WIND DATA REPORT

Ragged Mt Maine

March1st 2008 to May 31^{tst} 2008

by

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NOTICE AND ACKNOWLEDGEMENTS

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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 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.

The season covered by this report is March 1, 2008 to May 31, 2008. The quarterly mean recorded wind speed at 30 m was 9.03 m/s (20.0 mph)* and the prevailing direction was from the west-northwest. The gross data recovery percentage (the actual percentage of data received) for the quarter was 93.3% and the net data recovery (the percentage of expected data which was received and passed all quality assurance tests) was 73.0%.

The data logger failed during the winter quarter requiring a new data logger installation on March 7th. Analysis of data from 50 m suggests that all instruments at this level are failing. Thus, only data from the lower 30 m level is presented in this report. Details can be found in the data collection and maintenance section of this report.

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

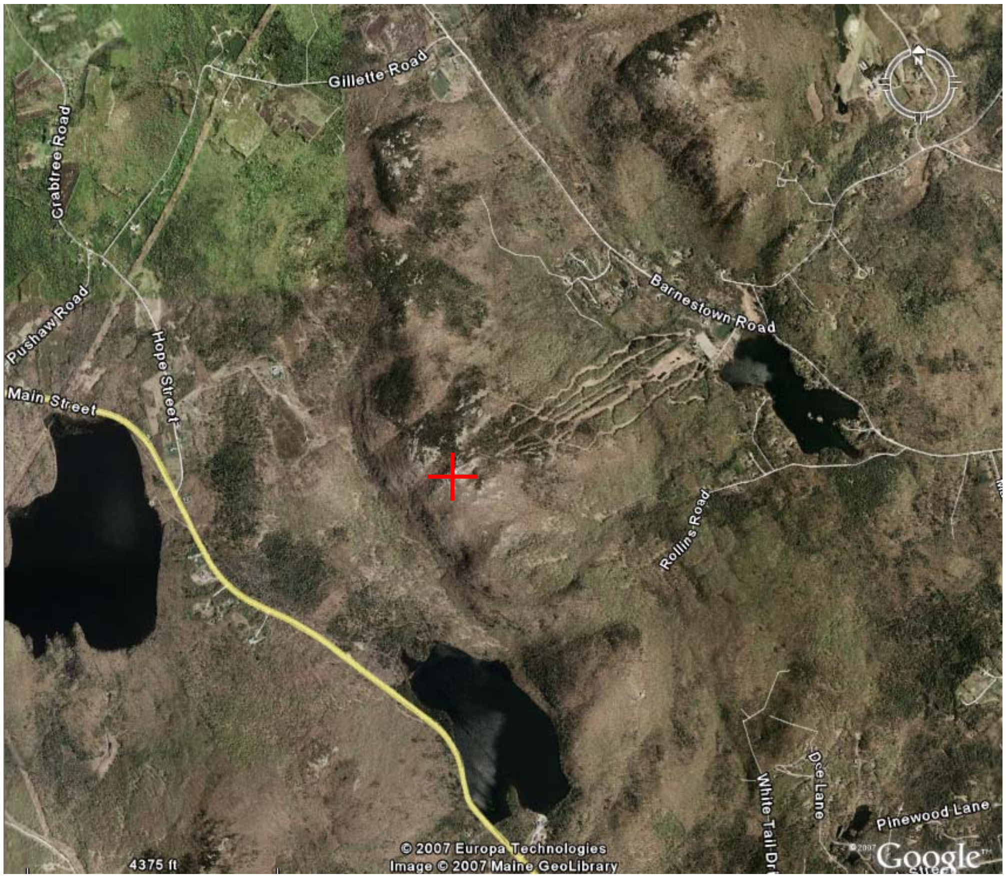

Figure 1– Ragged Mountain

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 (replaced a Second Wind Nomad Two).

- 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).

The data from the Symphonie logger is sent to RERL via a cellular modem once a day. The logger samples wind speed and direction once every second. These samples are combined into 10-minute averages and are put into a binary file along with the maximum, minimum and standard deviation for each 10-minute interval. The binary files are converted to ASCII text files using NRG software. These text files are then imported into a database software program where they are subjected to quality assurance tests prior to data usage.

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
Height Units	**50 m [m/s]**	**50 m [m/s]**	**50 m**	**30 m [m/s]**	**30 m [m/s]**	**30 m**
March 2008	N/A	N/A	N/A	11.62	27.12	N
April 2008	N/A	N/A	N/A	8.77	24.37	WNW
May 2008	N/A	N/A	N/A	8.38	23.29	WNW
March 2008 - May 2008	**N/A**	**N/A**	**N/A**	**9.03**	**27.12**	**WNW**

Wind data statistics in the table are representative of the 73.0% of expected data for the quarter that was collected and passed quality assurance tests.

