WIND DATA REPORT

WBZ Tower, Hull, MA

9/1/07-11/30/07

Prepared for

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NOTICE AND ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

All the work presented in this Wind Data Report including installation and decommissioning of the meteorological tower and instrumentation, and the data analysis and reporting was preformed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data measured at the WBZ AM radio tower in Hull, MA. Installed on August 28, 2006, the wind monitoring sensors have been in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 118m (387 ft), 87m (285 ft), and 61m (200 ft).

The period covered by this report is September through November 2007. The mean recorded wind speed for this period was 6.73 m/s (15.1 mph)[1] at 118 meters and the prevailing wind direction was from the southwest. The gross data recovery percentage (the actual percentage of expected data received) was 94.3% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 94.3%. The gross data recovery amount is low because the tower data have been filtered based on the presence of spurious data measurements that occur sporadically. Further detail regarding the removal of data is given below.

Additional information about interpreting the data presented in this report can be found in the Fact Sheet, "Interpreting Your Wind Resource Data," produced by RERL and the Massachusetts Technology Collaborative (MTC). This document is found through the RERL website:

http://www.ceere.org/rerl/about_wind/RERL_Fact_Sheet_6_Wind_resource_interpretation.pdf

[1] 1m/s=2.237 mph

SECTION 1 - Station Location

Figure 1: WBZ Site Location in Hull, MA

The WBZ radio tower is located near the salt marsh on the west coast of the Hull isthmus that is located on the southern portion of the Boston Harbor. The site coordinates are 42° 16' 44.11" N by 70° 52' 34.39" W. These coordinates correspond to the NAD83 datum.

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on an existing radio tower, known as the WBZ AM broadcast tower. All of the wind speed sensors come from NRG Systems, and consists of the following items:

- 6 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 118 m (387 ft), two at 87 m (285 ft) and one at a height of 61 m (200 ft).

- 3 - #200P Wind direction vanes. They are located at heights of 118m (387 ft), 87m (285 ft) and 61m (200 ft) each.
- Shielded sensor wire
- 2 - Climatronix aspirated temperature sensors mounted at ground level and at 118m (387 ft).
- Nomad2 SecondWind data logger box
- One Y-shaped sensor boom at each level that hosts two anemometers and one wind direction sensor. The booms face due east and the sensors are located approximately 14 feet away from the closest tower leg

The data from the SecondWind Nomad2 logger is emailed to the Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a daily basis. The logger samples wind speed and direction once every second. These data are then combined into 10-minute averages and, along with the standard deviation for those 10-minute periods, are put into a binary file. These binary files are converted to ASCII text files using the Nomad2 software. These text files are then imported into a database software program where they are subjected to quality assurance (QA) tests prior to using the data.

SECTION 3- Data Summary

A summary of the wind speeds and wind directions measured during the reporting period is included in Table 1. Table 1 includes the mean wind speeds measured at each measurement height, the maximum instantaneous wind speed measured at each measurement height and the prevailing wind direction measured at each measurement height. These values are provided for each month of the reporting period and for the whole reporting period.

Table 1. Wind Speed and Direction Data Summary

Date	**Mean Wind Speed**	**Max Wind Speed**	**Prevailing Wind Direction**	**Mean Wind Speed**	**Max Wind Speed**	**Prevailing Wind Direction**	**Mean Wind Speed**	**Max Wind Speed**	**Prevailing Wind Direction**
Height Units	**118 m [m/s]**	**118 m [m/s]**	**118m [m/s]**	**87 m [m/s]**	**87 m [m/s]**	**87 m [m/s]**	**61 m [m/s]**	**61 m [m/s]**	**61 m [m/s]**
Sept 2007	6.61	12.69	SW	6.14	13.15	SSW	5.63	13.24	SSW
Oct 2007	6.39	12.84	SW	5.98	12.93	SW	5.67	15.02	SW
Nov 2007	7.25	13.52	NW	5.90	13.72	WNW	6.97	15.88	WW
Sept'07-Oct'07	**6.73**	**13.52**	**SW**	**6.32**	**13.72**	**SSW**	**6.07**	**15.88**	**SSW**

Note that the statistics in Table 1 are reported with only 94.3% of the total amount of data that were available during the period that is summarized by this report. While 100% of data were recorded for the quarter, a fraction of the data were not averaged due to their spurious nature. These periods of error have been identified and removed by a rigorous data filtering process. A description of the data filters that were applied in the processing of these data are supplied in Section 7. This same filtering process is responsible for the fact that higher maximum wind speed measurements are recorded at the lowest measurement height. This result is unavoidable and directly related to the fact that the data filters remove varying amounts of data from each measurement height on the tower.

No measurement of wind speed or direction can be perfectly accurate. Wind speed measurement errors occur due to anemometer manufacturing variability, anemometer calibration errors, the response of anemometers to turbulence and vertical air flow and due to air flows caused by the anemometer mounting system. Every effort is made to reduce the sources of these errors. Nevertheless, the values reported in this report have an expected uncertainty of about ± 2% or ± 0.2 m/s, whichever is greater. Wind direction measurement errors occur due to sensor measurement uncertainty, tower effects, boom alignment measurement errors and twisting of pipe sections during the raising of a pipe tower. Efforts are also made to reduce these errors, but the reported wind directions are estimated to have an uncertainty of +/- 5 degrees.

A summary of the turbulence intensity and mean wind shear measured at each measurement height during the reporting period is included In Table 2. These values are provided for each month of the reporting period and for the whole reporting period. Turbulence Intensity is calculated by dividing the standard deviation of the wind speed by the mean wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. Turbulence intensity varies with wind speed. The average turbulence intensity presented in Table 2 is the mean turbulence intensity when the wind speed is between 10 and 11 m/s.

