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Lake Michigan Wind Assessment Project Data Summary and Analysis: September 2013

Lake Michigan Offshore Wind Assessment Project

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Lake Michigan Wind Assessment Project

Data Summary and Analysis

September 2013

Part I – 2013 Data

This report summarizes the data collected by the Laser Wind Sensor (LWS) #8 with collection information as follows.

Location: Lake Michigan – Near Muskegon (4316.542N, 8630.347W)

Date: September 1 through September 30, 2013 (UTC)

Range Gates 1-6: 75, 90, 105, 125, 150, 175 meters

Cup Anemometer: 3 meters mounted on the buoy

Observations: 10-minute averages

Number of Observations: 30 days at 6 observations per hour = 4320 observations

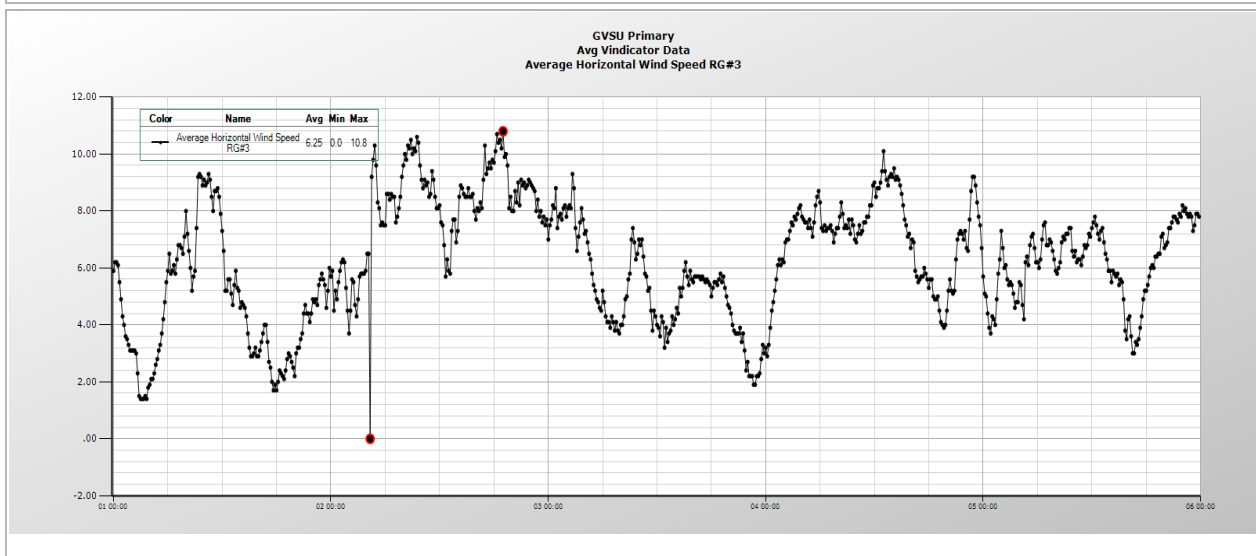
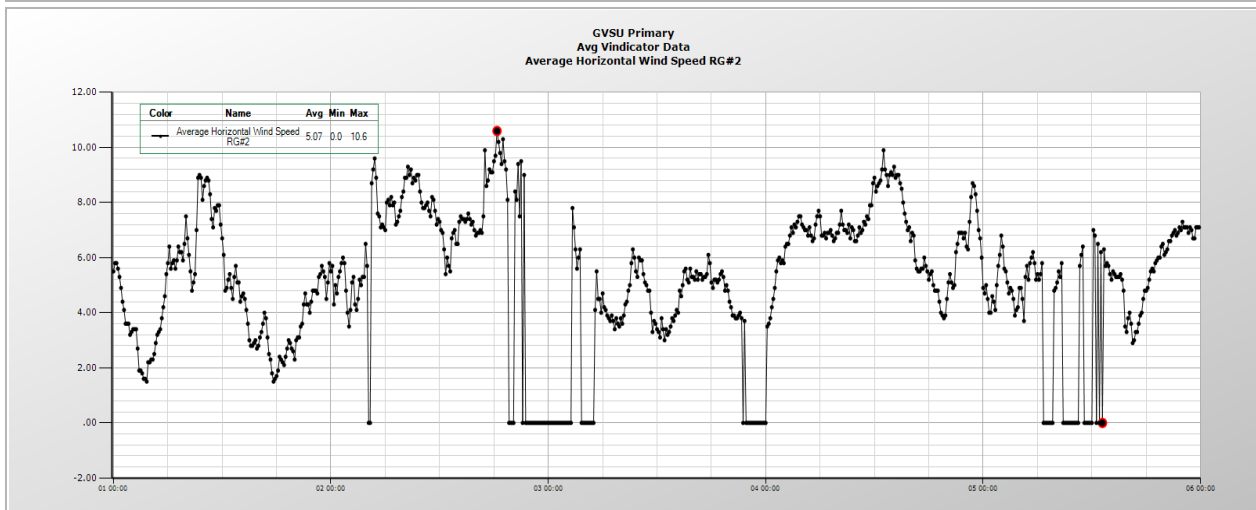
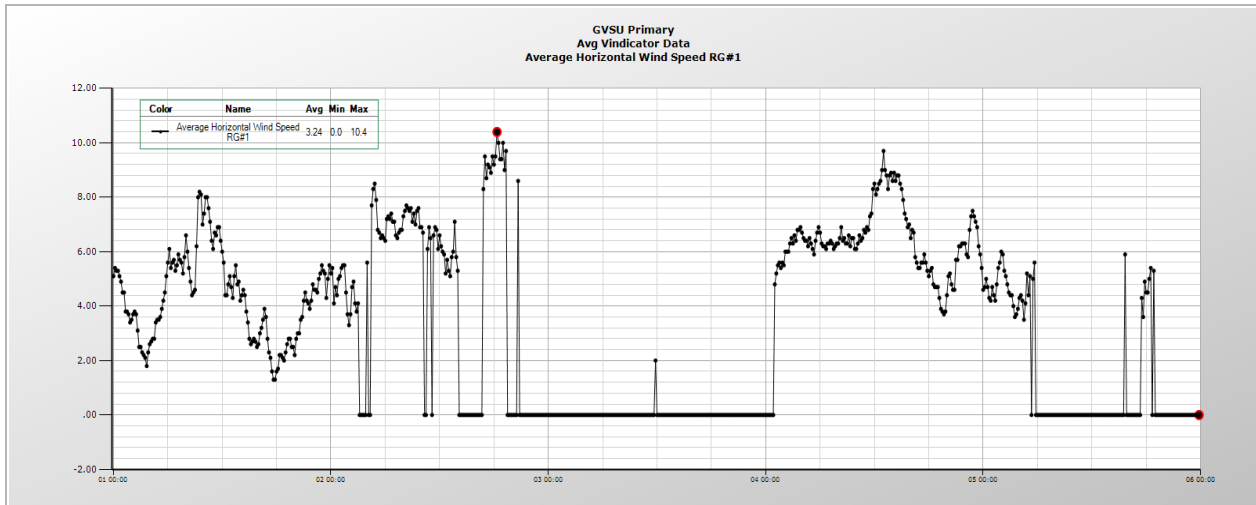
Missing Observations: None

