# WIND DATA REPORT

# Mt. Tom

September 1, 2004 – November 30, 2004

Prepared for

Massachusetts Technology Collaborative
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# NOTICE AND ACKNOWLEDGE7MENTS

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), pursuant to work order number 05-1. 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 wind measurement station is installed on the FAA tower at Mt. Tom in Holyoke, MA. Installed in December of 1999, the station is in continuous operation to this day. Two sets of two anemometers and one wind vane are mounted at 24 m (78.7 ft) and 37 m (121.4 ft), respectively.

During the period covered by this report, September 2004 – November 2004, the mean recorded wind speed for this quarter was 5.83 m/s (13.04 mph)* and the prevailing wind direction was from the northwest. The gross data recovery percentage (the actual percentage of expected data received) was 88.889% and the net data recovery percentage (the percentage of expected data which passed all of the quality assurance tests) was 88.508%. The low gross data recovery is due to the fact that a Symphonie logger was installed on August 4, 2004 to replace a failed 9302 Cellogger. Symphonie loggers do not collect logger internal temperature or battery voltage data. These missing data are not directly used in quarterly reports, but they still contribute to the low gross data recovery percentage. The closeness of the net data recovery value to the gross data recovery value suggests that all of the sensors are working well.

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.

* 1m/s = 2.24 mph

# SECTION 1 - Station Location

The Mt. Tom site is located at an existing FAA tower on top of Mt. Tom in Holyoke, MA. Some trees are located in the vicinity, as is an ESI-80 wind turbine. The location of the tower base is at 42°-14'-59.2" N, 72°-38'-42.2" W (NAD 27).

