WIND DATA REPORT

Ipswich

March 1,2004 – May 31,2004

Prepared for

Town of Ipswich
Massachusetts

by

James F. Manwell
Anthony F. Ellis
Mohit Dua

July 16, 2004

Report template version 1.1

TABLE OF CONTENTS

Table of Contents 1
Table of Figures 2
Executive Summary 3
SECTION 1 - Station Location 4
SECTION 2 - Instrumentation and Equipment 4
SECTION 3 - Data Collection and Maintenance 5
SECTION 4 - Significant Meteorological Events 5
SECTION 5 - Data Recovery and Validation 5
  Test Definitions 5
  Sensor Statistics 7
SECTION 6 - Data Summary 7
SECTION 7 - Graphs 8
  Wind Speed Time Series 9
  Wind Speed Distributions 9
  Monthly Average Wind Speeds 10
  Diurnal Average Wind Speeds 10
  Turbulence Intensities 11
  Wind Roses 12
APPENDIX A – Sensor Performance Report 13
  Test Definitions 13
  Sensor Statistics 14
APPENDIX B - Plot Data 15
  Wind Speed Distribution Data 15
  Monthly Average Wind Speed Data 16
  Diurnal Average Wind Speed Data 17
  Wind Rose Data 18

TABLE OF FIGURES

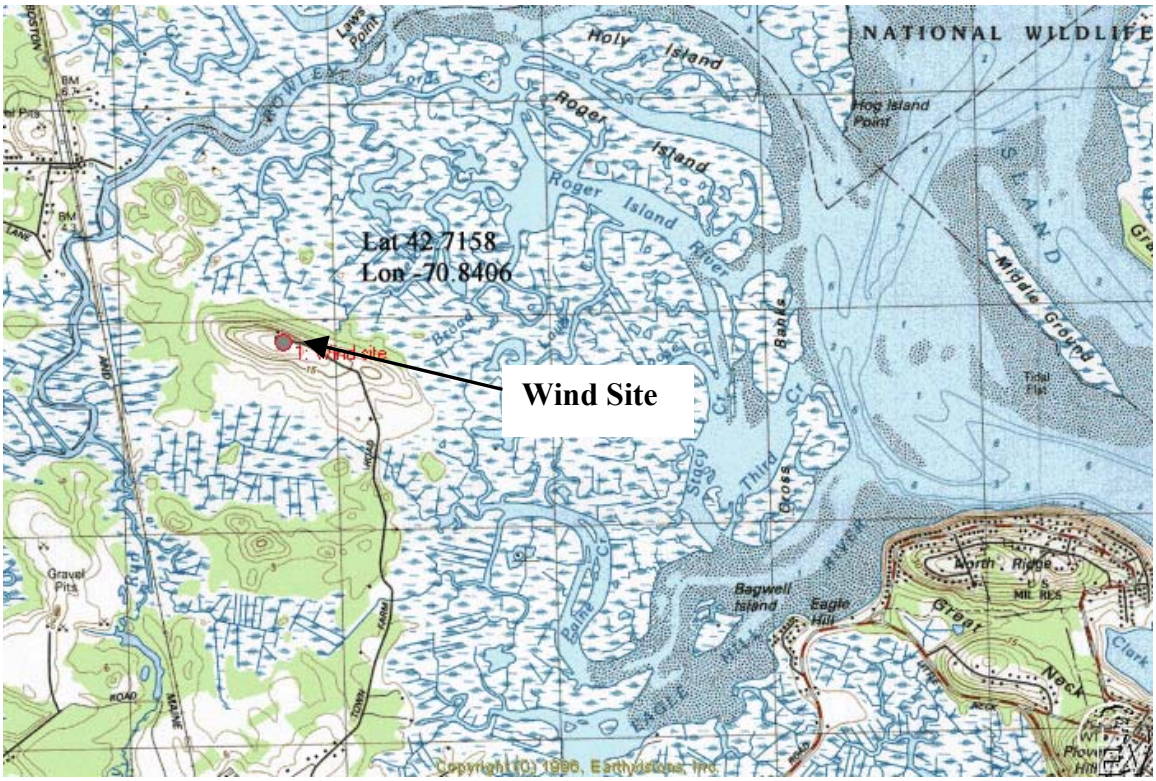
Figure 1 – Wind Speed Time Series, March 2004 – May 2004 9
Figure 2 – Wind Speed Distribution, March 2004 – May 2004 9
Figure 3 – Monthly Average Wind Speeds..... 10
Figure 4 – Diurnal Wind Speed, March 2004 – May 2004 10
Figure 5 – Turbulence Intensity vs Wind Speed, March 2004 – May 2004..... 11
Figure 6 - Wind Rose, March 2004 – May 2004 12

