The Winds of Hat Creek

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Abstract

The 1994-present six-year wind data synopsis and the 1998-present complete weather record for the Hat Creek observatory site is analyzed to characterize the winds at Hat Creek for antenna survival and pointing purposes. Wind loading from building design codes is discussed, as well as a more specific analysis of antenna wind loading using wind tunnel data. The expected 50- and 100-year winds are presented both from the tabulated codes and extrapolation from the measured data.

The maximum wind gust measured was 73 mph and the fastest one-minute-average wind ("1min-wind") was 61 mph over the six-year record. The median and 98 percentile gusts were 5 and 23 mph, respectively; while the median and 98 percentile 1min-winds were 3 mph and 14 mph respectively. The full statistical data are presented in two tables and nine figures at the end of this memo. Several other tables and figures in the text help summarize the discussion.

Section IV serves as a brief executive summary. In other words, for the condensed, one-page version of this memo, just print out page 8.

I. Introduction

The weather station at the Hat Creek site contains an anemometer sitting on a tower located about 40 feet from the main control building near the BIMA array "T". There are no large trees nearby, and it is at a height of ~20 feet, which is a few feet higher than the control building's peak.

Wind data is logged every three minutes and records:

1.) peak gust within a ten-minute window (referred to as "*gust*"),
2.) one-minute average wind (referred to as "*1min-wind*"),
3.) wind direction and
4.) wind direction rms.

The data recorded will tend to skew the gust distribution since one large gust may be recorded for up to three samples and the averaged data does not record contiguous wind due to the one minute averaging on a three minute sample time. However, the data do give a fair representation of the wind history at the Hat Creek site.

The data have been taken more or less continuously since 1994 and are archived at the University of Illinois. The datafiles are quite large so a synopsis record of the daily maxima/minima for the gust and 1min-wind over the whole period are also maintained. Thanks to Rick Forster for maintaining and providing this data. In addition to the wind data, the weather station records air temperature, surface pressure, relative humidity, rainfall, and dewpoint.

Section II presents a summary of the data, while Section III provides some discussion in context of building practices under wind-load conditions and design maxima, followed by a brief summary and conclusions (Section IV).

II. Data Summary

Several statistics have been computed in order to summarize the data, which consists of the full 3-min sampled record for 1998-present (June 6, 2000) and the daily gust and 1min-wind extrema from 1994-present. In addition, non-contiguous "wind-mile" values for 1/98 – 6/00 are shown, as well as additional averaged values. The basic statistical set for the windspeed data consists of the maximum and minimum recorded values over the time period, the average and standard deviation, the most likely value (different from the average and median, since these are not symmetric distributions), the median value and 98 percentile value. The data are presented in two tables and nine figures detailing the wind history, which are included at the end of this memo. A summary of all of the tables and figures is given below:

Table I: Summary of Figures and Tables.

Table I	This table.
Table II	Statistics for 6 year synopsis record (1994-present). [Page 10].
Table III	Statistics for 3 minute sampled yearly data (1998-present). [Page 10].
Table IV	Extrapolated 50- and 100-year wind recurrence.
Table V	Summary of wind data.
Table VI	Summary of maximum winds.
Figure 1	Time record from 1994: daily gust and 1min-wind maxima.
Figure 2	Time record for Mar 3, 1999: 3min-sampled 1min-wind and gust.
Figure 3	Time record for Feb 14, 2000: 3min-sampled 1min-wind and gust.
Figure 4	1/98 – 6/00 monthly-hourly summary of the 3min-sampled 1min-wind.
Figure 5	1/98 – 6/00 monthly-hourly summary of the 3min-sampled gusts.
Figure 6	Distributions for daily gust and 1min-wind maxima from 1994-present.
Figure 7	Distribution for 1/98 – 6/00 3min-sampled data.
Figure 8	Distribution for 1/98 – 6/00 wind direction.
Figure 9	1/98 – 6/00 monthly-hourly summary of the wind direction.
Figure 10	Reduced frequency analysis for extreme values.
Figure 11	Axial forces on a 5-meter antenna.

The columns in the tables are fairly self-explanatory, with the exception of the "wind-mile" column. The wind-mile is the average speed in miles per hour in which one mile of wind passes the anemometer. For example, a sustained 10 mph wind would push one mile of wind past the anemometer in 6 minutes. This number is computed by adding up the averaged values, dividing by the averaging time (one minute) until one mile of wind is exceeded, then linearly interpolating back to the one-mile mark. The inverse is then the average speed over that mile of wind. Note that these are not contiguous miles, since the 1min-wind values have two minutes of gap before the next averaged value. It may be assumed that the average wind-mile speeds are correct but that the outliers (*e.g.*, the critical "fastest mile" value) will be undervalued. Similarly, the derived five-minute and thirty-minute averages are not contiguous and the maximum values may be somewhat undervalued.

Expected Daily Values

1min-wind and wind-mile

Based on the detailed 1/98 – 6/00 data (Table III), the most likely (*i.e.*, the peak in the distribution) 1min-wind is about 1 mph, while the average is 3.8 mph and the median is 2.7 mph, no matter what the averaging time. Figure 4 shows the hourly averages by month for the 1min-wind, which indicate that they ramp up beginning shortly before noon and taper off more quickly near dusk, with a seasonal difference in magnitude. This diurnal effect is most pronounced in the spring and summer. In the winter, the 1min-wind has a diurnal difference of about 2 mph, which increases to about an 8 mph difference in the summer. Both seasons have a nighttime 1min-wind average of about 2-3mph.

On the average, one mile of wind goes by in about 9 minutes, for an average wind-mile speed of 6.7 mph, a median speed of 6.2 mph and a most likely speed of 1.5 mph.

Figure 7a shows the relevant distributions, which all peak near the origin and fall off nearly monotonically (with some exceptions, most notably the wind-mile statistic, which has another peak at about 7 mph; and the 30min-wind, which peaks at 1-2 mph). Figure 7b shows the cumulative distribution functions for the gust and 1min-wind data.

Gusts

The most likely wind gust at any particular point in time is about 2.5 mph. The gust average is greater at 6.3 mph, with a median value of 4.8 mph. The gusts have a similar diurnal feature to the 1min-wind, but with a slightly greater diurnal and seasonal variation (see Figure 5, note the different ordinate scale). In the winter, the diurnal variation is about 5 mph, while in the summer it increases to about 12 mph difference average gust. On a yearly basis the average nighttime gust is 2-4 mph.

Figure 7a (top frame) shows the gust distribution, which peaks between 2-3mph and then tapers monotonically.

Wind direction

The wind direction data are shown in Figure 8, and indicate that the most likely direction to expect wind from is the northwest (top frame). The bottom frame shows that the weakest winds come from the east and strongest from the west. The most likely direction falls at an azimuth of about 305° (WNW). Figure 9 shows a minor diurnal variation, with the nighttime direction slightly more consistently west-northwesterly. It plots “average” wind direction, which is an unreliable number since averaging a north wind at 359° and a north wind at 1°, produces a south wind at 180°. The data were analyzed in different ways (*e.g.*, looking at the most likely direction), which all produced a similar result, however.

Extreme Values

The fastest wind gust in the entire record is 73 mph and occurred on November 4, 1997 (see Table II). The fastest 1min-wind occurred on August 28, 1997, which was 61 mph and is hence also the fastest measured mile in the wind record.

The maximum wind gust and also the fastest mile in 2000 (54 and 30 mph respectively) occurred on February 14, 2000 (Figure 3). Judging from the gap in the data, the anemometer didn't like the 54-mph wind, as the anemometer didn't come back on-line for about 8 hours, although it had survived similar winds in the past *(e.g.* Figure 2, which shows the windiest day in 1999). The minimum values are not reported here since they are all zero. In Figures 2 and 3, which show the detailed wind data for two very windy days, note the "calm before the storm" and that the high winds are sustained for many hours. One can also see the daily cycle of afternoon wind resumes. Figure 1 shows the 6-year maxima time record for both gusts (top) and 1min-wind (bottom), which exhibits the seasonal dependence similar to the previous discussion for the expected values.

1min-winds and wind-mile

The most likely daily maximum 1min-wind is about 14 mph and the 98%ile value is about 26 mph (Table II). Figure 4 displays the monthly-hourly 1min-wind maxima, which shows a fairly strong diurnal component from April – September (which is when the expected values also display the strong diurnal component) and a fairly random nature for the remaining months. The average-plus-one-sigma values track the average values in this plot (middle line). The summertime maxima are typically in the mid-to-upper-teens and the wintertime maxima are typically less than 10 mph (Figures 1 and 4). Figure 6a (bottom) shows the histogram of the daily maximum 1min-wind, with Figure 6b (bottom) showing the cumulative distribution.