Shear coefficients provide a measure of the change in wind speed with height. When data at multiple heights are available, shear coefficients, α, have been determined. They can be used in the following formula to estimate the average wind speed, $U(z)$, at height z, when the average wind speed, $U(z_r)$, at height z_r is known:

$$U(z)=U(z_r)\left(\frac{z}{z_r}\right)^{\alpha}$$

The change in wind speed with height is a very complicated relationship related to atmospheric conditions, wind speed, wind direction, time of day and time of year. This formula will not always provide the correct answer at any given site. Nevertheless the calculated shear coefficient, based on measurements at two heights, can be used to characterize the degree of increase in wind speed with height at a site.

The mean wind shear coefficient that is provided here is calculated based on the mean wind speeds in Table 1, where z_{high} and z_{low} are the heights of the higher and lower mean wind speeds used in the calculation and $U(z_{low})$ and $U(z_{high})$ are the mean wind speeds at the two heights.

$$\alpha = \log\left(\frac{U(z_{high})}{U(z_{low})}\right) \Big/ \log\left(\frac{z_{high}}{z_{low}}\right)$$

Table 2. Shear and Turbulence Intensity Data Summary

Date	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Turbulence Intensity at 10 m/s	Mean Wind Shear Coefficient, α
Height Units	**118 m [-]**	**87 m [-]**	**61 m [-]**	**Between 118 m and 87 m [-]**
Sept 2007	0.08	0.09	0.10	0.24
Oct 2007	0.08	0.09	0.10	0.22
Nov 2007	0.09	0.10	0.11	0.16
Sept'07-Nov'07	**0.09**	**0.10**	**0.11**	**0.21**

SECTION 4- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from September 1st, 2007 to November 30th, 2007 at a height of 118 meters**.** The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. Time series data is shown in Figure 2.
- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The wind speed distribution data is shown below in Figure 3. During the report summary period, the most commonly occurring wind speed bin was 6-7 m/s, occurring 13.75% of the time.
- Monthly Average – A plot of the monthly average wind speed over a 12-month period. This graph shows the trends in the wind speed over the year. The monthly average wind speed data is shown below in Figure 4.

- Diurnal – A plot of the average wind speed for each hour of the day. The diurnal average wind speed data is shown below in Figure 5. During the report summary period, the WBZ site exhibited relatively stable average wind speeds throughout the morning and evening hours of a typical day, but slightly smaller averages values during the midday hours.

- Wind Rose – A plot, by compass direction showing the percentage of time that the wind comes from a given direction and the average wind speed in that direction. The wind rose plot is shown below in Figure 6. The prevailing wind direction for this period was from the southwest, occurring 15.6% of the time with an average wind speed of 7.82 m/s.

Data for the wind speed histograms, monthly and diurnal average plots, and wind roses are included in APPENDIX B.

