WIND DATA REPORT

Eastham

September 1, 2003 – November 30, 2003

Prepared for

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by

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EXECUTIVE SUMMARY

Wind monitoring equipment was first installed in Eastham on July 17, 2003. Anemometers and wind direction vanes are installed at 30 and 39 m above the tower base. There is an additional anemometer at 10 m. Data cards have been exchanged four times to date.

This data report is the second written since the installation and it summarizes the wind data collected between September 1 and November 30. This is the first full quarter since the tower installation. The mean recorded wind speed was 5.07 m/s (11.34 mph) at 39 m and the prevailing wind direction was from the south. The average wind shear factor of 0.53 is much greater than the rule-of-thumb value 0.14 (the shear factor is calculated from data from the 39 m and 30 m anemometers). The average turbulence intensity at 39 m was 0.21, well within the normal values recorded at other sites in eastern MA. The turbulence intensity at 10 m was 0.42, possibly the result of low wind speeds at that height.

The gross data recovery percentage (the actual percentage of expected data received) was 100% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 99.709%. Both of these percentages are very high, indicating that the sensors and data logger were performing well.

SECTION 1 - Station Location

The Eastham, MA station is located on town land next to privately owned dirt piles and a cell phone tower. Small (15-25 ft) pine trees surround the site to the north, west, and south. Several trees were removed to create a clearing for the tower. The location of the tower base is 41^0- 52.026' North, 069^0- 58.922' West.

Figure 1 – Map of Eastham site.

Source: www.topozone.com.

SECTION 2 - Instrumentation and Equipment

Wind monitoring equipment is mounted on a standard NRG 40m tall 6in diameter tilt-up guyed tower. Wind vanes and anemometers are located at three heights on the tower: 10m, 30m, and 39m. Redundant anemometers exist at 30m and 39m. Additional equipment and models:

- NRG model Simphonie Cellogger®
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s)
- 3 - #200P Wind direction vanes
- 3 – Sensor booms, 54" length
- Lightning rod and grounding cable
- Shielded sensor wire

Figure 2 – 40m data tower in Eastham during installation.

SECTION 3 - Data Collection and Maintenance

There are no problems to report with data collection and no maintenance was performed during this period. On two occasions since the last report, data cards were manually removed from the logger by Fred Fenlon and mailed to staff at RERL.

Data Statistics Summary

	Anemometer 39m			Anemometer 30m			Anemometer 10m			30m to 39m	Vane 39m	Vane 30m
Date	Mean [m/s]	Max [m/s]	Turb. Int. [ ]	Mean [m/s]	Max [m/s]	Turb. Int. [ ]	Mean [m/s]	Max [m/s]	Turb. Int. [ ]	Shear [ ]	Prev. Dir	Prev. Dir
Sep 2003	4.16	10.32	0.2	3.65	9.42	0.24	1.82	6.07	0.45	0.52	NNE	NNE
Oct 2003	5.3	15.24	0.21	4.62	14.07	0.24	2.41	9.49	0.42	0.56	SSE	SSE
Nov 2003	5.73	17.05	0.22	5.05	14.86	0.25	2.83	9.88	0.4	0.50	W	W
Sep 01 – Nov 30	5.07	17.05	0.21	4.44	14.86	0.24	2.36	9.88	0.42	0.53	SSW	SSW

SECTION 4 - Significant Meteorological Events

There was only one significant meteorological events that occurred between September 30, 2003 and November 30, 2003 in Eastham. On Thursday November 13 strong winds hit much of the northeast. The winds gusted to more than 70 mph in places on Thursday and gusts as high as 45 mph swept over some areas Friday. This wind storm is visible in the wind time series plot during this period.

In general, September and November were slightly warmer and had less precipitation than usual and October was slightly cooler and wetter than usual, but no extreme events took place. There was a new record for precipitation on October 29th (1.49") (www.erh.noaa.gov/box/MonthlyClimate2.shtml).

SECTION 5 - 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. 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 [%]	100.0
Net Data Recovered [%]	99.709

Test Definitions

All raw data were subjected to a series of 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.

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

Icing Test: An icing event is 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, the wind speed (TF1) is greater than Factor 2, and the temperature (CF2) is less than Factor 3.

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

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.

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

Sensor Statistics

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*.