Gusts

The most likely daily maximum wind gust speed is about 22 mph, which is also approximately the average and median daily maximum gust. The 98%ile daily gust maximum is 43 mph. The time record for the daily gust maximum is shown in Figure 1 (top), which also indicates the seasonal dependence. It shows a lower median value in the winter, but typically with more variability. The summertime daily maximum gusts seem consistently in the lower 20' s and in the wintertime around 10 mph. Figure 6a (top) shows the histogram of the daily gust maxima distribution, with Figure 6b (top) showing the cumulative distribution.

Figures 2 and 3 are a look at the windiest days in 1999 and 2000 (March 3 and February 14, respectively). The 3-min record shows the rapid onset of the strong winds, which are preceded by a lull. Figure 5 plots the monthly-hourly values for the gust maxima data, which exhibits a fairly strong diurnal component in the summer (June-September) and is somewhat random for the remaining months. The average-plus-one-sigma values track the average values in this plot (middle line).

III. Discussion

Building Codes

Construction of any civilian building is governed by the relevant building code, which addresses wind loading among other factors. Among a myriad of local variations, there are primarily three civilian building codes, which are themselves similar:

-Standard Building Code (Southern Building Code Congress International)

Used primarily in the southeast.

Used primarily in the midwest and west.

-Basic (or National) Building Code (Building Officials and Code Administration)
Used primarily in the northeast.

These codes are all generally very similar and are all based in large part on the National Standard ANSI A58.1, which is currently under the jurisdiction of the American Society of Civil Engineers (ASCE) with the current revision ASCE 7-98. The codes are based on five interrelated parameters to produce the estimated wind loading (in units of pressure):

-Basic wind speed
-Importance parameter (probability of exceeding design load)
-Exposure coefficient
-Gust response
-Pressure and moment coefficients

The basic wind speed is characterized by the fastest-mile at 33 feet above the ground and the design is typically for the 50-year recurrence value, although the Importance Parameter may be used to modify this in the actual calculation. The newest standard (ASCE 7-98), however, no longer uses the familiar fastest-mile windspeed, but rather the three-second-gust, which increases the design windspeed used.

Note that within the boundary layer of the earth's surface (up to about 1500 ft) the wind will increase with altitude due to the slowing of the prevailing high winds as they interact with the surface. This is often represented as a power law:

$$\frac{V(h)}{V_o} = \left(\frac{h}{h_o}\right)^{\alpha}$$

where $V(h)$ is the mean velocity at height h, V_o is the mean velocity at the reference height h_o, and α is the power law coefficient. For the Hat Creek site, the most likely value for α is between 1/7 and 2/9. Note that other, more complex, models exist, but given the scatter in the actual atmosphere are somewhat useless. Furthermore, the 1hT antennas are relatively short and will be at or below the anemometer level used, so the anemometer values should provide good upper limits.

Using the ANSI standard code (ASCE 7-88) to determine the static loading on a 5-meter antenna in the "wind-sock" position (*i.e.* pointed at the horizon facing the direction of the wind flow) yields a value of 3857 pounds of drag force for a 75 mph wind (see below). Note that this is an upper bound for that windspeed, since the antenna is essentially viewed as a flat billboard, rather than a curved structure. A more detailed analysis is shown below, using tabulated force data measured in a wind tunnel with various antennas.

Design Maxima

Building code tabulated values for the fastest-mile design criterion exist for the US, primarily in the form of a contour map. Using this map for the Hat Creek site, indicates a 50-year fastest-mile in the mid-70's mph. In addition, there are also methods to convert the fastest-mile to maximum gust values. These are typically functions of height or terrain type. For Hat Creek, a value of 1.5 seems reasonable, for a 50-year gust of 112.5 mph. The 100-year values are not significantly greater (say, 78mph and 117 factor of 1.3, so the above values may be upper limits. Also, recall that the new standard specifies the three-second-gust rather than the fastest-mile, with an associated 50-year gust of 85 mph and 100-year gust of 91 mph. One final note, other versions of the fastest-mile maps indicate a faster windspeed of about 80 mph for a 50-year recurrence (*e.g.* Sachs 1972, p. 304).

The extrapolated 50- and 100-year recurrence values based on the measured data may also be computed by a reduced frequency analysis, whereby the recorded yearly maxima are ranked by order (index m) and a frequency is computed as $F=m/(N+1)$, where N is the total number of years for which data exists. The reduced frequency is $y = -\ln(\ln(-F))$ and the resulting reduced frequency-max plot is roughly linear (see Figure 10) and may be extrapolated via linear regression. Obviously, the more years of data that exist the better. This analysis has N=6 from the recorded data, assuming that the 2000 maximum has already occurred (?). This yields numbers less than the tabulated values above for wind gusts (see Table IV).

The extrapolation above implicitly assumes a particular form of the probability density function called the Fisher-Tippett, or Gumbel, distribution. Given this distribution, the recurrence values may be analytically calculated given the mean and standard deviation of the data as:

$$v_r = \langle v_A \rangle + 0.78[\ln(T_R) - 0.577]\sigma_A$$

where v_r is the speed exceeded after recurrence time T_R, with T_R expressed in units of the averaging time scale, A (*e.g.* $T_R = 365\times50$ for the 50-year recurrence with a daily max averaging time), $\langle v_A \rangle$ is the average speed over that time scale and σ_A is the standard deviation. This distribution is plotted in Figure 6 with the corresponding histogram, and the recurrence values are given in Table IV using the averaging time scales of one day and one year (again, assuming the year 2000 maximum values have occurred).

Table IV: Extrapolated maxima.

	Reduced frequency		Fisher-Tippett (day)		Fisher-Tippett (year)	
	50-year	**100-year**	**50-year**	**100-year**	**50-year**	**100-year**
Gust max.	92.7	99.7	84.3	89.0	82.4	87.5
1min-wind max	81.2	89.5	52.7	55.6	69.9	76.1

Vortex Shedding

In addition to the static load, vortex shedding and gusting clearly impacts the wind performance/survival. Vortex shedding is the phenomenon of the wind splashing off at right angles to the incident wind direction due to the structure and seems to be periodic (*i.e.* left-right-left-…). This will tend to make the structure “ring”. An estimate of the exciting frequency may be obtained from the structure diameter and the Strouhal number (S), a dimensionless number for structures that quantifies this phenomenon. Note that the Strouhal number is not a constant for a given structure, but varies with wind speed. For a cylinder at high wind-speeds, S=0.2, which is also taken as the canonical value since S seems to vary from about 0.1 – 0.3 for many geometries. Note, however, that it may take larger values and wind tunnel measurements are needed to get the true value for a structure at a particular wind speed.

Given the Strouhal number, the frequency of the vortex shedding is given by $f = V\text{S}/\text{D}$, where f is the frequency in Hertz, V the wind velocity and D the diameter. You frequency using the maximum sustained wind speed. Using a fastest-mile speed of 75 mph (33.5 m/s) and a diameter of 5 m, yields f = 1.34 Hz for S=0.2 and 2.01 Hz for S=0.3. This is for survival of the structure. In terms of operating, for the median 1min-wind of about 3mph, the frequency is f<0.1 Hz. At the 98%ile 1min-wind of 14 mph, f<0.4 Hz. These will also be a strong function of the antenna position. The discussion of vortex shedding is based on the study of cylinders with certain ranges of Reynolds number (another dimensionless number that characterizes structure interaction with wind) and is therefore presented only to illustrate possible frequencies that may be induced.

Antenna Forces

A more accurate indication of the forces on an antenna may be obtained from studies conducted at JPL with parabolic antennas, as summarized in Levy 1996. (See pp 102-128 as well as Sachs 1972, pp. 288-295). Appendix 4.2 lists the measured force and moment coefficients for a solid surface antenna with an f/D of 0.313. The JPL Publication (78-16) lists similar data for other f/D and meshes. The "windsock" drag force for the canonical 5m antenna is 2920 lbs, which is less than the maximum value derived from the ASCE algorithm, as expected. Figure 10 shows the expected axial forces for the antenna for several elevations, both facing into the wind and facing away. Although these values have been scaled to a 75mph wind and a 5-meter antenna, they are merely illustrative, since the details depend heavily on the geometric details of the antenna. Also note that scaling the windspeed up to 100mph, yields a windsock drag force of 5190 lbs, since the force scales as the square of the windspeed.

The windsock forces are quoted, since that is the proposed windstow configuration as it is believed that withstanding the drag force in that configuration is preferable to withstanding the pitch moments at zenith for this antenna (Matt Fleming, personal communication). The drag force at zenith is on the order of 1000 lbs (as opposed to 5200 lbs in a windsock pointing with 100 mph wind). The pitch moments are 9200 lb-ft pointing at zenith and 1950 lb-ft as a windsock. The drag forces have fairly substantial pipes opposing them, while the pitch moments have the less substantial drive gears opposing them, hence the preferred windstow position.

In terms of pointing, if the dish is pointed into a median gust (5 mph), only 20 lbs of drag force are produced (with a 4 lb-ft pitch moment). Pointing into a 98%ile gust (23 mph) produces 420 lbs of drag force (the maximum), with a 90 lb-ft pitching moment. The maximum pitch moment occurs with a rear wind at a relatively high elevation angle (say 60°), producing about 300 lb-ft for the 98%ile gust of 23 mph.

