WIND DATA REPORT

Truro, Massachusetts

December, 2006 1st to February 28th, 2007

Prepared for

Massachusetts Technology Collaborative
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by

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NOTICE AND ACKNOWLEDGEMENTS

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

This quarterly report covers wind data measured at a meteorological tower installed in Truro, MA. The tower was installed and began collecting data on March 24th, 2006. At 50 m (164.0 ft) and 38 m (124.7 ft), two sets of two anemometers and one wind vane are mounted. Also, there is one anemometer at 35 m (114.8 ft) and there is one wind vane at 30 m (98.4 ft).

The season covered by this report is December 1st, 2006 to February 28th, 2007 (Winter quarter). During this time, the mean recorded wind speed was 8.53 m/s (19.08 mph)* at 50 m and the prevailing wind direction was from the west-northwest (WNW) direction. 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 98.1 %.

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 = 2.237 mph.

SECTION 1 - Station Location

The meteorological tower is located at the heliport at the former DEW (Distance Early Warning) radar location. The latitude and longitude of the tower location are N 042° 01.790’ and W 070° 03.068’ (NAD83). The elevation at the site is 39.3 m. Figure 1 shows the location of the wind monitoring tower.

Figure 1 - Location of Truro Wind Tower

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164.0 ft) Second Wind tower. All other 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 (164.0 ft), two at 38 m (124.7 ft) and one at a height of 35 m (114.8 ft).
- 3 - #200P Wind direction vanes. They are located at heights of 50 m (164.0 ft.), 38 m (124.7 ft.) and 30m (98.4 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 Renewable Energy Research Laboratory at the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. 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 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 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	**50 m [m/s]**	**50 m [m/s]**	**50 m [m/s]**	**38 m [m/s]**	**38m [m/s]**	**38 m [m/s]**	**35 m [m/s]**	**35 m [m/s]**	**35 m [m/s]**
Dec 2006	8.17	18.6	WNW	7.49	17	WNW	7.24	16.6	SW
Jan 2007	8.68	18.6	NW	8.02	17.3	NW	7.75	16.9	NW
Feb 2007	8.78	21.6	WNW	8.12	20.3	WNW	7.88	19.5	W
Dec 2006 -Feb 2007	**8.53**	**21.6**	**WNW**	**7.86**	**20.3**	**WNW**	**7.61**	**19.5**	**W**

Wind data statistics in the table are reported when more than 90% of the data during the reporting period are valid. In cases when a larger amount of data is missing, the percent of the available data that are used to determine the data statistics is noted.

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 at the highest measurement height is between 9.5 and 10.5 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_{high} 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	**50 m [-]**	**38 m [-]**	**35 m [-]**	**Between 50 m and 40 m [-]**
Dec 2006	0.18	0.18	0.18	0.317
Jan 2007	0.16	0.18	0.18	0.288
Feb 2007	0.17	0.18	0.18	0.285
Dec 2006 -Feb 2007	**0.17**	**0.18**	**0.18**	**0.298**

SECTION 4- Graphs

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. Figure 2 shows the time series of the wind speeds at 50 m.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed. The wind blows most frequently between 8 m/s and 9 m/s, for approximately 11.8 % of the time. The wind speed distribution is shown in Figure 3.

- 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 April 2006 to February 2007. Figure 4 shows the monthly average wind speeds at 50 m.

- Diurnal – A plot of the average wind speed for each hour of the day. During this quarterly average, the wind speeds are highest between 6 am and 7 am and between 7 pm and 8 pm at 8.92 m/s, and lowest between 4 pm and 5 pm at 8.02 m/s. The diurnal variation plot is shown in Figure 5.

- 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. In general, turbulence intensity range from 0.1 to 0.4; for Truro, the average turbulence intensity at 50 m at 10 m/s was 0.17 for this quarter. The turbulence intensity plot is shown in Figure 6.

- 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 wind rose shows the prevailing direction from the west-northwest and wind speeds are greatest from the northwest. The wind rose plot is shown in Figure 7.

