# WIND DATA REPORT

# Swan's Island, ME

September 1, 2007 – November 30, 2007

Prepared for

US Department of Energy

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 US Department of Energy. The opinions expressed in this report do not necessarily reflect those of the US DOE 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 summarizes the wind data recorded for the fall quarter, September 2007 through November 2007, at Swan's Island, ME. Average wind speeds for the quarter were found to be around 6.49 m/s at a height of 50m. The prevailing wind direction for the quarter was WSW. The amount of valid data recorded for the quarter was 94.73%.

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 station is a cell phone tower operated by U.S. Cellular, located at Stockbridge Hill on Swans Island, Maine. The coordinates for the tower are 44.11161 N, 68.42218 W. The base of the tower is at an altitude of 54.86 m (180 ft) above mean sea level.


**Figure 1 - Location of the Swans Island tower**

# SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on the cell phone tower at a height of 50 m and 40 m. At each height two NRG #40 anemometers with standard calibration (Slope – 0.765 m/s, Offset – 0.350 m/s) and one NRG #200P wind vane are installed. A #110S temperature sensor is mounted at the base of the tower at an approximated height of 2 m. The data is logged by an NRG Symphonie logger and is mailed to the University of Massachusetts, Amherst on a regular basis. The logger samples wind speed and direction once every two seconds. These samples are combined into 10-minute averages and are put into a binary file along with the standard deviation for each 10-minute interval. The 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 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** | **40 m [m/s]** | **40 m [m/s]** | **40 m** |
| Sept 2007 | 5.88 | 13.11 | WSW | 5.42 | 11.77 | SW |
| Oct 2007 | 6.25 | 15.65 | WSW | 5.76 | 14.65 | SW |
| Nov 2007 | 7.34 | 21.88 | NNW | 6.81 | 20.02 | NW |
| **Sept 2007 -Nov 2007** | **6.49** | **21.88** | **WSW** | **6** | **20.02** | **SW** |

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 are 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 each 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.

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

**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 [-]** | **40 m [-]** | **Between 50 m and 40 m [-]** |
| Sept 2007 | 0.14 | 0.16 | 0.37 |
| Oct 2007 | 0.15 | 0.17 | 0.37 |
| Nov 2007 | 0.17 | 0.19 | 0.34 |
| **Sept 2007 -Nov 2007** | **0.15** | **0.17** | **0.35** |

# 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.

The wind speed time series in Figure 2 shows a possible winter storm front passing through the site on November 3rd. Over this quarter the wind speed is between 4 m/s and 7 m/s over one third of the time and between 3 m/s and 8 m/s over half of the time as shown in Figure 3. The monthly average in Figure 4 shows an increasing trend as it moves into the winter months as expected The hourly average over the day does not vary by much though as shown by Figure 5. The winds have a tendency to come in from the WSW direction during this quarter as shown by 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