SECTION 6 - Data Summary

This report contains the following types of wind data graphs:

- Time Series – 10-minute average wind speeds are plotted against time.
- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The distribution peak occurs between 4 and 5 m/s.
- 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. With four months of complete data September shows the lowest average and November the highest. This is consistent with trends seen in other parts of the state.
- Diurnal – A plot of the average wind speed for each hour of the day. This site has a fairly even diurnal distribution, with a slight increase in wind speeds at midday.
- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed. Turbulence Intensity is calculated as the standard deviation of the wind speed divided by the wind speed and is a measure of the gustiness of a wind resource. Lower turbulence results in lower mechanical loads on a wind turbine. The average turbulence intensity was at 39m was 0.21, similar to other sites in eastern MA.
- 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. This graph shows a very even distribution with no clear prevailing direction.

SECTION 7 - Graphs

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

Wind Speed Time Series

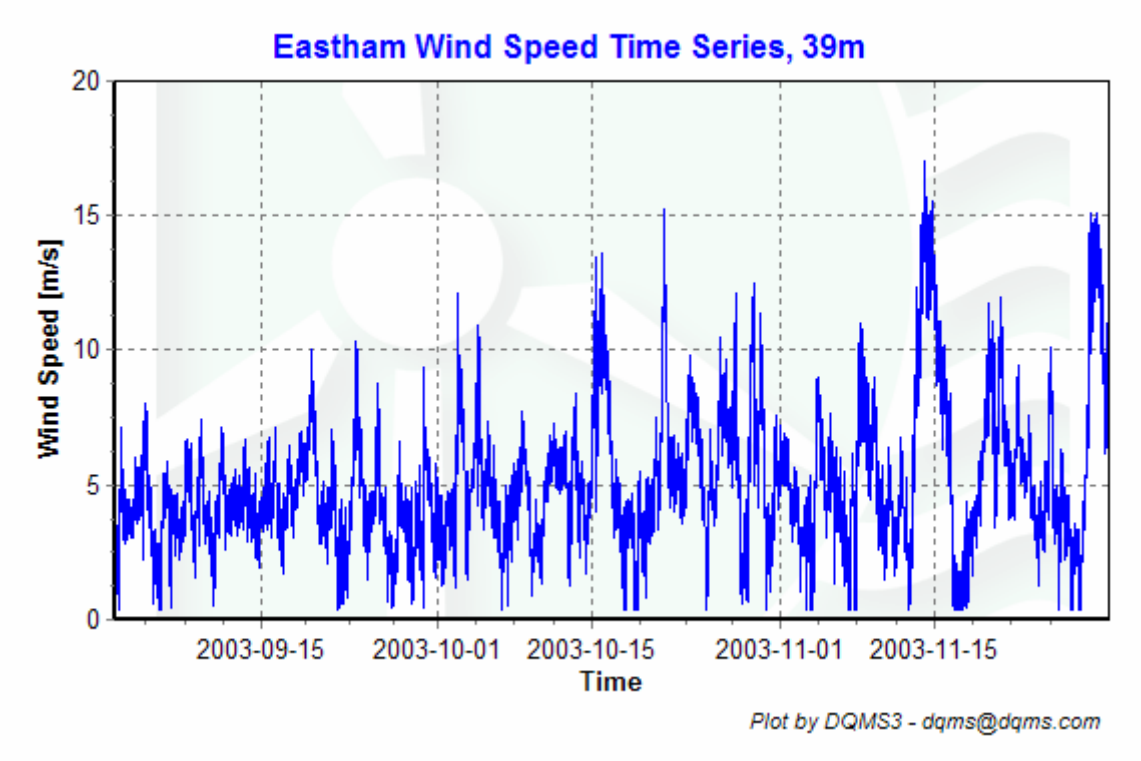

Figure 3 – Wind Speed Time Series, September 1, 2003 – November 30, 2003

Wind Speed Distributions

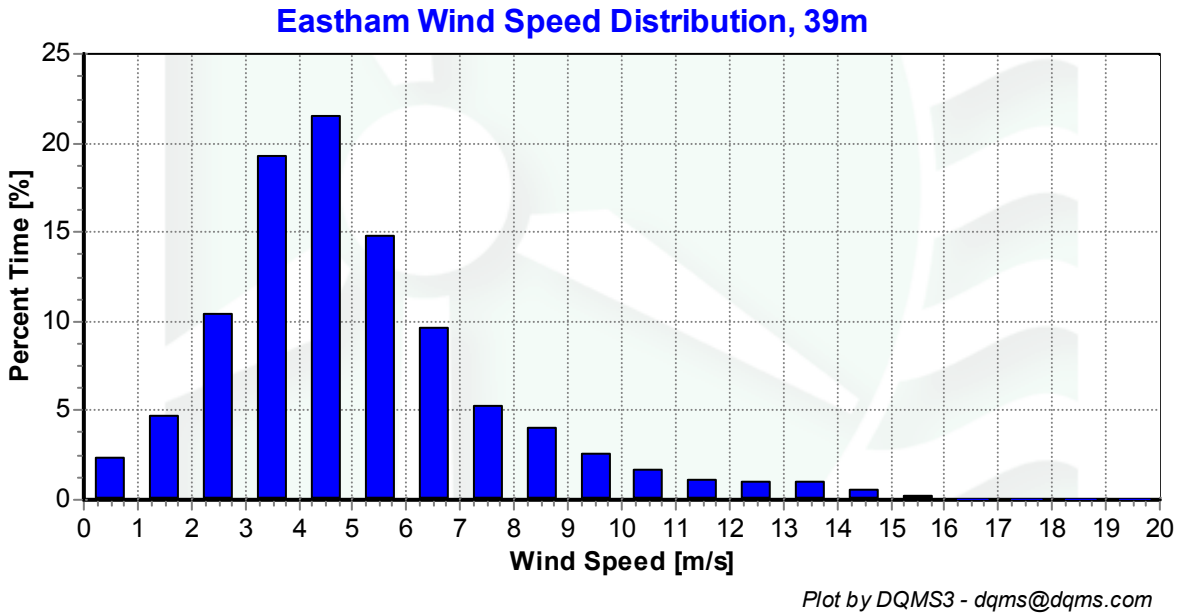

Figure 4 – Wind Speed Distribution, September 1, 2003 – November 30, 2003

Monthly Average Wind Speeds

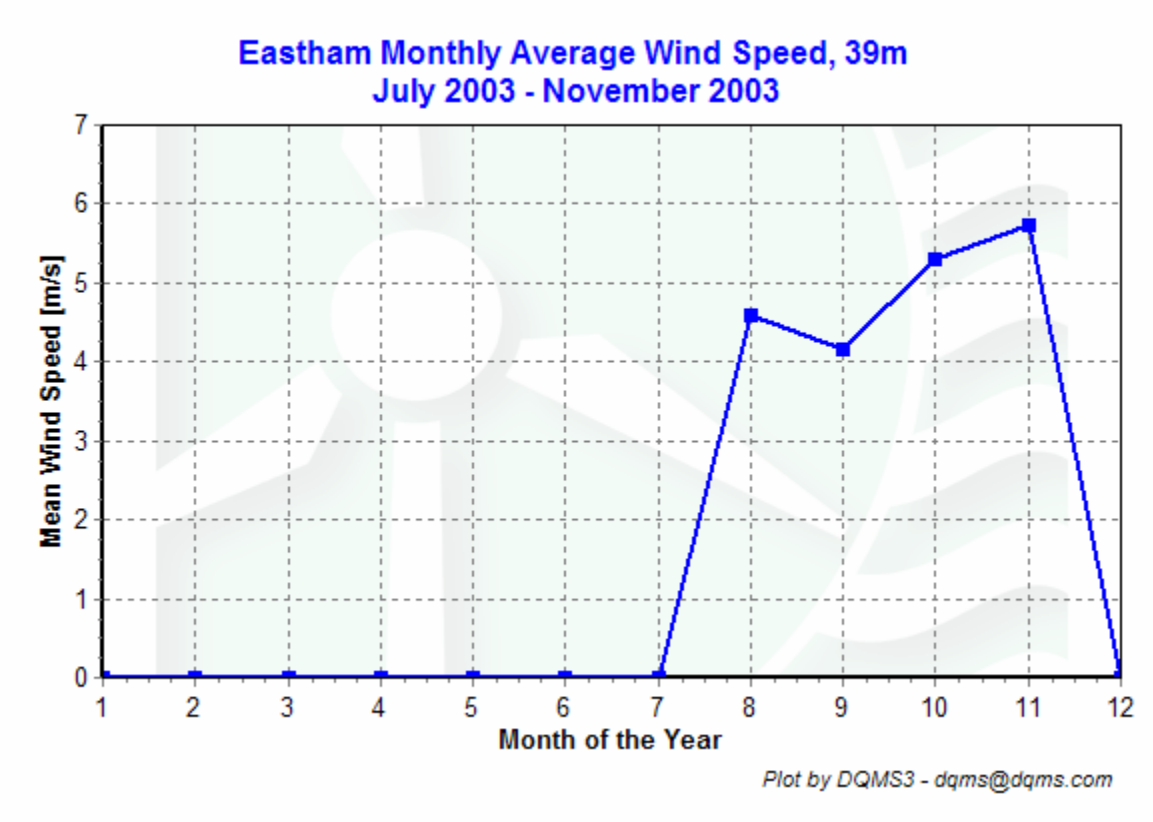

Figure 5 – Monthly Ave Wind Speed

Diurnal Average Wind Speeds

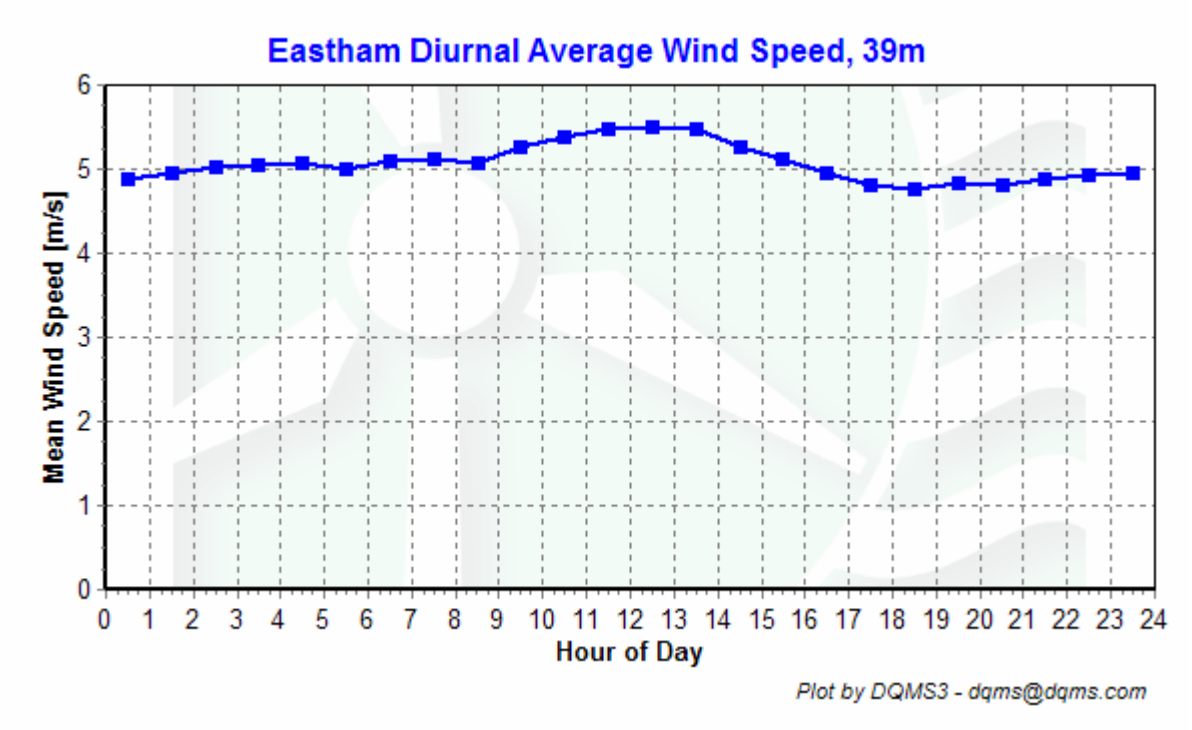

Figure 6 – Diurnal Wind Speed, September 1, 2003 – November 30, 2003

Turbulence Intensities

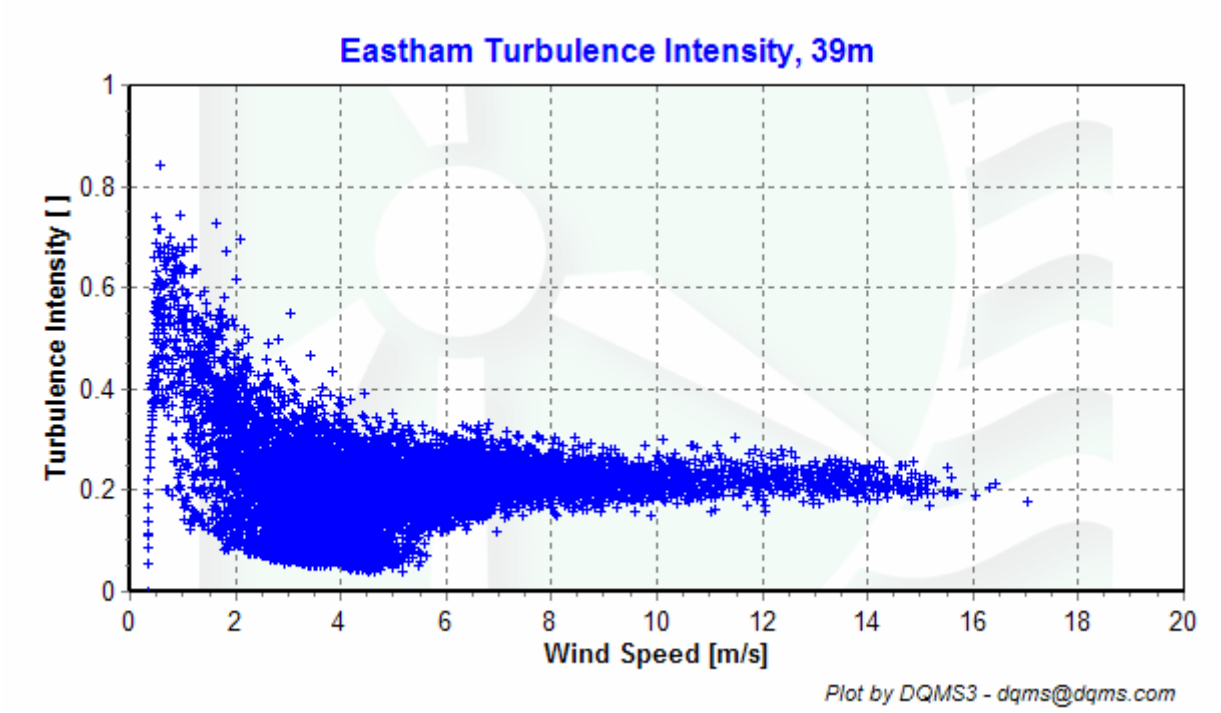

Figure 7 – Turbulence Intensity vs Wind Speed, September 1, 2003 – November 3, 2003

