WIND DATA REPORT

Upper Cape Cod Regional Technical School
Bourne, MA

March 1, 2005 – May 31, 2005

Prepared for

Massachusetts Technology Collaborative
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by

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NOTICE AND ACKNOWLEDGMENTS

This report was prepared by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst, in the course of performing work sponsored by the Renewable Energy Trust (RET), as administered by the Massachusetts Technology Collaborative (MTC), pursuant to work order number 05-1. The opinions expressed in this report do not necessarily reflect those of MTC or the Commonwealth of Massachusetts, and reference to any specific product, service, process, or method does not constitute an implied or expressed recommendation or endorsement of it.

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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 performed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts, Amherst.

This report covers wind data measured at a meteorological tower installed at the Upper Cape Cod Regional Technical School in Bourne, MA. Installed on July 30, 2004, the wind monitoring station has been in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 50 m (164.1 ft) and 39 m (128.0 ft), and an additional vane and anemometer are mounted at 20 m (65.6 ft).

The season covered by this report is March 2005 – May 2005. The mean recorded wind speed for this quarter was 5.77 m/s (12.92 mph)* and the prevailing wind direction was from the southwest. The gross data recovery percentage (the actual percentage of expected data received) was 100.00 % and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 97.26 %. The high gross recovery indicates that the logger is performing perfectly. However, multiple icing events during this quarter, particularly in April, resulted in the lower net recovery percent.

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 m/s = 2.24 mph

SECTION 1 – Station Location

The Bourne station is located at the Upper Cape Cod Regional Technical School in Bourne, MA. The tower base is located at NAD 27, 41° 44’ 35.9” North, 070° 34’ 25.3” West (Figure 1). The elevation at the station is approximately 130 feet above sea level.