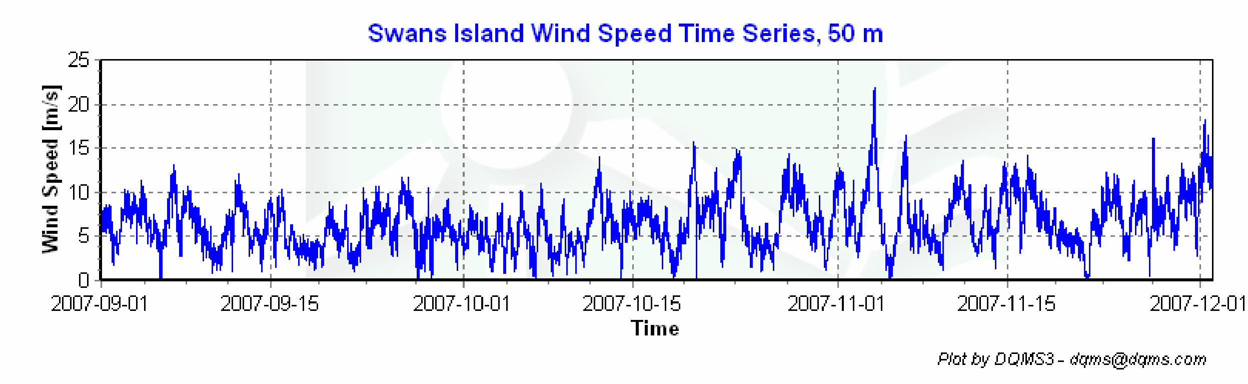


**Figure 2 – Wind Speed Time Series, September 1, 2007 – November 30, 2007**

## Wind Speed Distributions

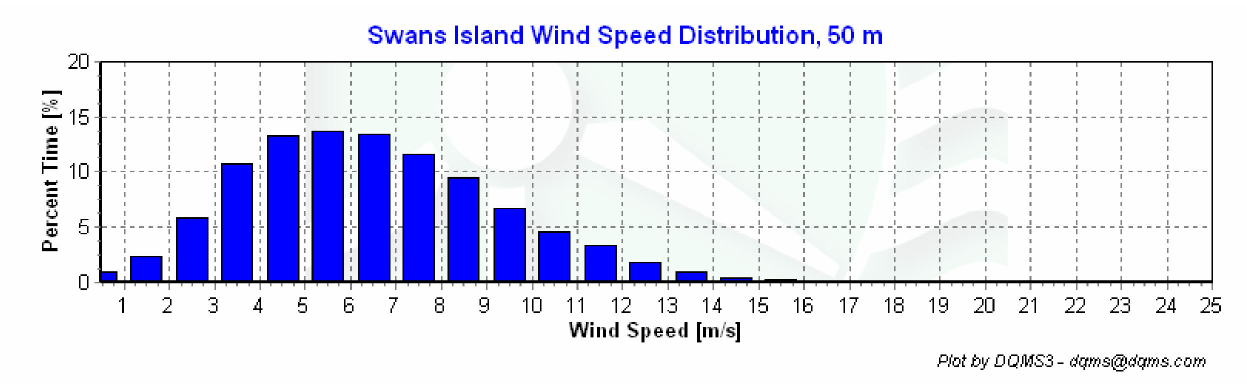


**Figure 3 – Wind Speed Distribution, September 1, 2007 – November 30, 2007**

## Monthly Average Wind Speeds

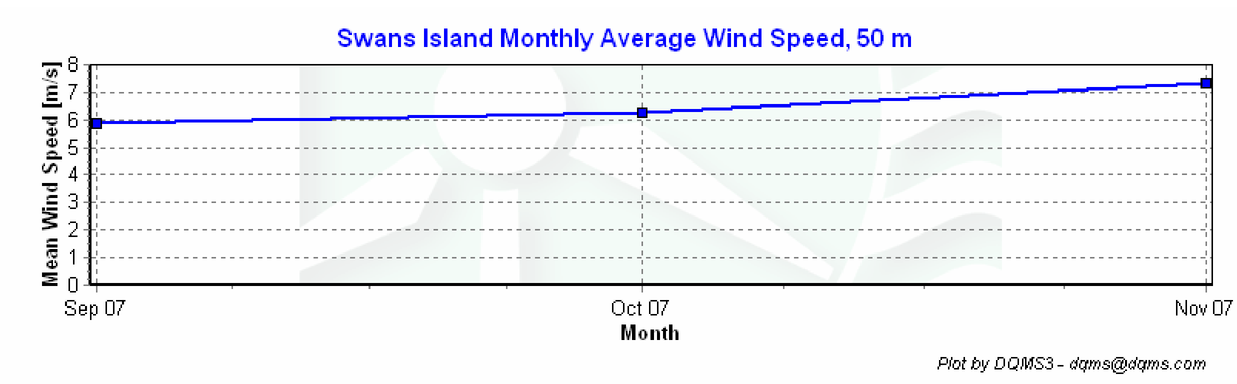


**Figure 4 – Monthly Average Wind Speed September 2007 – November 2007**

## Diurnal Average Wind Speeds

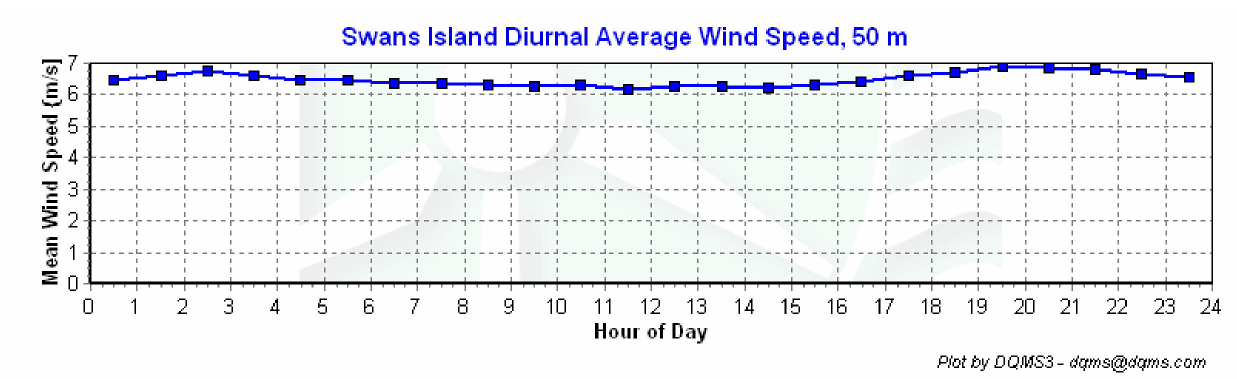


**Figure 5 – Diurnal Average Wind Speed, September 1, 2007 – November 30, 2007**

## Turbulence Intensities

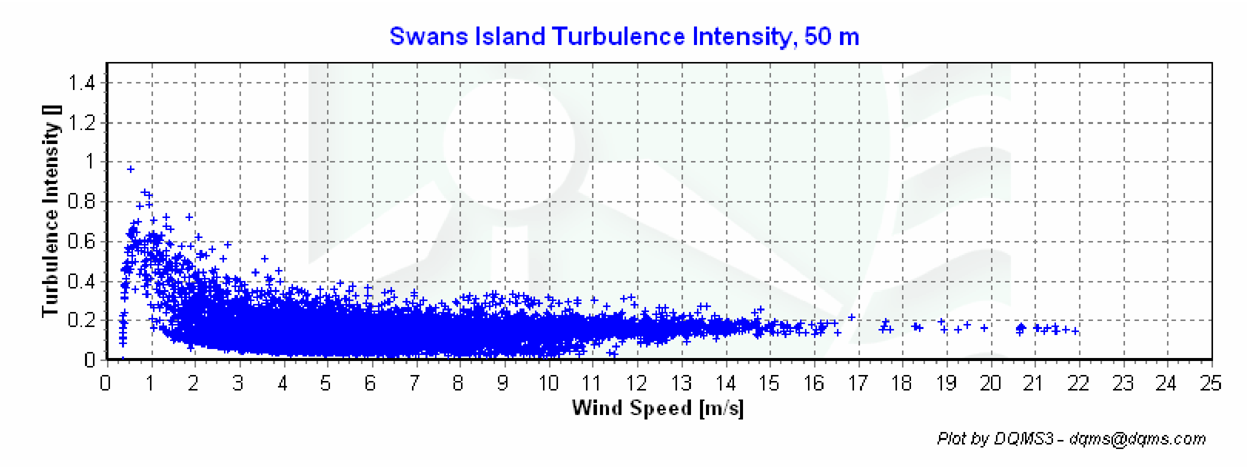


**Figure 6 – Turbulence Intensity, September 1, 2007 – November 30, 2007**

## Wind Roses

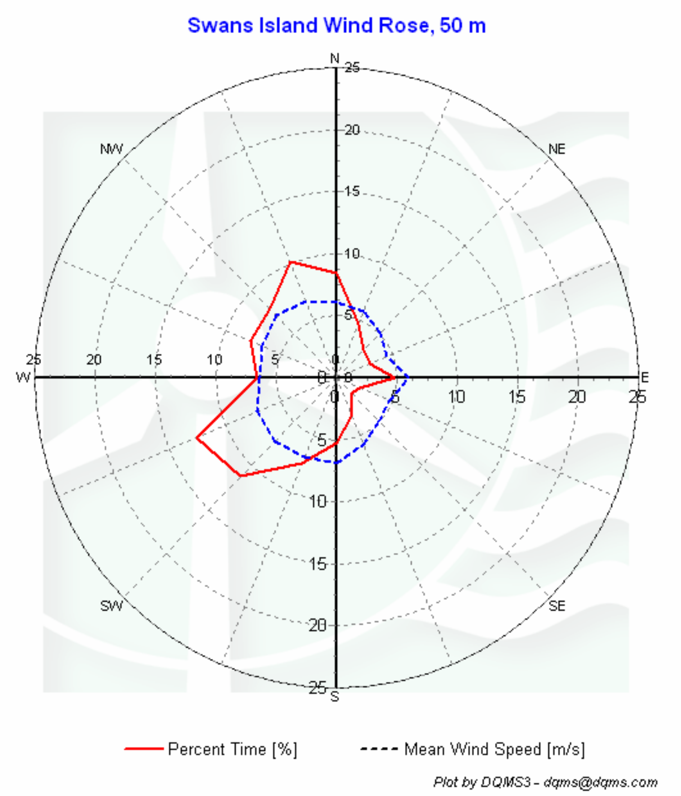


**Figure 7 – Wind Rose, September 1, 2007 – November 30, 2007**

# SECTION 5 - Significant Meteorological Events

There were no significant meteorological events occuring in the region between September 2007 and November 2007.

# SECTION 6 - Data Collection and Maintenance

There were no maintenance issues with the equipment for this quarter and data collection went well.

# 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 [%] | 94.73 |

**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.

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