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

Wind Speed Time Series

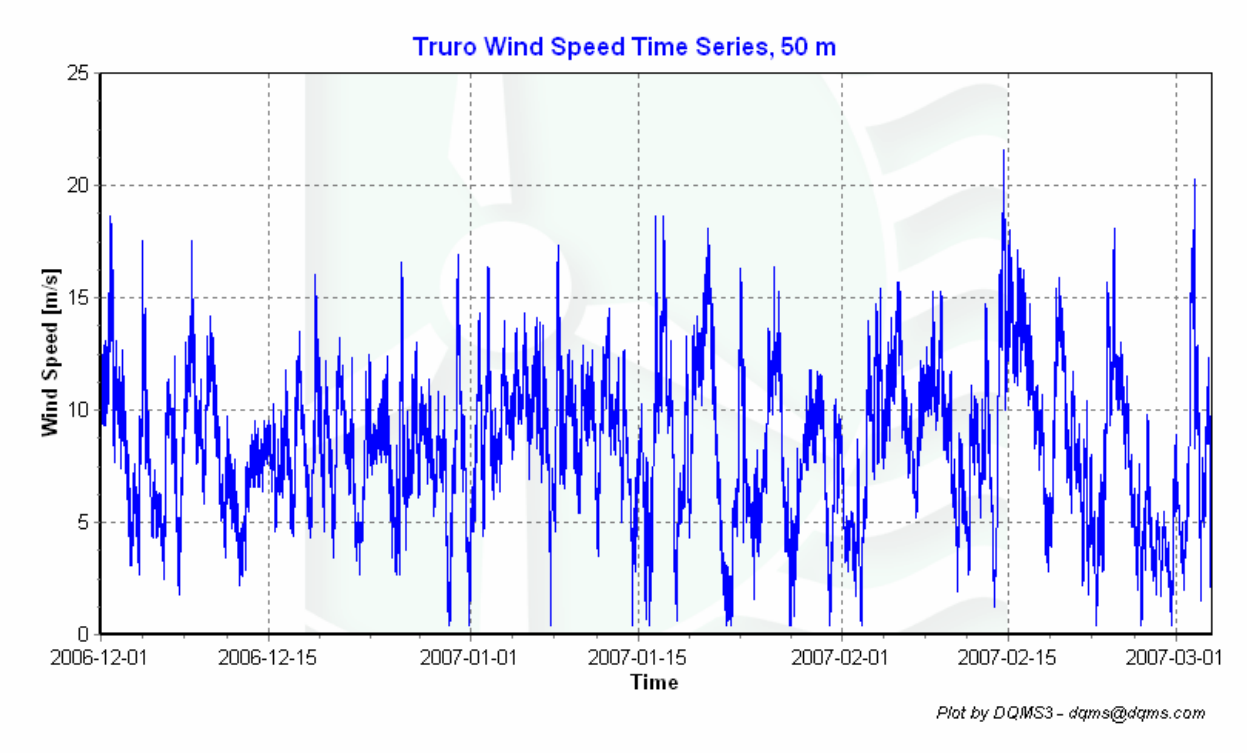

Figure 2 - Truro Wind Speed Time Series, December 1, 2006 – February 28, 2007

Wind Speed Distributions