Wind Speed Time Series

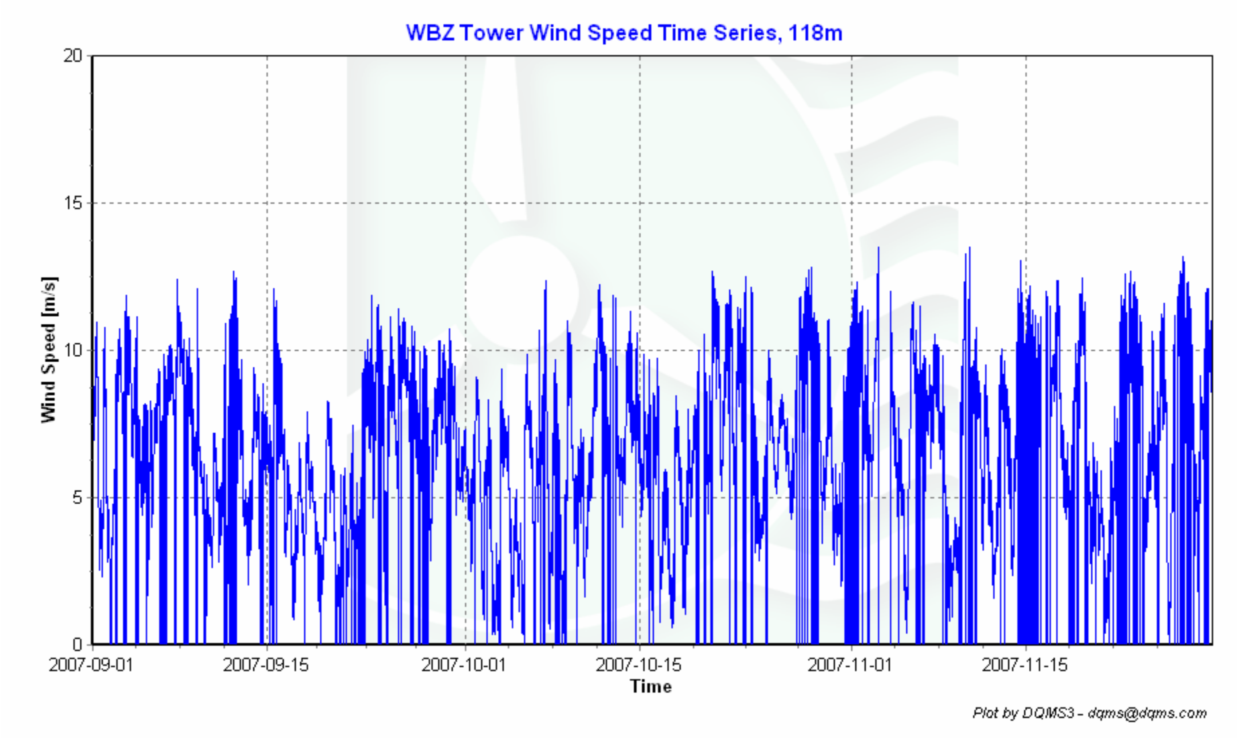

Figure 2 - WBZ Tower Wind Speed Time Series for September 1 to November 30

Wind Speed Distributions

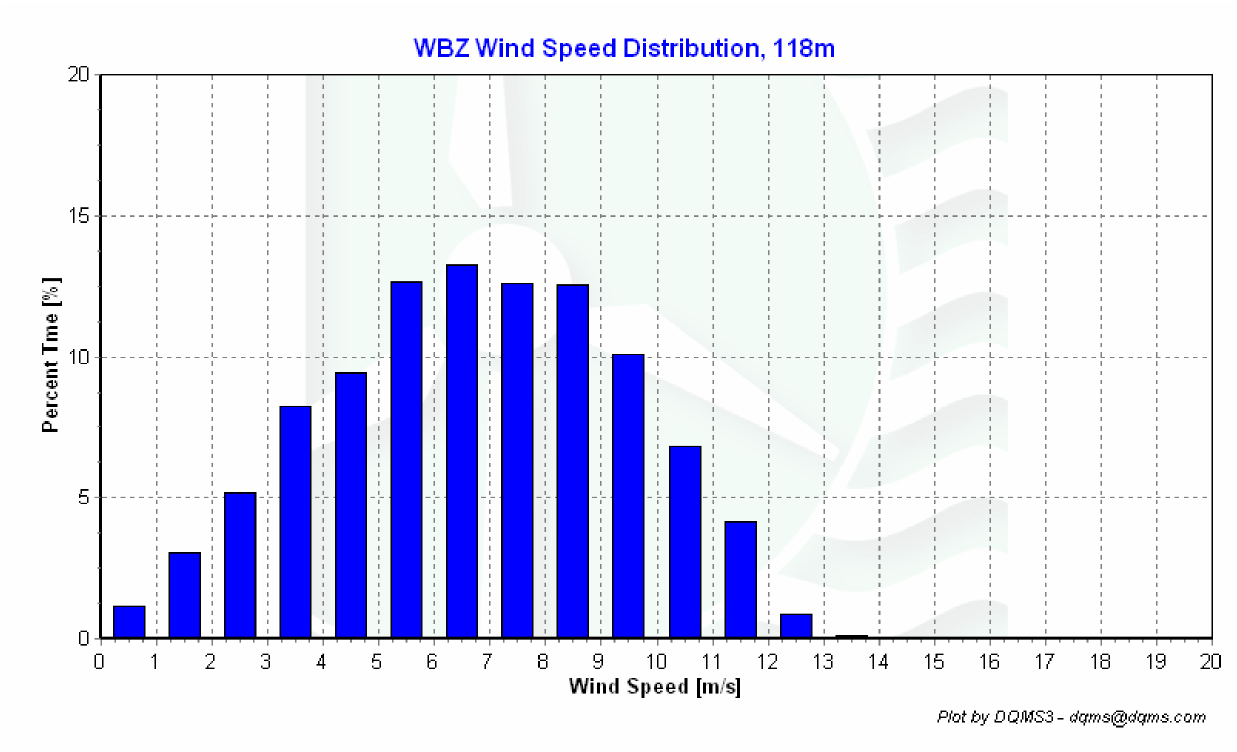

Figure 3 - WBZ Tower Wind Speed Distribution for September 1 to November 30

Monthly Average Wind Speeds

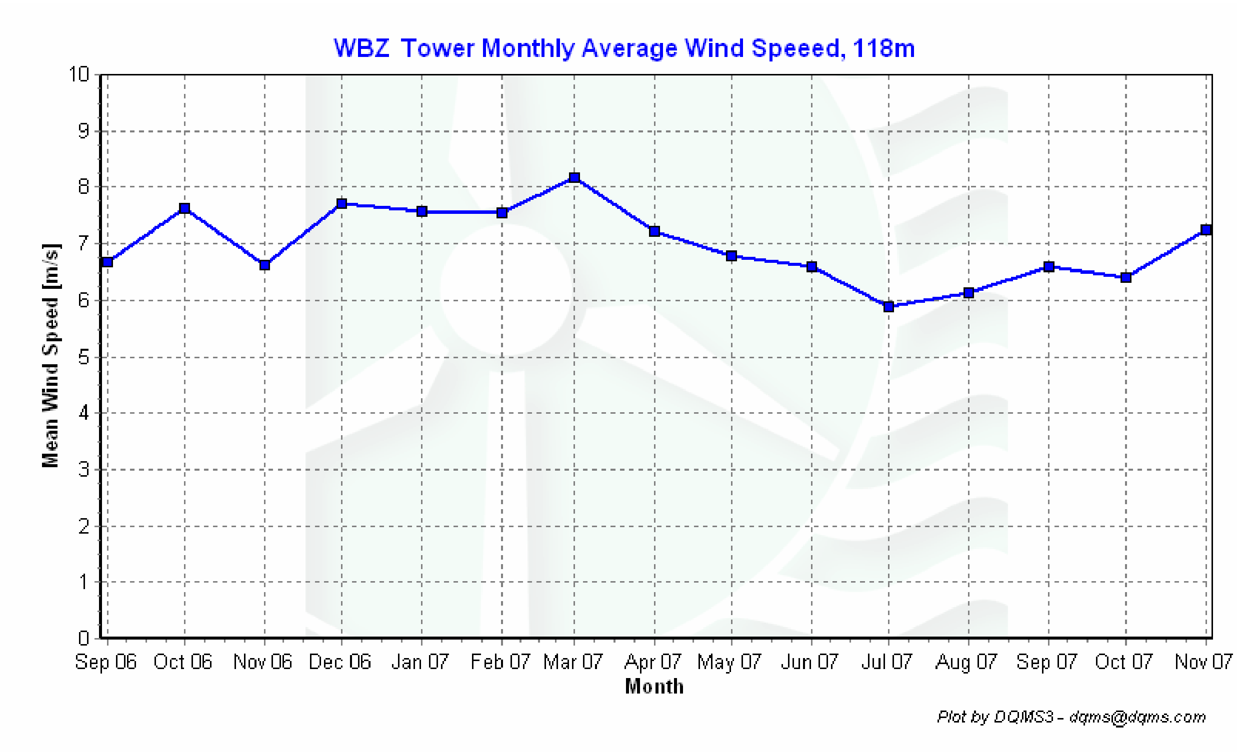

Figure 4 - WBZ Tower Monthly Average Wind Speed

Diurnal Average Wind Speeds

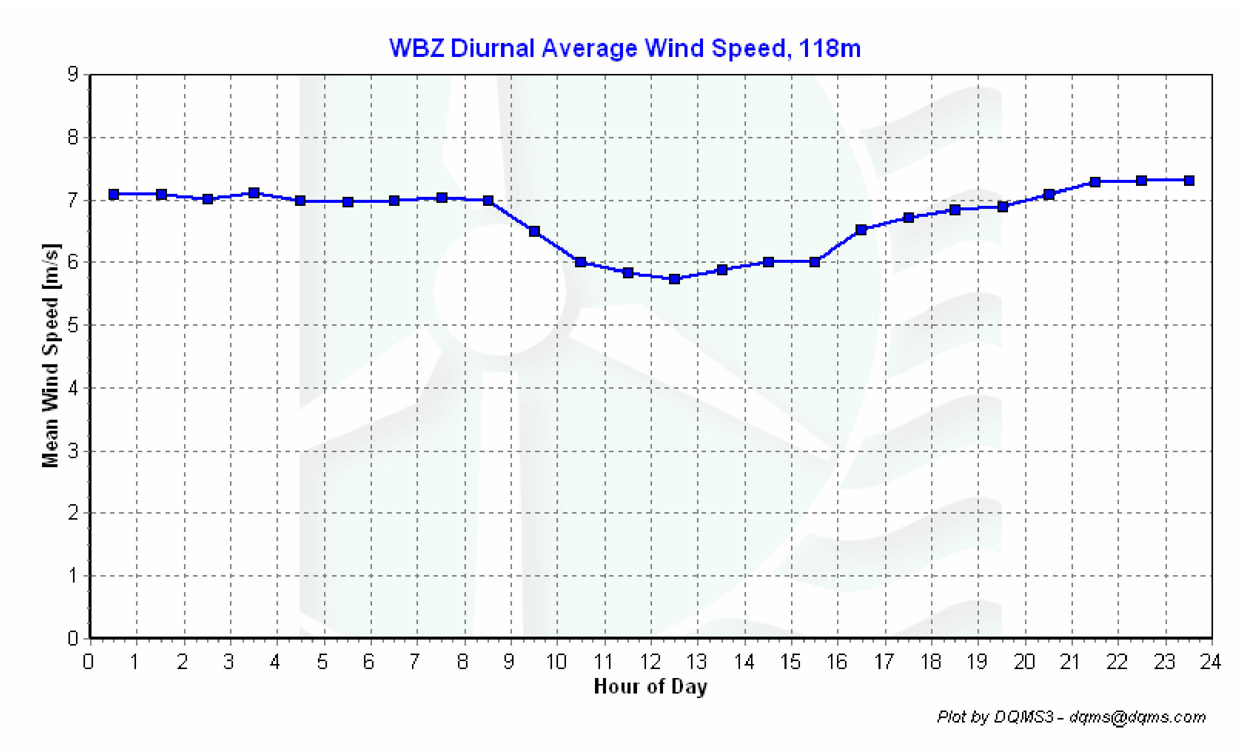

Figure 5 - WBZ Tower Diurnal Average Wind Speed for September 1 to November 30

Wind Roses

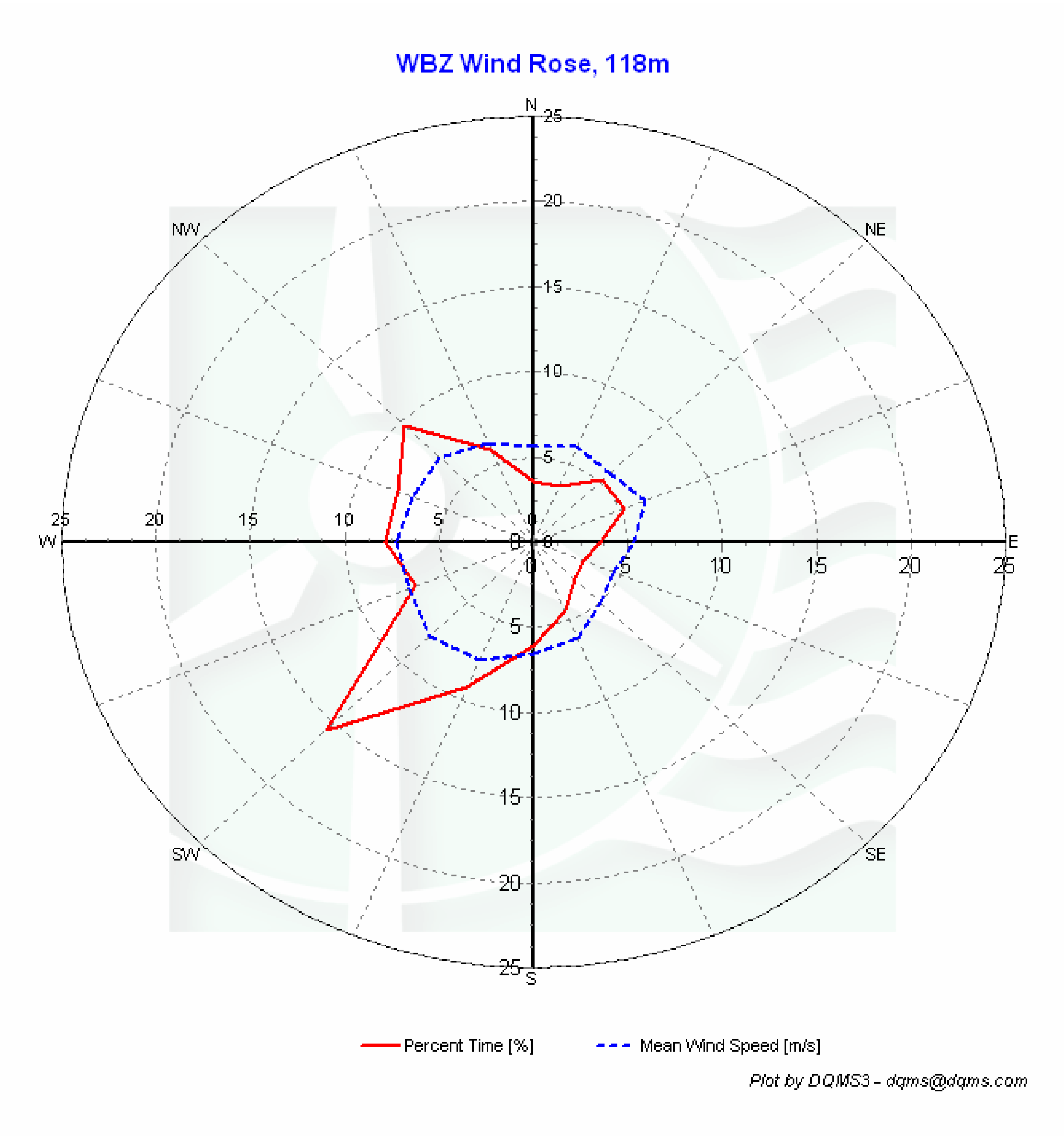

Figure 6 - WBZ Tower Wind Rose for September 1 to November 30

SECTION 5 - Significant Meteorological Events

During the period summarized in this report, there were no sustained aberrations in the behavior of the weather that would significantly skew the averages presented above in the data statistics summary.

SECTION 6 - Data Collection and Maintenance

The following maintenance/equipment problems occurred during the report period, and the following corrective actions were taken:

- Based on the data provided by a separate, laser anemometer system at the site, the measurements were found to occasionally misrepresent the true wind speed. The erroneous data have been successfully identified and removed.