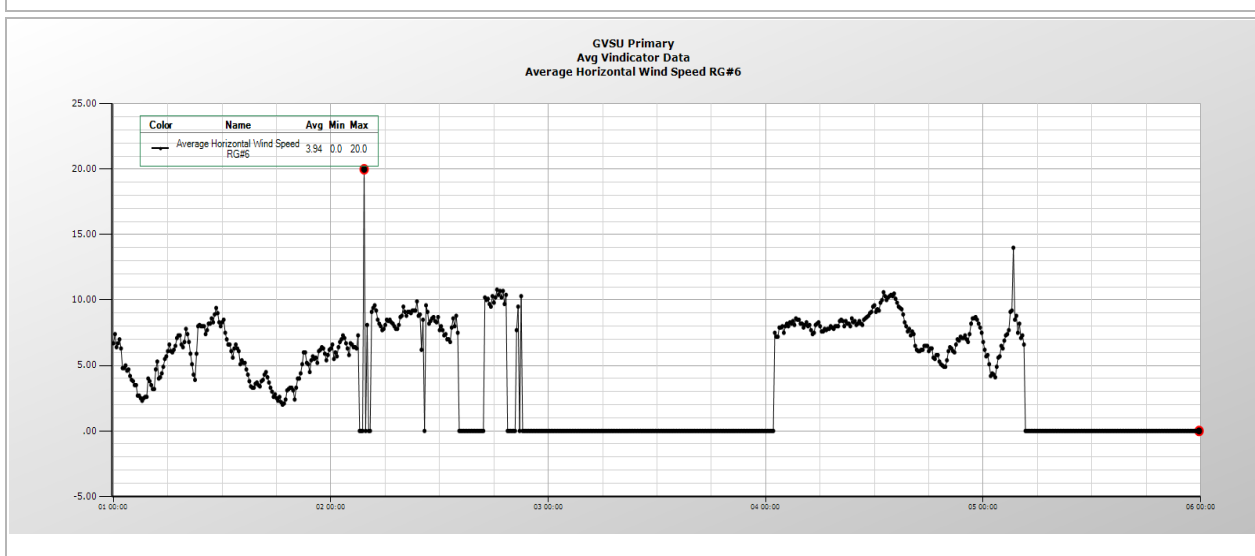
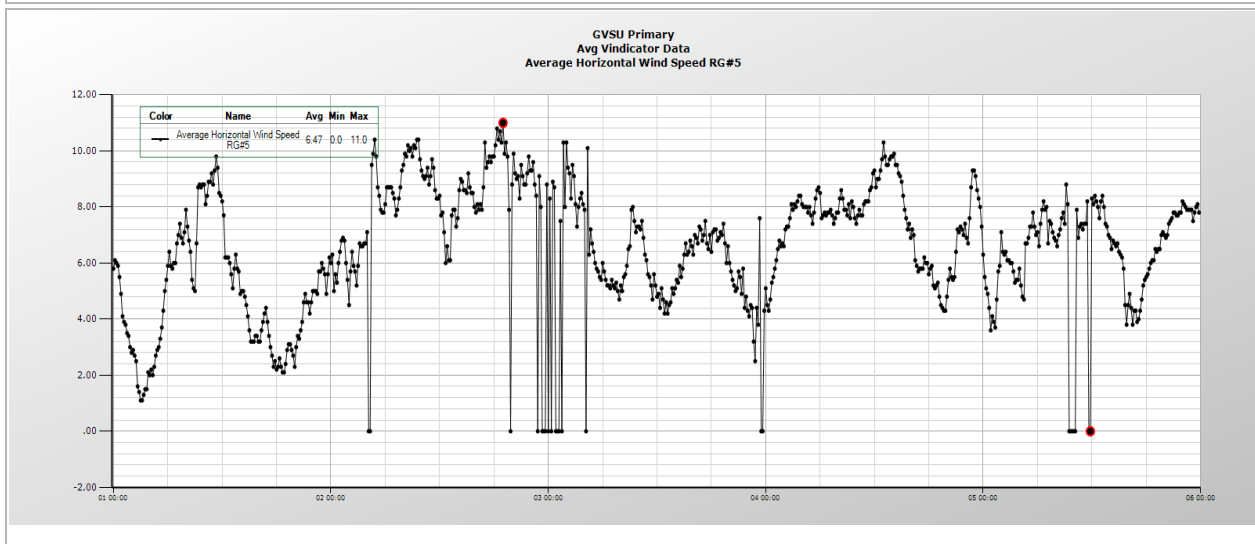