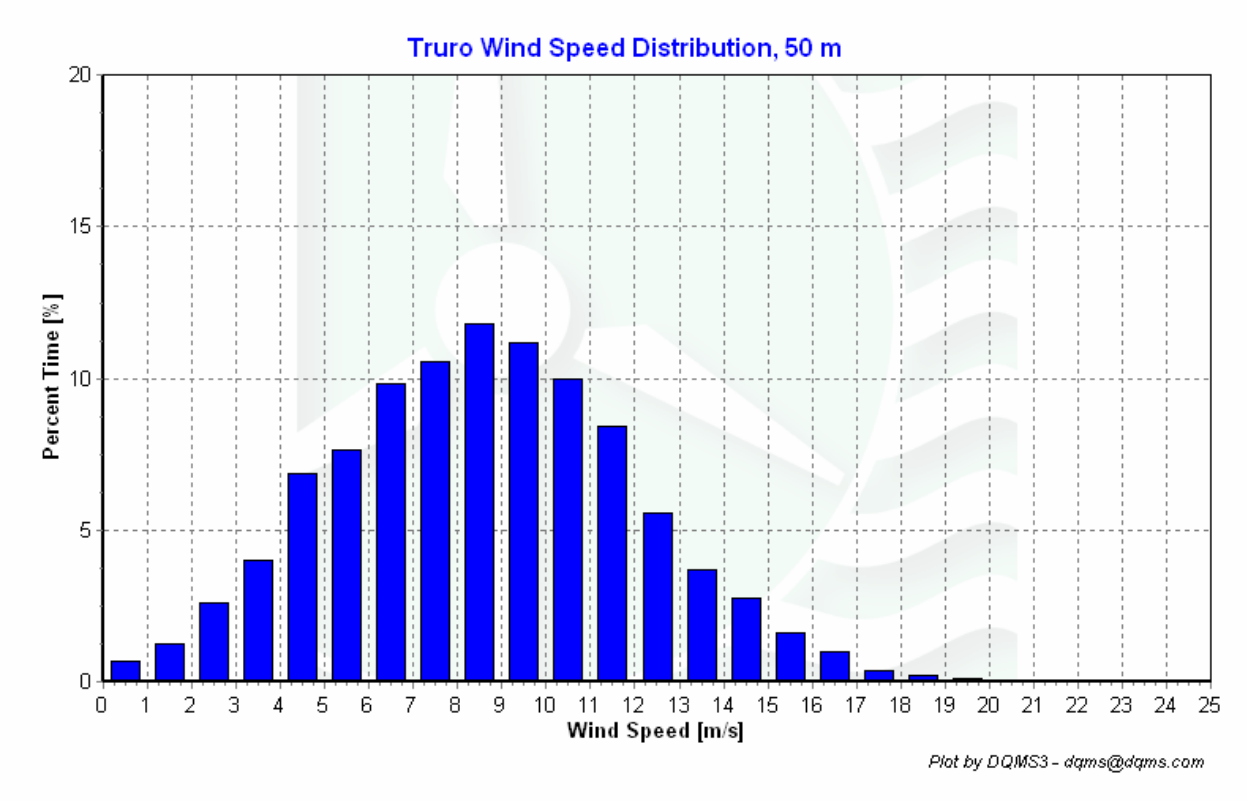

Figure 3 – Truro Wind Speed Distribution, December 1, 2006 – February 28, 2007

Monthly Average Wind Speeds

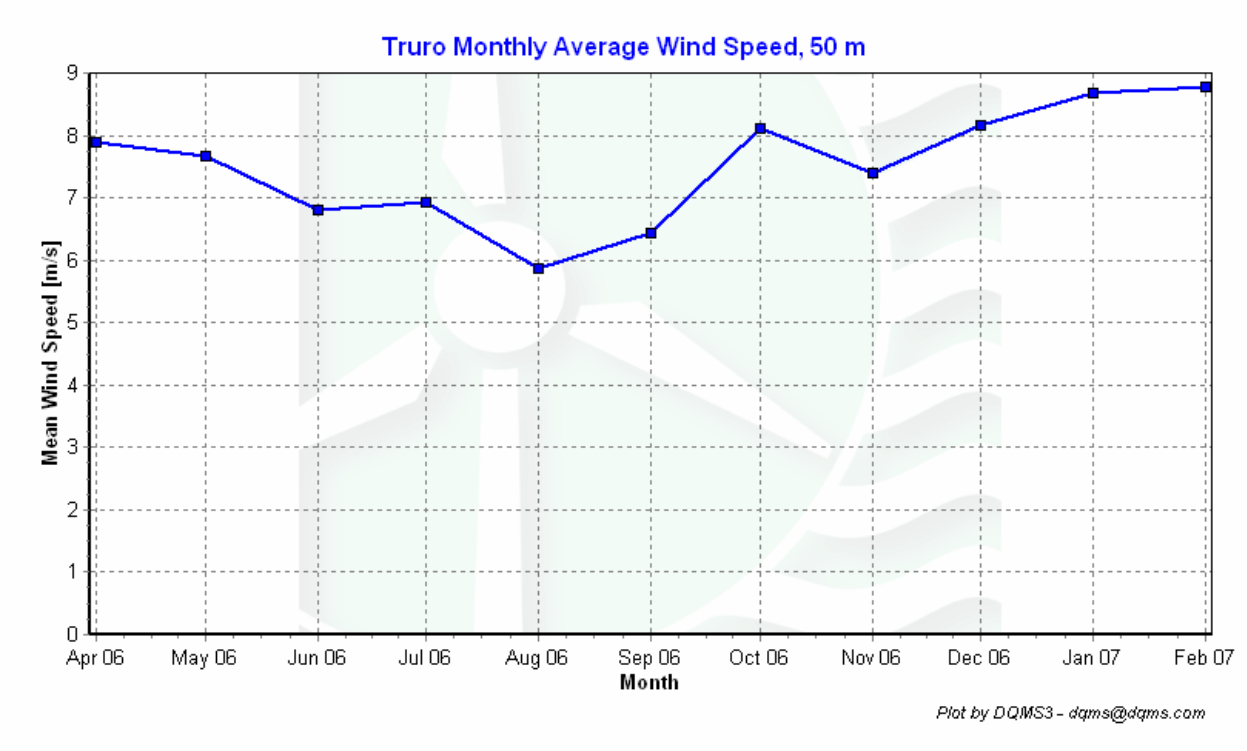