- The sporadic removal of such data causes the maximum wind speed records to appear larger at lower heights (shown above in the data statistics summary table). This phenomenon is unavoidable given that unique data filters were defined for the measurements at each height which resulted in varying degrees of data removal.

SECTION 7- Data Recovery and Validation

All raw wind data are subjected to a series of tests and filters to weed out data that are faulty or corrupted. Definitions of these quality assurance (QA) controls are given below under Test Definitions and Sensor Statistics. These control filters were designed to automate the quality control process and used many of the previous hand-worked data sets made at UMass to affect a suitable emulation. This particular site has unique characteristics, so an additional data filtering test was developed to further ensure the overall quality of the data that are summarized in this report.

The gross percentage of data recovered (ratio of the number of raw data points received to data points expected) and net percentage (ratio of raw data points which passed all QA control tests to data points expected) are shown below.

Gross Data Recovered [%]	93.6
Net Data Recovered [%]	93.6

Test Definitions

All raw data were subjected to a series of standard validation tests, as described below. The sensors tested and the parameters specific to each sensor are given in the Sensor Performance Report which is included in APPENDIX A. Data which were flagged as invalid were not included in the statistics presented in this report.

MinMax Test: All sensors are expected to report data values within a range specified by the sensor and logger manufacturers. If a value falls outside this range, it is flagged as invalid. A data value from the sensor listed in Test Field 1 (TF1) is flagged if it is less than Factor 1 (F1) or greater than Factor 2. This test has been applied to the following sensors (as applicable): wind speed, wind speed standard deviation, wind direction, temperature, and solar insolation.

$$F1 > TF1 > F2$$

MinMaxT Test: This is a MinMax test for wind direction standard deviation with different ranges applied for high and low wind speeds. A wind direction standard deviation data value (TF1) is flagged either if it is less than Factor 1, if the wind speed (TF2) is less than Factor 4 and the wind direction standard deviation is greater than Factor 2, or if the wind speed is greater than or equal to Factor 4 and the wind direction standard deviation is greater than Factor 3.

$$\begin{gathered}(TF1 < F1) \\ \text{or } (TF2 < F4 \text{ and } TF1 > F2) \\ \text{or } (TF2 \geq F4 \text{ and } TF1 > F3)\end{gathered}$$