## 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

| Test Order | TestField1 | TestField2 | TestField3 | CalcField1 | CalcField2 | Calc Field3 | TestType | Factor 1 | Factor 2 | Factor 3 | Factor 4 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Anem50aMS | | | | | | MinMax | 0 | 90 | | |
| 2 | Anem50bMS | | | | | | MinMax | 0 | 90 | | |
| 3 | Anem40aMS | | | | | | MinMax | 0 | 90 | | |
| 4 | Anem40bMS | | | | | | MinMax | 0 | 90 | | |
| 5 | Anem50yMS | | | | | | MinMax | 0 | 90 | | |
| 6 | Anem40yMS | | | | | | MinMax | 0 | 90 | | |
| 7 | Vane50aDEG | | | | | | MinMax | 0 | 359.9 | | |
| 8 | Vane40aDEG | | | | | | MinMax | 0 | 359.9 | | |
| 9 | Etemp2aDEGF | | | | | | MinMax | -30 | 60 | | |
| 10 | Batt2aVDC | | | | | | MinMax | 10.5 | 15 | | |
| 11 | Turb50zNONE | | | | | | MinMax | 0 | 2 | | |
| 12 | Turb40zNONE | | | | | | MinMax | 0 | 2 | | |
| 13 | AnemSD50aMS | | | | | | MinMax | 0 | 4 | | |
| 14 | AnemSD50bMS | | | | | | MinMax | 0 | 4 | | |
| 15 | AnemSD40aMS | | | | | | MinMax | 0 | 4 | | |
| 16 | AnemSD40bMS | | | | | | MinMax | 0 | 4 | | |
| 17 | AnemSD50yMS | | | | | | MinMax | 0 | 4 | | |
| 18 | AnemSD40yMS | | | | | | MinMax | 0 | 4 | | |
| 21 | EtempSD2a DEGF | | | | | | MinMax | -30 | 60 | | |
| 22 | BattSD2aVDC | | | | | | MinMax | 0 | 5 | | |