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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 10 and 11 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.

$$\alpha = \log\left(\frac{U(z_{high})}{U(z_{low})}\right) \Bigg/ \log\left(\frac{z_{high}}{z_{low}}\right)$$

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 [-]
March 2008	N/A	0.13	N/A
April 2008	N/A	0.11	N/A
May 2008	N/A	0.12	N/A
March 2008 –May 2008	**N/A**	**0.12**	**N/A**

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.
- 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 year.
- Diurnal – A plot of the average wind speed for each hour of the day.
- 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.
- 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.

Figure 2, the average wind speed time series, shows that the highest speed at 30 meters of 27.12 m/s occurred towards the end of March. The wind speed distribution, shown in figure 3, indicates that the most frequently occurring wind speeds were between 8 and 9 m/s. The plot of monthly average wind speeds, shown in figure 4, shows that the monthly average wind speed decreased in February before peaking in March. Note that this only represents 9 days of data for February (see data collection and maintenance section) and that the wind speed data for March through May is from 30 meters while the data for the previous months is from 50 meters . Figure 5 shows that the average wind speeds remain relatively constant throughout the day with a decrease in the daylight hours. The plot of turbulence intensity, shown in figure 6, shows a decrease in turbulence intensity with an increase in wind velocity. The wind rose, shown in figure 7, shows that the prevailing winds occur from the west-northwest with highest wind speeds occurring from the southeast.

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

Wind Speed Time Series

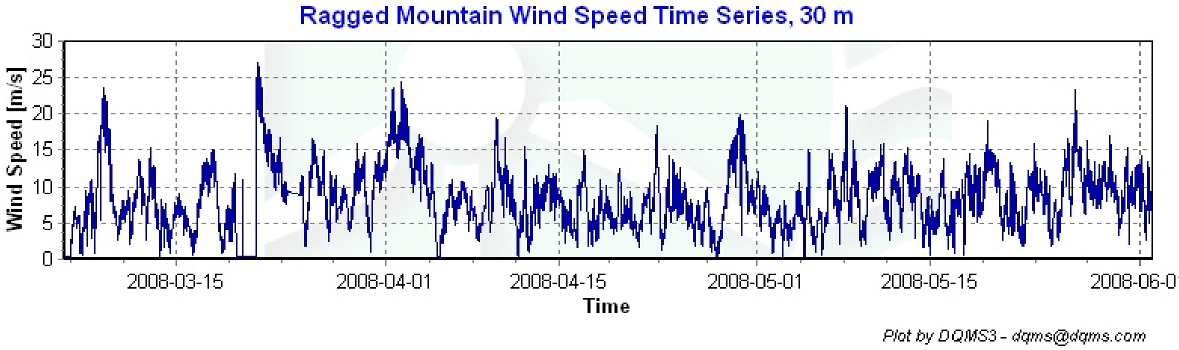

Figure 2– Wind Speed Time Series, March 1, 2008 – May 31, 2008.

Wind Speed Distributions

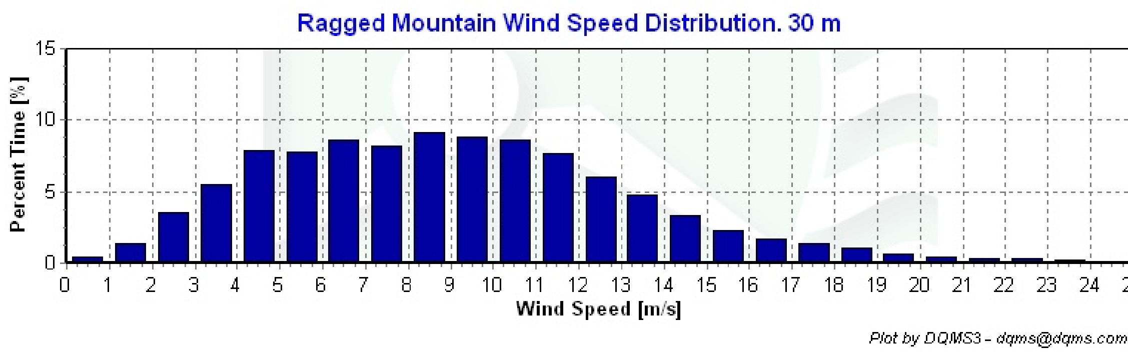

Figure 3– Wind Speed Distribution, March 1, 2008 – May 31, 2008.