EXECUTIVE SUMMARY

Wind monitoring at Ipswich commenced on May 20, 2003. Wind speed and direction monitoring are being done at three heights 39m, 30m and 10m. This report is for the last quarter from March 2004 through May 2004. Data collection for the period has been good with 99.85% of the data points passing the quality assurance controls. This is higher than the data collection from the previous quarter of 97.17%, due primarily to reduced icing of the sensors. Average wind speed for the spring quarter is 5.54 m/s at 39m with NNW being the predominant wind direction. A decrease in wind speed is observed as we move from winter to spring. For the winter quarter, average wind speed was observed to be 5.99 m/s.

SECTION 1 - Station Location

Ipswich, is one of the oldest towns in the United States, located on the North Shore of Massachusetts, approximately 28 miles north of Boston. The town is 33 square miles and has a landscape that includes marshes, dunes and beaches, upland, forests, fields, and farmland. The monitoring tower is installed at the town transfer station (old landfill) on a small hill with salt marshes to the west and some trees to the north. The site is located at 42°42’58’’N and 70°50’30’’W. The figure below shows the site location.



SECTION 2 - Instrumentation and Equipment

The monitoring at the site is being done at three heights, 39m, 30m and 10m. The table below gives the description of the sensors and data collection equipment along with the number installed.

Description	39 m	30 m	10 m	Base
Maximum #40 Anemometer	2	2	1	-
NRG 200P Wind Vane	1	1	1	-
NRG 11S temperature Sensor	-	-	-	1
Datalogger Type: 9300 Cellogger	-	-	-	1

SECTION 3 - Data Collection and Maintenance

Data collection during this period was good, with the redundant wind speed sensor installed to cover for the primary ones if they failed. The data is summarized below.

Date	Mean Wind Speed [m/s]	Max Wind Speed [m/s]	Turbulence Intensity [ ]	Prevailing Wind Direction [ ]
Mar 2004	5.94	17.57	0.19	NNW
Apr 2004	5.80	16.22	0.20	ENE
May 2004	4.90	12.62	0.22	WSW
Mar 04 – May 04	**5.54**	**17.57**	**0.20**	**NNW**

SECTION 4 - Significant Meteorological Events

A late season winter storm passing south east of New England brought heavy snowfall to most of Massachusetts. Snowfall of 5 to 10 inches was observed from the east slopes of Berkshires across central and eastern Massachusetts down to the part of the south coast. Heavy rain and winds were observed during the beginning of April.

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 [%]	99.992
Net Data Recovered [%]	99.855

Test Definitions

All raw data were subjected to a series of validation tests, as described below. The sensors tested and the parameters specific for 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 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 speed (TF2) is less than or equal to Factor 1 (F1), the wind direction standard deviation (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.

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

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 several types of wind data graphs. Unless otherwise noted, each graph represents data from 1 quarter (3 months). The following graphs are included:

- 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 most likely wind speed for spring is around 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 from June 2003 to May 2004. The meteorological tower was installed at the end of May, therefore the average for May is not plotted. The wind speed remains fairly uniform from June to September. There is a rise in wind speed thereafter, with a maximum monthly average wind speed reported for December of 6.76 m/s. This is similar to the

trend observed throughout New England, with the highest wind speeds reported in winter. January to April also sees fairly uniform wind speed between 5 and 6 m/s.

- Diurnal – A plot of the average wind speed for each hour of the day. For spring, the wind speed tends to peak in the middle of the day, with highest wind speeds for the day reported between 1:00 PM and 4:00 PM. Lowest wind speeds are reported around midnight.