Icing Test: An icing event occurs when ice collects on a sensor and degrades its performance. Icing events are characterized by the simultaneous measurements of near-zero standard deviation of wind direction, non-zero wind speed, and near- or below-freezing temperatures. Wind speed, wind speed standard deviation, wind direction, and wind direction standard deviation data values are flagged if the wind direction standard deviation (CF1) is less than or equal to Factor 1 (F1), the wind speed (TF1) is greater than Factor 2 (F2), and the temperature (CF2) is less than Factor 3 (F3). To exit an icing event, the wind direction standard deviation must be greater than Factor 4.

$$CF1 \leq F1 \text{ and } TF1 > F2 \text{ and } CF2 < F3$$

CompareSensors Test: Where primary and redundant sensors are used, it is possible to determine when one of the sensors is not performing properly. For anemometers, poor performance is characterized by low data values. Therefore, if one sensor of the pair reports values significantly below the other, the low values are flagged. At low wind speeds (Test Fields 1 and 2 less than or equal to Factor 3) wind speed data are flagged if the absolute difference between the two wind speeds is greater than Factor 1. At high wind speeds (Test Fields 1 or 2 greater than Factor 3) wind speed data are flagged if the absolute value of the ratio of the two wind speeds is greater is greater than Factor 2.

$$\begin{gathered}[\ TF1 \leq F3 \text{ and } TF2 \leq F3 \text{ and } \mathrm{abs}(TF1 - TF2) > F1\ ] \\ \text{or } [\ (TF1 > F3 \text{ or } TF2 > F3) \text{ and } (\mathrm{abs}(1 - TF1 / TF2) > F2 \text{ or } \mathrm{abs}(1 - TF2 / TF1) > F2)\ ]\end{gathered}$$

Additional Data Test: Standard Deviation Filter

In addition to the standard QA tests that are defined above, another data filter was defined to eliminate instances of erroneous wind speed measurements based on the presence of uncharacteristically high values of standard deviation. The motivation behind the definition of the standard deviation data filter criterion is demonstrated by inspection of Figure 7 where standard deviation data from a nearby meteorological tower (Thompson Island) is juxtaposed with those of the data that are collected at the WBZ tower. Figure 7 demonstrates the expected behavior of the standard deviation as wind speed increases and the actual behavior of the standard deviation observed at the WBZ tower.

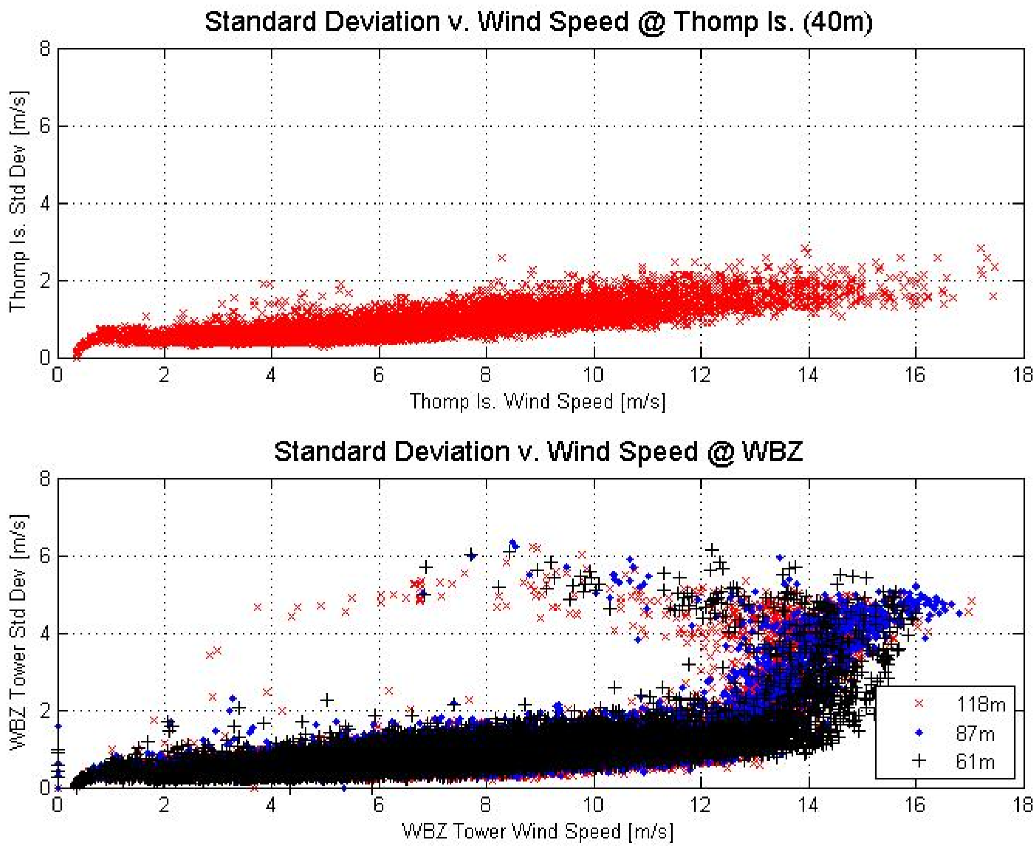

Figure 7: Standard Deviation Comparison Before Standard Deviation Filtering

After the data have been filtered to remove the records that contain spurious standard deviation measurements, the behavior of the standard deviation at the WBZ tower appear as shown in Figure 8. The standard deviation data filter removes data based on a linear cut-off criterion. This feature removes wind data records whenever abnormally large standard deviation measurements are recorded.