| 200 | VaneSD50a DEG | Anem50yMS | | | | | MinMaxT | 0 | 100 | 100 | 10 |
| 201 | VaneSD40a DEG | Anem40yMS | | | | | MinMaxT | 0 | 100 | 100 | 10 |
| 300 | Anem50aMS | AnemSD50a MS | Vane50a DEG | VaneSD50a DEG | Etemp2a DEGF | | Icing | 0.5 | 1 | 2 | 4 |
| 301 | Anem50bMS | AnemSD50b MS | Vane50a DEG | VaneSD50a DEG | Etemp2a DEGF | | Icing | 0.5 | 1 | 2 | 4 |
| 302 | Anem40aMS | AnemSD40a MS | Vane40a DEG | VaneSD40a DEG | Etemp2a DEGF | | Icing | 0.5 | 1 | 2 | 4 |
| 303 | Anem40bMS | AnemSD40b MS | Vane40a DEG | VaneSD40a DEG | Etemp2a DEGF | | Icing | 0.5 | 1 | 2 | 4 |
| 400 | Anem50aMS | Anem50bMS | | | | | Compare Sensors | 1 | 0.25 | 3 | 0 |
| 401 | Anem40aMS | Anem40bMS | | | | | Compare Sensors | 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 | 18036 | 18036 | 100 | 0.167 | 100.833 | 162.833 | 91.22 |
| Anem50bMS | 18036 | 18036 | 100 | 0 | 100.667 | 128.833 | 92.37 |
| Anem40aMS | 18036 | 18036 | 100 | 0.333 | 83.667 | 156.5 | 92.00 |
| Anem40bMS | 18036 | 18036 | 100 | 0.167 | 84.833 | 103.333 | 93.74 |
| Vane50aDEG | 18036 | 18036 | 100 | 0 | 101 | 0 | 96.64 |
| Vane40aDEG | 18036 | 18036 | 100 | 0.167 | 85.167 | 0 | 97.16 |
| Etemp2aDEGF | 18036 | 18036 | 100 | 0 | 0 | 0 | 100 |
| **Total** | **126252** | **126252** | **100** | **0.834** | **556.167** | **551.499** | **94.73** |

