WIND DATA REPORT

Ragged Mountain, ME

July 18th 2007 – October 17th 2008

by

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TABLE OF CONTENTS

TABLE OF FIGURES

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 report covers wind data measured on Ragged Mountain in Camden, Maine. Two anemometers and one direction vane were installed at both 30 m (98.4 ft) and 50 m (164.1 ft) on a communications tower at the summit on July 07, 2007, as well as a temperature probe at the base.

Data was collected between July 18, 2007 and October 17, 2008. Statistics are, however, calculated for the time period between October 1, 2007 to September 30, 2008 in order to provide information for a single complete year. The mean wind speed at 50 m was 8.62 m/s (19.28 mph)* and the prevailing direction was from the north-northeast at 30 m for this period. The gross data recovery percentage (the actual percentage of data received) for the quarter was 84.0% and the net data recovery (the percentage of expected data which was received and passed all quality assurance tests) was 62.7%.

The data logger failed during the winter quarter requiring a new data logger installation on March 7th 2008. Analysis of data from 50 m suggests that all instruments at this level began to fail from the Spring quarter of 2008. Thus, only data from the lower 30 m level are measured data. A Measure-Correlate-Predict algorithm was then used to estimate the wind speed at the 50 m height from March 1st 2008 onwards. Details can be found in the data collection and maintenance section of this report.

The Measure-Correlate-Predict algorithm was also used between data from the 30 m level and a buoy in Penobscot Bay to estimate a longer term average. The long term average at 80 m height is estimated to be 8.92 m/s (19.95 mph)* at the site. A 1.5 MW wind turbine is predicted to have a capacity factor of 0.515 if full availability is assumed.

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 communications tower is located at the peak of Ragged Mt in Camden, Maine. The tower base is located at 44.21093° N, 69.15097° W (WGS84/NAD83) (Figure 1). The cross indicates the approximate location of the tower.