Figure 4 - Truro Monthly Average Wind Speed at 50 m, April 2006 – February 2007

Diurnal Average Wind Speeds

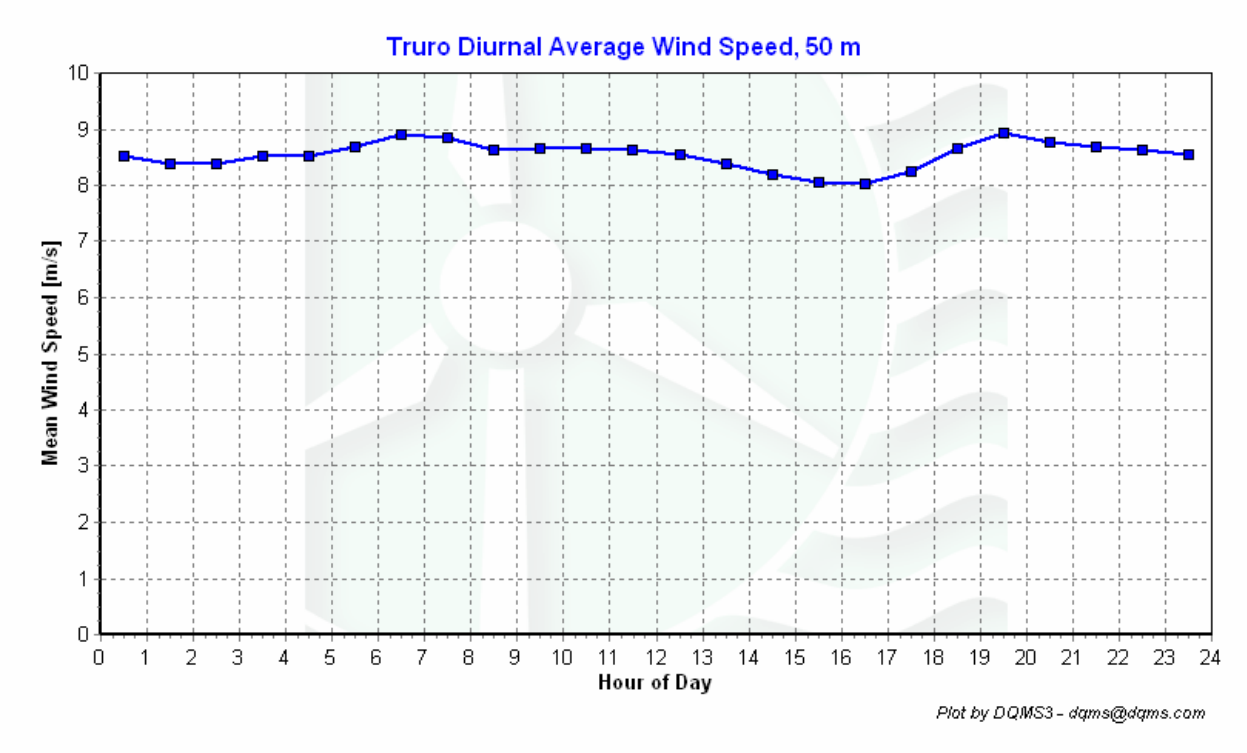

Figure 5 - Truro Diurnal Average Wind Speed at 50 m, December 1, 2006 – February 28, 2007

