WIND DATA REPORT

Eastham

December 1, 2003 – February 29, 2004

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 10 m, 30 m, and 39 m above the tower base. Redundant anemometers were installed at the 30 m and 39 m level. Data cards have been exchanged on a monthly basis since the site was commissioned.

This data report is the third written since the installation and it summarizes the wind data collected between December 1, 2003 and February 29, 2004. This is the second full quarter since the tower installation. The mean recorded wind speed was 6.54 m/s (14.63 mph) at 39 m and the prevailing wind direction was from the west. The average wind shear factor of 0.49 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 high shear factor is almost certainly due to the surrounding trees. 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 high at 0.49, 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 99.893%. Both of these percentages are very high, indicating that the sensors and data logger were performing well during this period.

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 40 m tall 6 in diameter tilt-up guyed tower. Wind vanes and anemometers are located at three heights on the tower: 10 m, 30 m, and 39 m. Redundant anemometers exist at 30 m and 39 m. 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. Data cards have been were manually removed from the logger by Fred Fenlon and mailed to staff at RERL at the beginning of each month.

Data Statistics Summary

	Anemometer 39m			Anemometer 30m			Anemometer 10m			30m to 39m	Vane 39m	Vane 30m	Vane 10m
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	Prev. Dir
Dec 2003	7.23	18.11	0.2	6.52	9.63	0.23	3.69	6.17	0.38	0.47	WNW	WNW	WSW
Jan 2004	6.91	14.09	0.22	6.09	8.74	0.25	3.43	5.22	0.41	0.5	W	W	W
Feb 2004	5.48	14.22	0.21	4.84	7.65	0.23	2.68	4.96	0.4	0.51	WNW	WNW	WNW
Dec 03 – Feb 04	6.54	18.11	0.21	5.82	9.63	0.24	3.27	5.45	0.40	0.49	WNW	WNW	W

SECTION 4 - Significant Meteorological Events

A low pressure area formed over the southeastern states on December 5. At the same time, a large arctic high became established over eastern Canada. The storm tracked off the Virginia coastline on December 6, then took a track along the eastern seaboard as a classic nor'easter. The storm interacted with the strong high in eastern Canada, which caused it to move very slowly. It took over a day for the storm to move northeast of Cape Cod, which was not until late December 7. The result was the first major snowstorm of the early winter season across the Berkshires. Nine to 18 inches fell across the Berkshires with Dalton receiving 17 inches.

A low pressure area formed in the Gulf States early on December 14. This storm hugged the coast line as it tracked northward to become the second nor'easter of the winter season. This storm moved a little quicker than its predecessor. In addition, enough warm air moved in aloft to change the snow to sleet and freezing rain, thus reducing snow fall accumulations, especially in southern sections of the county. By the time the storm moved off the New England coastline, 5 to 10 inches of snow had accumulated in Berkshire County. The city of West Otis received 10.5 inches, the most reported in the county. (http://www4.ncdc.noaa.gov)

January began with a week of warm temperatures and rainy days. The entire Northeast was at least 2 degrees above normal from the 1st to the 7th of January, with the majority of the region between 8 and 12 degrees warmer than average during this period. Beginning on the 7th, the continental weather pattern changed drastically and January ended up the 11th coldest on record in the Northeast. Wave after wave of arctic air sank into the region from Canada setting many minimum temperature records at observation sites all over the Northeast. Cold snaps occurred from January 9-11, 13-16, and 24-26 causing pipe bursts across the region and prompting school closures even in the winter-hardy northern New England states. The entire region was more than 4 degrees below normal. Massachusetts recorded the coldest January in that state (16.4 degrees) since records began in 1895, surpassing the old record of 16.7 degrees that had stood since 1981. New York, Rhode Island, and Connecticut all fell more than 7 degrees below their respective normals setting January 2004 among the ten coldest on record in each state. The region as a whole was 5.7 degrees below normal and, at 17.3 degrees, was the coldest month since 1994 and 0.8 degrees colder than last January.

When the region changed from warm to cold after the first week in January, it also went from wet to extremely dry. Many observation sites, especially in the northern half of the region, measured less than a quarter inch of rain/melted snow after the first week. All six New England states were more than 2 inches below the normal amount. Maine, New Hampshire and Vermont averaged only about an inch of precipitation (rain plus the liquid equivalent of snow) making this January one of the five driest on record in those states.. The near continuous fresh snow pack contributed to temperature departures in the 14 to 16 degree below normal range in these areas during the latter part of the month. Overall the Northeast fell more than 1 inch short of its January precipitation total but amazingly this was the wettest January since 2000. The lack of rain and snow this month puts an end to an 8-month streak of wet weather here in the Northeast.