IV. Summary and Conclusion

Based on a six-year record of wind data from the Hat Creek site, determinations of the survival design windspeed and most likely windspeeds have been obtained. In addition, the windspeed and patterns have been characterized to give an idea as to when problems may be expected, as well as the direction from which they are likely to originate. Table V summarizes these expected daily and extreme values from Table II and Table III, while Table VI summarizes the extrapolated/tabulated maxima.

Table V: Summary of wind data.

	Expected daily (1998-present)			**Max daily (1994-present)**		
	1min-wind	**Gust**	**Wind-mile**	**1min-wind**	**Gust**	**Wind-mile**
Maximum	36.0	56	30.1	61.3	73	62
Average	3.8	6.3	6.7	13.8	20.9	
Most Likely	0.5	2.5	1.5	14.5	22.5	
Median	2.7	4.8	6.2	12.8	20.1	
98%ile	13.8	22.7	16.7	26.4	43.6	

Table VI: Extrapolated and tabulated wind maxima.

	ASCE 7-88		**ASCE 7-98****		***Extrapolated***		**Fisher-Tippett**†	
	50-year	**100-year**	**50-year**	**100-year**	***50-year***	***100-year***	**50-year**	**100-year**
Gust	98*	101*	85	91	*92*	*100*	82	88
Fastest-mile	75	78						
1min-wind					*81*	*89*	70	76

*Gust factor 1.3 **3-second gust †one year averaging time scale

The winds generally originate from the west-northwest and are greatest in the afternoon and the summer, however the gust maximums tend to occur during the more unstable times in the early spring or late fall.

Applying the ASCE Building Code analysis, yields a maximum windsock drag force of about 3900 lbs, which uses the 75 mph fastest-mile (note that the new design speed is the three-second-gust, and will in general be greater) and assumes a flat billboard shape. Applying better models for parabolic antennas and using 100 mph as the design windspeed (the extrapolated value for a 100-year gust) yields a maximum windsock drag force of about 5200 lbs. The windsock configuration is used as the windstow position since the pitching moments are much less than for zenith pointing (1950 lb-ft vs. 9200 lb-ft), even though the drag forces are much greater (5200 lb. vs. 1000 lb.).

In terms of pointing, if the dish is pointed into a median gust (5 mph), only 20 lbs of drag force are produced (with a 4 lb-ft pitch moment). Pointing into a 98%ile gust (23 mph) produces 420 lbs of drag force (the maximum), with a 90 lb-ft pitching moment. The maximum pitch moment occurs with a rear wind at a relatively high elevation angle (say 60°), producing about 300 lb-ft for the 98%ile gust of 23 mph.

Vortex shedding will cause the antenna to "ring", with a driving frequency between 1-3 Hz in windstow. In terms of pointing during use, the vortex shedding drive frequency will be less than about 0.5 Hz for the 98%ile gust speed.

The force, pitch and frequency numbers above are illustrative only, since the actual values are highly dependent upon the specific geometry, as is the vortex shedding frequency. It is recommended that the extrapolated maxima values via the reduced

V. Bibliography

ASCE Standard 7-98, "Minimum Design Loads for Buildings and Other Structures", American Society of Civil Engineers, 2000.

Lawson, T. V., "Wind Effects on Buildings: Volume 2, Statistics and Meteorology", Applied Science Publishers, 1980, London (TA654.5.L38X)

Levy, R., "Structural Engineering of Microwave Antennas For Electrical, Mechanical and Civil Engineers", IEEE Press, 1996, New York, NY.

Levy, R. and D. Kurtz, "Compilation of Wind Tunnel Coefficients for Parabolic Reflectors", JPL Publication 78-16, April 1978.

Liu, H. (ed.), "High Winds and Building Codes: Proceedings of the WERC/NSF Wind Engineering Symposium", 1987, Kansas City, MO. (TH891.W97X)

Liu, H., "Wind Engineering: A Handbook for Structural Engineers", Prentice-Hall, Inc., 1991, Englewood Cliffs, NJ. (TA654.5.L58)

Mehta, K. C. and R. D. Marshall, "Guide to the Use of the Wind Load Provisions of ASCI 7-95", ASCE Press, 1998, Reston, VA. (TH891.M45)

Sachs, P., "Wind Forces in Engineering", Pergamon Press, 1972, Oxford, UK. (TH891.S33X, TA654.5.S22 2nd ed. 1978)

Taranath, B. S., "Structural Analysis and Design of Tall Buildings", McGraw-Hill Co., 1988, New York, NY. (TH845.T33)

Table II: Statistics for the synopsis daily max data.

1994–date	Daily gust max	Daily 1min-wind max
Maximum	73.1	61.3
Average	20.9	13.8
Most likely	22.5	14.5
σ	8.8	5.4
Median	20.1	12.8
98%ile	43.6	26.4

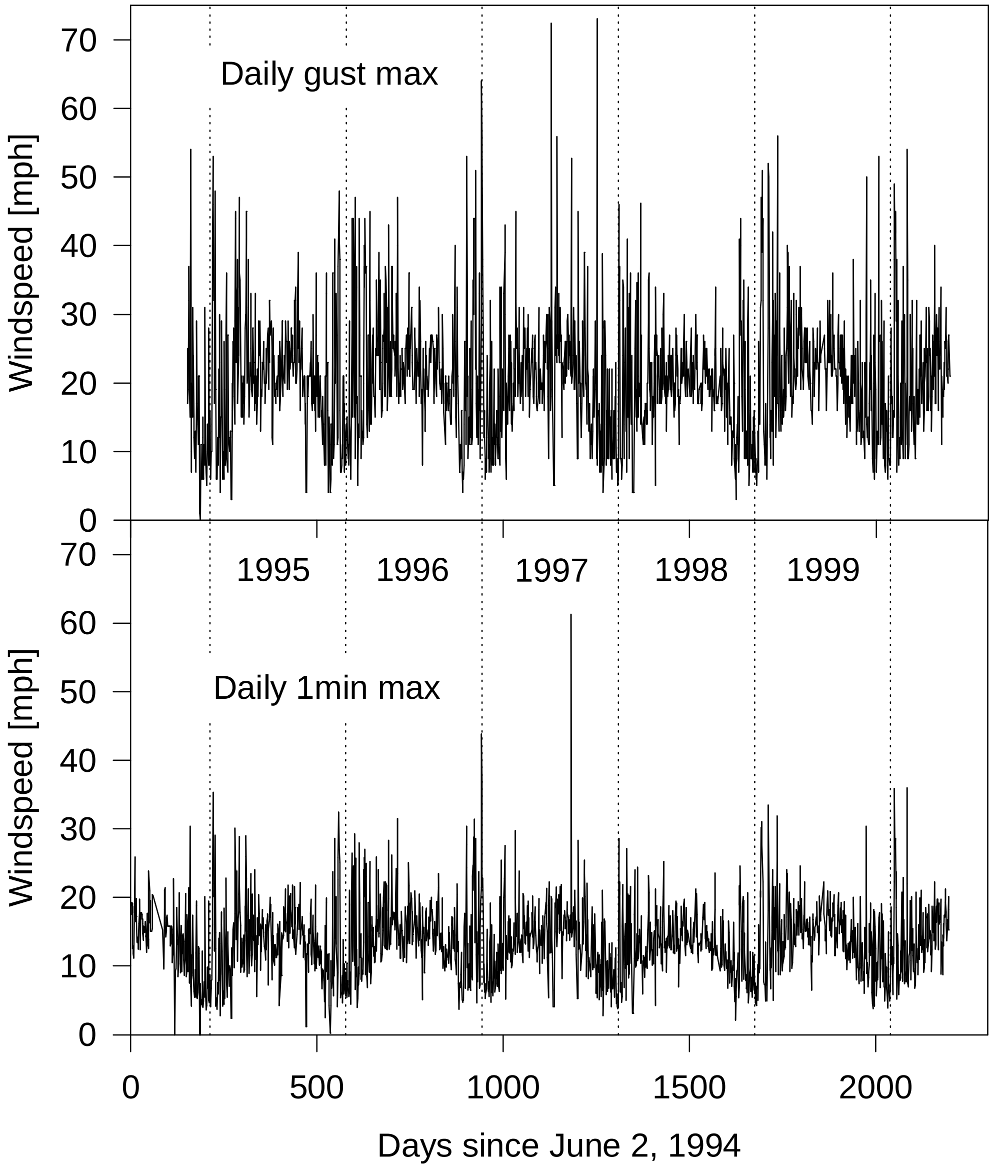
Table III: Statistics for the 3 minute sampled data (1998, 1999, YTD2000 and cumulative). The italicized integers tally the number of data points used.

