	76.103º W	12.70	59	78.4
KART	WATERTOWN AP	NY	43.992º N	76.022º W	10.20	52	98.7
KFOK	WESTHAMPTON GABRESKI AP	NY	40.844º N	72.632º W	2.00	46	85.5
KHPN	WHITE PLAINS WESTCHESTER CO A	NY	41.067º N	73.708º W	12.10	47	92
KBFD	BRADFORD REGIONAL AP	PA	41.803º N	78.64º W	65.50	52	70.2
KERI	ERIE INTERNATIONAL AP	PA	42.08º N	80.183º W	22.50	61	76.1
KUUU	NEWPORT	RI	41.517º N	71.283º W	5.20	28	119
KPJI	POINT JUDITH (CGS)	RI	41.35º N	71.467º W	0.20	22	103.5
KPVD	PROVIDENCE T F GREEN STATE AR	RI	41.722º N	71.433º W	1.90	38	82.2
KBTV	BURLINGTON INTERNATIONAL AP	VT	44.468º N	73.15º W	10.40	53	74.9
KMPV	MONTPELIER AP	VT	44.203º N	72.579º W	34.20	42	86.7
K9B2	NEWPORT	VT	44.933º N	72.2º W	233.00	14	79.9

It was desired to analyze the wind speeds at each station spatially and interpolate wind contours between each station. This was accomplished by entering the station data from Table 2 into PLS-CADD, a transmission line design software package. The X and Y axis points were longitude and latitude, and the extreme wind speed was entered as an elevation. The terrain contour feature in PLS Cadd successfully interpolated wind speeds between each station and produced a contour map which could be overlaid on an existing UST transmission map (See Figure 4.)