- 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. Turbulence intensity is frequently in the range of 0.1 to 0.4. For this site turbulence intensity for the quarter is 0.20.

- 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. For spring most of the time wind is blowing from the SW and NNW directions. This is also true for most of the sites that UMass has monitored.

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

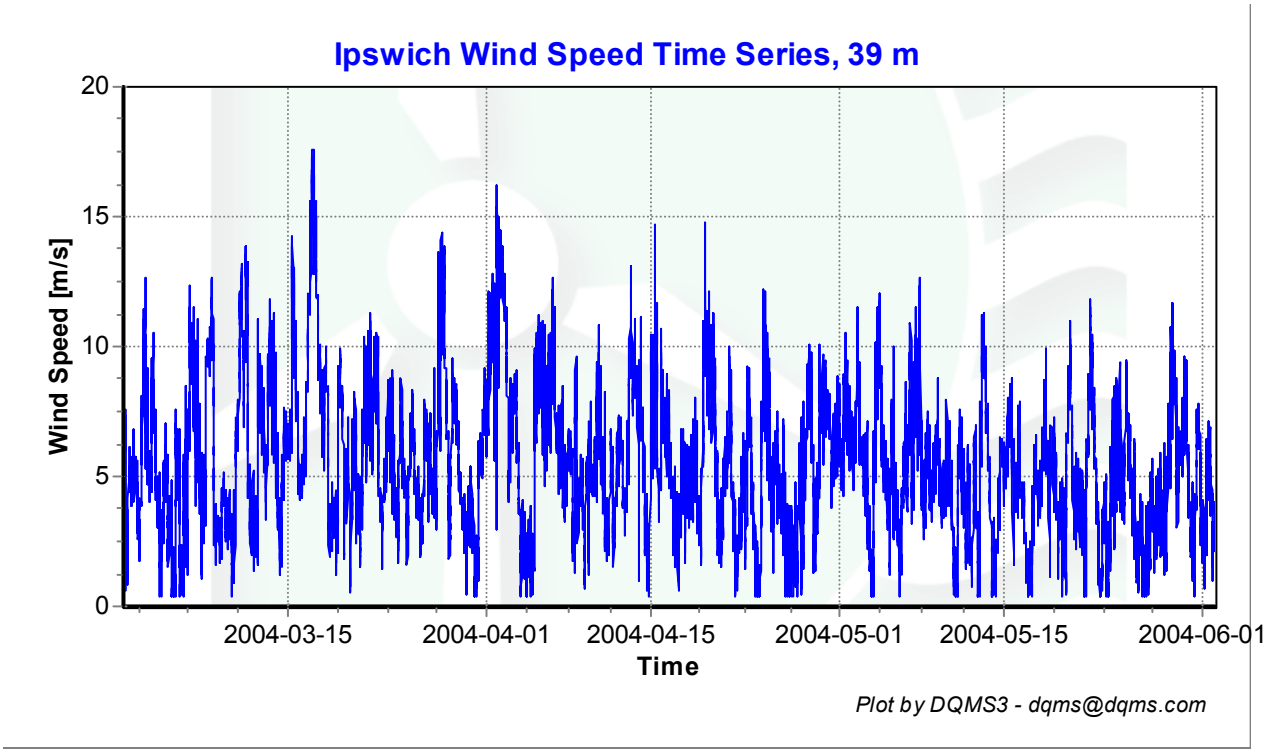


Figure 1 – Wind Speed Time Series, March 2004 – May 2004