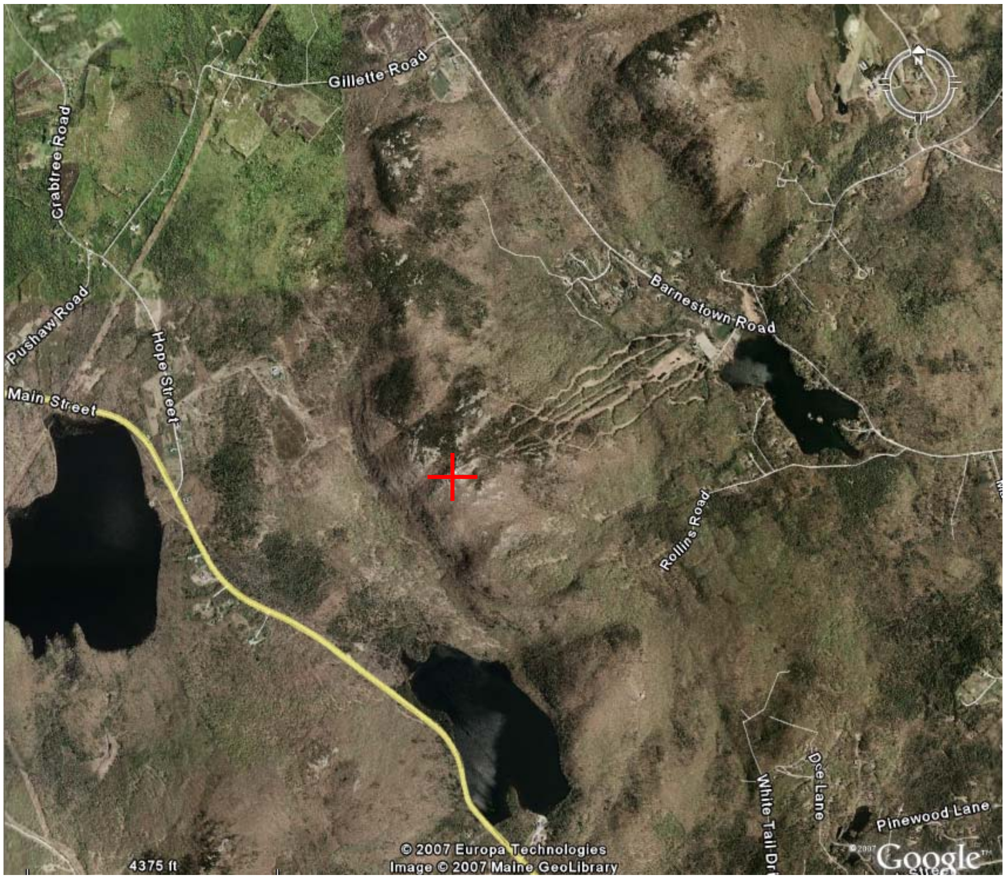

Figure 1– Ragged Mountain (Source: Google Earth)

SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 50 m (164 ft) lattice communications tower. The wind monitoring equipment comes from NRG systems and consists of the following items:

- NRG Symphonie data logger with internal temperature (this replaced a malfunctioning Second Wind Nomad 2 logger).

- 4 – NRG #40 Anemometers, standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at 50 m (164 ft) and two anemometers are located at 30 m (98.4 ft)

- 2 – NRG #200P Wind direction vanes. The vanes are located at 50 m (164 ft) and 30 m (98.4 ft).

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 Height Units	Mean Wind Speed 50 m [m/s]	Max Wind Speed 50 m [m/s]	Prevailing Wind Direction 50 m	Mean Wind Speed 30 m [m/s]	Max Wind Speed 30 m [m/s]	Prevailing Wind Direction 30 m
Aug 2007[1]	7.81	19.19	N	7.74	19.09	N
Sep 2007	8.59	19.72	W	8.39	20.18	WNW
Oct 2007	9.29	26.09	W	9.12	26.06	W
Nov 2007	10.27	27.61	N	10.07	26.53	N
Dec 2007	9.40	25.40	NNW	9.52	25.59	NNW
Jan 2008	10.51	25.95	W	10.46	26.15	WNW
Feb 2008[2]	6.92	20.26	N/A	6.92	20.84	N/A
Mar 2008	11.84/[3]	N/A	N/A	11.62	27.12	N
Apr 2008	8.90[2]	N/A	N/A	8.77	24.37	WNW
May 2008	8.47[2]	N/A	N/A	8.38	23.29	WNW
Jun 2008	7.26[2]	N/A	N/A	7.2	18.34	NNE
Jul 2008	7.96[2]	N/A	N/A	7.85	19.57	NNE
Aug 2008	6.67[2]	N/A	N/A	6.62	17.03	NNE
Sep 2008	8.40[2]	N/A	N/A	8.28	22.74	NNE
Oct 07-Sep 08	**8.62[4]**	**N/A**	**N/A**	**8.61**	**27.12**	**NNE**

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. There is no reliable data from the 50m anemometry past February 10, 2008. Data from the 30 m height is used to estimate these values, through a process called Measure-Correlate-Predict (MCP).

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[1] Calculated from less than 60% of expected data
[2] Calculated from less than 30% of expected data
[3] Calculated from MCP
[4] These averages/values include the MCP data.

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_{low} 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	Mean Wind Shear Coefficient, α
Height Units	50 m [-]	30 m [-]	Between 50 m and 30 m [-]
Aug 2007[5]	0.09	0.10	0.018
Sep 2007	0.10	0.10	0.046
Oct 2007	0.09	0.10	0.036
Nov 2007	0.10	0.11	0.038
Dec 2007	0.09	0.09	-0.025
Jan 2008	0.09	0.10	0.0093
Feb 2008[6]	0.09	0.11	0
Mar 2008	N/A	0.11	N/A
Apr 2008	N/A	0.10	N/A
May 2008	N/A	0.12	N/A
Jun 2008	N/A	0.10	N/A
Jul 2008	N/A	0.1	N/A
Aug 2008	N/A	0.1	N/A
Sep 2008	N/A	0.09	N/A
Oct 2007 – Sep 2008	**N/A**	**0.10**	**0.0023**[7]

SECTION 4- Long Term Estimate and Capacity Factor

Wind speed varies year by year and the mean obtained over the measurement period may be less or more compared to what is seen over a longer time period. Therefore, the use of the long term mean at the site is preferred when projecting the performance of a wind turbine. The long term mean at a site may be estimated by using the Measure-Correlate-Predict (MCP) method.