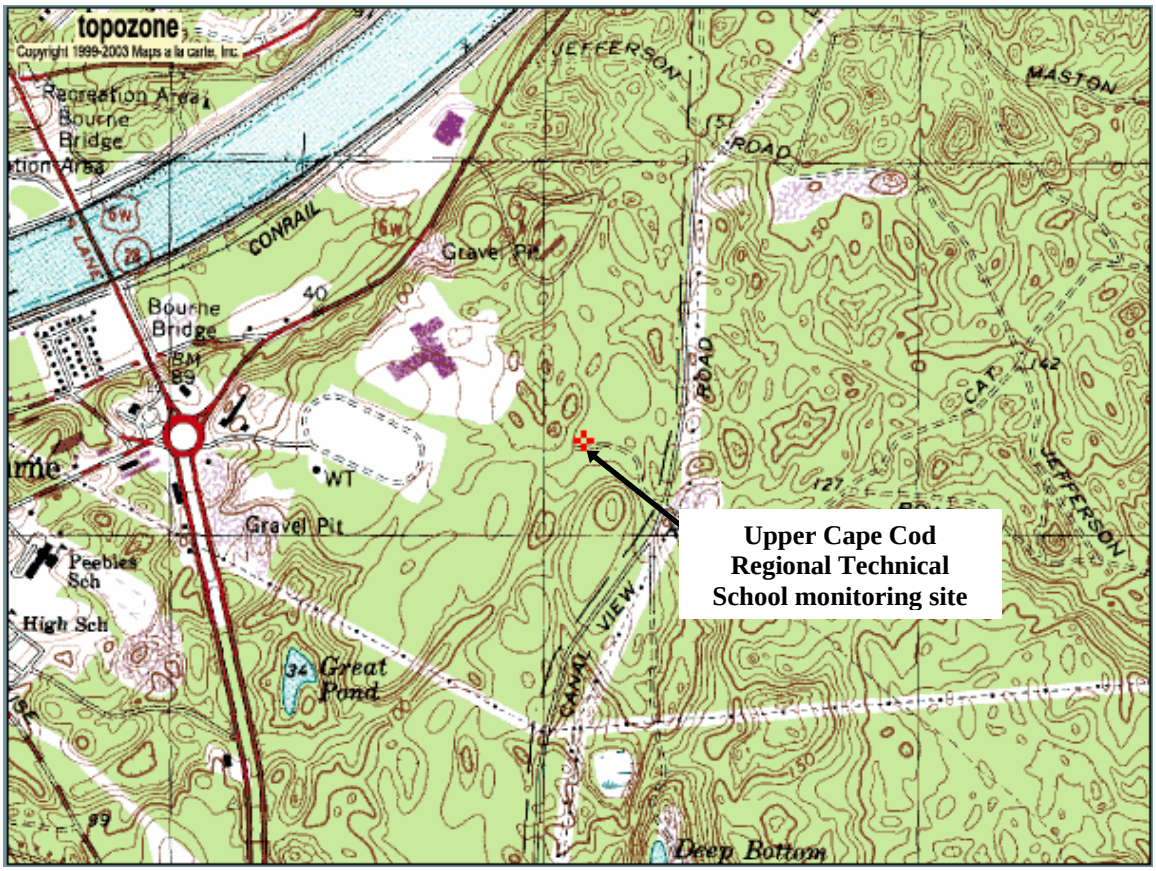

Figure 1 - Site location at Upper Cape Cod Regional Technical School, Bourne, MA

www.topozone.com

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164.0 ft) Second Wind tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger
- Electrical enclosure box
- 5 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 50 m (164.1 ft), two at 39 m (128.0 ft) and one at a height of 20 m (65.6 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 50 (164.1), 39 (128.0) and 20 m (65.6 ft) each.
- 5 – Sensor booms, 54" length
- Lightning rod and grounding cable
- Shielded sensor wire

The data from the Symphonie logger is mailed to the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These 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 NRG software BaseStation®. 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 Collection and Maintenance

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

- No problems with the data were encountered.
- No maintenance operations were needed or performed.

No measurement of wind speed can be perfectly accurate. 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.

Data Statistics Summary

Date	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Turbulence Intensity	Prevailing Wind Direction	Mean Wind Speed	Max Wind Speed	Prevailing Wind Direction
Heights, units	**50 m, [m/s]**	**50 m, [m/s]**	**50 m, [ ]**	**50 m, [ ]**	**39 m, [m/s]**	**39 m, [m/s]**	**39 m, [ ]**	**39 m, [ ]**	**20 m, [m/s]**	**20 m, [m/s]**	**20 m, [ ]**
Mar 2005	5.67	16.7	0.18	WNW	5.13	16.1	0.20	W	3.86	14.0	WNW
Apr 2005	5.99	14.9	0.19	SSW	5.45	13.9	0.22	SSW	3.97	11.3	SW
May 2005	5.65	19.8	0.20	NNE	5.18	18.1	0.23	NNE	3.82	13.5	NNE
Mar 2005 – May 2005	5.77	19.8	0.19	SW	5.25	18.1	0.21	SSW	3.88	14.0	SW

SECTION 4 - Significant Meteorological Events

The spring quarter, comprising March, April, and May 2005, had close to average wind conditions. The wind speed time series shows that there were some fairly high winds in the first half of May. The spring of 2005 was the coldest on record since 1984, but this did not cause abnormal wind conditions. These cold temperatures resulted in multiple icing events throughout the spring.

Source: http://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 QA controls are given below under Test Definitions and Sensor Statistics. 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 [%]	100.00
Net Data Recovered [%]	97.26

The high Gross Data Recovery Percentage is an indication that the logger was recording and transmitting perfectly. While icing conditions resulted in the lower net data recovery, the sensors were otherwise functioning properly.

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 that is included in APPENDIX A. Data that 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: wind speed, wind speed standard deviation, wind direction, and temperature.

$$F1 > TF1 > F2$$

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 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 less 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.

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

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 that 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. It should be noted that, while this test is tuned to detect sensor icing events, it is possible for the conditions that are representative of icing to occur at other times. The error due to this possibility is considered to be insignificant.

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 several types of wind data graphs. Unless otherwise noted, each graph represents data at a height of 50 m (164.1 ft) for the spring quarter comprising of March, April, and May of 2004.

- Time Series – In Figure 2, 10-minute average wind speeds are plotted against time for all data starting on March 1, 2005 at midnight through May 31, 2005 at 11:50 PM.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed is shown in Figure 3. This plot shows that the wind speeds ranged between 4 and 5 m/s (8.9 and 11.2 mph) 17.2 % of the time.

- Diurnal Average Wind Speeds– Figure 4 is a plot of the average wind speed for each hour of the day. The hourly average varied between 4.93 and 6.88 m/s (11.04 and 15.41 mph), with the highest average speeds between 1 pm and 3 pm. The lowest wind speeds where between 5 am and 7 am.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed is shown in Figure 5. 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. In general, turbulence intensities range from 0.1 to 0.4; for Bourne, the average turbulence intensity was 0.19.