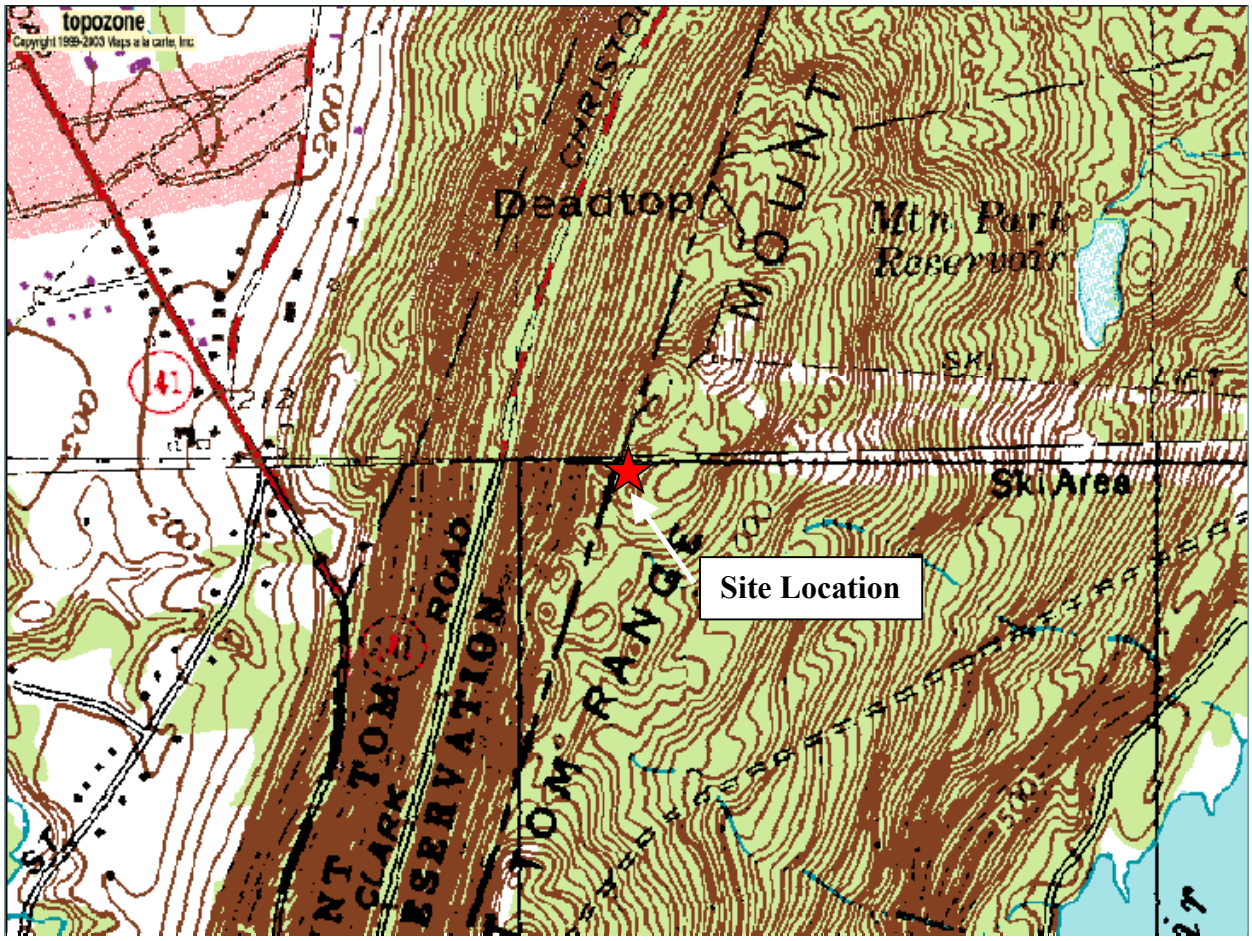


**Figure 1: Station location of Mt. Tom.**

**www.topozone.com**

# SECTION 2 - Instrumentation and Equipment

The wind monitoring equipment is mounted on a 160 ft lattice tower. All the remaining monitoring equipment comes from NRG Systems, and consists of the following items:

- Symphonie Data Logger (from 8/04/2004 to 12/02/2004)
- Electrical enclosure box
- Yagi directional antenna and mount
- 4 – #40 Anemometers, standard calibration (Slope - 0.765 m/s, Offset – 0.350 m/s). Two anemometers are located at both 37 m (121.4 ft) and 24 m (78.7 ft).
- 2 - #200P Wind direction vanes. They are located at 37 m (121.4 ft) and 24 m (78.7 ft).
- 4 – Sensor booms, 43" length
- Lightning rod and grounding cable
- Shielded sensor wire

The data from the Symphonie logger was retrieved about once per month and delivered to the University of Massachusetts, Amherst. The wind speed and direction are sampled at 2 Hz. These samples 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 Collection and Maintenance

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

- In mid-summer, a Symphonie Data Logger was installed to replace a failed 9302 Cellogger. Unlike the 9302 Cellogger, the Symphonie does not collect logger internal temperature or battery voltage data. Therefore, for the entire fall quarter, there are no available logger internal temperature or battery voltage data. While these missing data do not affect the results in this report, they do contribute to lower gross data recovery percentages.
- No maintenance operations were needed or performed.

No measurement of wind speed can be perfectly accurate. 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.

**Data Statistics Summary**

| Date | Mean Wind Speed | Max Wind Speed | Turbulence Intensity | Prevailing Wind Direction | Mean Wind Speed | Max Wind Speed | Turbulence Intensity | Prevailing Wind Direction |
|---|---|---|---|---|---|---|---|---|
| **Heights, units** | **37 m, [m/s]** | **37 m, [m/s]** | **37 m, [ ]** | **37 m, [ ]** | **24 m, [m/s]** | **24 m, [m/s]** | **24 m, [ ]** | **24 m, [ ]** |
| Sept 2004 | 5.04 | 15.1 | 0.19 | NNE | 4.25 | 13.3 | 0.24 | N |
| Oct 2004 | 5.67 | 14.5 | 0.17 | NNE | 4.7 | 13.5 | 0.23 | NNE |
| Nov 2004 | 6.78 | 23 | 0.17 | NW | 5.79 | 20.1 | 0.22 | WNW |
| **Sept -- Nov 2004** | **5.83** | **23** | **0.18** | **NW** | **4.91** | **20.1** | **0.23** | **WNW** |

# SECTION 4 - Significant Meteorological Events

The fall quarter, comprising September, October, and November, had close to average wind conditions. There are no major wind events shown in the wind speed time series. The fall of 2004 had slightly more precipitation than an average fall, but this did not cause abnormal wind conditions.

Source: http://www.erh.noaa.gov/box/MonthlyClimate2.shtml.

# 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 [%] | 88.889 |
| Net Data Recovered [%] | 88.508 |

The low Gross Data Recovered Percentage is due to the fact that a Symphonie logger was installed on August 4, 2004 to replace a failed 9302 Cellogger. The Symphonie does not collect logger internal temperature or battery voltage data. These missing data are not directly used in quarterly reports, but they still contribute to the low gross data recovery percentage. The very small difference between the Gross Data Recovered Percentage and the Net Data Recovery Percentage indicates that the sensors were functioning properly.

## 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 that is included in APPENDIX A. Data that 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**

**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 that 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 at a height of 37 m (121.4 ft) for the fall quarter comprising of September, October, and November of 2004. The following graphs are included:

- Time Series – In Figure 2, 10-minute average wind speeds are plotted against time for all data starting on September 1, 2004 at midnight through November 30, 2004 at 11:50 P.M. The time series shows increased wind speeds in November.

- Wind Speed Distribution – A histogram plot giving the percentage of time that the wind is at a given wind speed is shown in Figure 3. This plot shows that the wind

speeds ranged between 4 and 5 m/s (8.9 and 11.2 mph) 14.98% of the time and between 5 and 6 m/s (11.2 and 13.4 mph) 14.77% of the time.