Wind Roses

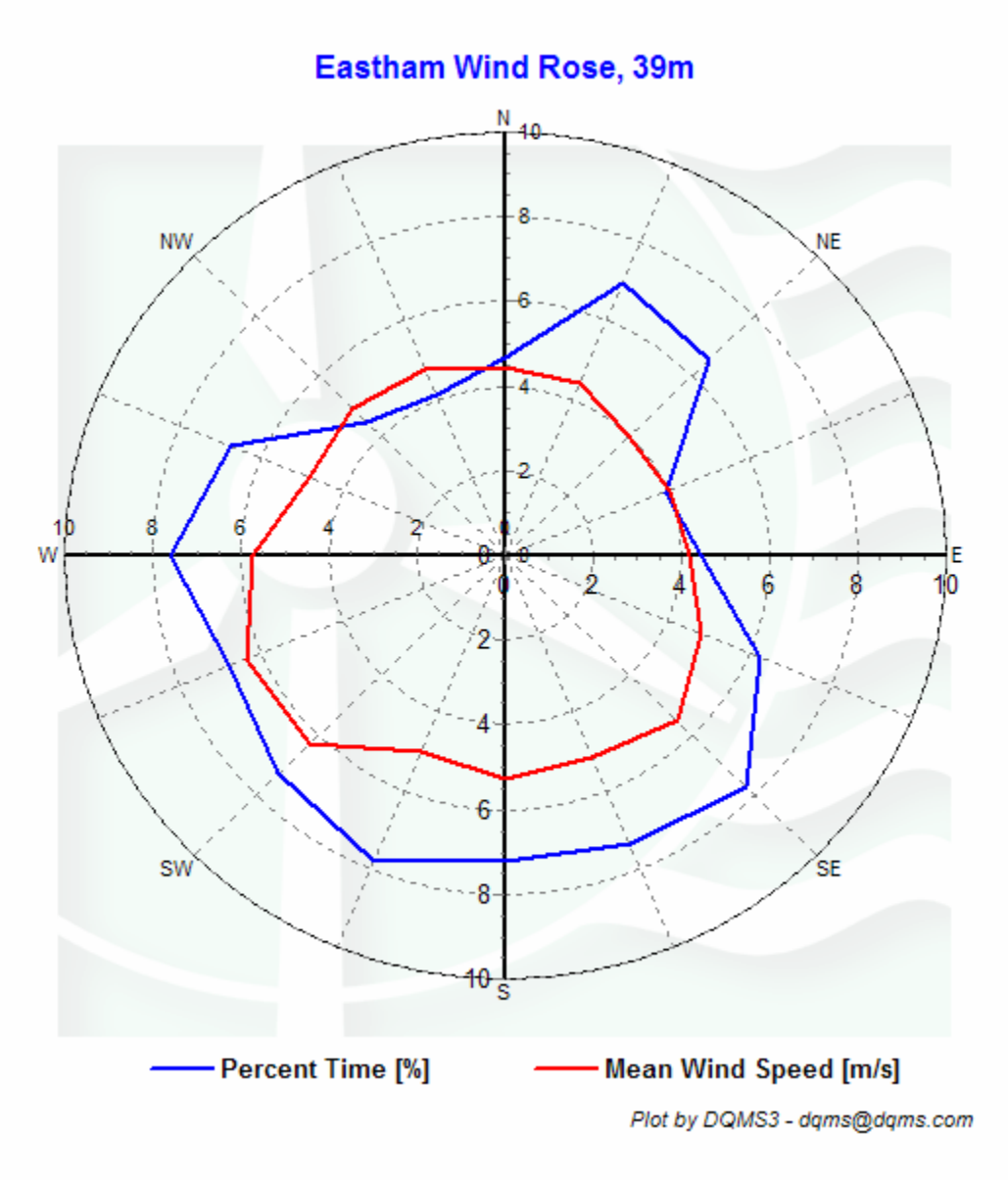

Figure 8 – Wind Rose, September 1, 2003 – November 30, 2003

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	Test Field1	Test Field2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor 1	Factor 2	Factor 3	Factor 4
1							TimeTest Insert				
4	Etmp2aDEGC						MinMax	-30	60		
5	EtmpSD2aDEGC						MinMax	-30	60		
10	Anem10aMS						MinMax	0	90		
11	Anem30aMS						MinMax	0	90		
12	Anem30bMS						MinMax	0	90		
13	Anem39aMS						MinMax	0	90		
14	Anem39bMS						MinMax	0	90		
15	Anem30yMS						MinMax	0	90		
16	Anem39yMS						MinMax	0	90		
20	AnemSD10aMS						MinMax	0	4		
21	AnemSD30aMS						MinMax	0	4		
22	AnemSD30bMS						MinMax	0	4		
23	AnemSD39aMS						MinMax	0	4		
24	AnemSD39bMS						MinMax	0	4		
30	Vane10aDEG						MinMax	0	359.9		
31	Vane30aDEG						MinMax	0	359.9		
32	Vane39aDEG						MinMax	0	359.9		
50	Turb10zNONE						MinMax	0	2		
51	Turb30zNONE						MinMax	0	2		
52	Turb39zNONE						MinMax	0	2		
60	Wshr0zNONE						MinMax	-100	100		
200	VaneSD10aDEG	Anem10aMS					MinMaxT	0	100	100	10
201	VaneSD30aDEG	Anem30yMS					MinMaxT	0	100	100	10