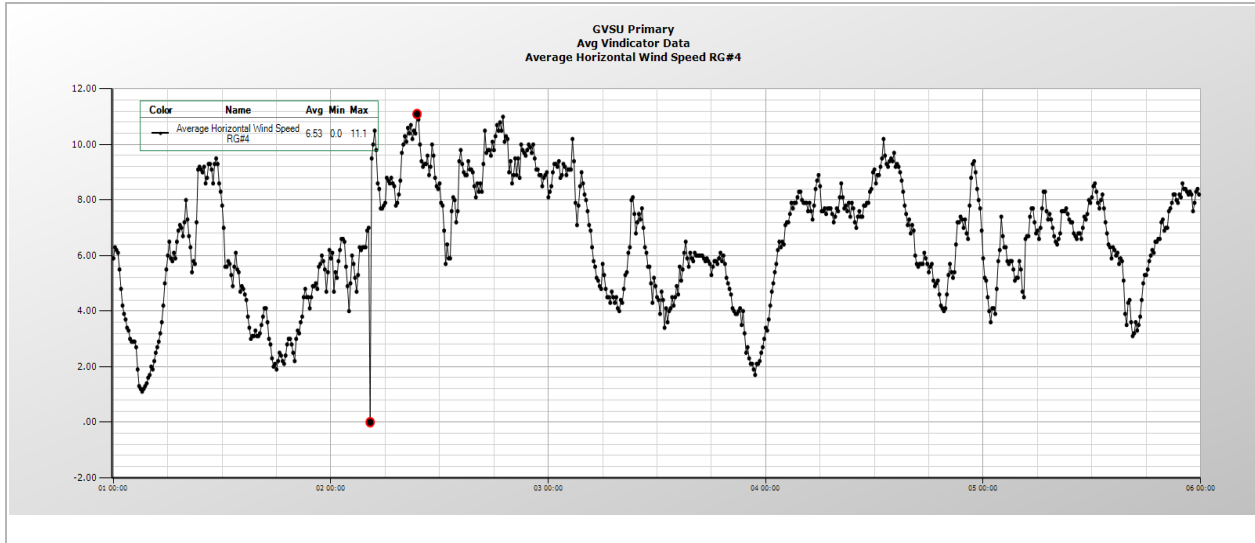
Good Observations: 4320 (100%)