Wind Speed Distributions

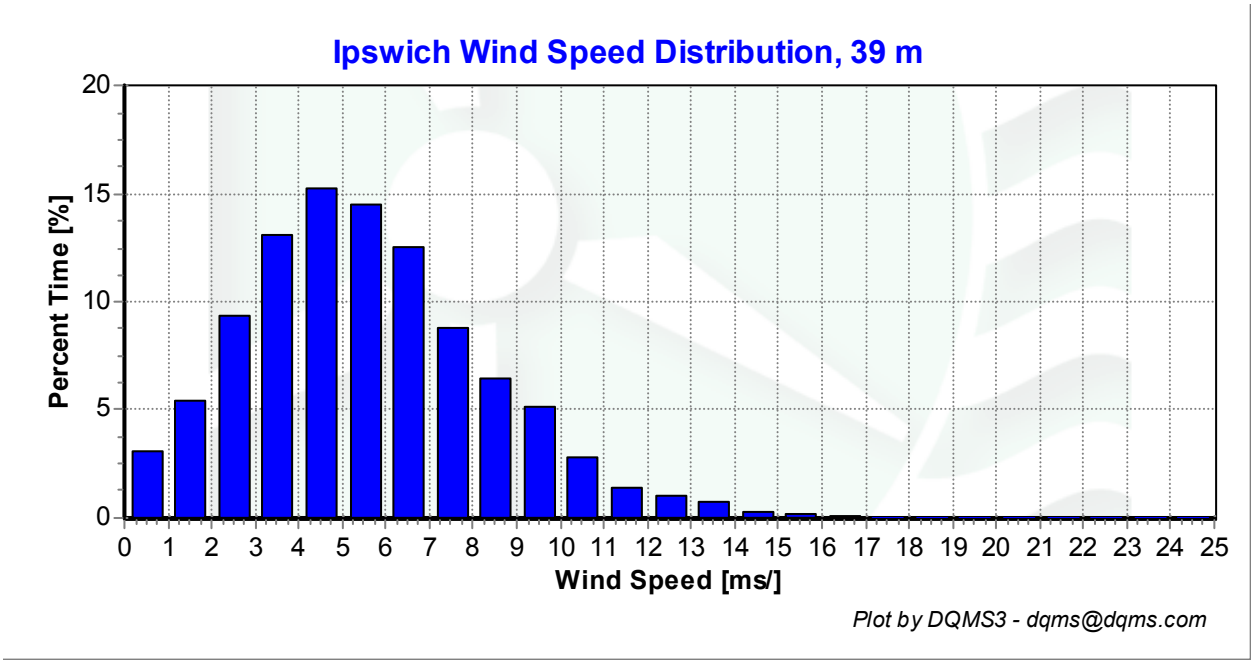


Figure 2 – Wind Speed Distribution, March 2004 – May 2004

Monthly Average Wind Speeds

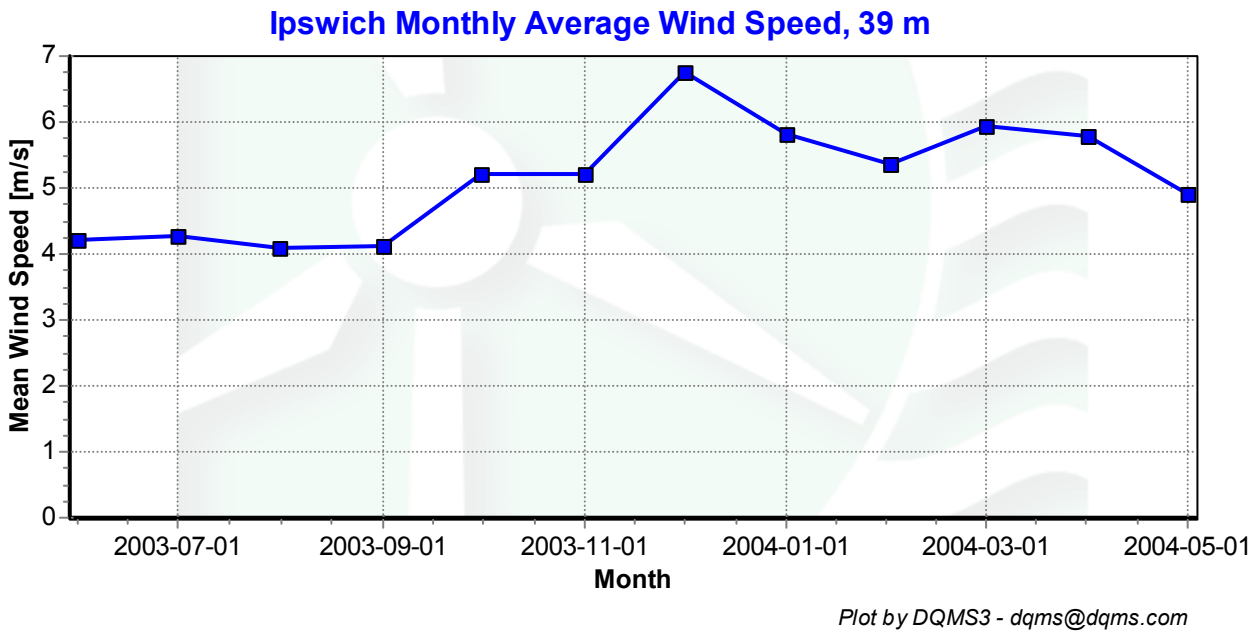


Figure 3 – Monthly Average Wind Speeds

Diurnal Average Wind Speeds

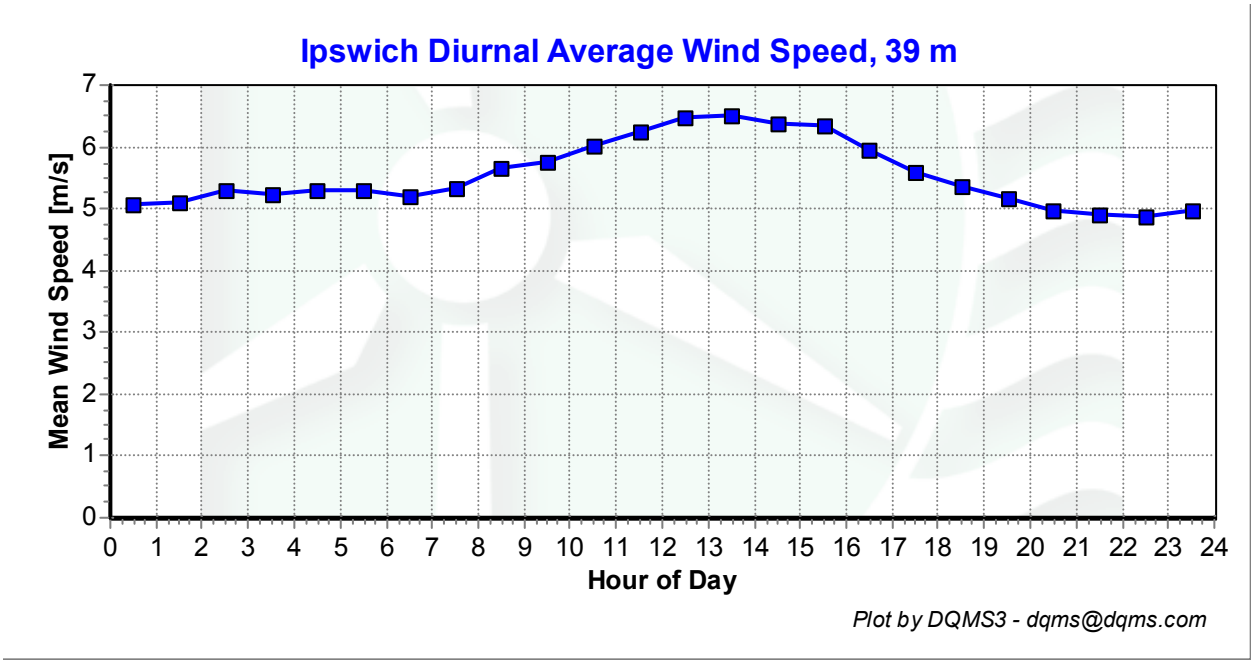


Figure 4 – Diurnal Wind Speed, March 2004 – May 2004

Turbulence Intensities

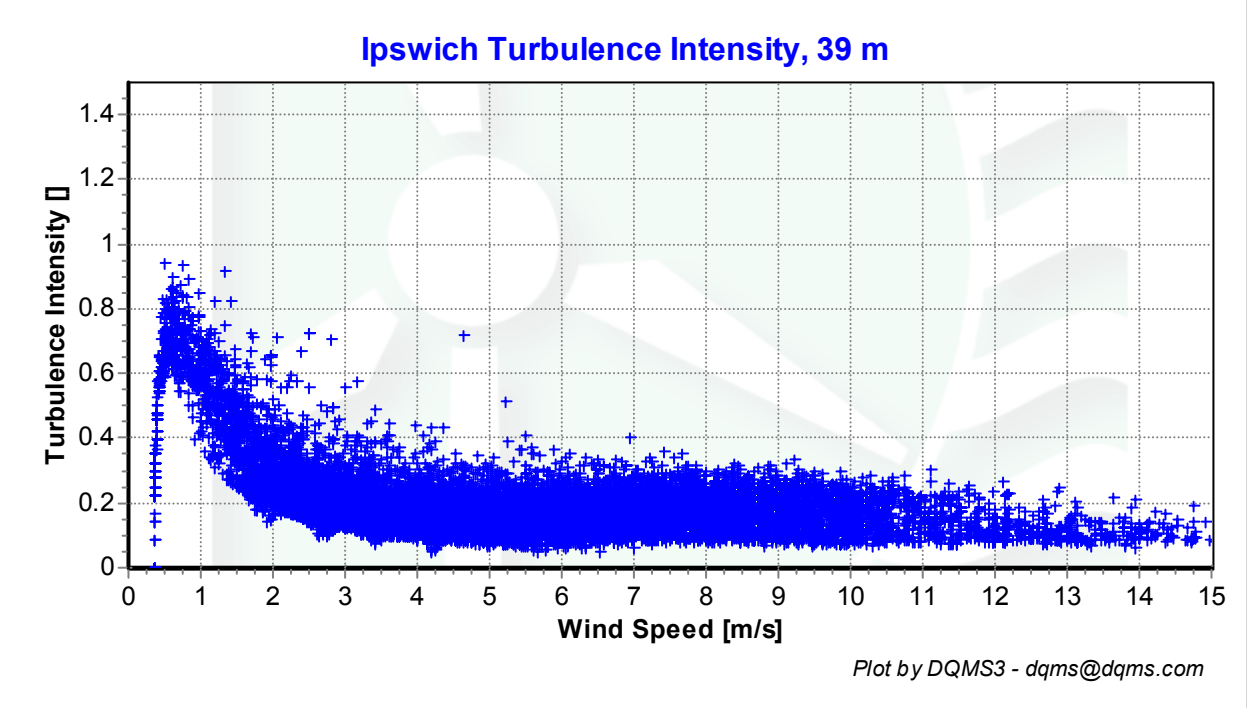


Figure 5 – Turbulence Intensity vs Wind Speed, March 2004 – May 2004

Wind Roses