Turbulence Intensities

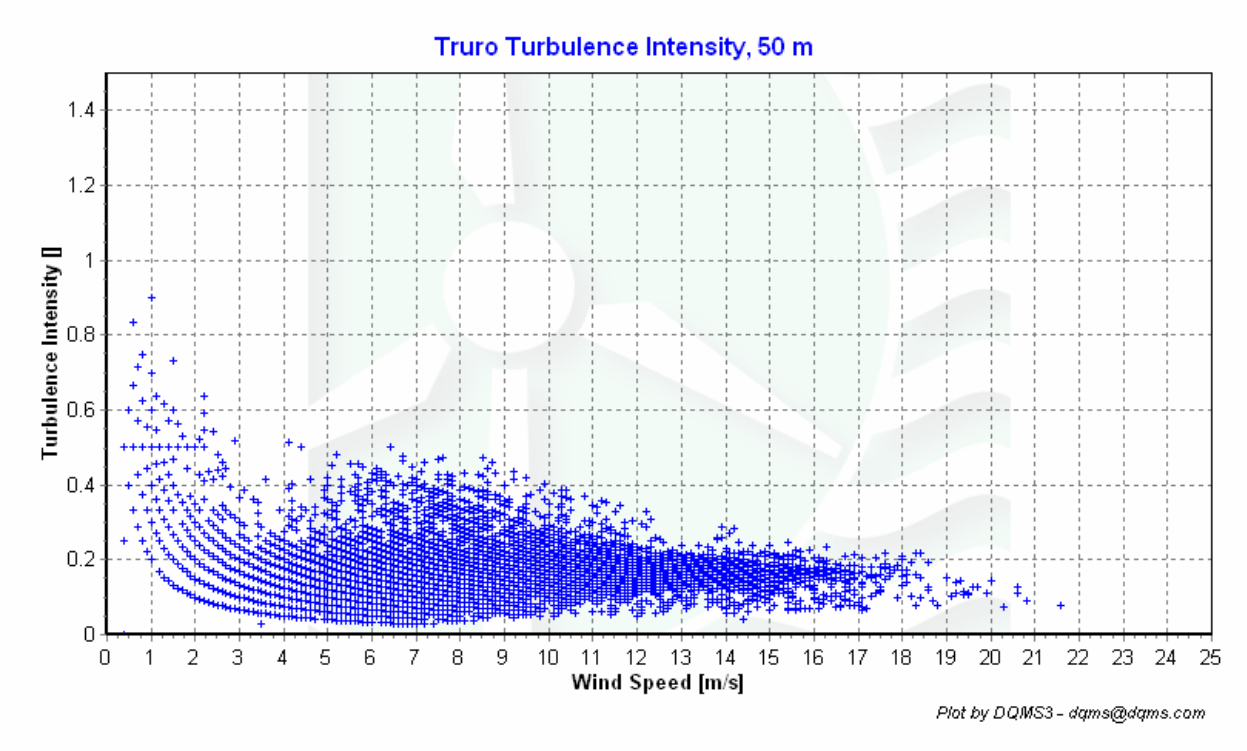

Figure 6 - Truro Turbulence Intensity at 50 m, December 1, 2006 – February 28, 2007