	gust	1min-wind	5min-wind	30min-wind	wind-mile
YTD2000	*74,935*		*14,987*	*2497*	*4797*
Maximum	54.0	36.0	31.1	23.0	30.1
Average	6.8	4.1	4.1	4.1	7.2
Most likely	2.5	0.5	1.5	1.5	1.5
σ	6.2	3.9	3.7	3.5	4.6
Median	5.1	2.9	2.8	2.8	6.8
98%ile	24.5	14.8	14.0	13.2	19.0
1999	*155,812*		*31,162*	*5193*	*9653*
Maximum	56.0	33.4	27.7	22.6	29.0
Average	6.7	4.0	4.0	4.0	7.0
Most likely	2.5	0.5	1.5	1.5	1.5
σ	6.2	3.9	3.7	3.5	4.4
Median	4.8	2.7	2.6	2.6	6.8
98%ile	23.0	14.2	13.4	12.8	17.3
1998	*158,128*		*31,625*	*5270*	*8590*
Maximum	46.2	28.6	22.0	20.0	24.7
Average	5.7	3.4	3.4	3.4	6.0
Most likely	2.5	0.5	0.5	1.5	1.5
σ	5.1	3.3	3.1	2.9	3.8
Median	4.6	2.6	2.5	2.5	5.4
98%ile	20.6	12.8	12.1	11.6	15.0
January 1998 – June 2000					
	388,875		*77,774*	*12,960*	*23,040*
Maximum	56.0	36.0	31.1	23.0	30.1
Average	6.3	3.8	3.8	3.8	6.7
Most likely	2.5	0.5	1.5	1.5	1.5
σ	6.2	3.7	3.5	3.3	4.2
Median	4.8	2.7	2.6	2.6	6.2
98%ile	22.7	13.8	13.0	12.4	16.7

— Figure 1—

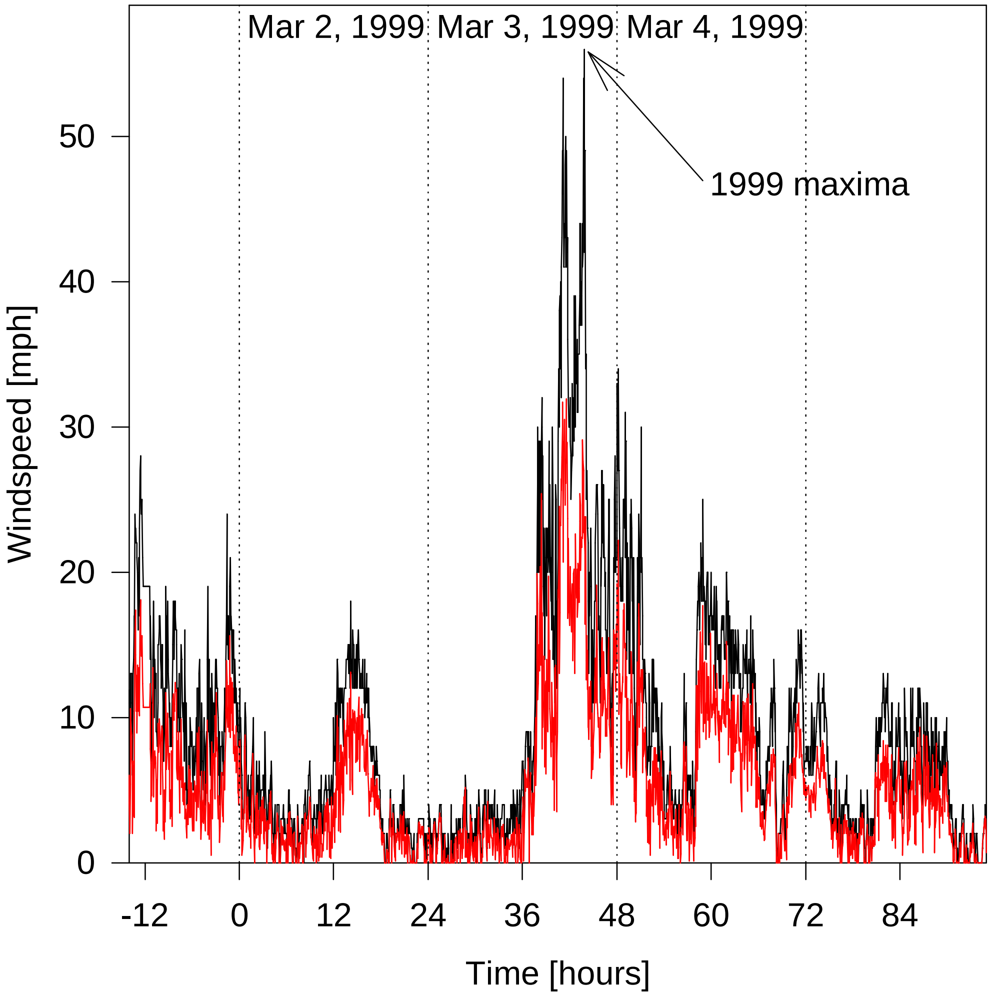
(Top) Daily gust maxima from November 1994 to date (June 6, 1994).

(Bottom) Daily 1min-wind maxima from June 1994 to date.



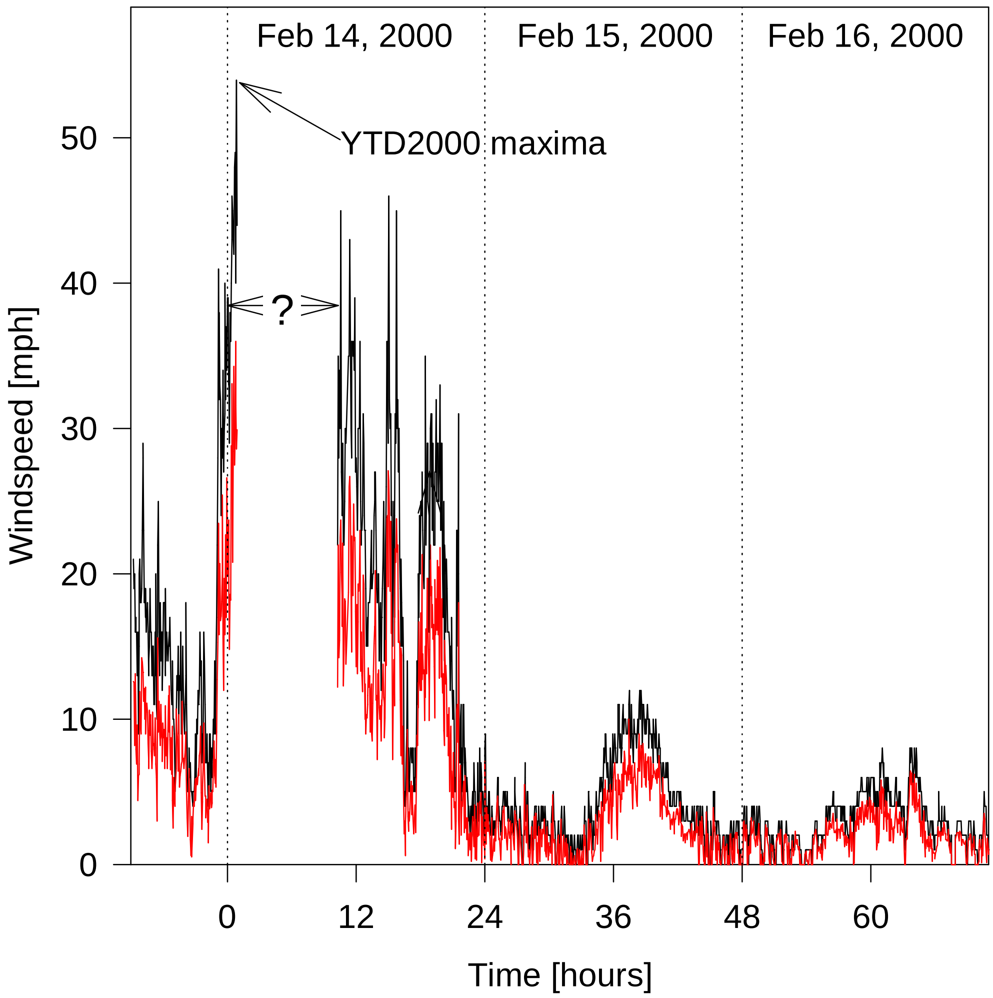
— Figure 2 —

Time record from around March 3, 1999, which was the windiest day of 1999, sampled every 3 minutes. The top/black line is the gust data and the bottom/red line is the 1min-wind.