The Northeast was very close to normal in terms of temperature this February. While southern portions of the region were at or slightly below normal this month, the New England states saw a more significant positive temperature departure. Overall, the land-area weighted regional average was 26.0 degrees, or 0.5 degrees above normal. While not a very impressive temperature departure, this month was 4.5 degrees warmer than February 2003. All six New England states were above normal, and all of these except Vermont were more than 1 degree above normal. The general weather pattern this February brought storm systems northward over the Appalachains rather than over the coast, keeping New England on the warm side of the storms. This western storm trend also prevented any deep or prolonged cold snaps from taking hold in the northern states which could potentially have dropped the average temperatures down a notch. New Jersey was the only other state above normal this month, and the remaining 5 states were all within 0.5 degrees of their respective averages. Whether warmer or colder than normal, February temperatures in all 12 states were a welcome change after a bitterly cold January. Many states in the region saw a temperature increase of over 10 degrees from last month to this month. In fact, the region as a whole was 8.7 degrees warmer in February than in January.

One trend that did continue from January was the lack of precipitation across the Northeast (rain and water equivalent of snow). The region's measure of 1.97 inches makes February 2004 the driest since 1991. Rain and snow from two storms early in the month was followed by 20 days of no significant precipitation. High pressure was dominant during this time and the majority of the region received less than 1/2 an inch of rain/melted snow. Large portions of the region didn't see even a quarter of an inch after the 8th of February. This dry period was more extreme in the region's southern states, but early rains in that area seemed to cover for the future lack. Northern states were the most dry overall. Of six states in the region falling more than an inch short of their normal amounts, five were in New England (the sixth was Delaware). New Hampshire and Vermont both totaled less than an inch and a half on the month which was enough to put 2004 among the ten driest on record for both states. West Virginia was the most wet state in the region at 2.98 inches but still failed to reach its average value (precipitation departure: -.13 inches). This February was the first month since January 2003 in which all 12 states in the Northeast were on the dry side of their respective normals. A precipitation total of 1.97 inches is the lowest of any month since November 2001. (http://met-www.cit.cornell.edu/climate/Impacts.html)

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 [%]	99.893

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.

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

Icing Test: An icing event 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.

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

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 nine months of complete data, September shows the lowest average and December 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 39 m 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 a clear prevailing direction from the West.