Monthly Average Wind Speeds

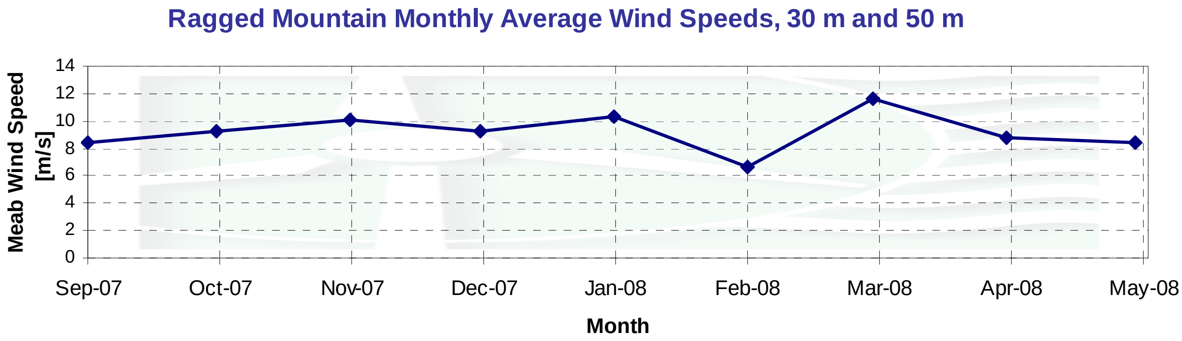

Figure 4– Monthly Average Wind Speeds, September 2007 – May 2008. Data for September through January is from 50 meters, March through May is from 30 meters.

Diurnal Average Wind Speeds

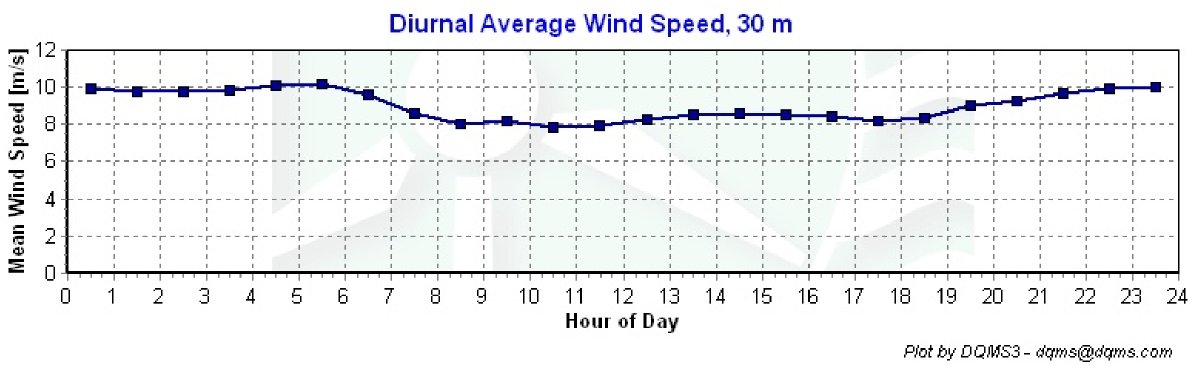

Figure 5– Diurnal Average Wind Speeds, March 1, 2008 – May 31, 2008.

Turbulence Intensities

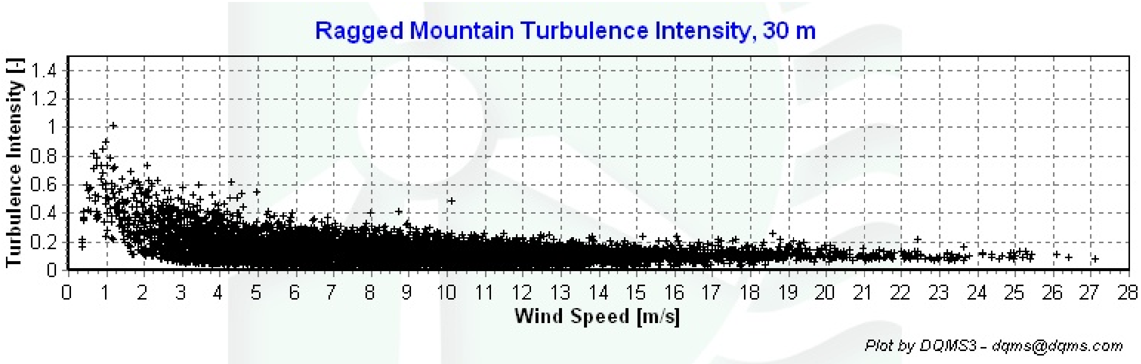

Figure 6– Turbulence Intensity vs. Wind Speed, March 1, 2008 – May 31, 2008.