Wind Roses

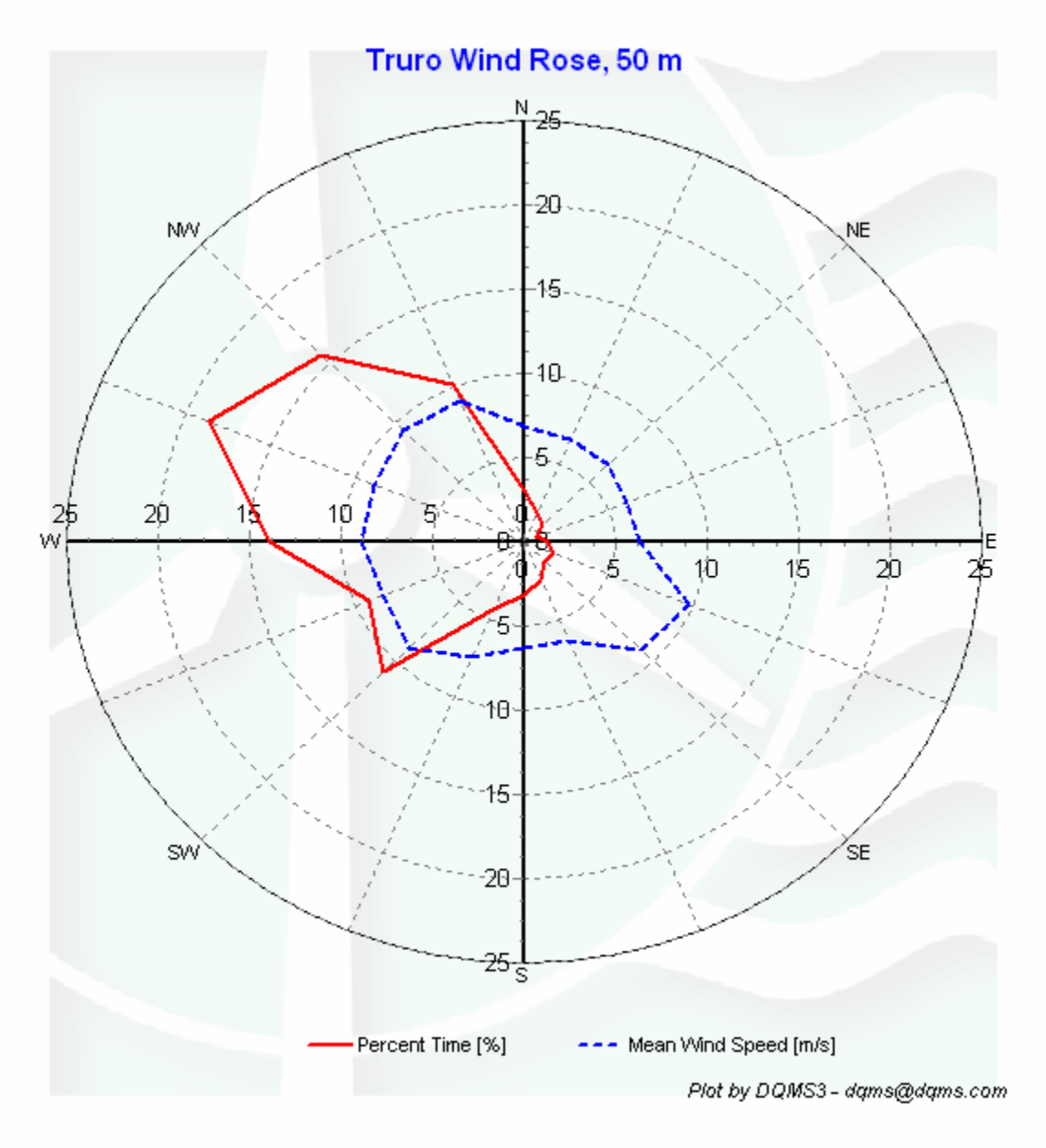

Figure 7 - Truro Wind Rose at 50 m, December 1, 2006 – February 28, 2007

SECTION 5 - Significant Meteorological Events

No significant meteorological events occurred during this data collection period.

SECTION 6 - Data Collection and Maintenance

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

No maintenance work was done in this quarter.

No equipment problems were encountered during this quarter.

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. 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 %
Net Data Recovered [%]	98.1 %

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 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.