SECTION 7 - Graphs

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

Wind Speed Time Series

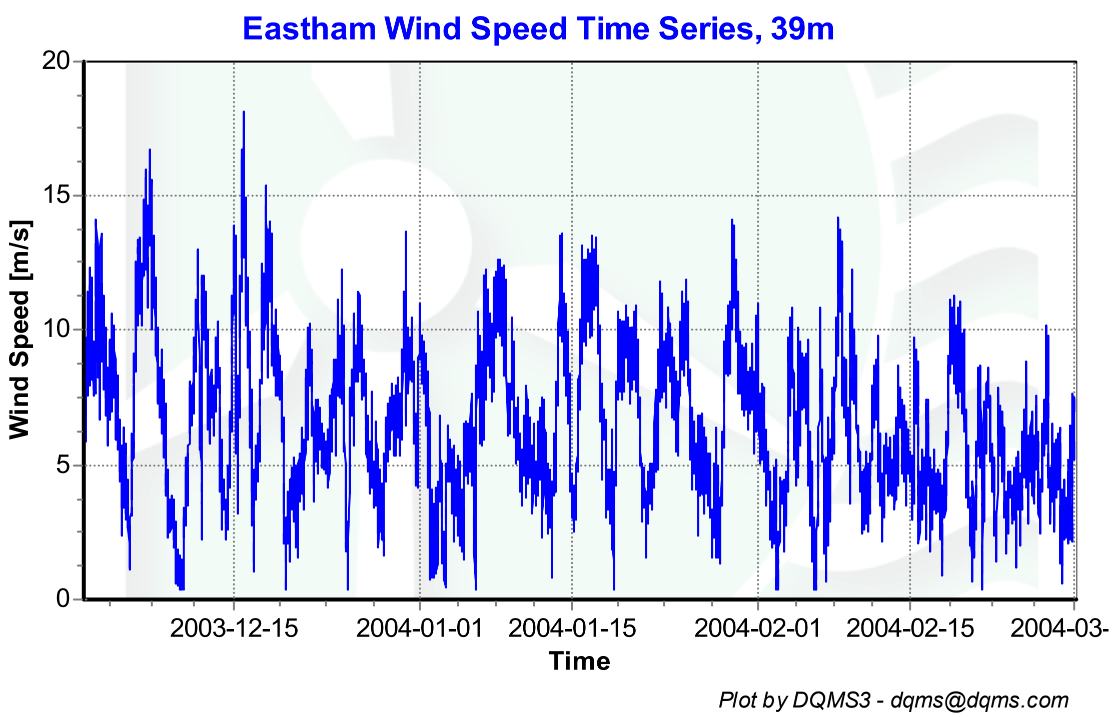

Figure 3 – Wind Speed Time Series, December 1, 2003 – February 29, 2004

Wind Speed Distributions