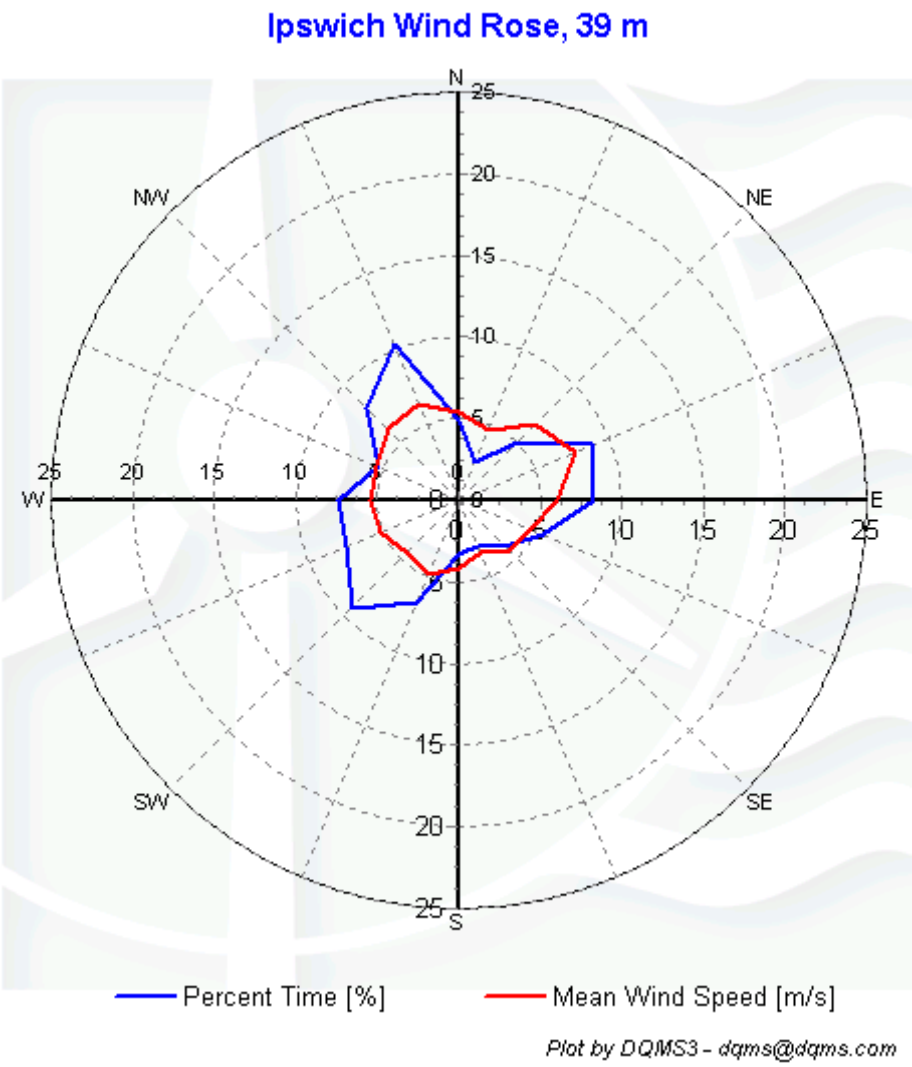


Figure 6 - Wind Rose, March 2004 – May 2004

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				
2	Itmp2aDEGC						MinMax	-30	60		
3	Batt2aVDC						MinMax	10.5	15		
10	Anem39aMS						MinMax	0	90		
11	Anem39bbMS						MinMax	0	90		
12	Anem30aMS						MinMax	0	90		
13	Anem30bMS						MinMax	0	90		
14	Anem10aMS						MinMax	0	90		
15	Anem39yMS						MinMax	0	90		
16	Anem30yMS						MinMax	0	90		
20	AnemSD39aMS						MinMax	0	4		
21	AnemSD39bMS						MinMax	0	4		