- Wind Rose – Figure 6 is 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 wind rose shows the prevailing direction from the southwest. Wind blew from this direction 11.64 % of the time with a mean wind speed of 5.89 m/s (13.19 mph). Wind blew from the north-northeast 9.97% and it had the highest mean wind speed at 7.39 m/s (16.56).

- Monthly Averages – A plot of the average monthly wind speed for each month of data is shown in Figure 7, starting in August 2004 through May 2005. This graph shows that for Bourne, the highest average monthly wind speed of 5.99 m/s (13.42 mph) was in April 2005. The lowest was in August 2004, with an average wind speed of 5.06 m/s (11.33 mph).

SECTION 7 - Graphs

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

Wind Speed Time Series

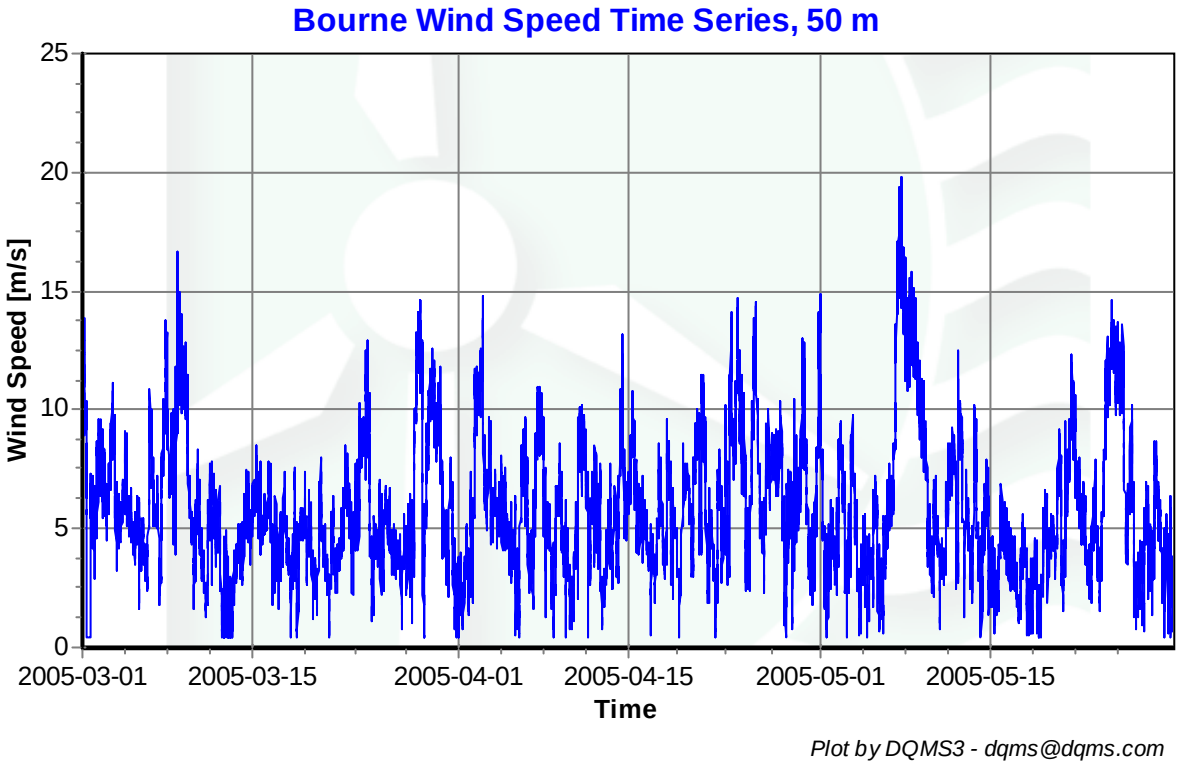

Figure 2 - Wind Speed Time Series, March 2005 – May 2005

Wind Speed Distribution

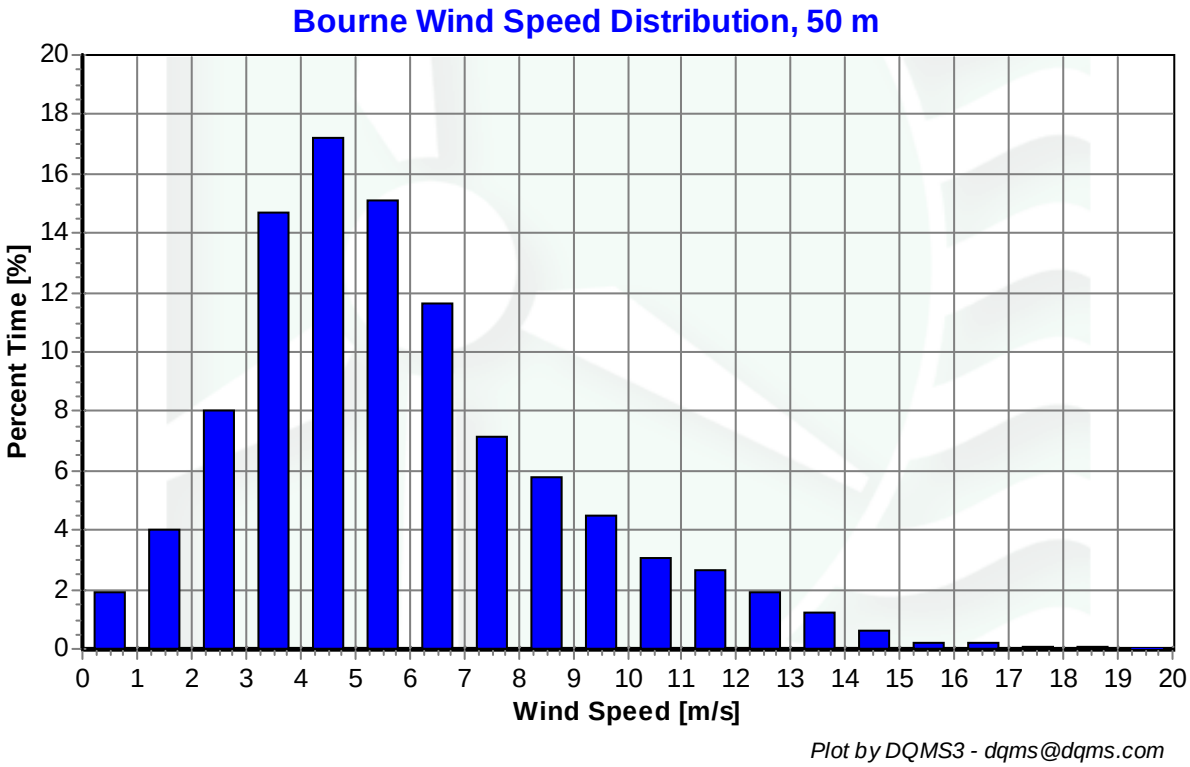

Figure 3 - Wind Speed Distribution, March 2005 – May 2005

Diurnal Average Wind Speeds

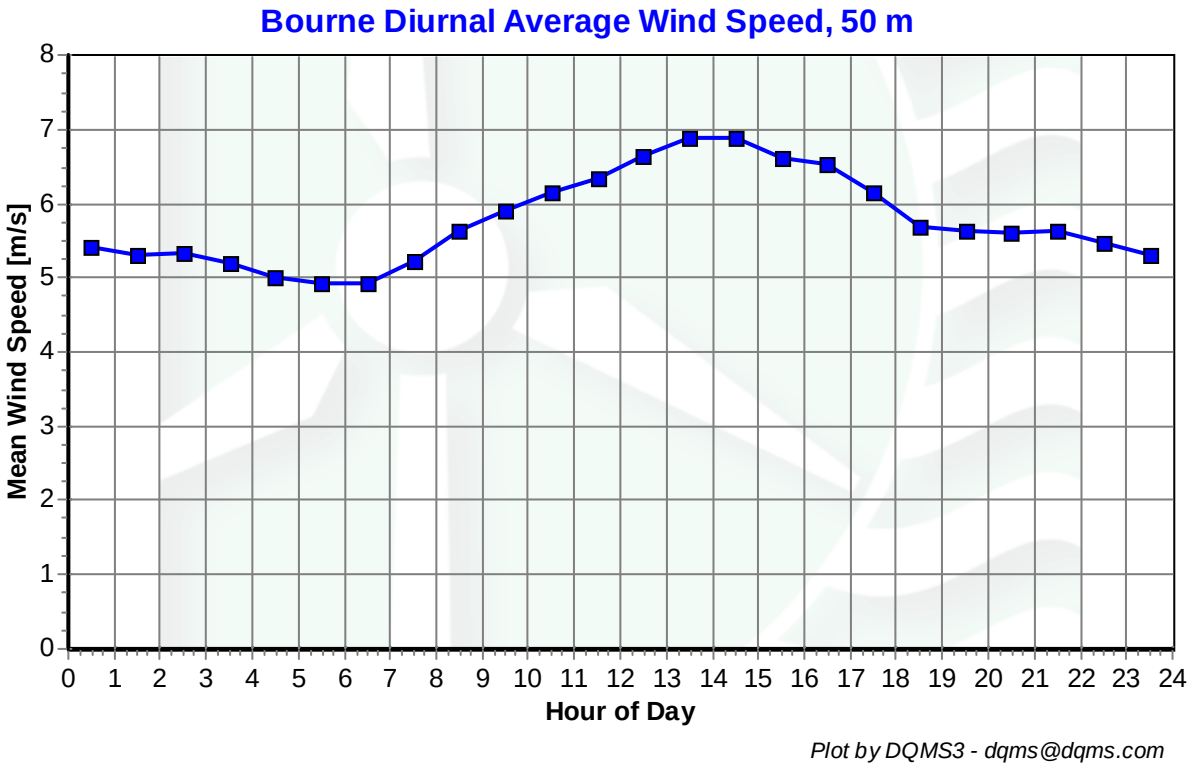

Figure 4 - Diurnal Average Wind Speed, March 2005 – May 2005

Turbulence Intensities

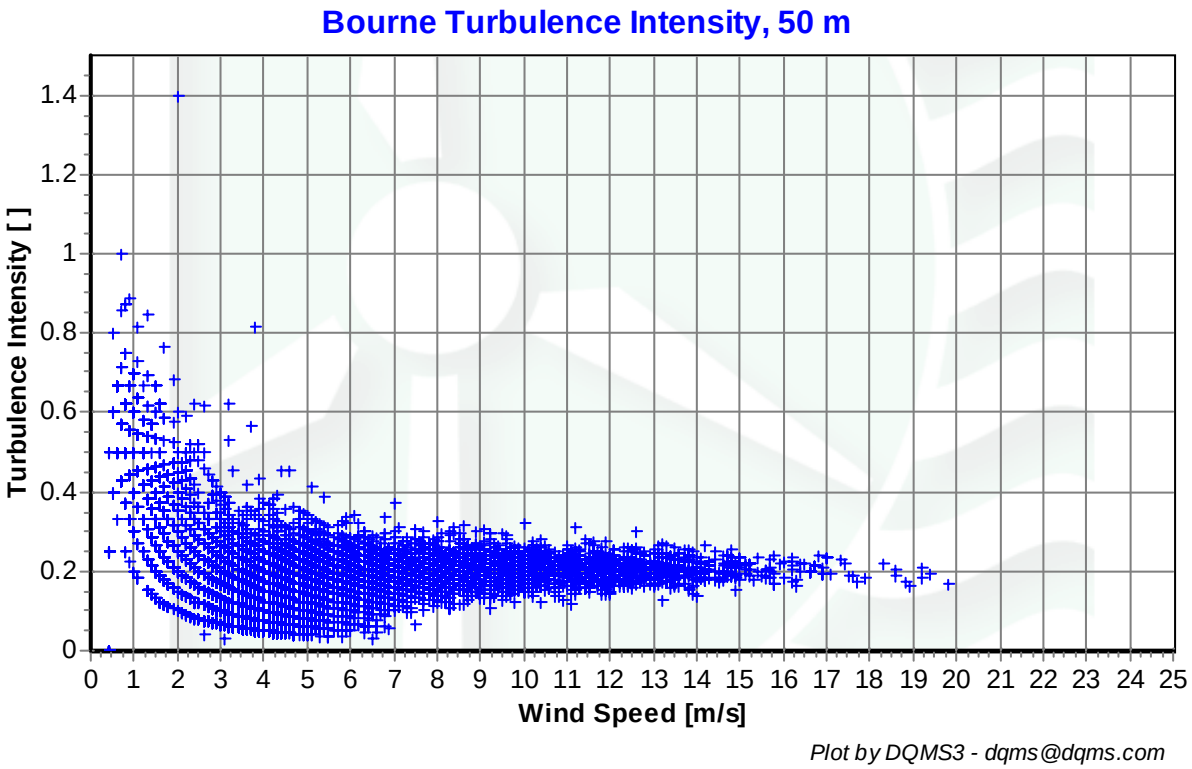