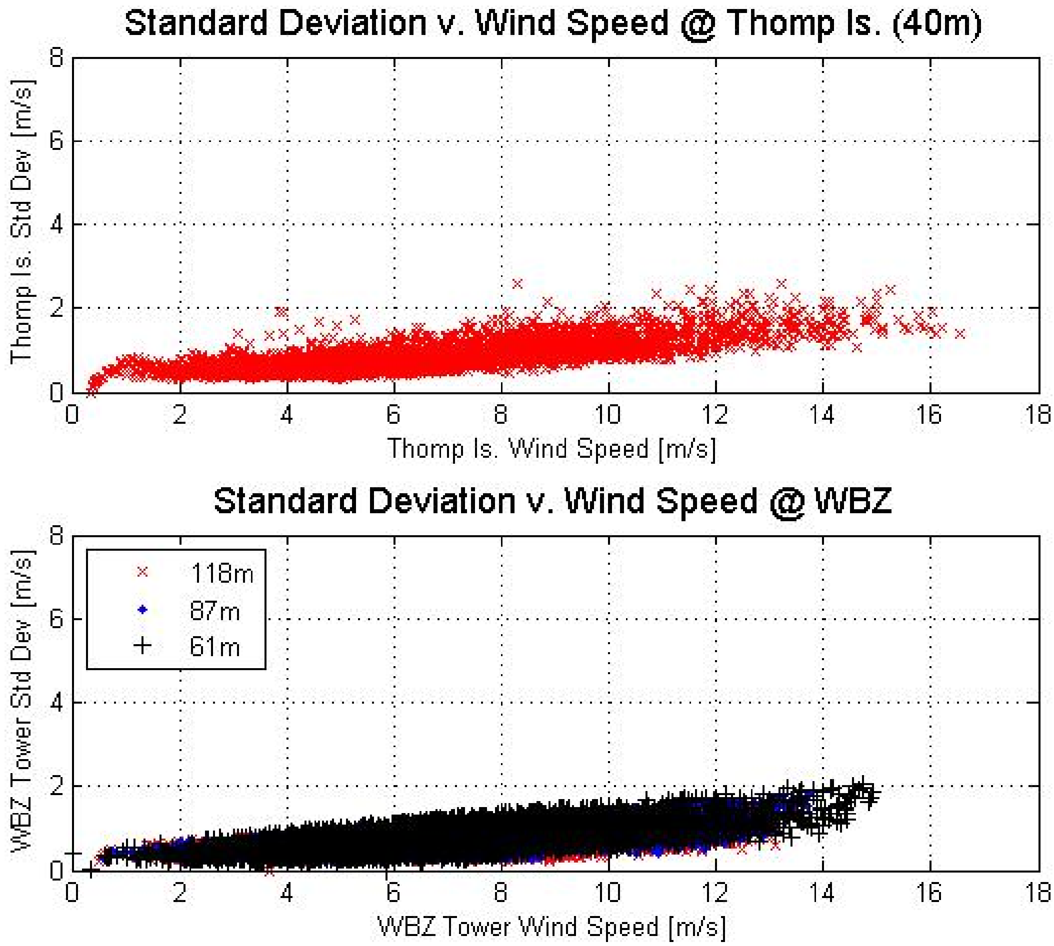

Figure 8: Standard Deviation Comparison After Standard Deviation Filtering

The standard deviation data filter and the standard QA tests ensure that the most accurate data are presented in this report.

Sensor Statistics

A summary of the results of the data collection and filtering are given in the Sensor Performance Report which is included in APPENDIX A. The following categories of information, tabulated for each sensor, are included in that report.

Expected Data Points: the total number of sample intervals between the start and end dates (inclusive).

Actual Data Points: the total number of data points recorded between the start and end dates.

% Data Recovered: the ratio of actual and expected data points (this is the *gross data recovered percentage*).

Hours Out of Range: total number of hours for which data were flagged according to MinMax and MinMaxT tests. These tests flag data which fall outside of an expected range.

Hours of Icing: total number of hours for which data were flagged according to Icing tests. This test uses the standard deviation of wind direction, air temperature, and wind speed to determine when sensor icing has occurred.

Hours of Fault: total number of hours for which data were flagged according to CompareSensors tests. These tests compare two sensors (e.g. primary and redundant anemometers installed at the same height) and flag data points where one sensor differs significantly from the other.

% Data Good: the filter results are subtracted from the gross data recovery percentage to yield the *net data recovered percentage*.

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
2	ETemp2DEGC					MinMax	-25	40	0	0
3	ETempSD2 DEGC					MinMax	-25	40	0	0
4	ETemp118 DEGC					MinMax	-25	40	0	0
5	ETempSD118 DEGC					MinMax	-25	40	0	0
6	ITtemp2aDEGC					MinMax	-25	40	0	0
7	Batt1aV					MinMax	5	14	0	0
8	Batt1bV					MinMax	5	14	0	0
10	Anem118aMS					MinMax	0	90	0	0
11	Anem118bMS					MinMax	0	90	0	0
12	Anem87aMS					MinMax	0	90	0	0
13	Anem87bMS					MinMax	0	90	0	0
14	Anem61aMS					MinMax	0	90	0	0
15	Anem61bMS					MinMax	0	90	0	0
16	Anem118yMS					MinMax	0	90	0	0
17	Anem87yMS					MinMax	0	90	0	0
18	Anem61yMS					MinMax	0	90	0	0
20	AnemSD118a MS					MinMax	0	4	0	0
21	AnemSD118b MS					MinMax	0	4	0	0
22	AnemSD87aMS					MinMax	0	4	0	0
23	AnemSD87bMS					MinMax	0	4	0	0
24	AnemSD61aMS					MinMax	0	4	0	0
25	AnemSD61bMS					MinMax	0	4	0	0
26	AnemSD118y MS					MinMax	0	4	0	0
27	AnemSD87yMS					MinMax	0	4	0	0
28	AnemSD61yMS					MinMax	0	4	0	0
30	Vane118aDEG					MinMax	0	359.9	0	0
31	Vane87aDEG					MinMax	0	359.9	0	0
32	Vane61aDEG					MinMax	0	359.9	0	0
50	Turb118zNONE					MinMax	0	2	0	0
51	Turb87zNONE					MinMax	0	2	0	0
52	Turb61zNONE					MinMax	0	2	0	0
70	Pwrd118zWMS					MinMax	0	5000	0	0
71	Pwrd87zWMS					MinMax	0	5000	0	0
72	Pwrd61zWMS					MinMax	0	5000	0	0
200	VaneSD118a DEG	Anem118yMS				MinMaxT	0	100	100	10
201	VaneSD87a DEG	Anem87yMS				MinMaxT	0	100	100	10