22	AnemSD30aMS						MinMax	0	4		
23	AnemSD30bMS						MinMax	0	4		
24	AnemSD10aMS						MinMax	0	4		
25	AnemSD39yMS						MiinMax	0	4		
26	AnemSD30yMS						MinMax	0	4		
30	Vane39aDEG						MiinMax	0	359.9		
31	Vane30aDEG						MinMax	0	359.9		
32	Vane10aDEG						MinMax	0	359.9		
50	Turb39zNONE						MinMax	0	2		
51	Turb30zNONE						MinMax	0	2		
52	Turb10zNONE						MinMax	0	2		
60	Wshr0zNONE						MinMax	-100	100		
200	VaneSD39aDEG	Anem39yMS					MinMaxT	0	100	100	10
201	VaneSD30aDEG	Anem30yMS					MinMaxT	0	100	100	10
202	VaneSD10aDEG	Anem10aMS					MinMaxT	0	100	100	10
300	Anem39aMS	AnemSD39aMS	Vane39aDEG	VaneSD39aDEG	Itmp2aDEGC		Icing	0.5	1	2	
301	Anem39bMS	AnemSD39bMS	Vane39aDEG	VaneSD39aDEG	Itmp2aDEGC		Icing	0.5	1	2	
302	Anem30aMS	AnemSD30aMS	Vane30aDEG	VaneSD30aDEG	Itmp2aDEGC		Icing	0.5	1	2	
303	Anem30bMS	AnemSD30bMS	Vane30aDEG	VaneSD30aDEG	Itmp2aDEGC		Icing	0.5	1	2	
304	Anem10aMS	AnemSD10aMS	Vane10aDEG	VaneSD10aDEG	Itmp2aDEGC		Icing	0.5	1	2	
400	Anem39aMS	Anem39bMS					CompareSensor	1	0.25	3	0
401	Anem30aMS	Anem30bMS					CompareSensor	1	0.25	3	0