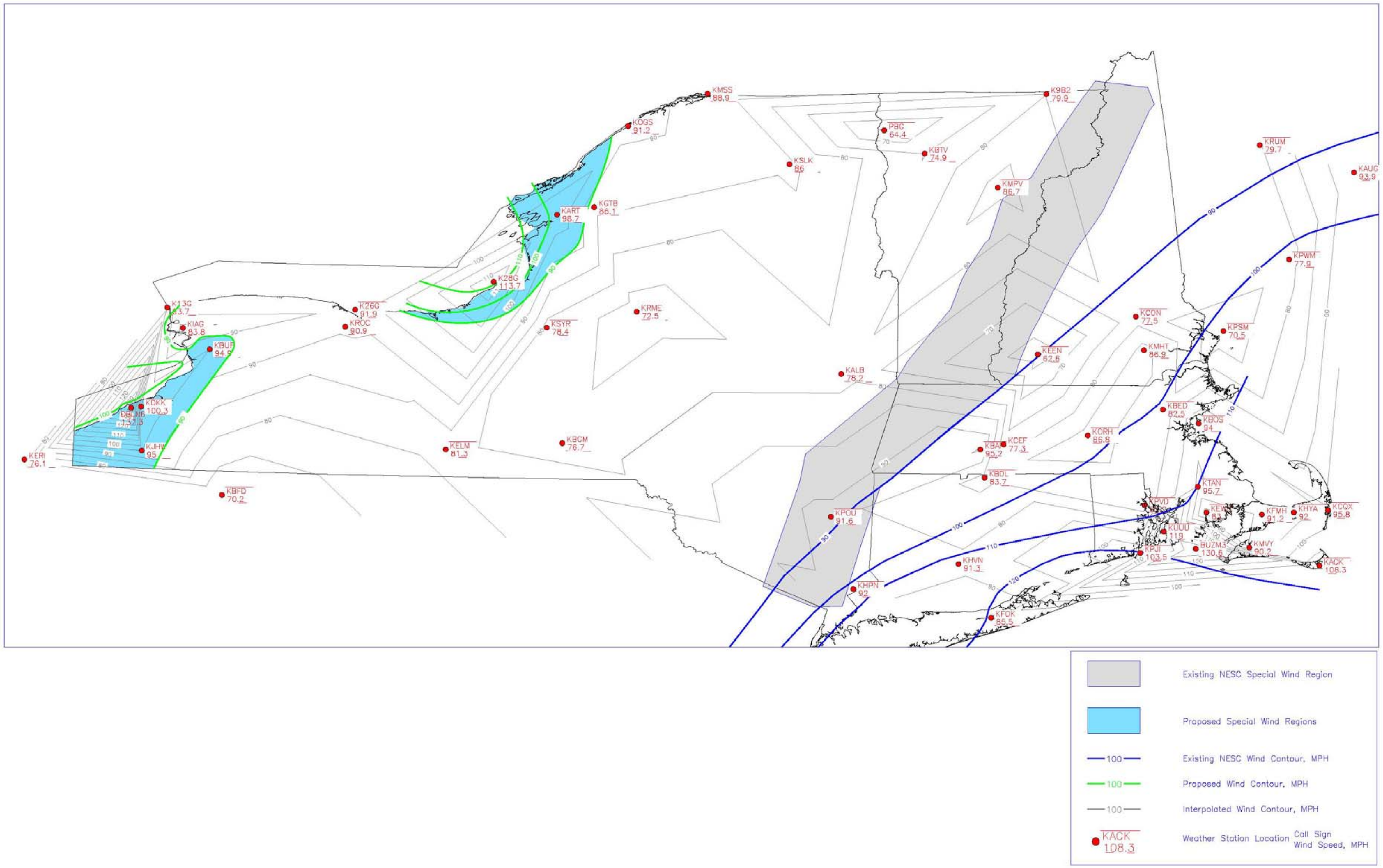


Figure 4. UST Transmission map with existing NESC wind contours and special wind region, PLS Cadd contours, and proposed wind contours.

The results show that the maximum wind speed in the special wind region in eastern New York is 90 mph. They also show two small areas along the coasts of Lake Erie and Lake Ontario where wind speeds could reach 100 mph, in excess of the NESC requirement of 90 mph.

Most weather station locations appear to be at or below the NESC basic wind speed requirements. There were some exceptions as follows:

- Station BUZM3 (Buzzards Bay) was calculated at 130.6 mph where the NESC requires approximately 118 mph (interpolated). This has no effect on UST facilities so this result can be ignored.

- Stations KPOU (Poughkeepsie) and KOGS (Ogdensburg International AP) were at 91.6 and 91.2 mph respectively. This is slightly above the minimum basic wind speed of 90 mph, so it is felt a change here is not necessary.

- Station KERI (Erie International Airport) was calculated at 76.1 mph despite being in close proximity to the Lake Erie coast line. It is felt that this station is not representative of an Exposure C due to the dense development around the airport and to the steep incline between the airport and the lake front.

5. Conclusions

The NESC special wind region is more clearly defined as a result of this research. Gumbel- Type I and II distributions were fitted to wind speed data from NIST, NCDC and the US Meteorological Service using software developed by NIST (NIST, 2008). From this, curves of probability distribution functions were developed. These were used to define probability P[X > = V30] and mean recurrence intervals of wind speeds.

Appendix B shows typical statistical analysis including the Gumbel type I and II fitted to the data.

The special wind region in eastern New York was found not to require a wind speed in excess of the basic NESC requirement of 90 mph. Therefore, a design wind speed of 90 mph is recommended.

Acknowledgements

The authors would like to acknowledge comments and revisions suggested to rewrite this paper by Dr.Emil Simiu, NIST Fellow, BFRL, National Institute of Standards and Technology, Gaithersburg, MD. Prof.William E.Saul, Michigan State University, East Lansing, MI, also provided some comments. The authors acknowledge this help.

References

American Society of Civil Engineers (ASCE), 1991a. Guidelines for Electrical Transmission Line Structural Loadings. 18-24

American Society of Civil Engineers (ASCE), 1991b. Guidelines for Electrical Transmission Line Structural Loadings. 21

American Society of Civil Engineers (ASCE), 1991c. Guidelines for Electrical Transmission Line Structural Loadings. 6

Institute of Electrical & Electronics Engineers Inc (IEEE), 1997. National Electrical Safety Code C2-1997. McGraw-Hill. 151

Institute of Electrical & Electronics Engineers Inc (IEEE), 2006. National Electrical Safety Code C2-2007. McGraw-Hill. 183