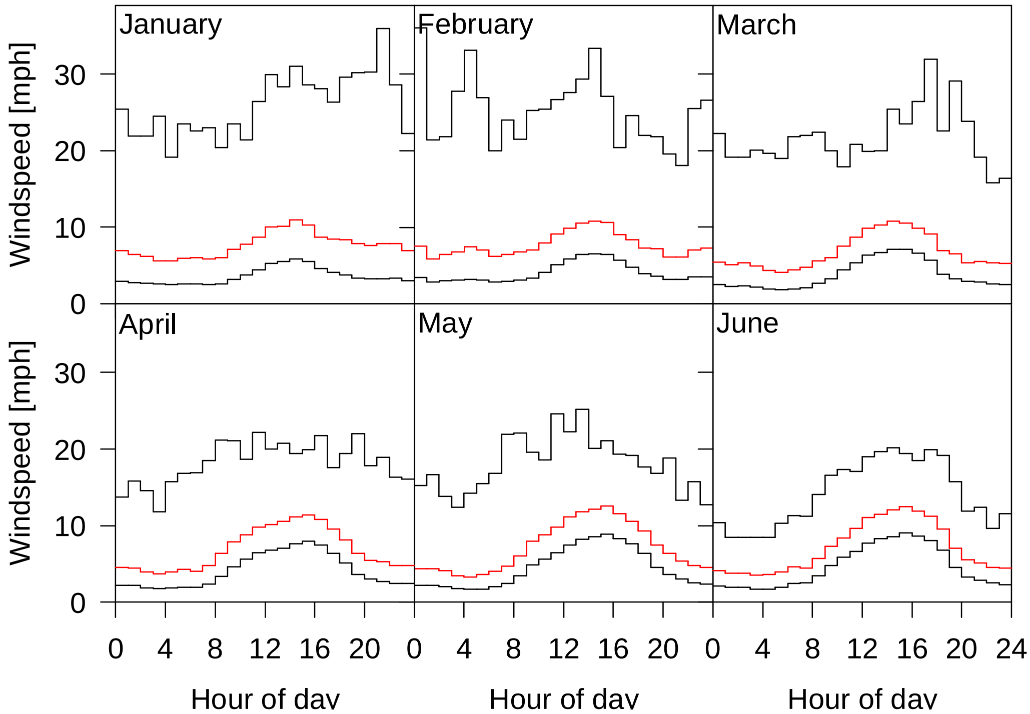


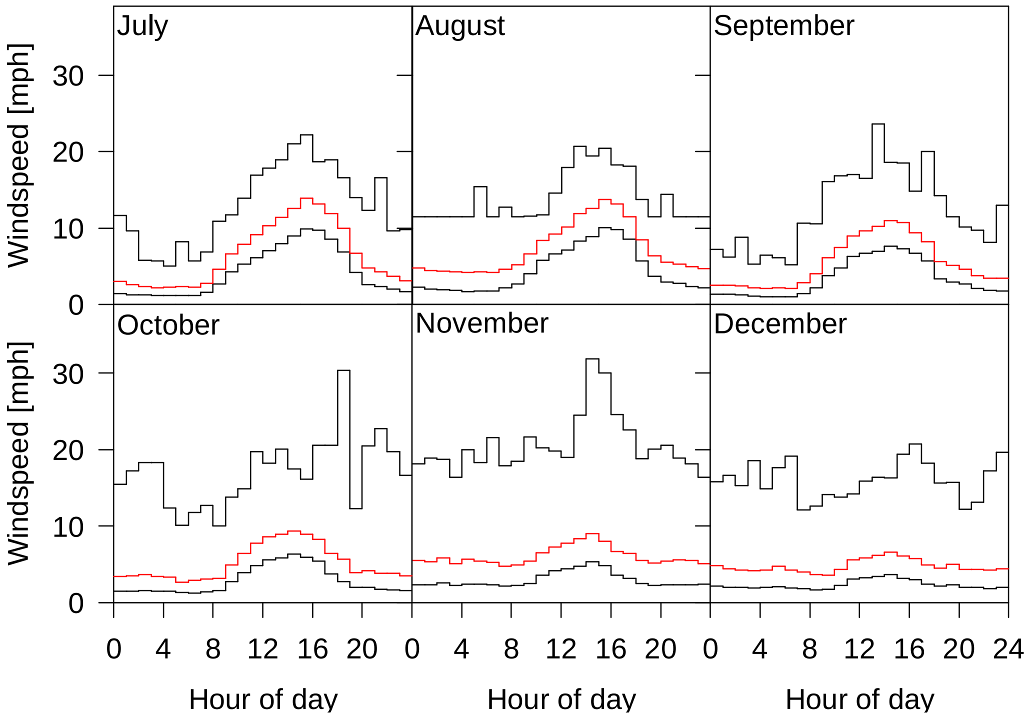
— Figure 3 —

Time record from February 14, 2000, which was the windiest day of YTD2000, sampled every 3 minutes. The top/black line is the gust data and the bottom/red line is the 1min-wind. Note that the anemometer apparently didn't like the high windspeeds.

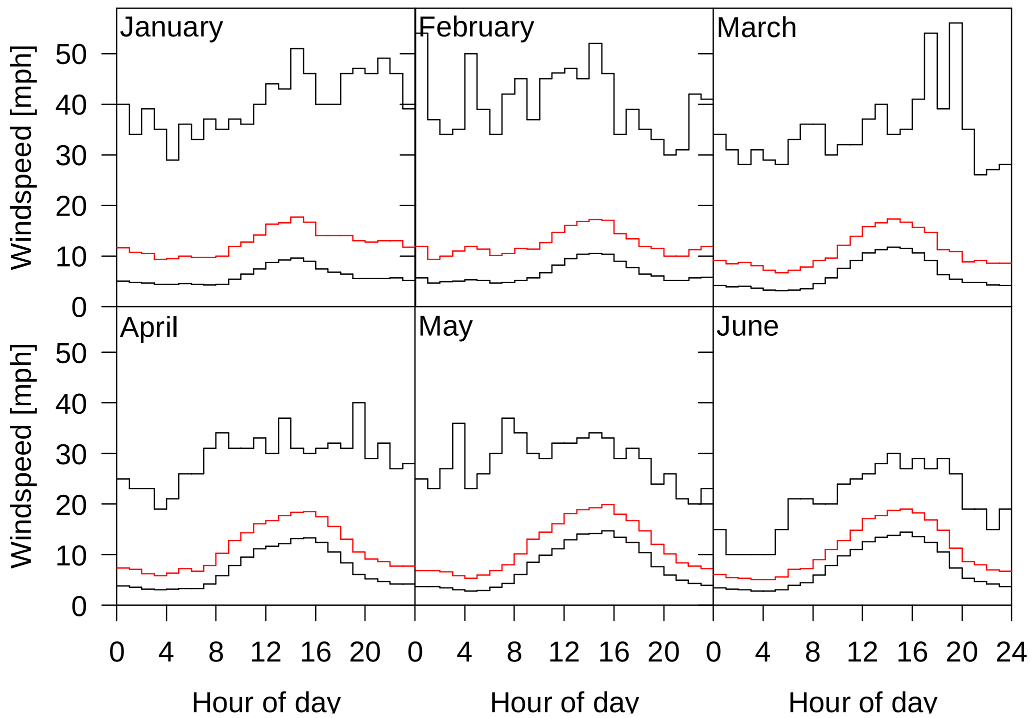


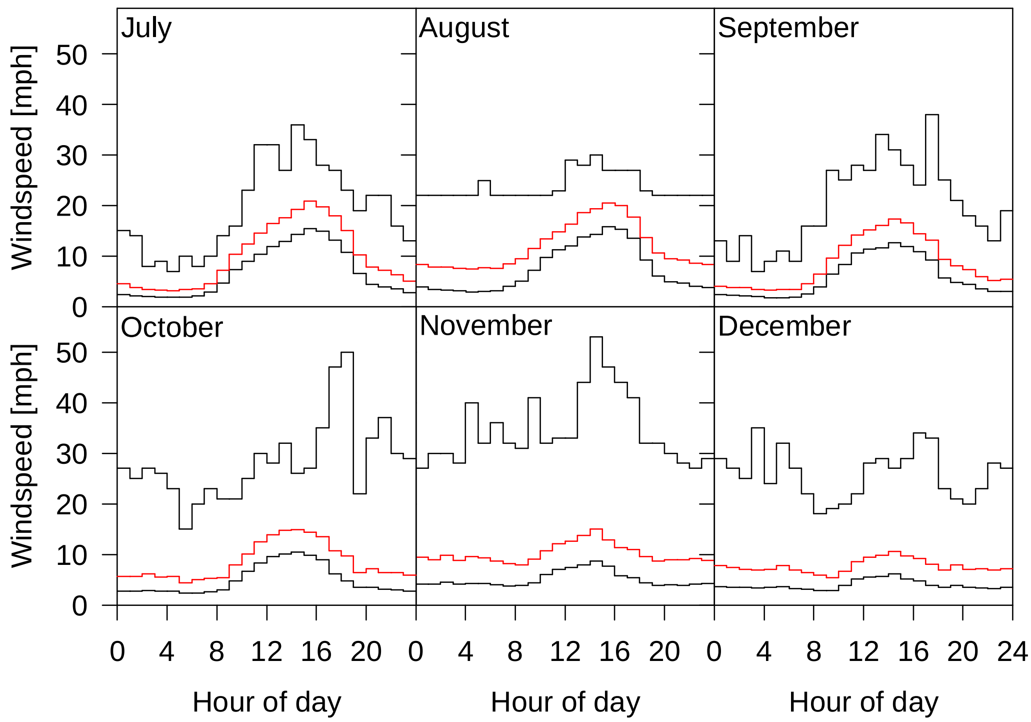
Monthly-hourly summary of 1998-present 3min-sampled 1min-wind data. Each frame is one month, with the top/black line being the maximum 1min-wind within that hour of the day, the bottom/black line is the average 1min-wind within that hour, and the middle/red line is the average plus one standard deviation.