The MCP method correlates wind speed measurements at the target site to a reference site which collects data over the same period of time and has been collecting data for a much longer period. Based on this correlation, the reference wind speed data is used to predict long term mean at the site.

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[5] Calculated from less than 60% of expected data
[6] Calculated from less than 30% of expected data
[7] Calculated with results from MCP

Long term data from a NOAA buoy in the Penobscot Bay (Station 44033) between January 1st, 1998 and December 31st, 2007 (mean wind speed of 5.1 m/s) is used as reference in the case of Ragged Mt. Correlation between the two sites are obtained from concurrent data between October 1st, 2007 and September 31st, 2007. The long term mean at Ragged Mt at 30 m is estimated to be 8.90 m/s with an uncertainty of 7.3% for the MCP process. This estimate may also be used to calculate the long term mean at different heights by using the mean wind shear at site and the equation described in the previous section. The long term mean wind speed at 80 m height is estimated at 8.92 m/s.

The capacity factor of a wind turbine at a given site depends on the hub height, wind speed distribution at the hub height, the wind turbine power curve and any assumptions about down time and losses due to wake effects from upwind wind turbines, etc. If the hub height wind speed is estimated from data at lower heights, then the capacity factor will also depend on the estimated wind shear and the wind speeds measured at lower heights. No simple estimate of capacity factor at a site could take all of these effects and choices into account. Nevertheless, an estimate of the capacity factor of a wind turbine at this site is provided here to help the reader understand the order of magnitude of the wind resource at this site.

The estimates assume a GE 1.5 sl turbine with a hub height of 80 m and the long term mean wind speed estimate at the highest measurement height and the mean wind shear at the site, in order to determine the mean hub height wind speed, in this case 8.92 m/s. The wind speed probability distribution is assumed to be given by a Rayleigh distribution. The average wind turbine power is then estimated from:

$$\overline{P_W} = \int_0^\infty P_W(U)p(U)dU$$

where $P_W(U)$ is the wind turbine power curve and $p(U)$ is the wind speed probability distribution. The capacity factor is then calculated from:

$$CF = \frac{\overline{P_W}}{P_{rated}}$$

where P_{rated} is the rated capacity of the turbine, i.e., 1500 kW. Based on this equation, the estimated capacity factor of a wind turbine at this site would be about 0.515.

SECTION 5- Graphs

This report contains several types of wind data graphs. Unless otherwise noted, each graph represents data from one year (October 2007 to September 2008). The following graphs are included:

- Time Series – 10-minute average wind speeds are plotted against time. This graph includes all of the collected data, as well as the MCP generated data starting on October 12, 2007.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed.

- 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 whole period of data collection.

- Diurnal – A plot of the average wind speed for each hour of the day. This plot is for the 50m height, and includes the MCP generated data.

- 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 given for the 30 m wind data.

- 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. The wind rose shows data from the 30 m sensors.