Test Definitions, continued

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
202	VaneSD61a DEG	Anem61yMS				MinMax	0	100	100	10
300	Anem118aMS	AnemSD118aMS	Vane118a DEG	VaneSD118a DEG	ETemp2 DEGC	Icing	0.5	1	2	10
301	Anem118bMS	AnemSD118bMS	Vane118a DEG	VaneSD118a DEG	ETemp2 DEGC	Icing	0.5	1	2	10
302	Anem87aMS	AnemSD87a MS	Vane87aDEG	VaneSD87a DEG	ETemp2 DEGC	Icing	0.5	1	2	10
303	Anem87bMS	AnemSD87b MS	Vane87aDEG	VaneSD87a DEG	ETemp2 DEGC	Icing	0.5	1	2	10
304	Anem61aMS	AnemSD61a MS	Vane61aDEG	VaneSD61a DEG	ETemp2 DEGC	Icing	0.5	1	2	10
305	Anem61bMS	AnemSD61b MS	Vane61aDEG	VaneSD61a DEG	ETemp2 DEGC	Icing	0.5	1	2	10
400	Anem118aMS	Anem118bMS				Compare Sensors	1	0.25	3	0
401	Anem87aMS	Anem87bMS				Compare Sensors	1	0.25	3	0
402	Anem61aMS	Anem61bMS				Compare Sensors	1	0.25	3	0
500	Wshr0zNONE					MinMax	-100	100	0	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	% Data Good
ITtemp2aDEGC	13104	13104	100	0	100
Vane118aDEG	13104	11776	89.866	0.333	89.85
Vane87aDEG	13104	11770	89.82	0.5	89.797
Vane61aDEG	13104	13104	100	0.333	99.985
ETemp2DEGC	13104	13104	100	0	100
ETempSD2DEGC	13104	13104	100	0	100
ETemp118DEGC	13104	13104	100	0	100
ETempSD118DEGC	13104	13104	100	0	100
Batt1aV	13104	13104	100	0	100
Anem118aMS	13104	11776	89.866	0	89.866
AnemSD118aMS	13104	11776	89.866	0	89.866
Anem118bMS	13104	11776	89.866	0	89.866
AnemSD118bMS	13104	11776	89.866	0	89.866
Anem87aMS	13104	11770	89.82	0	89.82
AnemSD87aMS	13104	11770	89.82	0	89.82
Anem87bMS	13104	11770	89.82	0	89.82
AnemSD87bMS	13104	11770	89.82	0	89.82
Anem61aMS	13104	12144	92.674	0	92.674
AnemSD61aMS	13104	12144	92.674	0	92.674
Anem61bMS	13104	12144	92.674	0	92.674
AnemSD61bMS	13104	12144	92.674	0	92.674
XPwrV	13104	13104	100	0	100
XPwrMinV	13104	13104	100	0	100
Total	301392	284242	94.31	1.167	94.307

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent Time [%]
0.5	1.14
1.5	3.04
2.5	5.17
3.5	8.21
4.5	9.44
5.5	12.67
6.5	13.25
7.5	12.58
8.5	12.52
9.5	10.08
10.5	6.78
11.5	4.12
12.5	0.89
13.5	0.11
14.5	0
15.5	0
16.5	0
17.5	0
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Sept 2006	6.67
Oct	7.63
Nov	7.26
Dec	7.72
Jan 2007	7.58
Feb	7.55
Mar	8.17
Apr	7.23
May	6.80
Jun	6.60
Jul	5.88
Aug	6.14
Sept	6.61
Oct	6.39
Nov	7.25

Diurnal Average Wind Speed Data

hr	Mean Wind Speed [m/s]
0.5	7.1
1.5	7.09
2.5	7.02
3.5	7.12
4.5	7
5.5	6.96
6.5	6.98
7.5	7.05
8.5	6.98
9.5	6.5
10.5	6.01
11.5	5.83
12.5	5.73
13.5	5.89
14.5	6.01
15.5	6.02
16.5	6.51
17.5	6.71
18.5	6.84
19.5	6.89
20.5	7.09
21.5	7.27
22.5	7.31
23.5	7.31

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent Time [%]
N	5.59	3.54
NNE	6.06	3.58
NE	5.7	5.16
ENE	6.37	5.18
E	5.3	3.52
ESE	4.61	2.85
SE	5.04	3.07
SSE	6.1	4.32
S	6.54	6.09
SSW	7.48	9.24
SW	7.82	15.57
WSW	7.16	6.73
W	7.26	7.84
WNW	6.97	7.76
NW	7.04	9.64
NNW	6.33	5.89