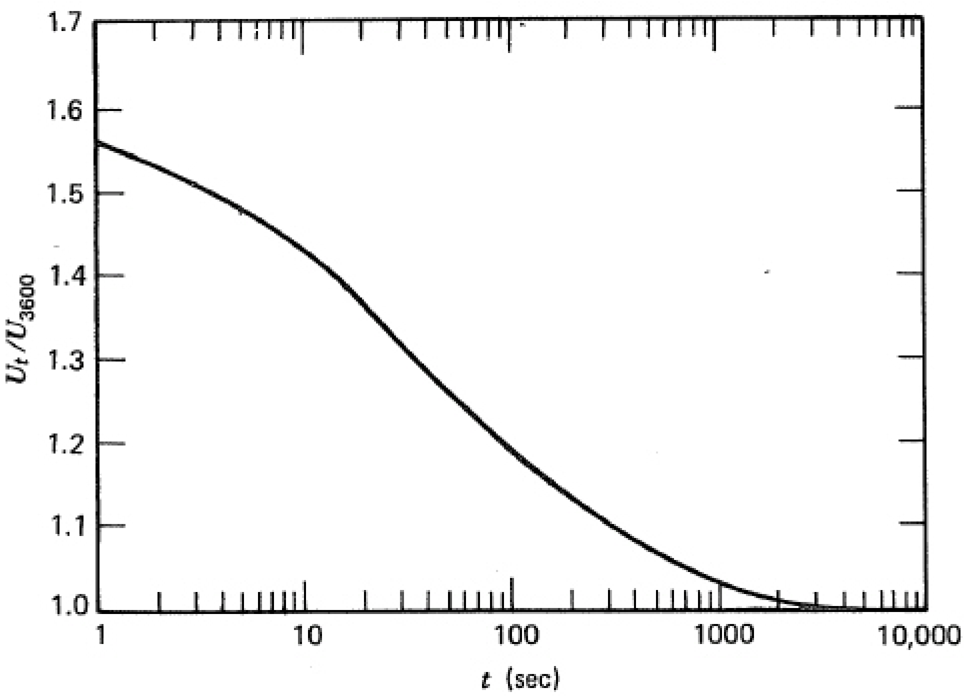
National Climatic Data Center (NCDC), 2008. National Environmental Satellite, Data, and Information Services (NESDIS), www.ncdc.noaa.gov

National Institute of Standards & Technology (NIST), 2008. Extreme Wind and Wind Effects on Structures, www.itl.nist.gov

Simiu, E. & Scanlan, R.H., 1978, Wind Effects on Structures. John Wiley & Son's, Inc. 62

Appendix A

Ratio of probable maximum speed averaged over period t to that averaged over one hour (Simiu and Scanlan, 1978).



Appendix B

Example of Extreme Type I Gumbel distribution for Buffalo – Niagara Airport years 1942 – 2008.