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

Wind Speed Time Series

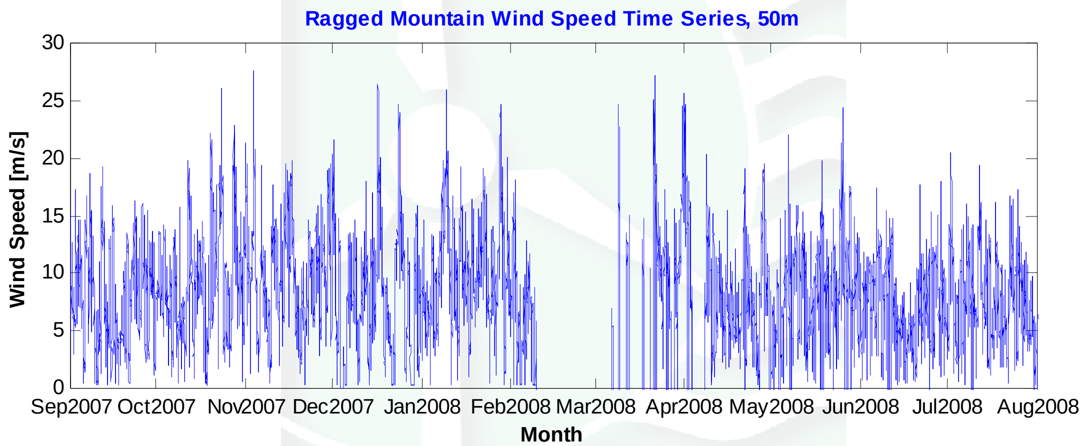

Figure 2 – Wind Speed Time Series, September 2007 – August 2008

Wind Speed Distributions

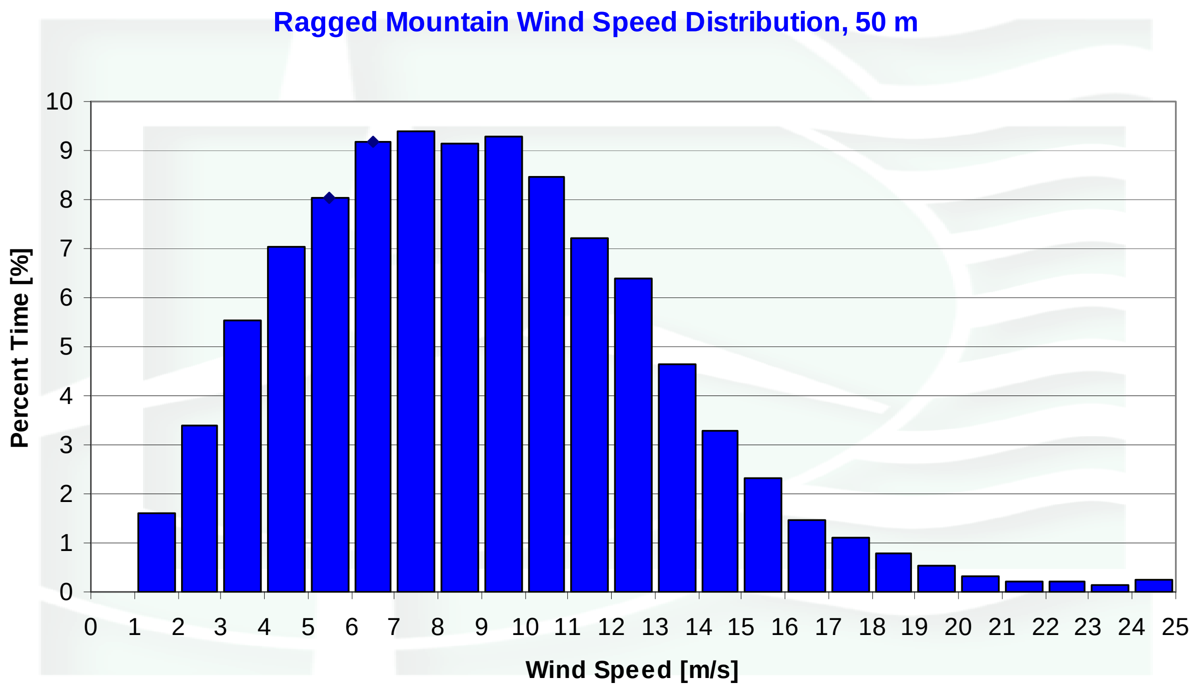

Figure 3 – Wind Speed Distribution, October 2007 – September 2008

Monthly Average Wind Speeds

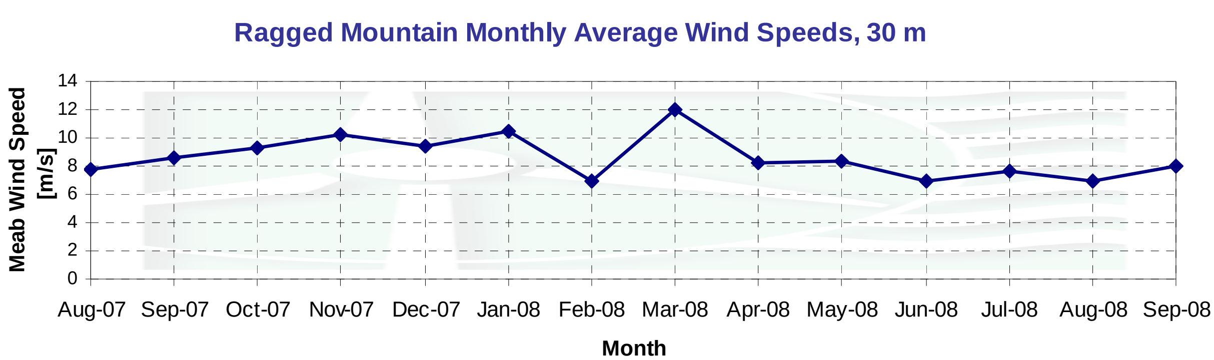

Figure 4 – Monthly Average Wind Speed, August 2007 – September 2008

Diurnal Average Wind Speeds

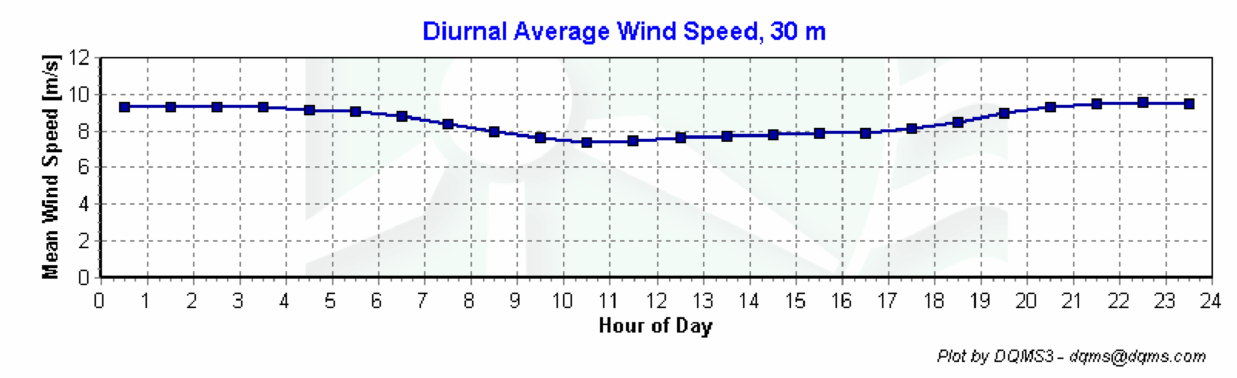

Figure 5 – Diurnal Average Wind Speed, October 2007 – September 2008

Turbulence Intensities

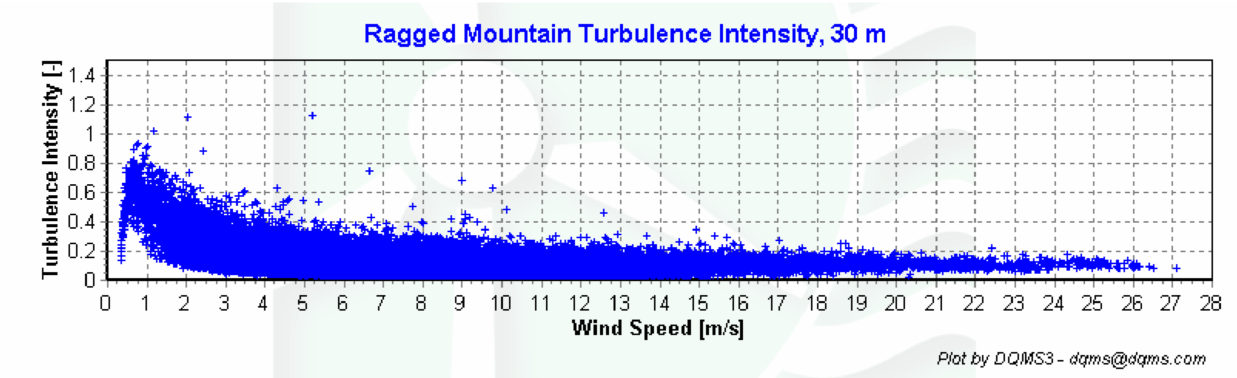