- Monthly Average – A plot of the average monthly wind speed over a 12-month period is shown in Figure 4. The monthly averages for July and August 2004 were not calculated because more than 10% of the data was missing due to a failed logger. However, this graph still demonstrates the trend that average wind speeds are generally higher in the winter months, with a maximum average wind speed of 7.65 m/s (17.11 mph) in January 2003.

- Diurnal Averages – Figure 5 is a plot of the average wind speed for each hour of the day. The hourly average varied between 3.79 and 6.41 m/s (8.48 and 14.34 mph), with the highest average speeds between 7 and 10 p.m., as is typical.

- Turbulence Intensity – A plot of turbulence intensity as a function of wind speed is shown in Figure 6. 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 intensities range from 0.1 to 0.4; for Mt. Tom, the average turbulence intensity for the quarter was 0.18. In the graph, the turbulence intensity flattens out between 3 and 4 m/s (6.7 and 8.9 mph).

- Wind Rose – Figure 7 is 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 northwest. Wind blew from this direction 11.88% of the time with a mean wind speed of 6.96 m/s (15.57 mph).

# 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**

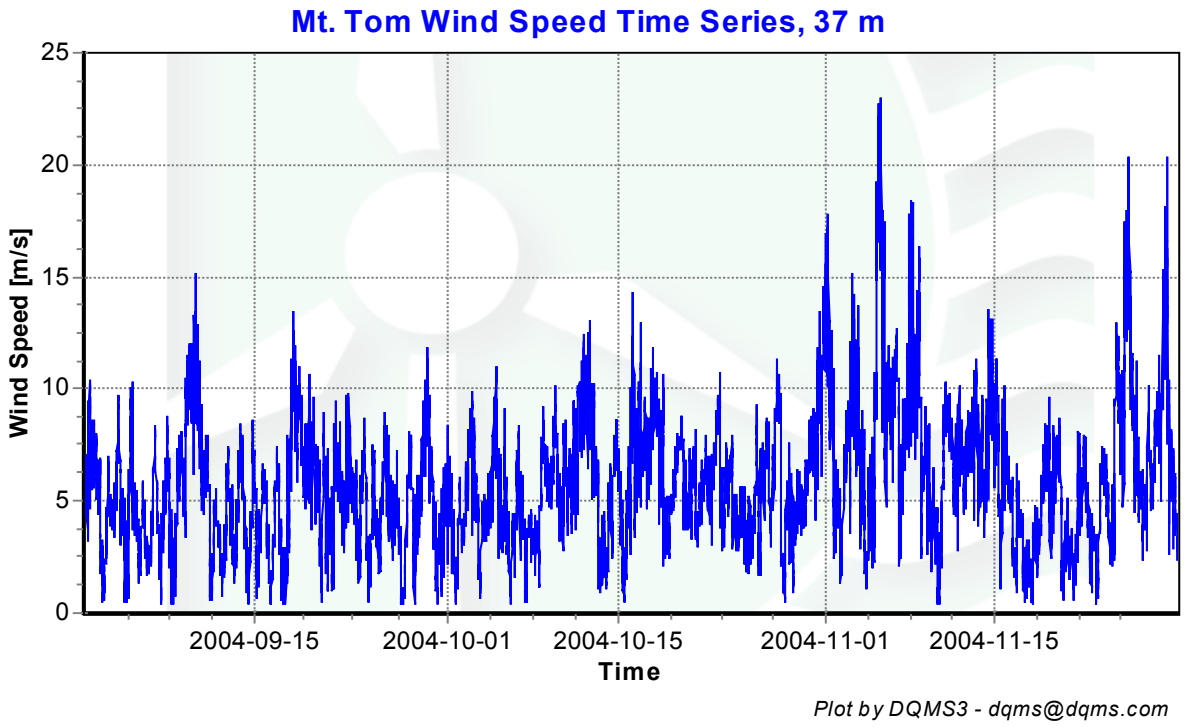


**Figure 2 - Wind Speed Time Series, September 2004 – November 2004**

## Wind Speed Distribution

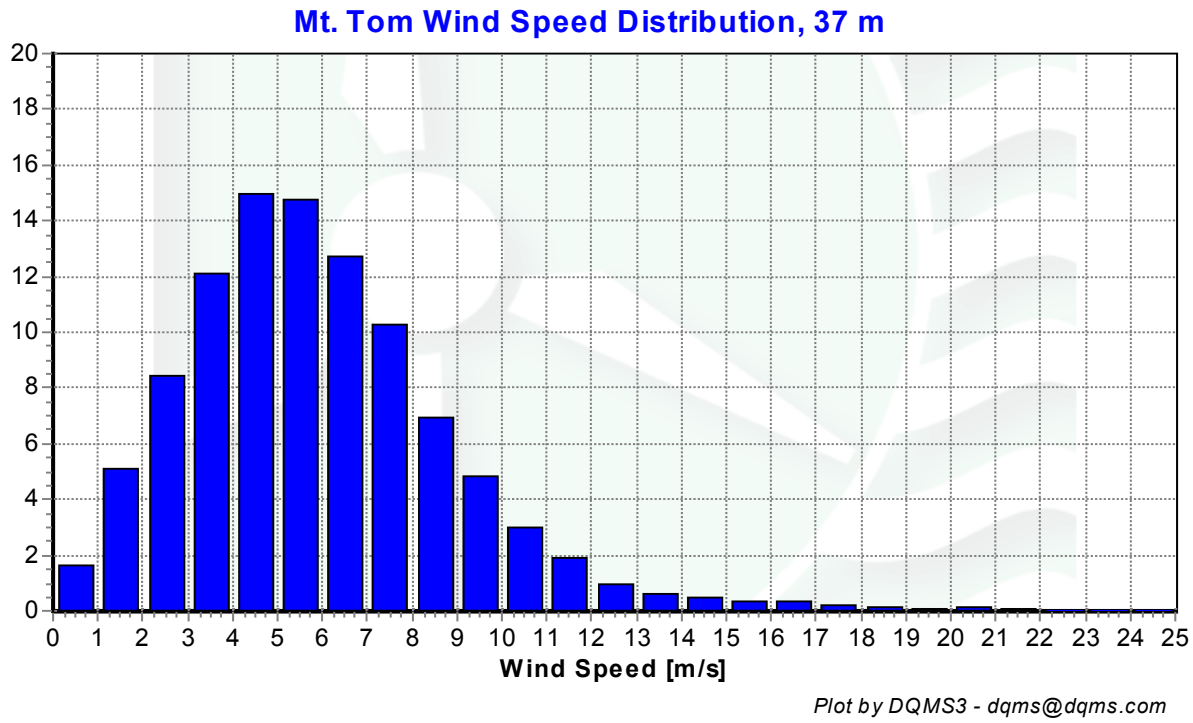


**Figure 3 – Wind Speed Distributions, September 2004 – November 2004**

## Monthly Average Wind Speeds

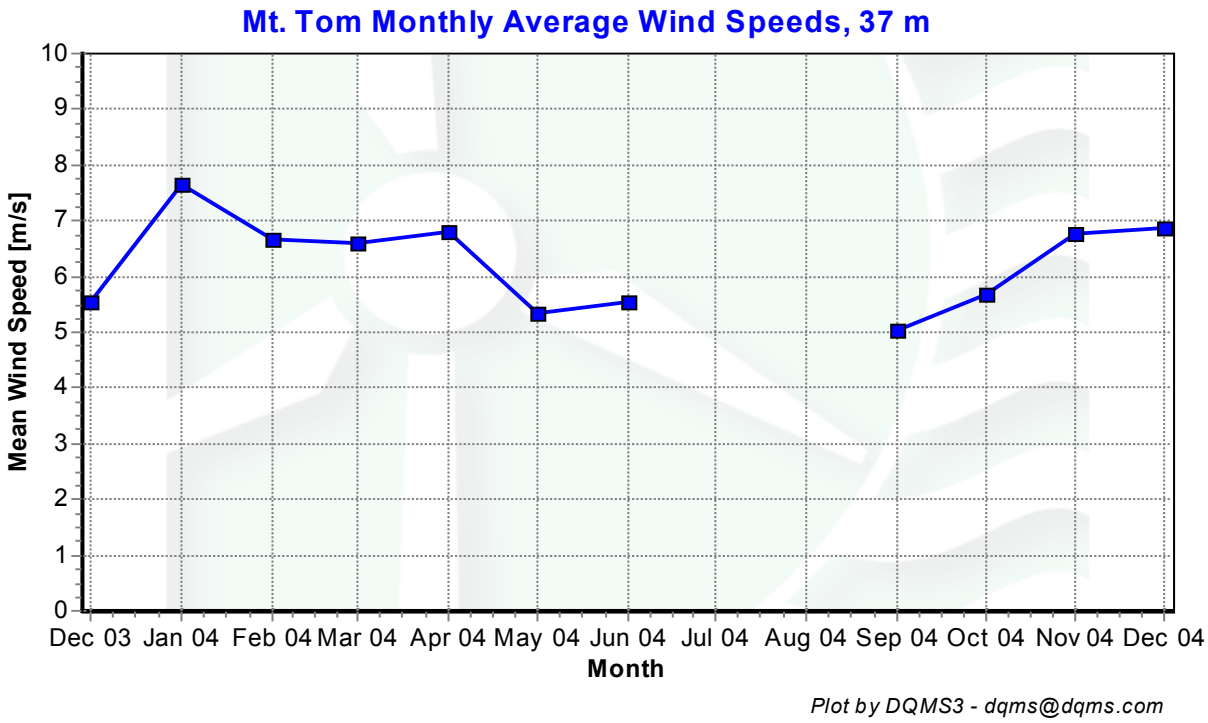


**Figure 4 - Monthly Averages, December 2003 – November 2004**

## Diurnal Average Wind Speeds

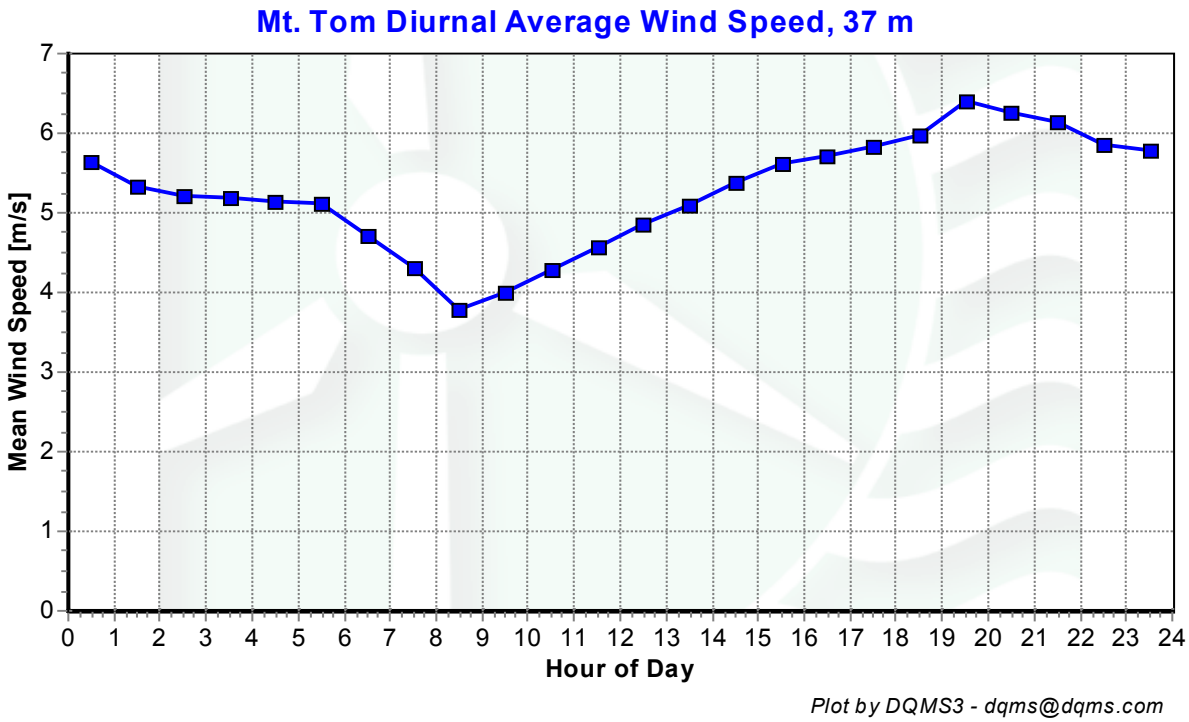


**Figure 5 - Diurnal Average Wind Speed, September 2004 – November 2004**

## Turbulence Intensities

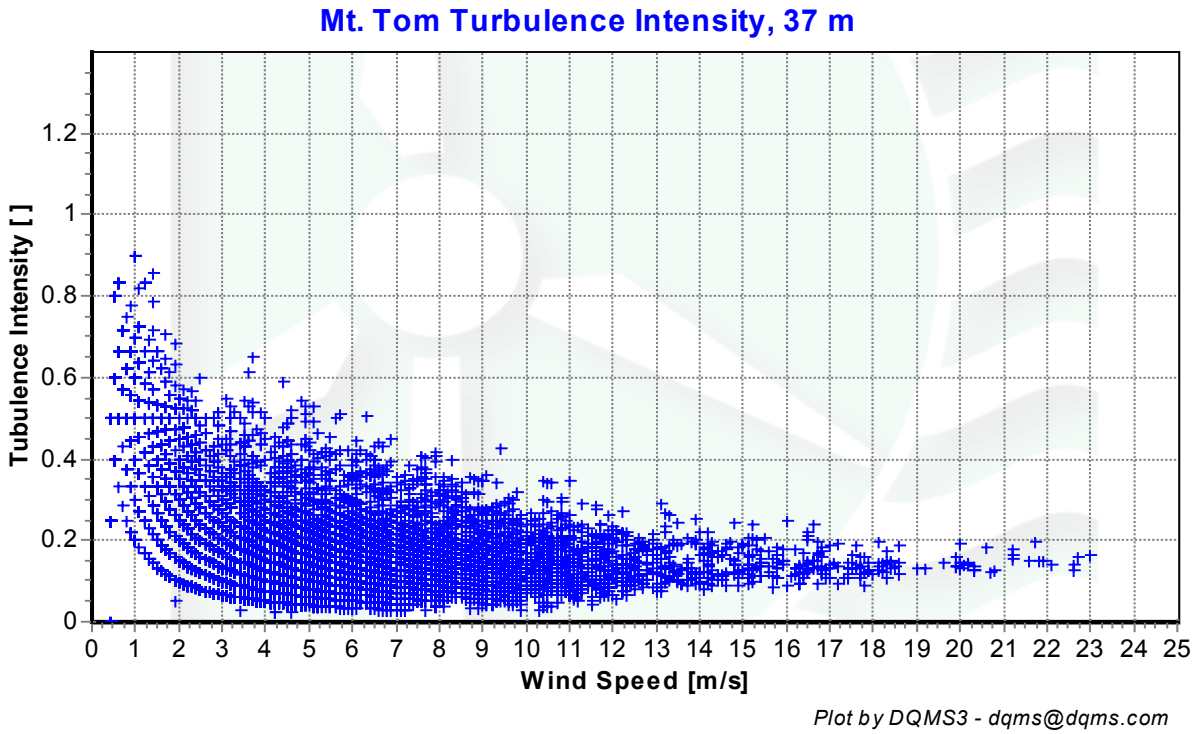


**Figure 6 - Turbulence Intensity vs. Wind Speed, September 2004 – November 2004**

## Wind Rose

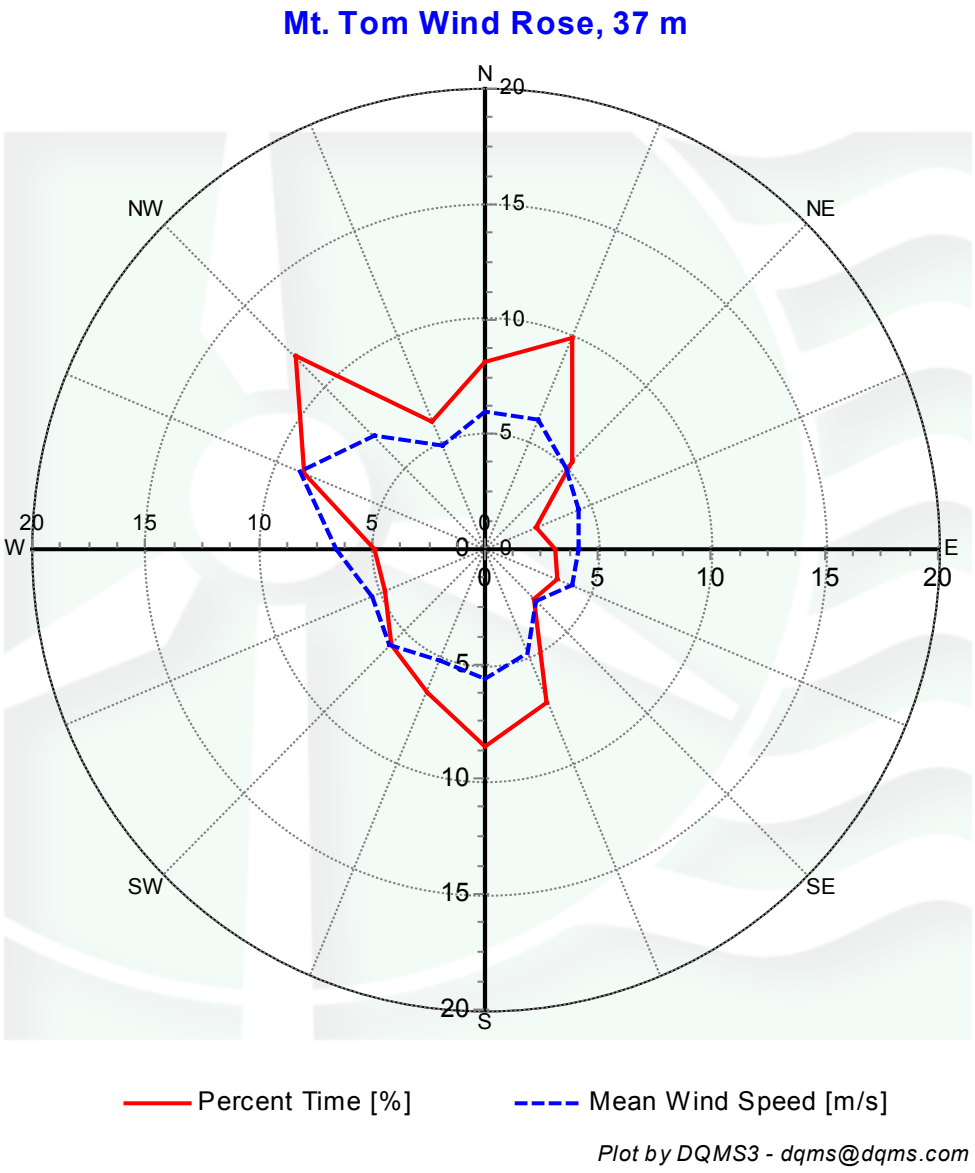


**Figure 7 - Wind Rose, September 2004 – November 2004**

# APPENDIX A - Sensor Performance Report

## Test Definitions

| Test Order | TestField1 | TestField2 | TestField3 | CalcField1 | CalcField2 | TestType | Factor1 | Factor2 | Factor3 | Factor4 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | TimeTest Insert | | | | |