Figure 5 - Turbulence Intensity vs. Wind Speed, March 2005 – May 2005

Wind Rose

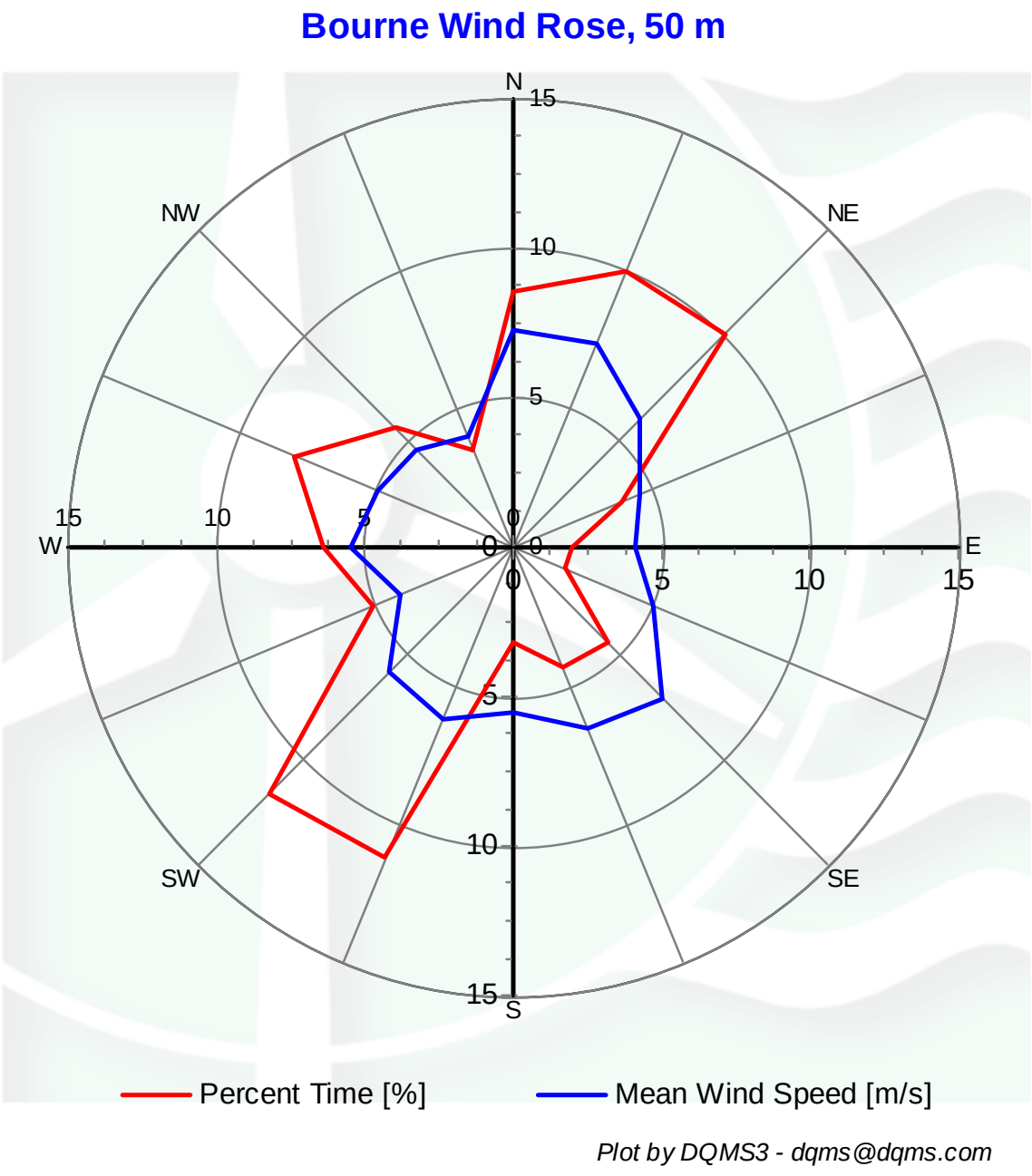

Figure 6 - Wind Rose, March 2005 – May 2005

Monthly Averages

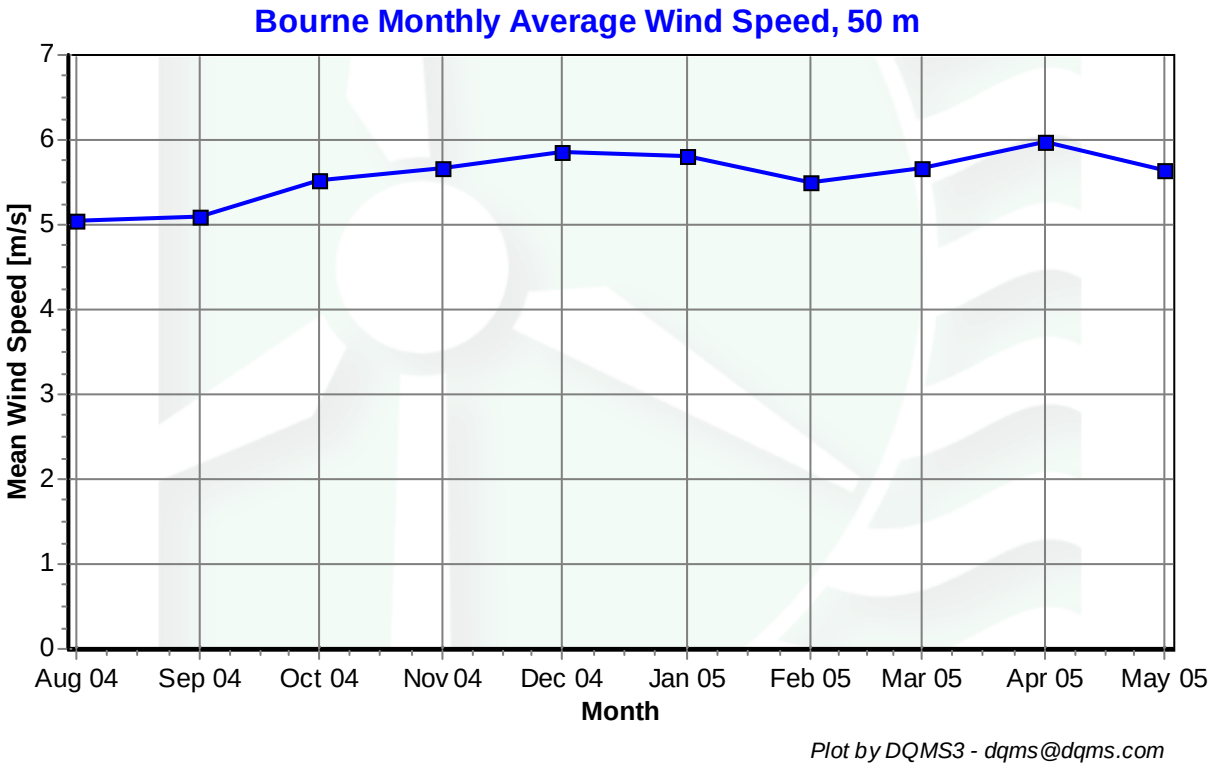

Figure 7 - Monthly Averages, August 2004 – May 2005

APPENDIX A - Sensor Performance Report

Test Definitions

Test Order	TestField1	TestField2	TestField3	CalcField1	CalcField2	TestType	Factor1	Factor2	Factor3	Factor4
1						TimeTest Insert				
2	Etmp2aDEGC					MinMax	-30	60		
3	Etmx2aDEGC					MinMax	-30	60		
4	Etmn2aDEGC					MinMax	-30	60		
5	EtmpSD2aDEGC					MinMax	-30	60		