Figure 6 - Turbulence Intensity, October 2007 – September 2008

Wind Rose

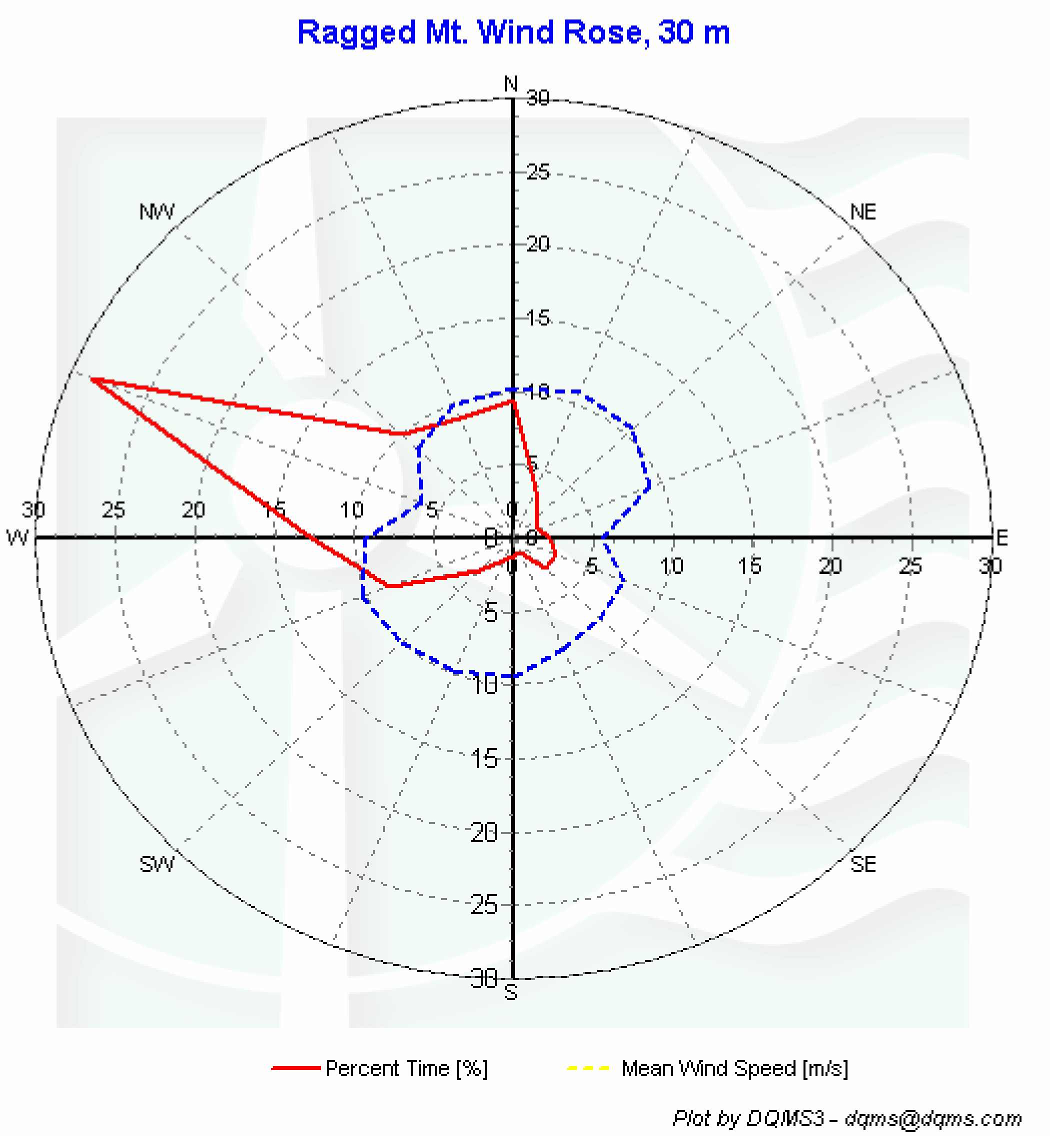

Figure 7 – Wind Rose, October 2007 – September 2008

SECTION 6 - Significant Meteorological Events

There were no extreme metrological events during this data collection period.

SECTION 7- Data Collection and Maintenance

The main power supply to the Nomad2 data logger failed due to a blown fuse on January 10th. After this failure, the direction vanes and external temperature sensor ceased to function because of it's need for an active power supply. The Nomad2 continued to log wind speed data using backup batteries until it lost power on February 9th, after which no data was logged. The failed Nomad2 was replaced with an NRG Symphonie logger on March 7th.

The primary 50 meter anemometer was found to have failed in the first week of March at which point it gave readings of almost exclusively 0.349 m/s. It then began reporting data again at the end of March, albeit at a lower wind speed relative to those reported at 30 m. The data from the secondary 50 m anemometer consistently shows low wind speeds relative to the 30 meter data as well as unusually high turbulence intensity and completely failed in the middle of March. It is believed that the sensor has degraded and that the data is inaccurate. The 50 meter direction vane has also failed during this period. It is showing an unusually narrow direction distribution centered around 0 degrees (North). This is generally indicative of a vane failure. Thus, data from the 50 m level was classified as faulty past February 10th, when the Nomad2 logger failed.

A Measure-Correlate-Predict process was conducted with the 50 m level as the target and the 30 m level as the reference to estimate the monthly means. These results were reported for the months between March to September of 2008.

All of the sensors were removed from the tower on October 17, 2008.

SECTION 8 - 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. The statistics shown below are for the entire period, September 2007 – September 2008.