Monthly-hourly summary of 1998-present 3min sampled gust data. Each frame is one month, with the top/black line being the maximum gust within that hour of the day, the bottom/black line is the average gust speed within that hour, and the middle/red line is the average plus one standard deviation.

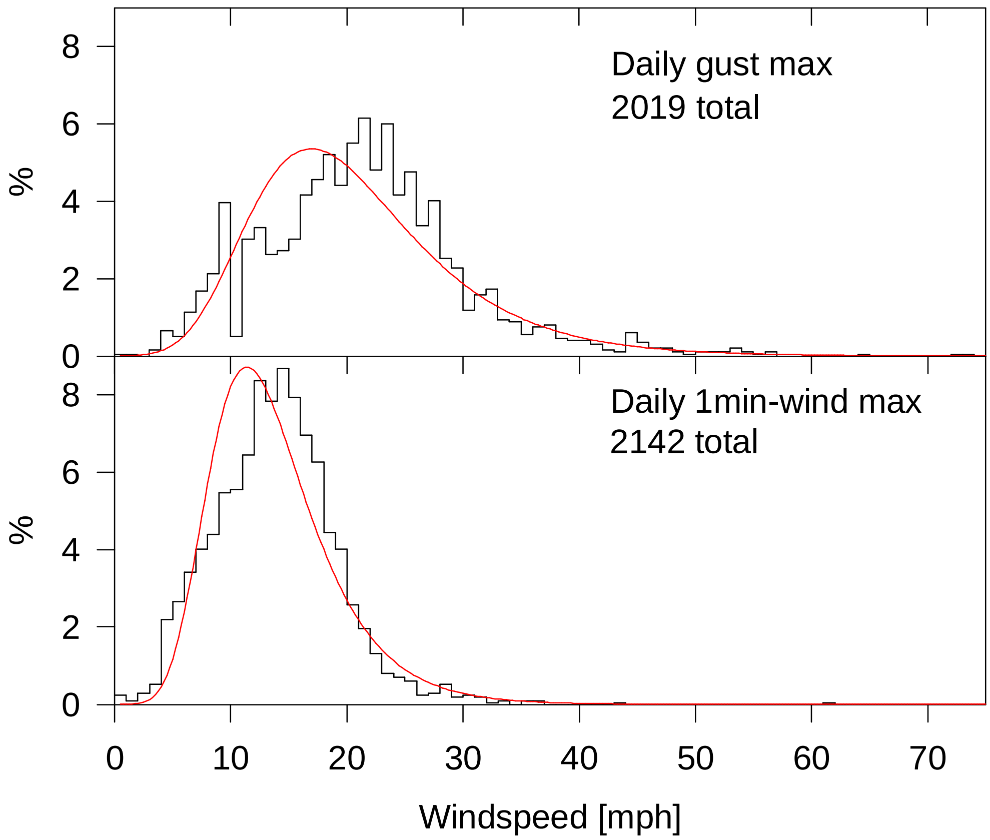




— Figure 6a —

(Top) Distribution of the daily gust maximum values from November 1994 to June 2000. The red (smooth) line is the Fisher-Tippett (Gumbel) distribution for the gust data.

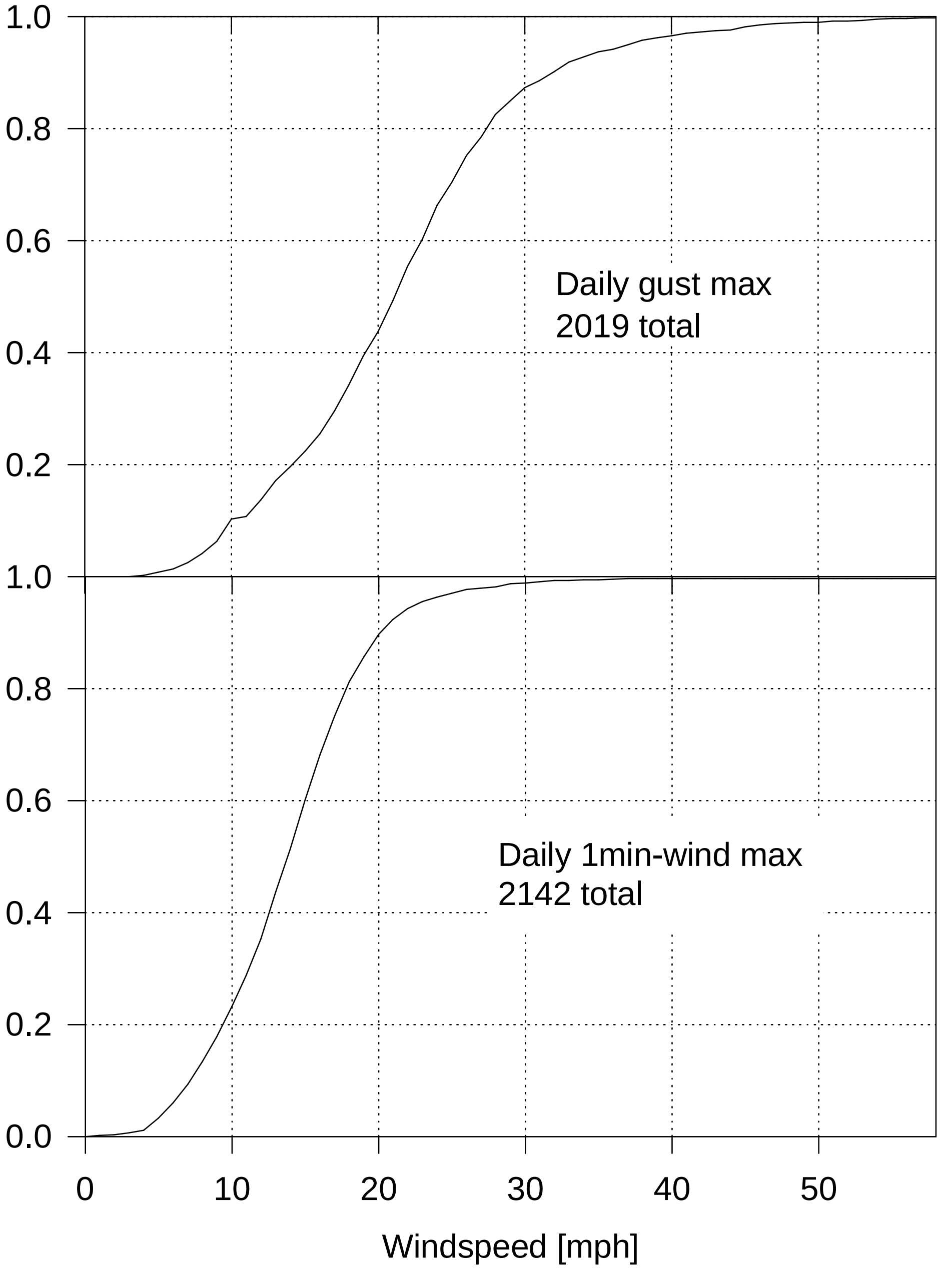
(Bottom) Distribution of the daily 1min-wind maximum values from June 1994 to June 2000. The red (smooth) line is the Fisher-Tippett (Gumbel) distribution for the 1min-wind data.