Wind Roses

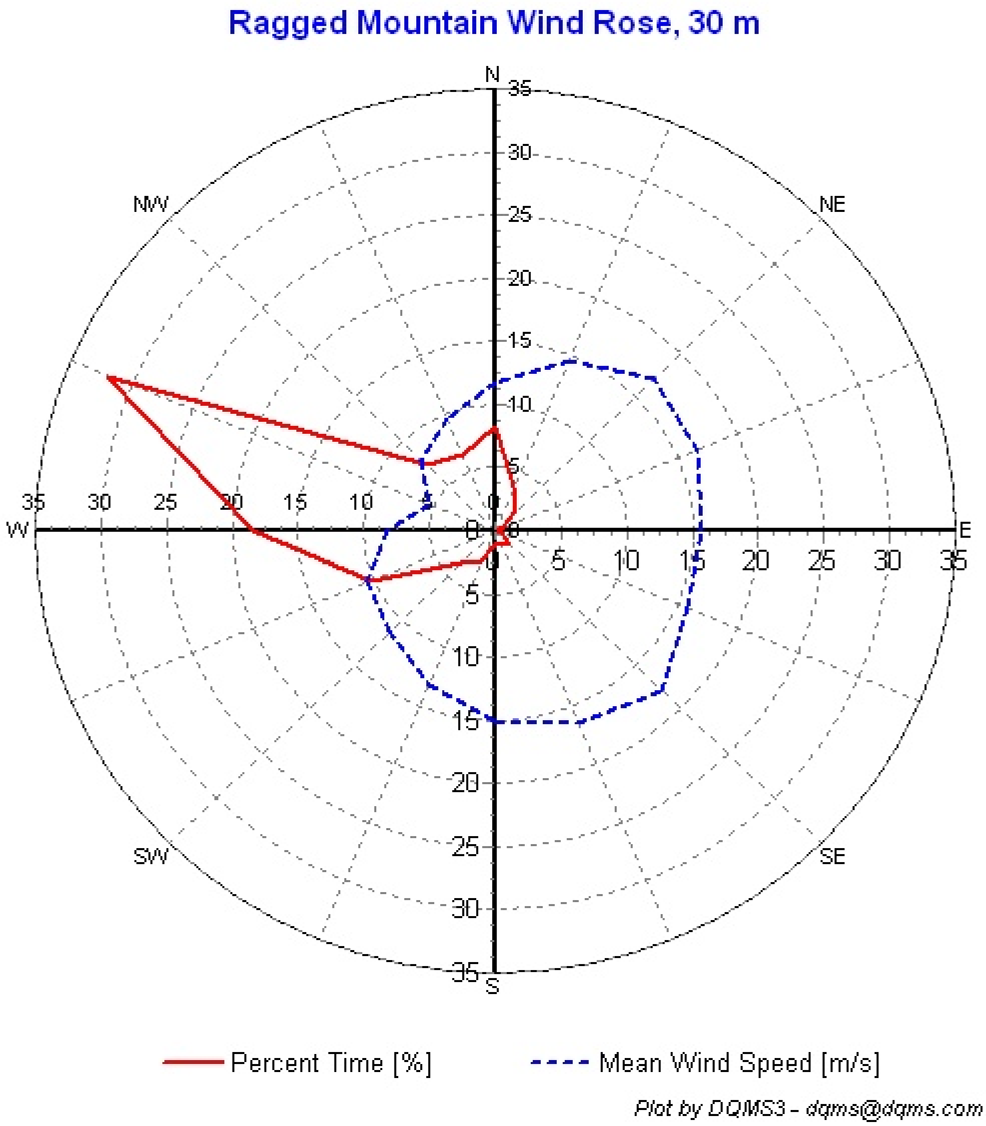

Figure 7– Wind Rose, March 1, 2008 – May 31, 2008.

SECTION 5 - Significant Meteorological Events

There were no extreme metrological events during this data collection period. The highest recorded wind speed was 27.12 m/s (60.67 mph).

SECTION 6 - Data Collection and Maintenance

The main power supply to the Nomad 2 data logger failed due to a blown fuse on January 10th. After this failure, the direction vanes and external temperature sensor ceased to function. The Nomad 2 continued to log wind speed data using backup batteries until it lost power on February 9th, after which no data was logged. The failed Nomad 2 was replaced with an NRG Symphonie logger on March 7th.

The primary 50 meter anemometer failed in the first week of March at which point it gave readings of almost exclusively 0.349 m/s. 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. 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.