| 2 | Itmp3aDEGC | | | | | MinMax | -30 | 60 | | |
| 3 | Batt3aVDC | | | | | MinMax | 10.5 | 15 | | |
| 4 | Etmp3aDEGC | | | | | MinMax | -30 | 60 | | |
| 5 | EtmpSD3aDEGC | | | | | MinMax | 0 | 4 | | |
| 10 | Anem24yMS | | | | | MinMax | 0 | 90 | | |
| 11 | Anem37yMS | | | | | MinMax | 0 | 90 | | |
| 12 | Anem24aMS | | | | | MinMax | 0 | 90 | | |
| 13 | Anem24bMS | | | | | MinMax | 0 | 90 | | |
| 14 | Anem37aMS | | | | | MinMax | 0 | 90 | | |
| 15 | Anem37bMS | | | | | MinMax | 0 | 90 | | |
| 16 | Anem18bMS | | | | | MinMax | 0 | 90 | | |
| 17 | Anem21aMS | | | | | MinMax | 0 | 90 | | |
| 20 | AnemSD24aMS | | | | | MinMax | 0 | 7 | | |
| 21 | AnemSD24bMS | | | | | MinMax | 0 | 7 | | |
| 22 | AnemSD37aMS | | | | | MinMax | 0 | 7 | | |
| 23 | AnemSD37bMS | | | | | MinMax | 0 | 7 | | |
| 24 | AnemSD18bMS | | | | | MinMax | 0 | 7 | | |
| 25 | AnemSD21aMS | | | | | MinMax | 0 | 7 | | |
| 26 | AnemSD24yMS | | | | | MinMax | 0 | 7 | | |
| 27 | AnemSD37yMS | | | | | MinMax | 0 | 7 | | |
| 40 | Pyro6aWMS | | | | | MinMax | 0 | 1500 | | |
| 41 | PyroSD6aWMS | | | | | MinMax | 0 | 1000 | | |