— Figure 6b —

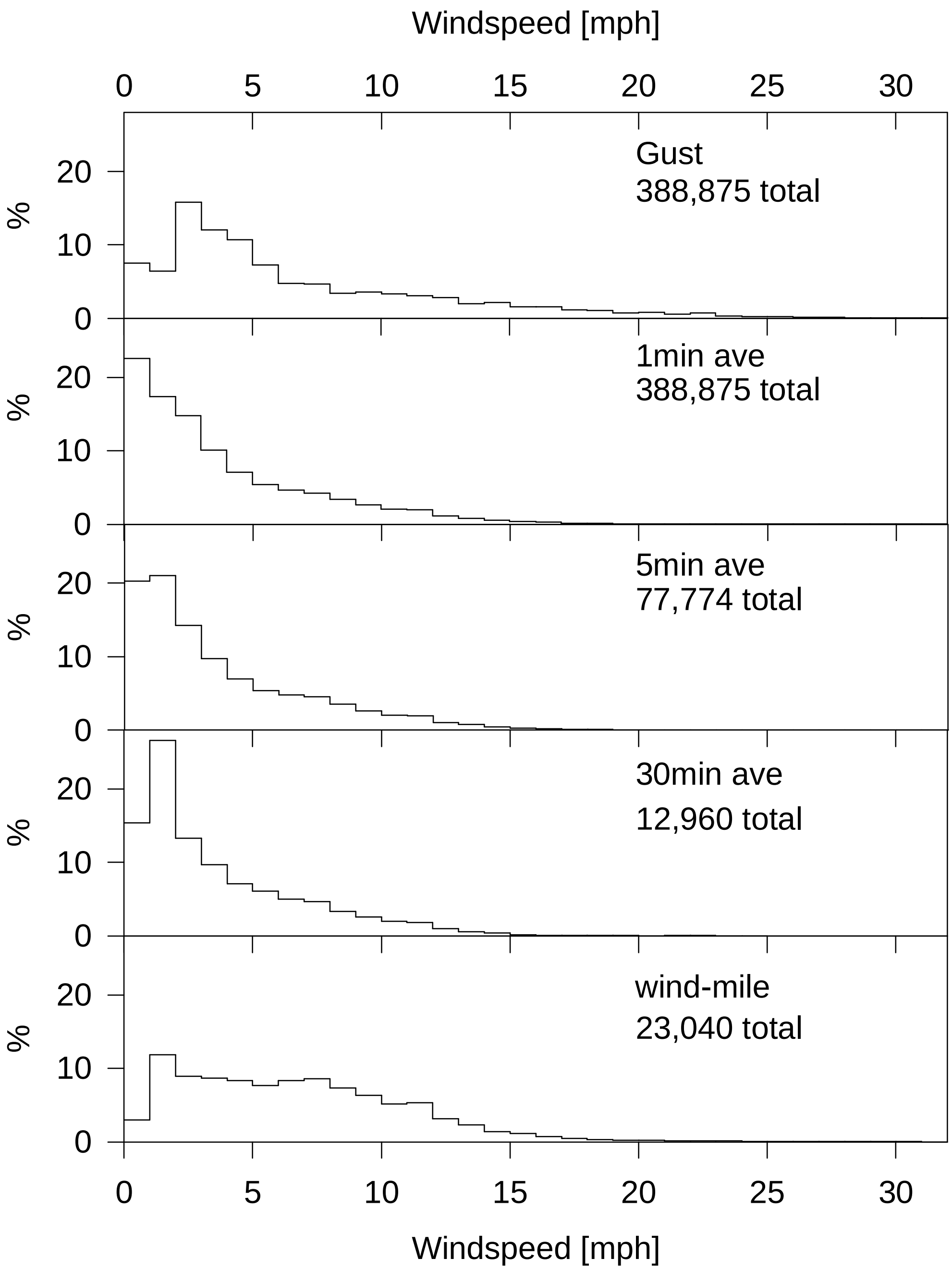
(Top) Cumulative distribution function of the daily gust maximum values from November 1994 to June 2000.

(Bottom) Cumulative distribution function of the daily 1min-wind maximum values from June 1994 to June 2000.



— Figure 7a —

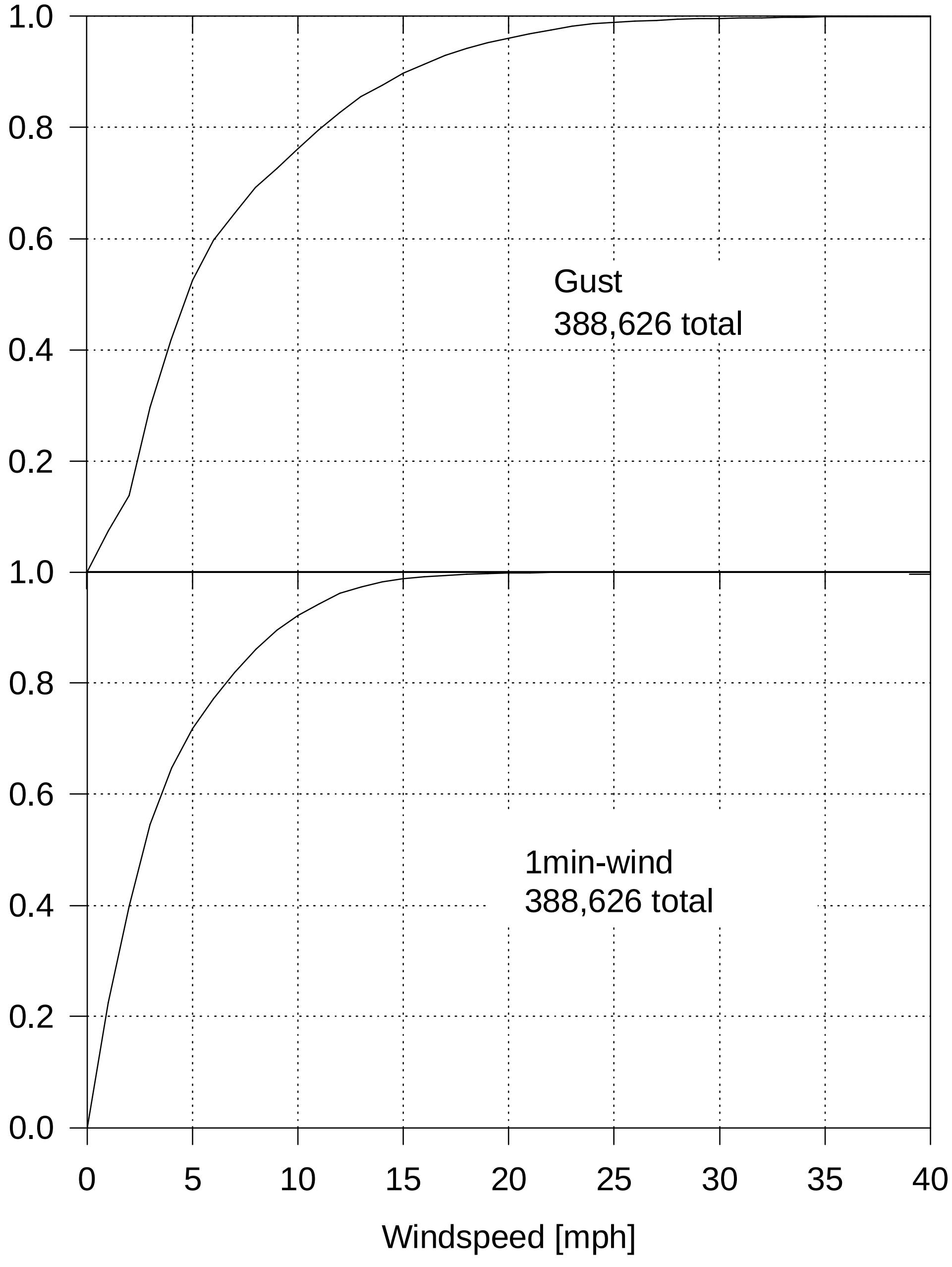
Distributions of the 1998-present 3-min sampled data, with a bin-size of 1 mph. The text in each frame tells the data type and the total number of points used to compute the statistic.



— Figure 7b —

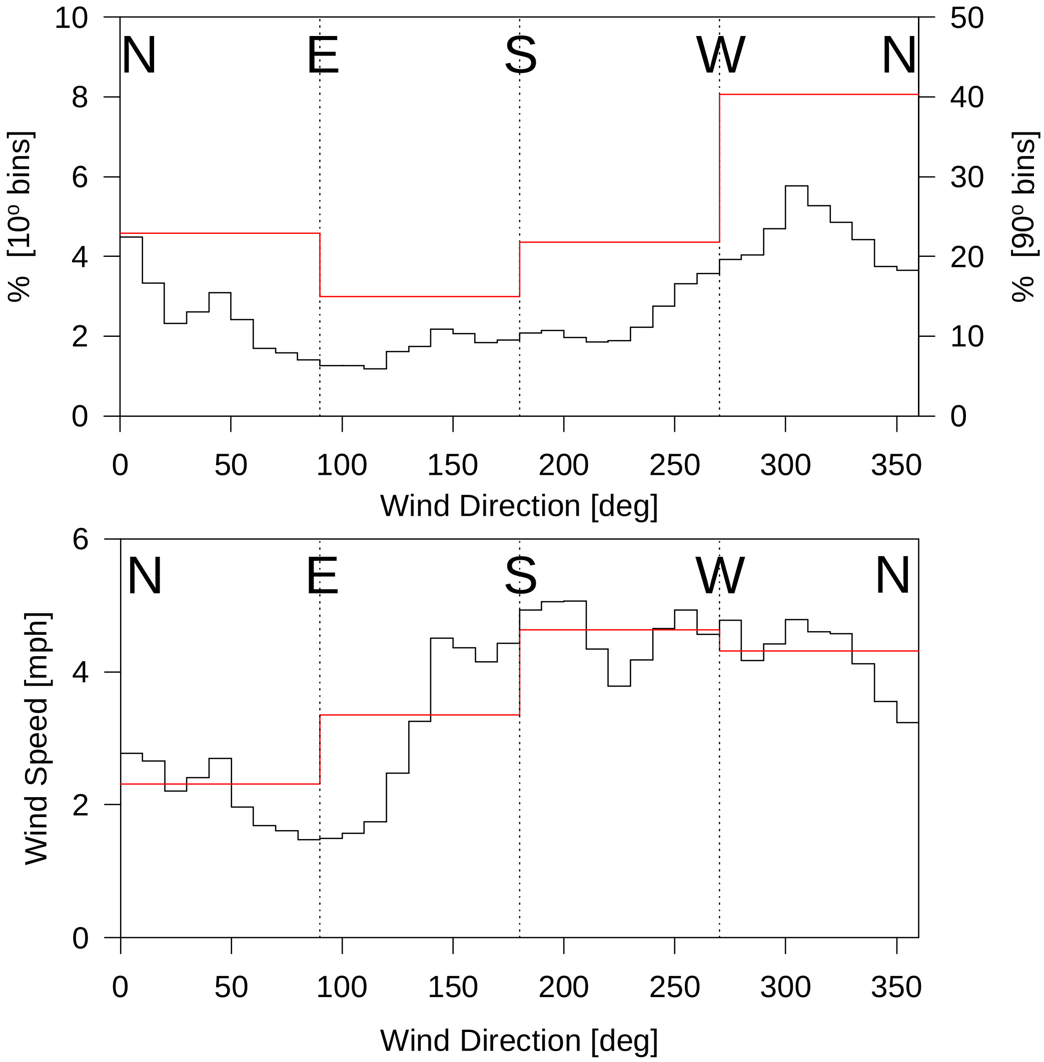
(Top) Cumulative distribution function of the gust values from January 1998 to June 2000.