# APPENDIX B - Plot Data

## Wind Speed Distribution Data

| Wind Speed [m/s] | Time [%] |
|---|---|
| 0.5 | 0.94 |
| 1.5 | 2.37 |
| 2.5 | 5.82 |
| 3.5 | 10.82 |
| 4.5 | 13.25 |
| 5.5 | 13.77 |
| 6.5 | 13.38 |
| 7.5 | 11.64 |
| 8.5 | 9.53 |
| 9.5 | 6.74 |
| 10.5 | 4.68 |
| 11.5 | 3.29 |
| 12.5 | 1.83 |
| 13.5 | 0.96 |
| 14.5 | 0.46 |
| 15.5 | 0.21 |
| 16.5 | 0.08 |
| 17.5 | 0.03 |
| 18.5 | 0.04 |
| 19.5 | 0.02 |
| 20.5 | 0.04 |
| 21.5 | 0.08 |
| 22.5 | 0 |
| 23.5 | 0 |
| 24.5 | 0 |

## Diurnal Average Wind Speed Data

| Hour of day | Wind Speed [m/s] |
|---|---|

| | |
|---|---|
| 0.5 | 6.47 |
| 1.5 | 6.59 |
| 2.5 | 6.73 |
| 3.5 | 6.62 |
| 4.5 | 6.48 |
| 5.5 | 6.48 |
| 6.5 | 6.34 |
| 7.5 | 6.36 |
| 8.5 | 6.31 |
| 9.5 | 6.27 |
| 10.5 | 6.33 |
| 11.5 | 6.18 |
| 12.5 | 6.26 |
| 13.5 | 6.26 |
| 14.5 | 6.24 |
| 15.5 | 6.32 |
| 16.5 | 6.41 |
| 17.5 | 6.6 |
| 18.5 | 6.72 |
| 19.5 | 6.88 |
| 20.5 | 6.87 |
| 21.5 | 6.79 |
| 22.5 | 6.68 |
| 23.5 | 6.56 |

## Monthly Average Wind Speed Data

| **Month** | **50 m Mean Wind Speed** |
|---|---|

| | [m/s] |
|---|---|
| September 2007 | 5.88 |
| October 2007 | 6.25 |
| November 2007 | 7.34 |

## Wind Rose Data

| Wind Direction | Mean Wind Speed [m/s] | Percent of Time [%] |
|---|---|---|
| N | 6.06 | 8.45 |
| NNE | 5.83 | 4.72 |
| NE | 5.09 | 3.14 |
| ENE | 4.46 | 2.98 |
| E | 5.97 | 4.75 |
| ESE | 4.76 | 2.03 |
| SE | 4.96 | 1.81 |
| SSE | 5.76 | 3.28 |
| S | 6.93 | 5.29 |
| SSW | 6.86 | 7.5 |
| SW | 7.26 | 11.23 |
| WSW | 7.09 | 12.52 |
| W | 6.37 | 6.59 |
| WNW | 6.69 | 7.77 |
| NW | 7.09 | 7.84 |
| NNW | 6.64 | 10.11 |