| 50 | Turb24zNONE | | | | | MinMax | 0 | 2 | | |
| 51 | Turb37zNONE | | | | | MinMax | 0 | 2 | | |
| 60 | Wshr0zNONE | | | | | MinMax | -100 | 100 | | |
| 70 | Pwrd24zWMC | | | | | MinMax | 0 | 10000 | | |
| 71 | Pwrd37zWMC | | | | | MinMax | 0 | 10000 | | |
| 200 | VaneSD24aDEG | Anem24yMS | | | | MinMaxT | 0 | 100 | 100 | 10 |
| 201 | VaneSD37aDEG | Anem37yMS | | | | MinMaxT | 0 | 100 | 100 | 10 |
| 250 | Vane24aDEG | | | | | MinMax | 0 | 359.9 | | |
| 251 | Vane37aDEG | | | | | MinMax | 0 | 359.9 | | |
| 252 | Vane19aDEG | | | | | MinMax | 0 | 359.9 | | |
| 300 | Anem24aMS | AnemSD24aMS | Vane24aDEG | VaneSD24aDEG | Etmp3aDEGC | Icing | 0.5 | 1 | 2 | 10 |
| 301 | Anem24bMS | AnemSD24bMS | Vane24aDEG | VaneSD24aDEG | Etmp3aDEGC | Icing | 0.5 | 1 | 2 | 10 |
| 302 | Anem37aMS | AnemSD37aMS | Vane37aDEG | VaneSD37aDEG | Etmp3aDEGC | Icing | 0.5 | 1 | 2 | 10 |
| 303 | Anem37bMS | AnemSD37bMS | Vane37aDEG | VaneSD37aDEG | Etmp3aDEGC | Icing | 0.5 | 1 | 2 | 10 |
| 400 | Anem24aMS | Anem24bMS | | | | CompareSensors | 1 | 0.25 | 3 | 0 |
| 401 | Anem37aMS | Anem37bMS | | | | 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 |
|---|---|---|---|---|---|---|---|