Title
Buffalo 1942-2009

100 Year Return Period		
		3 Sec Gust
-ln(Pv)	-ln(-ln(Pv))	V(x years)
0.01005	4.600149	**100.7**

50 Year Return Period		
		3 Sec Gust
-ln(Pv)	-ln(-ln(Pv))	V(x years)
0.020203	3.901939	**94.9**

Weather Station Data

65 Enter graph variables **y =** 8.3385 **x** + 62.389

Station number (WMO/DATS AV3 number)	WBAN number "Weather Bureau Air Force Navy"	YEARMO DA Year, Month, Day	U3, mph	m	N	Pv	-ln(Pv)	-ln(-ln(Pv))
725280	14733	1961	49.5	1	65	0	4.75605	-1.559418
725280	14733	1969	52.8	2	65	0	3.731546	-1.316823
725280	14733	1999	52.8	3	65	0	3.236224	-1.174407
725280	14733	1973	54.3	4	65	0.1	2.906471	-1.06694
725280	14733	1993	54.3	5	65	0.1	2.658909	-0.977916
725280	14733	1995	54.3	6	65	0.1	2.460634	-0.900419
725280	14733	1998	54.3	7	65	0.1	2.295241	-0.830838
725280	14733	1958	56.0	8	65	0.1	2.153361	-0.76703
725280	14733	1960	56.0	9	65	0.1	2.029132	-0.707608
725280	14733	1962	56.0	10	65	0.1	1.918644	-0.651619
725280	14733	2001	56.0	11	65	0.2	1.819158	-0.598374
725280	14733	2004	56.0	12	65	0.2	1.728681	-0.547359
725280	14733	1968	57.6	13	65	0.2	1.645715	-0.498175
725280	14733	1970	57.6	14	65	0.2	1.569107	-0.450507
725280	14733	1966	59.1	15	65	0.2	1.497954	-0.4041
725280	14733	1980	59.1	16	65	0.2	1.431528	-0.358743
725280	14733	1988	59.1	17	65	0.3	1.369242	-0.314257
725280	14733	1994	59.1	18	65	0.3	1.310608	-0.270491
725280	14733	1996	59.1	19	65	0.3	1.255223	-0.227313
725280	14733	2006	60.7	20	65	0.3	1.202745	-0.184606
725280	14733	1975	61.1	21	65	0.3	1.152884	-0.142267
725280	14733	1944	62.4	22	65	0.3	1.105392	-0.1002
725280	14733	1952	62.7	23	65	0.3	1.060053	-0.058319
725280	14733	1964	62.7	24	65	0.4	1.016681	-0.016544
725280	14733	1987	62.7	25	65	0.4	0.975113	0.025202
725280	14733	2003	62.7	26	65	0.4	0.935203	0.066992
725280	14733	2002	64.2	27	65	0.4	0.896825	0.108894
725280	14733	1949	65.8	28	65	0.4	0.859866	0.150978
725280	14733	1963	65.8	29	65	0.4	0.824225	0.193312
725280	14733	1965	65.8	30	65	0.5	0.78981	0.235963
725280	14733	1974	65.8	31	65	0.5	0.75654	0.279
725280	14733	1981	65.8	32	65	0.5	0.724341	0.322493
725280	14733	1983	65.8	33	65	0.5	0.693147	0.366513
725280	14733	1984	65.8	34	65	0.5	0.662897	0.411136
725280	14733	1991	65.8	35	65	0.5	0.633535	0.45644
725280	14733	2000	65.8	36	65	0.5	0.60501	0.50251
725280	14733	2007	65.8	37	65	0.6	0.577277	0.549433
725280	14733	1954	67.5	38	65	0.6	0.550292	0.597306
725280	14733	1990	67.5	39	65	0.6	0.524016	0.646233
725280	14733	1978	69.1	40	65	0.6	0.498413	0.696326
725280	14733	1982	69.1	41	65	0.6	0.473449	0.74771
725280	14733	1986	69.1	42	65	0.6	0.449094	0.800524
725280	14733	1989	69.1	43	65	0.7	0.425317	0.854921
725280	14733	1956	70.6	44	65	0.7	0.402092	0.911073
725280	14733	2005	70.6	45	65	0.7	0.379395	0.969177
725280	14733	1992	72.2	46	65	0.7	0.357202	1.029455
725280	14733	1955	72.6	47	65	0.7	0.33549	1.092163
725280	14733	1971	72.6	48	65	0.7	0.31424	1.157599
725280	14733	1997	72.6	49	65	0.7	0.293432	1.226111
725280	14733	1957	74.2	50	65	0.8	0.273048	1.298109
725280	14733	1959	74.2	51	65	0.8	0.253071	1.374085
725280	14733	1985	74.2	52	65	0.8	0.233486	1.454635
725280	14733	1942	75.7	53	65	0.8	0.214276	1.540489
725280	14733	1948	75.7	54	65	0.8	0.195429	1.632557
725280	14733	2008	75.7	55	65	0.8	0.176931	1.731997
725280	14733	1976	77.0	56	65	0.9	0.158768	1.84031
725280	14733	1947	79.0	57	65	0.9	0.14093	1.959494
725280	14733	1951	79.0	58	65	0.9	0.123404	2.092293
725280	14733	1953	79.0	59	65	0.9	0.10618	2.242621
725280	14733	1946	80.6	60	65	0.9	0.089248	2.416342
725280	14733	1967	84.1	61	65	0.9	0.072597	2.62283
725280	14733	1979	86.9	62	65	0.9	0.056219	2.878493
725280	14733	1943	87.2	63	65	1	0.040106	3.216239
725280	14733	1977	90.5	64	65	1	0.024247	3.719447
725280	14733	1950	97.3	65	65	1	0.008637	4.751735