10	Anem50aMS					MinMax	0	90		
11	Anem50bMS					MinMax	0	90		
12	Anem39aMS					MinMax	0	90		
13	Anem39bMS					MinMax	0	90		
14	Anem20aMS					MinMax	0	90		
15	Anem50yMS					MinMax	0	90		
16	Anem39yMS					MinMax	0	90		
20	AnemSD50aMS					MinMax	0	4		
21	AnemSD50bMS					MinMax	0	4		
22	AnemSD39aMS					MinMax	0	4		
23	AnemSD39bMS					MinMax	0	4		
24	AnemSD20aMS					MinMax	0	4		
25	AnemSD50yMS					MinMax	0	4		
26	AnemSD39yMS					MinMax	0	4		
30	Vane50aDEG					MinMax	0	359.9		
31	Vane39aDEG					MinMax	0	359.9		
32	Vane20aDEG					MinMax	0	359.9		
50	Turb50zNONE					MinMax	0	2		
51	Turb39zNONE					MinMax	0	2		
60	Wshr0zNONE					MinMax	-100	100		
70	Pwrd50zWMS					MinMax	0	5000		
71	Pwrd39zWMS					MinMax	0	5000		
200	VaneSD50aDEG	Anem50yMS				MinMaxT	0	100	100	10
201	VaneSD39aDEG	Anem39yMS				MinMaxT	0	100	100	10
202	VaneSD20aDEG	Anem20aMS				MinMax	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
302	Anem39aMS	AnemSD39aMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
303	Anem39bMS	AnemSD39bMS	Vane39aDEG	VaneSD39aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
304	Anem20aMS	AnemSD20aMS	Vane20aDEG	VaneSD20aDEG	Etmp2aDEGC	Icing	0.5	1	2	10
400	Anem50aMS	Anem50bMS				CompareSensors	1	0.25	3	0