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 [%]	93.3
Net Data Recovered [%]	73.0

<u>Test Definitions</u>

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.

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

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	13249	12366	93.335	422	578.5	150	41.233
Amax50aMS	13249	12366	93.335	0	0	0	93.335
Amin50aMS	13249	12366	93.335	0	0	0	93.335
AnemSD50aMS	13249	12366	93.335	422	578.5	150	41.233
Anem50bMS	13249	12366	93.335	494.167	69	1336.833	7.291
Amax50bMS	13249	12366	93.335	0	0	0	93.335
Amin50bMS	13249	12366	93.335	0	0	0	93.335
AnemSD50bMS	13249	12366	93.335	494.167	69	1336.833	7.291
Anem30aMS	13249	12366	93.335	14.5	449.667	39.667	70.519
Amax30aMS	13249	12366	93.335	0	0	0	93.335
Amin30aMS	13249	12366	93.335	0	0	0	93.335
AnemSD30aMS	13249	12366	93.335	14.5	449.667	39.667	70.519
Anem30bMS	13249	12366	93.335	14.167	449.667	266.5	60.261
Amax30bMS	13249	12366	93.335	0	0	0	93.335
Amin30bMS	13249	12366	93.335	0	0	0	93.335
AnemSD30bMS	13249	12366	93.335	14.167	449.667	266.5	60.261
Vane50aDEG	13249	12366	93.335	0	621.833	0	65.175
VaneSD50aDEG	13249	12366	93.335	0	621.833	0	65.175
Vane30aDEG	13249	12366	93.335	9	449.667	0	72.564
VaneSD30aDEG	13249	12366	93.335	9	449.667	0	72.564
ETempDEGC	13249	12366	93.335	13	0	0	92.747
ETempSDDEGC	13249	12366	93.335	13	0	0	92.747
ETempMaxDEGC	13249	12366	93.335	12.833	0	0	92.754
ETempMinDEGC	13249	12366	93.335	13.5	0	0	92.724
Total	317976	296784	93.335	1960	5236.667	3586	72.989

APPENDIX B - Plot Data

Wind Speed Distribution Data

Bin Center Wind Speed [m/s]	Percent of Time [%]
0.5	0.45
1.5	1.36
2.5	3.56
3.5	5.52
4.5	7.84
5.5	7.79
6.5	8.61
7.5	8.20
8.5	9.11
9.5	8.82
10.5	8.57
11.5	7.69
12.5	5.99
13.5	4.78
14.5	3.35
15.5	2.23
16.5	1.70
17.5	1.34
18.5	1.04
19.5	0.62
20.5	0.42
21.5	0.34
22.5	0.28
23.5	0.21

Table 1- Wind Speed Distribution, 30 m, March 1, 2008 – May 31, 2008.

Monthly Average Wind Speed Data

Month	Monthly Average Speed [m/s]
Sep-07	8.46
Oct-07	9.2
Nov-07	10.08
Dec-07	9.21
Jan-08	10.32
Feb-08	6.61
Mar-08	11.62
Apr-08	8.77
May-08	8.38

Table 2- Monthly average wind speed, 50 m, September 2007 – February 2008 and 30 m, March 2008 – May 2008.

Diurnal Average Wind Speed Data

Hour of Day	Average Wind Speed [m/s]
0.5	9.95
1.5	9.73
2.5	9.73
3.5	9.84
4.5	10.12
5.5	10.18
6.5	9.63
7.5	8.58
8.5	8.01
9.5	8.20
10.5	7.82
11.5	7.90
12.5	8.29
13.5	8.53
14.5	8.57
15.5	8.55
16.5	8.48
17.5	8.19
18.5	8.36
19.5	9.05
20.5	9.24
21.5	9.69
22.5	9.95
23.5	10.04

Table 3- Diurnal Average Wind Speeds, 30 m, March 1, 2008 – May 31, 2008.

Wind Rose Data

Direction	Percent of time [%]	Mean Wind Speed [m/s]
N	8.24	11.73
NNE	3.78	14.62
NE	2.13	17.10
ENE	0.69	16.70
E	0.12	15.65
ESE	0.56	15.79
SE	1.61	17.84
SSE	1.11	16.46
S	1.15	15.02
SSW	2.59	13.19
SWE	3.69	11.31
WSW	10.21	10.50
W	18.34	8.19
WNW	31.98	5.47
NW	7.30	7.93
NNW	6.48	9.68

Table 4- Wind Rose, Time Percentage, and Mean Wind Speed by Direction, 30 m, March 1, 2008 – May 31, 2008.