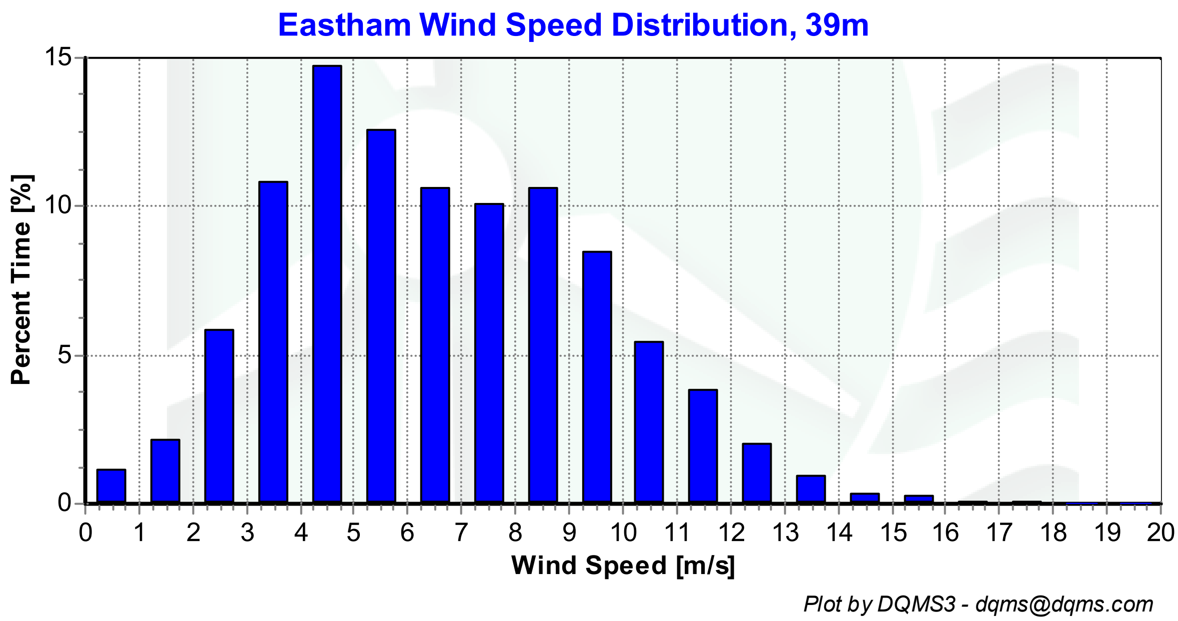

Figure 4 – Wind Speed Distribution, December 1, 2003 – February 29, 2004

<u>**Monthly Average Wind Speeds**</u>

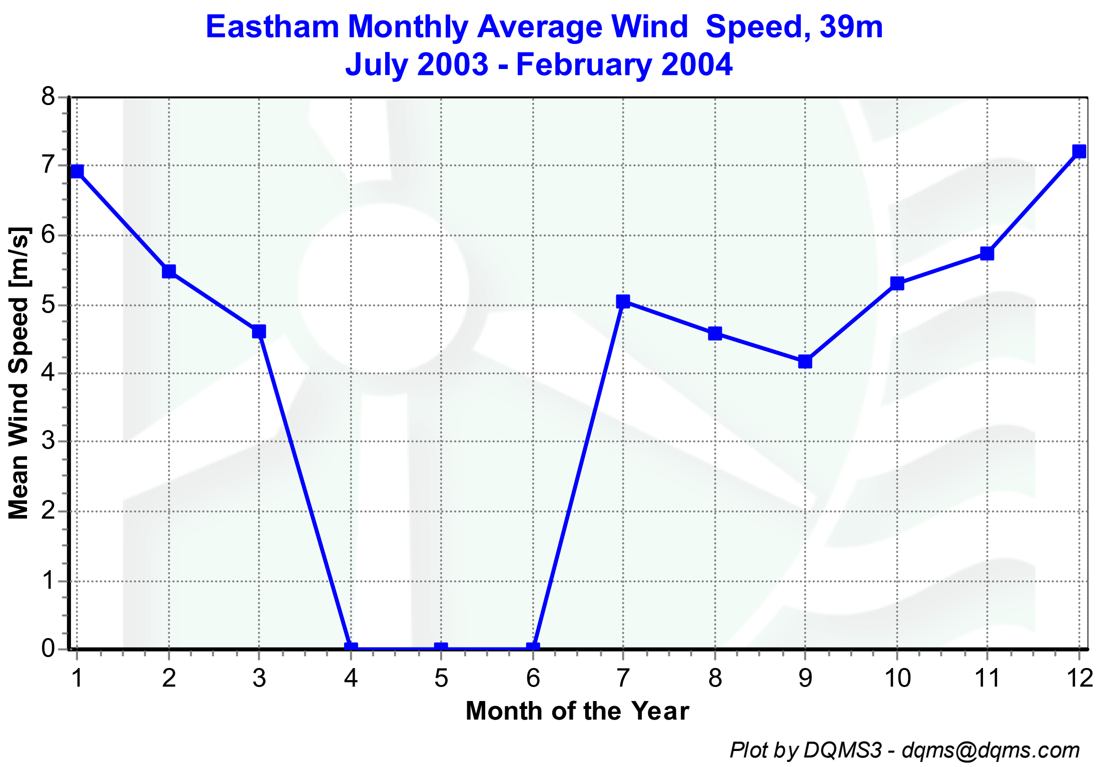

Figure 5 – Monthly Average Wind Speed

Diurnal Average Wind Speeds