401	Anem39aMS	Anem39bMS				CompareSensors	1	0.25	3	0
500	Amax50aMS					MinMax	0	90		
501	Amax50bMS					MinMax	0	90		
502	Amax39aMS					MinMax	0	90		
503	Amax39bMS					MinMax	0	90		
504	Amax20aMS					MinMax	0	90		
510	Amin50aMS					MinMax	0	90		
511	Amin50bMS					MinMax	0	90		
512	Amin39aMS					MinMax	0	90		
513	Amin39bMS					MinMax	0	90		
514	Amin20aMS					MinMax	0	90		
520	Vmax50aDEG					MinMax	0	359.9		
521	Vmax40aDEG					MinMax	0	359.9		
522	Vmax20aDEG					MinMax	0	359.9		
530	Vmin50aDEG					MinMax	0	359.9		
531	Vmin39aDEG					MinMax	0	359.9		
532	Vmin20aDEG					MinMax	0	359.9		

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Anem50aMS	13248	13248	100	0.167	71.833	1	96.694
AnemSD50aMS	13248	13248	100	0.167	71.833	1	96.694
Anem50bMS	13248	13248	100	0.667	53.167	11.167	97.056
AnemSD50bMS	13248	13248	100	0.667	53.167	11.167	97.056
Anem39aMS	13248	13248	100	0.333	74.833	8.833	96.196
AnemSD39aMS	13248	13248	100	0.333	74.833	8.833	96.196
Anem39bMS	13248	13248	100	0.333	94.5	3.167	95.562
AnemSD39bMS	13248	13248	100	0.333	94.5	3.167	95.562
Anem20aMS	13248	13248	100	0	27.167	0	98.77
AnemSD20aMS	13248	13248	100	0	27.167	0	98.77
Vane50aDEG	13248	13248	100	0.667	72	0	96.709
VaneSD50aDEG	13248	13248	100	0.667	72	0	96.709
Vane39aDEG	13248	13248	100	0.5	96.167	0	95.622
VaneSD39aDEG	13248	13248	100	0.5	96.167	0	95.622
Vane20aDEG	13248	13248	100	0.833	27.167	0	98.732
VaneSD20aDEG	13248	13248	100	0.833	27.167	0	98.732
Etmp2aDEGC	13248	13248	100	0	0	0	100
EtmpSD2aDEGC	13248	13248	100	0	0	0	100
Total	**238464**	**238464**	**100**	**7**	**1033.667**	**48.333**	**97.26**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	1.89
1.5	3.99
2.5	8.05
3.5	14.7
4.5	17.2
5.5	15.1
6.5	11.64
7.5	7.13
8.5	5.77
9.5	4.47
10.5	3.09
11.5	2.65
12.5	1.9
13.5	1.25
14.5	0.64
15.5	0.23
16.5	0.17
17.5	0.08
18.5	0.04
19.5	0.03
20.5	0
21.5	0
22.5	0
23.5	0
24.5	0

Table 1 - Wind Speed Distribution

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
Aug 2004	5.06
Sep	5.10
Oct	5.52
Nov	5.66
Dec	5.87
Jan 2005	5.80
Feb	5.49
Mar	5.65
Apr	5.99
May	5.65

Table 2 - Wind Speed Averages

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	5.4
1.5	5.31
2.5	5.32
3.5	5.2
4.5	5
5.5	4.93
6.5	4.93
7.5	5.22
8.5	5.64
9.5	5.91
10.5	6.15
11.5	6.34
12.5	6.65
13.5	6.87
14.5	6.88
15.5	6.62
16.5	6.54
17.5	6.16
18.5	5.69
19.5	5.62
20.5	5.61
21.5	5.63
22.5	5.46
23.5	5.3

Table 3 - Diurnal Average Wind Speeds

Wind Rose Data

Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	8.53	7.27
NNE	9.97	7.39
NE	10.1	6.07
ENE	3.93	4.63
E	1.97	4.11
ESE	1.87	5.1
SE	4.49	7.14
SSE	4.32	6.59
S	3.18	5.57
SSW	11.26	6.22
SW	11.64	5.89
WSW	5.13	4.14
W	6.42	5.51
WNW	8.01	4.98
NW	5.64	4.64
NNW	3.54	4.02

Table 4 - Wind Rose, Time Percentage and Mean Wind Speed by Direction