Gross Data Recovered [%]	84.0
Net Data Recovered [%]	62.7

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 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	Test Field3	TestType	Factor1	Factor2	Factor3	Factor4
1	ETempDEGF			MinMax	-50	140	0	0
2	ETempSDDEGF			MinMax	-50	140	0	0
3	Anem50aMS			MinMax	0	90	0	0
4	Anem50bMS			MinMax	0	90	0	0
5	Anem30aMS			MinMax	0	90	0	0
6	Anem30bMS			MinMax	0	90	0	0
7	Anem50yMS			MinMax	0	90	0	0
8	Anem30yMS			MinMax	0	90	0	0
9	AnemSD50aMS			MinMax	0	7	0	0
10	AnemSD50bMS			MinMax	0	7	0	0
11	AnemSD30aMS			MinMax	0	7	0	0
12	AnemSD30bMS			MinMax	0	7	0	0
13	AnemSD50yMS			MinMax	0	7	0	0
14	AnemSD30yMS			MinMax	0	7	0	0
15	Vane50aDEG			MinMax	0	359.9	0	0
16	Vane30aDEG			MinMax	0	359.9	0	0
17	Turb50zNONE			MinMax	0	2	0	0
18	Turb30zNONE			MinMax	0	2	0	0
19	Amax50aMS			MinMax	0	90	0	0
20	Amin50aMS			MinMax	0	90	0	0
21	Amax50bMS			MinMax	0	90	0	0
22	Amin50bMS			MinMax	0	90	0	0
23	Amax30aMS			MinMax	0	90	0	0
24	Amin30aMS			MinMax	0	90	0	0
25	Amax30bMS			MinMax	0	90	0	0
26	Amin30bMS			MinMax	0	90	0	0
27	ETempMaxDEGF			MinMax	-50	140	0	0
28	ETempMinDEGF			MinMax	-50	140	0	0
29	VaneSD50aDEG	Anem50yMS		MinMaxT	0	100	100	10
30	VaneSD30aDEG	Anem30yMS		MinMaxT	0	100	100	10
31	Anem50aMS	AnemSD50aMS	Vane50aDEG	Icing	0.5	1	36	10
32	Anem50bMS	AnemSD50bMS	Vane50aDEG	Icing	0.5	1	36	10
33	Anem30aMS	AnemSD30aMS	Vane30aDEG	Icing	0.5	1	36	10
34	Anem30bMS	AnemSD30bMS	Vane30aDEG	Icing	0.5	1	36	10
35	Anem50aMS	Anem50bMS		CompareSensors	1	0.25	3	0
36	Anem30aMS	Anem30bMS		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
Anem50aMS	52704	49794	94.479	24	24.167	4629.667	41.225
Anem50bMS	52704	49794	94.479	24	24.167	4682.5	40.623
Anem30aMS	52704	48911	92.803	43.333	480.5	262.667	83.849
Anem30bMS	52704	48911	92.803	40.833	480.5	1175.5	73.486
Vane50aDEG	52704	19009	36.067	0.667	24.167	0	35.785
Vane30aDEG	52704	44622	84.665	15.333	480.5	0	79.021
ETempDEGC	52704	48911	92.803	711.833	0	0	84.699
Total	**368928**	**256960**	**84.01**	**859.999**	**1514.001**	**10750.33**	**62.67**

APPENDIX B - Plot Data

Wind Speed Distribution Data

Wind Speed [m/s]	Percent Time [%]
0.5	0.00
1.5	1.62
2.5	3.38
3.5	5.53
4.5	7.02
5.5	8.05
6.5	9.17
7.5	9.40
8.5	9.14
9.5	9.29
10.5	8.45
11.5	7.23
12.5	6.40
13.5	4.65
14.5	3.28
15.5	2.31
16.5	1.48
17.5	1.10
18.5	0.79
19.5	0.55
20.5	0.32
21.5	0.21
22.5	0.22
23.5	0.15
24.5	0.26

Data from October 2007 – September 2008

Monthly Average Wind Speed Data

Month	Mean Wind Speed [m/s]
Aug-07	7.81
Sep-07	8.59
Oct-07	9.29
Nov-07	10.27
Dec-07	9.40
Jan-08	10.51
Feb-08	6.92
Mar-08	12.03
Apr-08	8.22
May-08	8.31
Jun-08	6.97
Jul-08	7.66
Aug-08	6.93
Sep-08	8.05

Data from October 2007 – September 2008

Diurnal Average Wind Speed Data at 30 m

Hour of Day	Mean Wind Speed [m/s]
0.5	9.35
1.5	9.29
2.5	9.33
3.5	9.3
4.5	9.17
5.5	9.1
6.5	8.85
7.5	8.38
8.5	7.95
9.5	7.66
10.5	7.4
11.5	7.46
12.5	7.61
13.5	7.7
14.5	7.83
15.5	7.87
16.5	7.89
17.5	8.16
18.5	8.48
19.5	8.99
20.5	9.3
21.5	9.45
22.5	9.57
23.5	9.5

Data from October 2007 – September 2008

Wind Rose Data

Wind Direction	Mean Wind Speed, 30m [m/s]	Percent of Time, 30m [%]
N	10.29	9.37
NNE	10.85	3.54
NE	10.51	2.04
ENE	9.21	1.62
E	5.58	2.21
ESE	7.52	2.84
SE	7.65	2.9
SSE	8.16	1.06
S	9.38	1.19
SSW	9.75	1.56
SW	9.96	3.02
WSW	10.26	8.46
W	9.28	12.65
WNW	6.28	28.68
NW	8.6	9.93
NNW	9.95	8.93

Data from October 2007 – September 2008