202	VaneSD39aDEG	Anem39yMS					MinMaxT	0	100	100	10
300	Anem10aMS	AnemSD10aMS	Vane10aDEG	VaneSD10aDEG	Etmp2aDEGC		Icing	0.5	1	2	
301	Anem30aMS	AnemSD30aMS	Vane30aDEG	VaneSD10aDEG	Etmp2aDEGC		Icing	0.5	1	2	
302	Anem30bMS	AnemSD30bMS	Vane30aDEG	VaneSD30aDEG	Etmp2aDEGC		Icing	0.5	1	2	
303	Anem39aMS	AnemSD39aMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC		Icing	0.5	1	2	
304	Anem39bMS	AnemSD39bMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC		Icing	0.5	1	2	
400	Anem30aMS	Anem30bMS					CompareSensors	1	0.25	3	0
401	Anem39aMS	Anem39bMS					CompareSensors	1	0.25	3	0
500	Amax10aMS						MinMax	0	90		
501	Amin10aMS						MinMax	0	90		
502	Amax30aMS						MinMax	0	90		
503	Amin30aMS						MinMax	0	90		
504	Amax30bMS						MinMax	0	90		
505	Amin30bMS						MinMax	0	90		
506	Amax39aMS						MinMax	0	90		
507	Amin39aMS						MinMax	0	90		
508	Amax39bMS						MinMax	0	90		
509	Amin39bMS						MinMax	0	90		
540	Vmax10aDEG						MinMax	0	359.9		
541	Vmin10aDEG						MinMax	0	359.9		
542	Vmax30aDEG						MinMax	0	359.9		
543	Vmin30aDEG						MinMax	0	359.9		
544	Vane39aDEG						MinMax	0	359.9		
560	Emax2aDEGC						MinMax	-30	60		