| Itmp3aDEGC | 13104 | 0 | 0 | 0 | 0 | 0 | 0 |
| Batt3aVDC | 13104 | 0 | 0 | 0 | 0 | 0 | 0 |
| Anem24aMS | 13104 | 13104 | 100 | 0 | 0 | 8 | 99.634 |
| AnemSD24aMS | 13104 | 13104 | 100 | 0 | 0 | 8 | 99.634 |
| Anem24bMS | 13104 | 13104 | 100 | 0 | 0 | 18.167 | 99.168 |
| AnemSD24bMS | 13104 | 13104 | 100 | 0 | 0 | 18.167 | 99.168 |
| Anem37aMS | 13104 | 13104 | 100 | 0 | 0 | 4.833 | 99.779 |
| AnemSD37aMS | 13104 | 13104 | 100 | 0 | 0 | 4.833 | 99.779 |
| Anem37bMS | 13104 | 13104 | 100 | 0 | 0 | 31 | 98.581 |
| AnemSD37bMS | 13104 | 13104 | 100 | 0 | 0 | 31 | 98.581 |
| Vane24aDEG | 13104 | 13104 | 100 | 8.833 | 0 | 0 | 99.596 |
| VaneSD24aDEG | 13104 | 13104 | 100 | 8.833 | 0 | 0 | 99.596 |
| Vane37aDEG | 13104 | 13104 | 100 | 4 | 0 | 0 | 99.817 |
| VaneSD37aDEG | 13104 | 13104 | 100 | 4 | 0 | 0 | 99.817 |
| Etmp3aDEGC | 13104 | 13104 | 100 | 0 | 0 | 0 | 100 |
| EtmpSD3aDEGC | 13104 | 13104 | 100 | 0 | 0 | 0 | 100 |
| Pyro6aWMS | 13104 | 13104 | 100 | 0 | 0 | 0 | 100 |
| PyroSD6aWMS | 13104 | 13104 | 100 | 0 | 0 | 0 | 100 |
| **Total** | **235872** | **209664** | **88.889** | **25.667** | **0** | **124** | **88.508** |