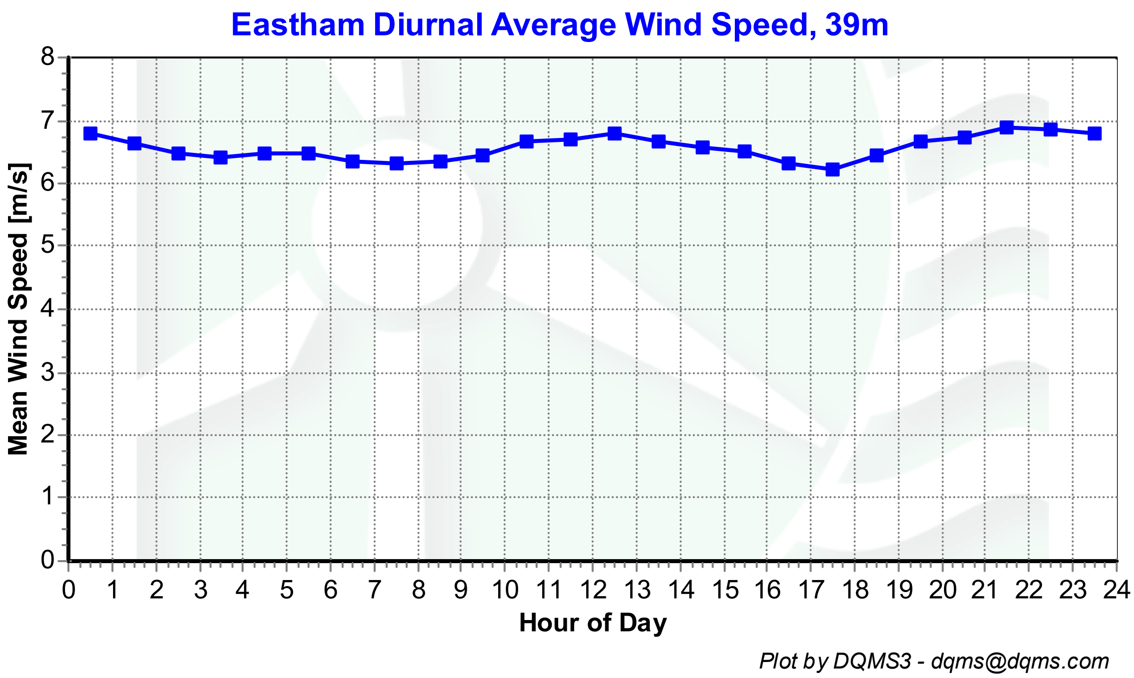

Figure 6 – Diurnal Wind Speed, December 1, 2003 – February 29, 2004

Turbulence Intensities

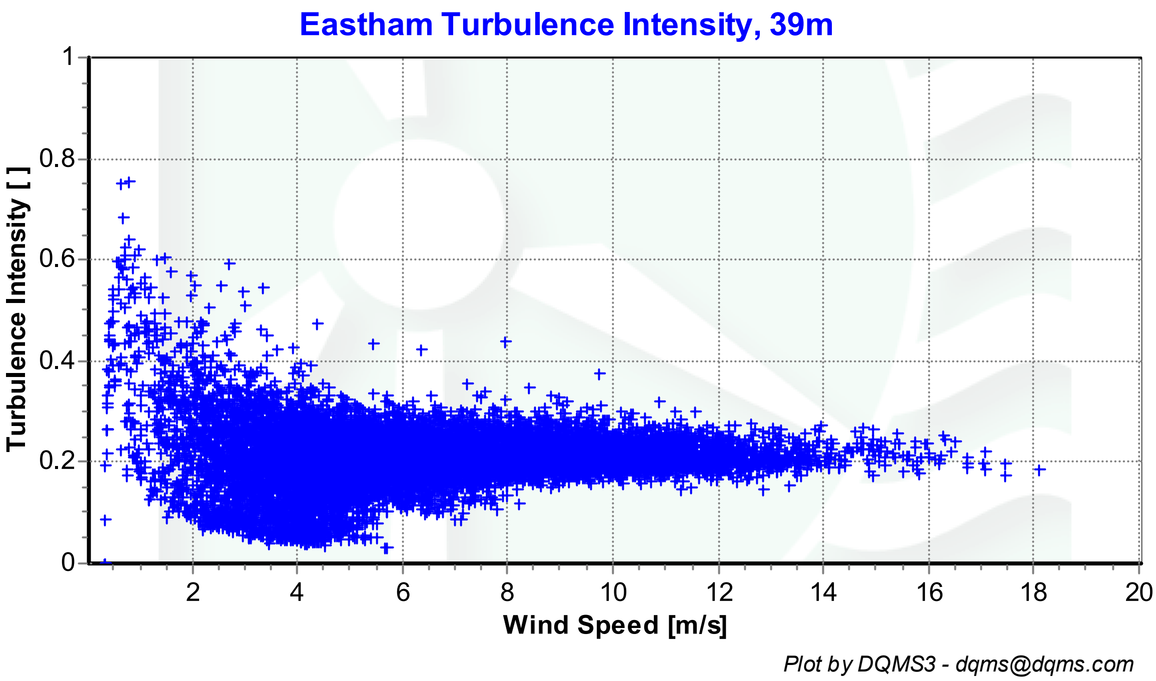

Figure 7 – Turbulence Intensity vs Wind Speed, December 1, 2003 – February 29, 2004