Test Order	Test Field1	Test Field2	Test Field3	Calc Field1	Calc Field2	Calc Field3	TestType	Factor 1	Factor 2	Factor 3	Factor 4
561	Emin2aDEGC						MinMax	-30	60		
562	Vmax39aDEG						MinMax	0	360		
563	Vmin39aDEG						MinMax	0	360		
564	Pwrd10zWMC						MinMax	0	500		
565	Pwrd30zWMC						MinMax	0	500		
566	Pwrd39zWMC						MinMax	0	500		

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem39aMS	13104	13104	100	0	2.667	0.167	99.87
AnemSD39aMS	13104	13104	100	0	2.667	0.167	99.87
Anem39bMS	13104	13104	100	0	3.167	0	99.855
AnemSD39bMS	13104	13104	100	0	3.167	0	99.855
Vane39aDEG	13104	13104	100	0.333	3.167	0	99.84
VaneSD39aDEG	13104	13104	100	0.333	3.167	0	99.84
Anem30aMS	13104	13104	100	0	19.333	0	99.115
AnemSD30aMS	13104	13104	100	0	19.333	0	99.115
Anem30bMS	13104	13104	100	0	2.167	0	99.901
AnemSD30bMS	13104	13104	100	0	2.167	0	99.901
Anem10aMS	13104	13104	100	0	0	0	100
AnemSD10aMS	13104	13104	100	0	0	0	100
Vane10aDEG	13104	13104	100	0.5	19.333	0	99.092
VaneSD10aDEG	13104	13104	100	0.5	19.333	0	99.092
Etmp2aDEGC	13104	13104	100	0	0	0	100
EtmpSD2aDEGC	13104	13104	100	0	0	0	100
Total	209664	209664	100	1.667	99.667	0.333	99.709

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent
0.5	2.34
1.5	4.69
2.5	10.4
3.5	19.29
4.5	21.52
5.5	14.82
6.5	9.62
7.5	5.24
8.5	3.98
9.5	2.53
10.5	1.69
11.5	1.14
12.5	0.98
13.5	0.97
14.5	0.57
15.5	0.18
16.5	0.02
17.5	0.01
18.5	0
19.5	0
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table B1: Wind Speed Distribution

Diurnal Average Wind Speed Data

Hour of Day	Wind Speed [m/s]
0	4.88
1	4.96
2	5.03
3	5.04
4	5.07
5	5.00
6	5.09
7	5.11
8	5.07
9	5.27
10	5.39
11	5.46
12	5.51
13	5.47
14	5.26
15	5.11
16	4.96
17	4.81
18	4.76
19	4.83
20	4.82
21	4.88
22	4.92
23	4.94

Table B3: Diurnal Wind Speed

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	4.69	4.44
NNE	6.97	4.43
NE	6.53	3.98
ENE	3.92	4.02
E	4.46	4.18
ESE	6.28	4.83
SE	7.75	5.53
SSE	7.38	5.16
S	7.22	5.29
SSW	7.8	5.03
SW	7.27	6.31
WSW	6.78	6.37
W	7.62	5.74
WNW	6.73	4.81
NW	4.48	4.88
NNW	4.11	4.75

Table B4: Wind Rose Time Percentage and Mean Wind Speed