# APPENDIX B - Plot Data

## Wind Speed Distribution Data

| Bin Center Wind Speed [m/s] | Percent of Time [%] |
|---|---|
| 0.5 | 1.62 |
| 1.5 | 5.12 |
| 2.5 | 8.43 |
| 3.5 | 12.13 |
| 4.5 | 14.98 |
| 5.5 | 14.77 |
| 6.5 | 12.71 |
| 7.5 | 10.26 |
| 8.5 | 6.95 |
| 9.5 | 4.82 |
| 10.5 | 2.96 |
| 11.5 | 1.9 |
| 12.5 | 0.97 |
| 13.5 | 0.6 |
| 14.5 | 0.46 |
| 15.5 | 0.37 |
| 16.5 | 0.33 |
| 17.5 | 0.23 |
| 18.5 | 0.14 |
| 19.5 | 0.05 |
| 20.5 | 0.11 |
| 21.5 | 0.05 |
| 22.5 | 0.03 |
| 23.5 | 0.01 |
| 24.5 | 0 |

**Table 1: Wind Speed Distribution**

## Monthly Average Wind Speed Data

| Date | 10 min Mean [m/s] |
|---|---|
| Dec 2003 | 5.53 |
| Jan 2004 | 7.65 |
| Feb | 6.65 |
| Mar | 6.59 |
| Apr | 6.79 |
| May | 5.36 |
| Jun | 5.55 |
| July | ---- |
| Aug | ---- |
| Sept | 5.04 |
| Oct | 5.67 |
| Nov | 6.78 |

**Table 2 - Wind Speed Averages**

## Diurnal Average Wind Speed Data

| Hour of Day | Average Wind Speed [m/s] |
|---|---|
| 0.5 | 5.64 |
| 1.5 | 5.33 |
| 2.5 | 5.21 |
| 3.5 | 5.19 |
| 4.5 | 5.13 |
| 5.5 | 5.12 |
| 6.5 | 4.71 |
| 7.5 | 4.3 |
| 8.5 | 3.79 |
| 9.5 | 4.01 |
| 10.5 | 4.29 |
| 11.5 | 4.57 |
| 12.5 | 4.85 |
| 13.5 | 5.1 |
| 14.5 | 5.38 |
| 15.5 | 5.62 |
| 16.5 | 5.72 |
| 17.5 | 5.83 |
| 18.5 | 5.96 |
| 19.5 | 6.41 |
| 20.5 | 6.27 |
| 21.5 | 6.14 |
| 22.5 | 5.85 |
| 23.5 | 5.78 |

**Table 3 - Diurnal Average Wind Speeds**

## Wind Rose Data

| Direction | Percent Time [%] | Mean Wind Speed [m/s] |
|---|---|---|
| N | 8.14 | 5.97 |
| NNE | 9.97 | 6.07 |
| NE | 5.41 | 4.99 |
| ENE | 2.39 | 4.46 |
| E | 3.07 | 4.11 |
| ESE | 3.47 | 4.16 |
| SE | 3.1 | 3.22 |
| SSE | 7.17 | 4.86 |
| S | 8.57 | 5.66 |
| SSW | 6.73 | 5.2 |
| SW | 5.82 | 5.92 |
| WSW | 4.76 | 5.43 |
| W | 4.92 | 6.59 |
| WNW | 8.59 | 8.85 |
| NW | 11.88 | 6.96 |
| NNW | 6.02 | 4.92 |

**Table 4: Wind Rose, Time Percentage and Mean Wind Speed by Direction**