Sensor Statistics

Sensor	Expected Data Points	Actual Data Points	% Data Recovered	Hours Out of Range	Hours of Icing	Hours of Fault	% Data Good
Itmp2aDEGC	13249	13248	99.992	0	0	0	99.992
Batt2aVDC	13249	13248	99.992	0	0	0	99.992
Anem39aMS	13249	13248	99.992	0	4.167	2.333	99.698
AnemSD39aMS	13249	13248	99.992	0	4.167	2.333	99.698
Anem39bMS	13249	13248	99.992	0	4	0.167	99.804
AnemSD39bMS	13249	13248	99.992	0	4	0.167	99.804
Anem30aMS	13249	13248	99.992	0	2	4.833	99.683
AnemSD30aMS	13249	13248	99.992	0	2	4.833	99.683
Anem30bMS	13249	13248	99.992	0	1.667	3.167	99.774
AnemSD30bMS	13249	13248	99.992	0	1.667	3.167	99.774
Anem10aMS	13249	13248	99.992	0	0.667	0	99.962
AnemSD10aMS	13249	13248	99.992	0	0.667	0	99.962
Vane39aDEG	13249	13248	99.992	1	4.167	0	99.758
VaneSD39aDEG	13249	13248	99.992	1	4.167	0	99.758
Vane30aDEG	13249	13248	99.992	0.667	2	0	99.872
VaneSD30aDEG	13249	13248	99.992	0.667	2	0	99.872
Vane10aDEG	13249	13248	99.992	2	0.667	0	99.872
VaneSD10aDEG	13249	13248	99.992	2	0.667	0	99.872
Anem39yMS	13249	13248	99.992	0	0	0	99.992
Anem30yMS	13249	13248	99.992	0	0	0	99.992
AnemSD39yMS	13249	13248	99.992	0	0	0	99.992
AnemSD30yMS	13249	13248	99.992	0	0	0	99.992
Total	291478	291456	99.992	7.333	38.667	21	99.855

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	March 2004 – May 2004 [%]
0.5	3.06
1.5	5.47
2.5	9.33
3.5	13.07
4.5	15.24
5.5	14.44
6.5	12.5
7.5	8.76
8.5	6.47
9.5	5.13
10.5	2.82
11.5	1.36
12.5	1.07
13.5	0.73
14.5	0.29
15.5	0.14
16.5	0.1
17.5	0.02
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]
2003 June	4.22
July	4.28
Aug	4.08
Sept	4.11
Oct	5.21
Nov	5.20
Dec	6.76
2004 Jan	5.81
Feb	5.35
Mar	5.94
Apr	5.80
May	4.90
June 2003 – May 2004	**5.14**

Diurnal Average Wind Speed Data

Hour of Day	March 2004 – May 2004 [m/s]
0	5.07
1	5.11
2	5.29
3	5.23
4	5.29
5	5.29
6	5.19
7	5.32
8	5.64
9	5.76
10	6.01
11	6.26
12	6.48
13	6.52
14	6.39
15	6.36
16	5.95
17	5.6
18	5.36
19	5.17
20	4.98
21	4.9
22	4.88
23	4.99

Wind Rose Data

	March 2004 to May 2004	
Direction	Percent Time [%]	Mean Wind Speed [m/s]
N	4.87	5.45
NNE	2.49	4.68
NE	4.77	6.54
ENE	8.97	7.67
E	8.28	6.05
ESE	5.56	4.69
SE	4.00	4.27
SSE	3.03	3.41
S	3.29	4.2
SSW	6.82	4.96
SW	9.31	4.59
WSW	7.51	5.13
W	7.38	5.36
WNW	5.35	5.41
NW	7.97	6.16
NNW	10.4	6.36