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

Sensor Statistics

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

TestOrder	TestField1	TestField2	TestField3	CalcField1	CalcField2	CalcField3	TestType	Factor1	Factor2	Factor3	Factor4
1							TimeTest Insert				
4	Etmp2aDEGC						MinMax	-30	60		
5	EtmpSD2aDEGC						MinMax	-30	60		
10	Anem50aMS						MinMax	0	90		
11	Anem50bMS						MinMax	0	90		
12	Anem38aMS						MinMax	0	90		
13	Anem38bMS						MinMax	0	90		
14	Anem35aMS						MinMax	0	90		
20	AnemSD50aMS						MinMax	0	4		
21	AnemSD50bMS						MinMax	0	4		
22	AnemSD38aMS						MinMax	0	4		
23	AnemSD38bMS						MinMax	0	4		
24	AnemSD35aMS						MinMax	0	4		
30	Vane50aDEG						MinMax	0	359.9		
31	Vane38aDEG						MinMax	0	359.9		
32	Vane30aDEG						MinMax	0	359.9		
50	Turb50zNONE						MinMax	0	2		
51	Turb38zNONE						MinMax	0	2		
52	Turb35zNONE						MinMax	0	2		
60	Wshr0zNONE						MinMax	-100	100		
200	VaneSD50aDEG	Anem50yMS					MinMaxT	0	100	100	10
201	VaneSD38aDEG	Anem38yMS					MinMaxT	0	100	100	10
202	VaneSD30aDEG	Anem35aMS					MinMaxT	0	100	100	10
300	Anem50aMS	AnemSD50aMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2	4
301	Anem50bMS	AnemSD50bMS	Vane50aDEG	VaneSD50aDEG	Etmp2aDEGC		Icing	0.5	1	2	4
302	Anem38aMS	AnemSD38aMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2	4
303	Anem38bMS	AnemSD38bMS	Vane38aDEG	VaneSD38aDEG	Etmp2aDEGC		Icing	0.5	1	2	4
304	Anem35aMS	AnemSD35aMS	Vane30aDEG	VaneSD30aDEG	Etmp2aDEGC		Icing	0.5	1	2	4
400	Anem50aMS	Anem50bMS					CompareSensors	1	0.25	3	0
401	Anem38aMS	Anem38bMS					CompareSensors	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
Etmp2aDEGC	12960	12960	100	0	0	0	100
EtmpSD2aDEGC	12960	12960	100	0	0	0	100
Anem50aMS	12960	12960	100	0	31	0.167	98.557
Anem50bMS	12960	12960	100	0	28.5	355.333	82.23
Anem38aMS	12960	12960	100	0	25.833	0	98.804
Anem38bMS	12960	12960	100	0	24.5	5.5	98.611
Anem35aMS	12960	12960	100	0	18.5	0	99.144
AnemSD50aMS	12960	12960	100	0.167	31	0	98.557
AnemSD50bMS	12960	12960	100	41.667	28.667	0	96.744
AnemSD38aMS	12960	12960	100	0.167	25.833	0	98.796
AnemSD38bMS	12960	12960	100	0.167	24.5	0	98.858
AnemSD35aMS	12960	12960	100	0.333	18.5	0	99.128
Vane50aDEG	12960	12960	100	0	31.5	0	98.542
VaneSD50aDEG	12960	12960	100	0	31.5	0	98.542
Vane38aDEG	12960	12960	100	0	25.833	0	98.804
VaneSD38aDEG	12960	12960	100	0	25.833	0	98.804
Vane30aDEG	12960	12960	100	0	18.5	0	99.144
VaneSD30aDEG	12960	12960	100	0	18.5	0	99.144
Total	**285120**	**285120**	**100**	**42.833**	**515.167**	**361**	**98.066**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent [%]
0.5	0.68
1.5	1.25
2.5	2.61
3.5	4
4.5	6.84
5.5	7.66
6.5	9.81
7.5	10.54
8.5	11.77
9.5	11.19
10.5	9.99
11.5	8.42
12.5	5.57
13.5	3.66
14.5	2.74
15.5	1.62
16.5	0.97
17.5	0.37
18.5	0.18
19.5	0.09
20.5	0.04
21.5	0.01
22.5	0
23.5	0
24.5	0

Monthly Average Wind Speed Data

Date	10 min Mean [m/s]
April 2006	7.89
May	7.66
June	6.81
July	6.93
August	5.87
September	6.44
October	8.12
November	7.41
December	8.17
January 2007	8.68
February	8.78

Diurnal Average Wind Speed Data

hr	Wind Speed [m/s]
0.5	8.51
1.5	8.39
2.5	8.39
3.5	8.52
4.5	8.53
5.5	8.68
6.5	8.92
7.5	8.85
8.5	8.63
9.5	8.65
10.5	8.65
11.5	8.62
12.5	8.55
13.5	8.39
14.5	8.19
15.5	8.04
16.5	8.02
17.5	8.24
18.5	8.65
19.5	8.92
20.5	8.76
21.5	8.68
22.5	8.62
23.5	8.55

Wind Rose Data

Direction	Mean Wind Speed [m/s]	Percent Time [%]
N	6.83	3.02
NNE	6.55	1.9
NE	6.5	1.42
ENE	6.08	0.8
E	6.29	1.3
ESE	9.7	1.68
SE	9.01	1.63
SSE	6.32	2.45
S	6.25	3.18
SSW	7.47	4.36
SW	8.94	10.85
WSW	8.37	9.17
W	8.88	13.87
WNW	8.88	18.61
NW	9.37	15.69
NNW	9.07	10.07