(Bottom) Cumulative distribution function of the 1min-wind values from January 1998 to June 2000.

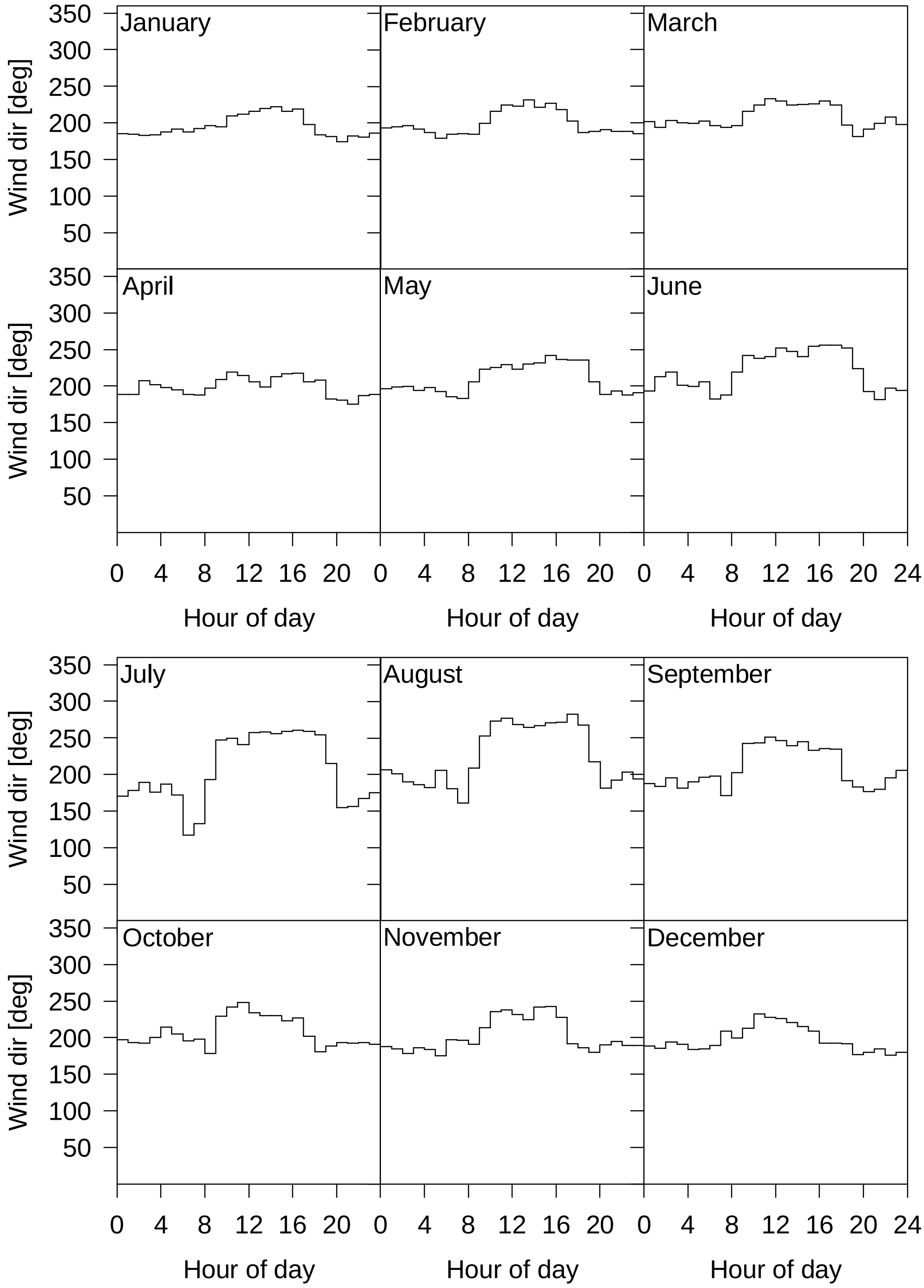


(Top) Wind direction distribution using the 3-minute sampled data for 1998-present, binned into 10° bins (black) and 90° bins (red).

(Bottom) Histogram correlated windspeed with wind directions using the 3-minute sampled data for 1998-present, binned into 10° bins (black) and 90° bins (red).

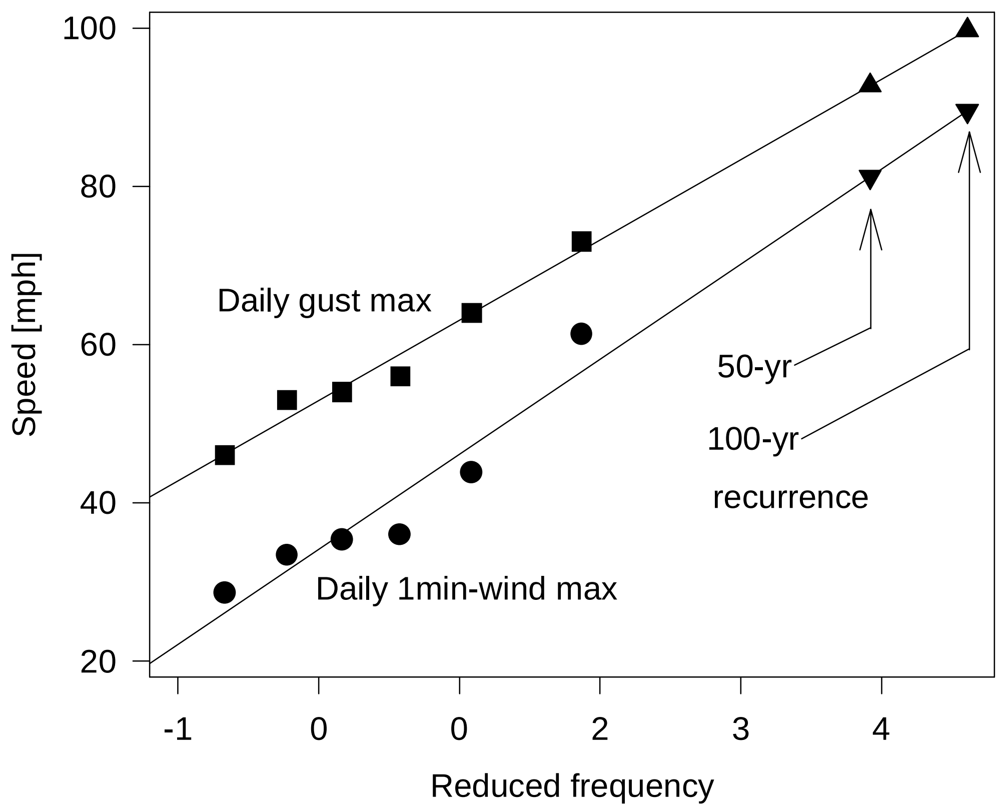


Monthly-hourly summary of 1998-present 3min-sampled wind direction data. Each frame is one month, and shows the “average” wind direction.



— Figure 10 —

Reduced frequency analysis to extrapolate to the 50- and 100-year recurrence values based on the six years of measured data.



— Figure 11 —

Calculated axial forces on a 5-meter antenna at different elevations, based on wind tunnel measurements of a f/D0.313 solid surface antenna (Levy 1996).