Wind Roses

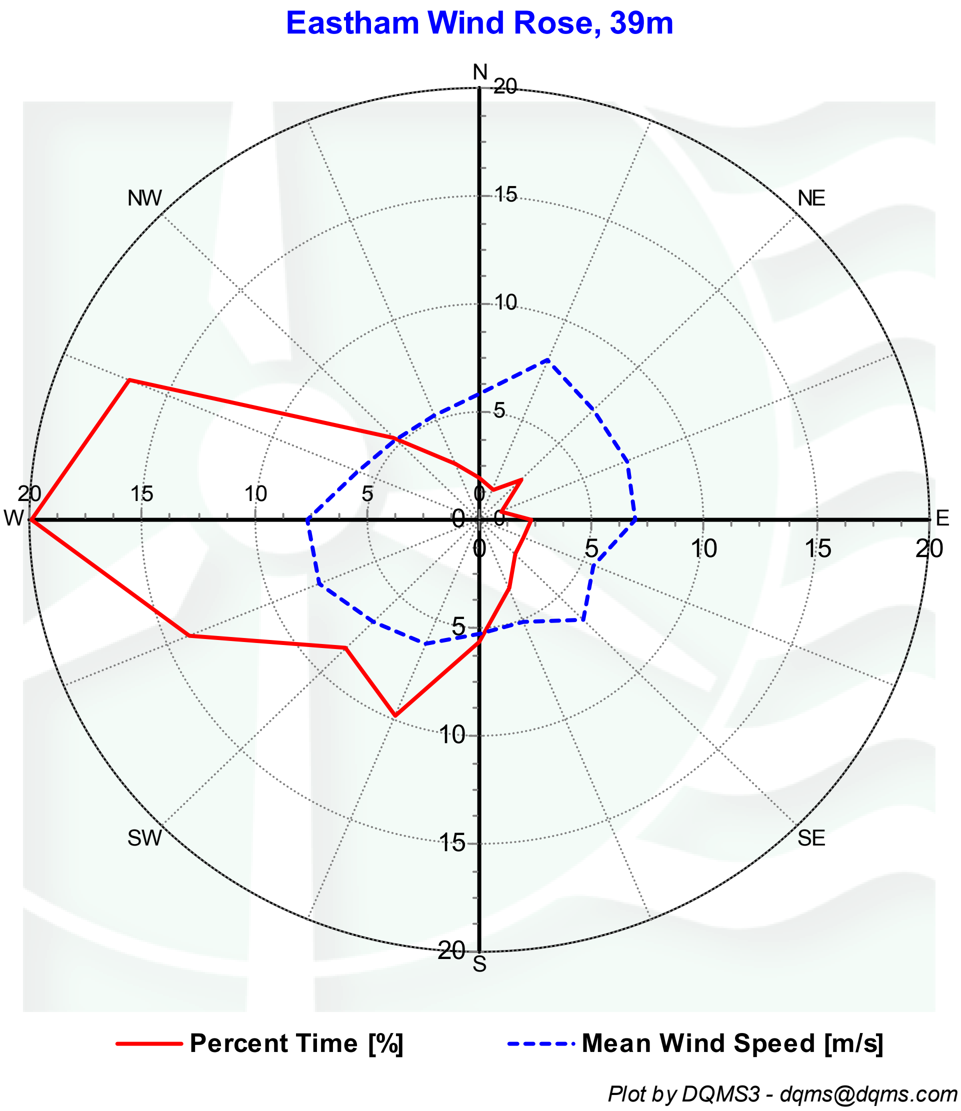

Figure 8 – Wind Rose, December 1, 2003 – February 29, 2004

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	13103	13103	100	0.333	17.5	0.167	99.176
AnemSD39aMS	13103	13103	100	0.333	17.5	0.167	99.176
Anem39bMS	13103	13103	100	0.167	20.5	0	99.054
AnemSD39bMS	13103	13103	100	0.167	20.5	0	99.054
Vane39aDEG	13103	13103	100	0	15.333	0	99.298
VaneSD39aDEG	13103	13103	100	0.167	20.667	0	99.046
Anem30aMS	13103	13103	100	0	62.167	0	97.153
AnemSD30aMS	13103	13103	100	0	62.167	0	97.153
Anem30bMS	13103	13103	100	0	17.667	0.833	99.153
AnemSD30bMS	13103	13103	100	0	17.667	0	99.191
Anem10aMS	13103	13103	100	0	5.667	0	99.741
AnemSD10aMS	13103	13103	100	0	5.667	0	99.741
Vane10aDEG	13103	13103	100	0	39	0	98.214
VaneSD10aDEG	13103	13103	100	0.167	62.167	0	97.146
Etmp2aDEGC	13103	13103	100	0	0	0	100
EtmpSD2aDEGC	13103	13103	100	0	0	0	100
Total	209648	209648	100	1.333	384.167	1.167	98.893

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent
0.5	1.11
1.5	2.17
2.5	5.82
3.5	10.82
4.5	14.71
5.5	12.59
6.5	10.66
7.5	10.08
8.5	10.62
9.5	8.46
10.5	5.48
11.5	3.82
12.5	1.99
13.5	0.91
14.5	0.35
15.5	0.24
16.5	0.1
17.5	0.05
18.5	0.01
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	7.48
1	7.55
2	7.82
3	8.06
4	7.83
5	7.91
6	7.75
7	7.77
8	7.77
9	7.76
10	7.87
11	7.48
12	7.32
13	7.58
14	7.53
15	7.24
16	7.15
17	7.35
18	7.54
19	7.66
20	7.94
21	7.54
22	7.37
23	7.38

Table B3: Diurnal Wind Speed

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	1.32	5.17
NNE	0.94	5.54
NE	2.03	5.36
ENE	2.02	4.8
E	4.47	2.56
ESE	1.92	3.44
SE	2.15	2.97
SSE	3.13	4.4
S	3.08	4.31
SSW	3.28	5.11
SW	4.51	6.19
WSW	5.56	7.43
W	15.47	11.26
WNW	29.5	8.99
NW	18.87	7.44
NNW	1.73	4.64

Table B4: Wind Rose Time Percentage and Mean Wind Speed