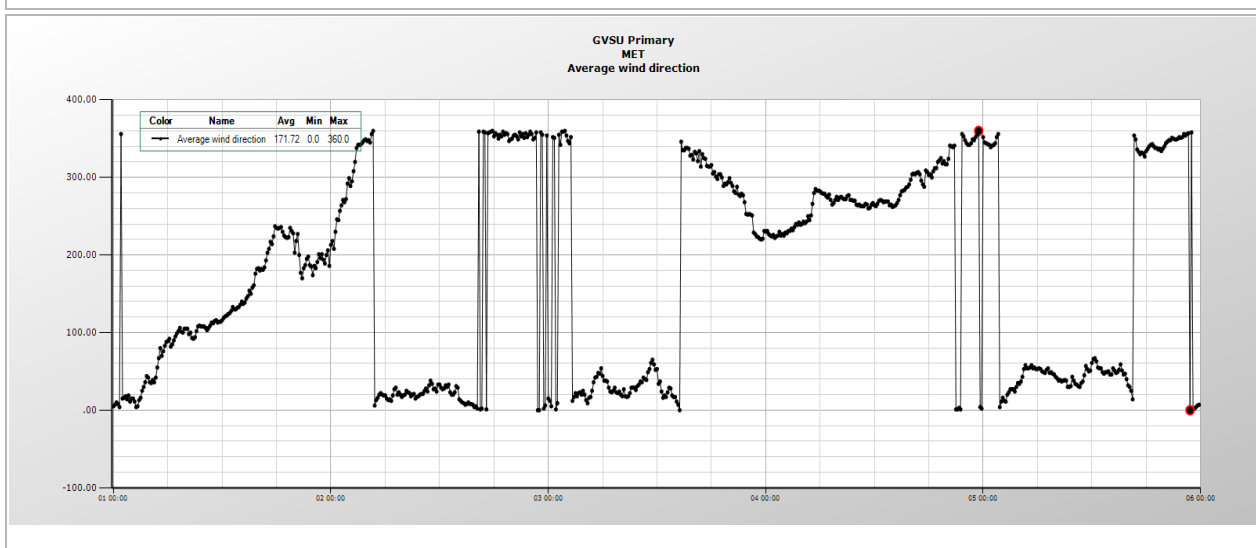
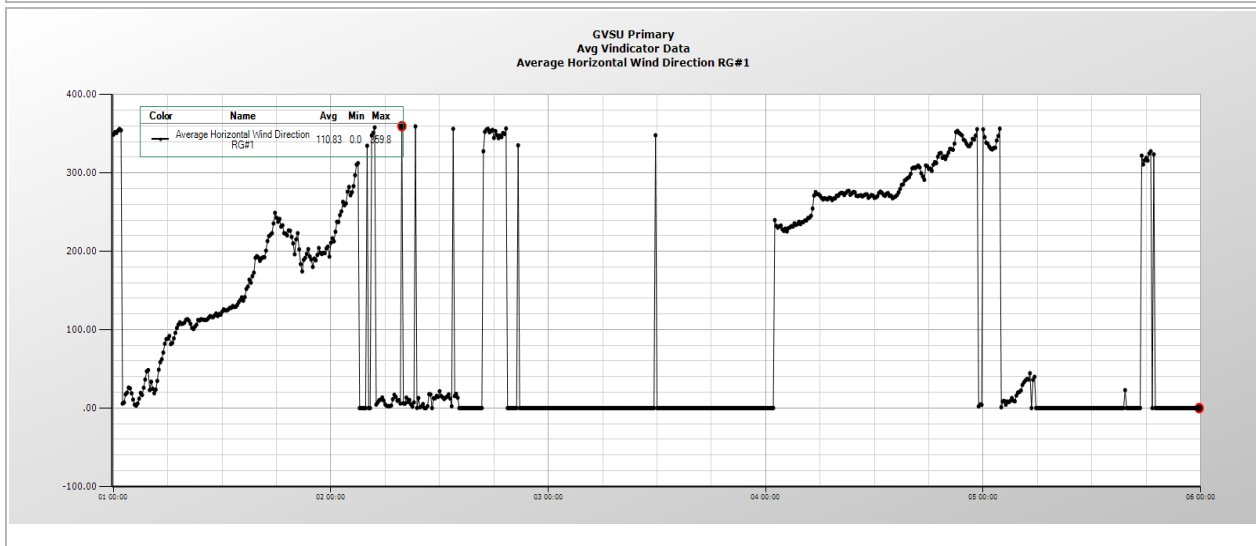
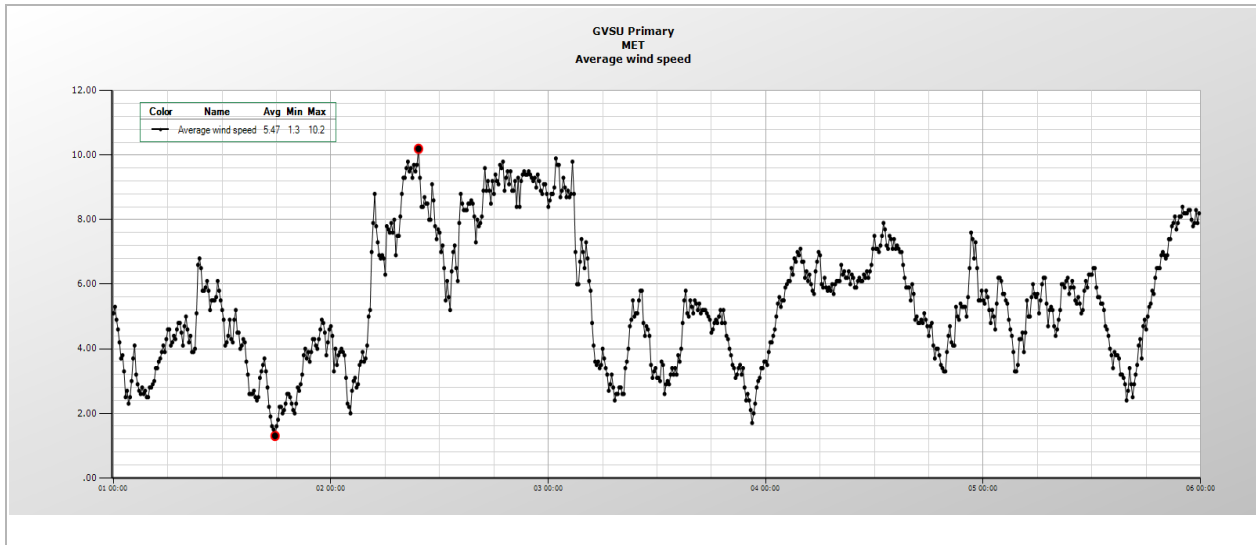
Notes:

- o Range Gate 6 (175 meters) is a test range gate to observe the performance of the sensor at the extreme operating height limit for this configuration. Thus, performance degradation was expected.
- o All high resolution 1 second data for all wind speeds is stored onboard the buoy and can be used for further detailed post processing as required.

Graphs for wind speed for all ranges as well as the cup anemometer follow. Graphs of the horizontal wind direction at the cup anemometer and range gate 1 are included as well.







Summary statistics for wind speed by range gate and for the cup anemometer are shown in the following tables. Good observations are 10-minute averages consisting of at least 300 one-second observations. There were 4320 observations of 10-minute averages in total.

Table 1: Horizontal Wind Speed (meters per second) Statistics by Range Gate

Statistic	N001S007 P006 Cup Anemometer	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
Good Obs.	4320	2898	3541	4131	4237	3850	2616
% of Total (4320)	100	67.1	82.0	95.6	98.1	89.1	60.6
Average	5.7	7.2	7.5	7.9	8.1	8.3	9.0
Std. Dev.	2.2	3.8	3.8	4.1	3.8	3.9	4.1
Coeff. of Variation	0.39	0.53	0.51	0.52	0.47	0.47	0.46
Minimum	0.3	0.5	0.4	0.5	0.9	0.7	0.9
Quartile 1	3.9	4.6	4.9	5.2	5.3	5.6	6.3
Median	5.7	6.5	6.9	7.4	7.7	7.8	8.4
Quartile 3	7.2	9.0	9.2	9.6	9.9	10.2	10.9
Maximum	12.8	20.4	20.8	50.6	22.1	22.7	23.9
99% CI- Lower Bound	5.6	7.0	7.3	7.7	7.9	8.1	8.8
99% CI Upper Bound	5.8	7.4	7.7	8.1	8.3	8.5	9.2

Table 2: Wind Speed Frequencies by Range Gate – Percent of Time in Each Wind Speed Range

Wind Speed Range (m/s)	N001S007 P006 Cup Anemometer	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
0-4	25.3	18.1	15.4	13.3	11.7	10.9	9.4
4-8	59.6	48.4	48.5	44.6	40.9	41.4	33.3
8-12	15.0	22.0	24.0	29.4	33.4	32.7	37.6
12-16	0.1	8.0	8.2	8.0	9.3	9.6	11.5
16-20	0	3.5	3.7	3.8	4.0	4.5	6.5
20-24	0	0	0.2	0.5	0.6	0.9	1.6
24-28	0	0	0	0.1	0	0	0
28-32	0	0	0	0	0	0	0
>32	0	0	0	0.2	0	0	0

Table 3: Wind Direction Frequencies by Range Gate – Percent of Time in Each Wind Direction Range

Wind Direction Range (Degrees)	N001S009P089 Average Horizontal Wind Direction RG#1	N001S009P083 Average Horizontal Wind Speed RG#1
0 – 45 (NNE)	6.8	5.2
45 – 90 (NE)	3.0	5.0
90 – 135 (SE)	18.0	5.9
135 – 180 (SSE)	25.6	7.7
180 – 225 (SSW)	15.8	8.1
225 – 270 (SW)	13.4	10.1
270 – 315 (NW)	6.1	6.2
315 – 360 (NNW)	11.3	5.8

Table 4 contains the summary statistics shown in table 1 for the subset of times when every range gate had a good observation that is there were 300 one-second observations for each range gate.

Table 4: Horizontal Wind Speed (meters per second) Statistics by Range Gate – All Range Gates with Good Observations (2673/4320= 59.9%)

Statistic	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
Average	2551	2551	2551	2551	2551	2551
Std. Dev.	59.1	59.1	59.1	59.1	59.1	59.1
Coeff. of Variation	7.5	8.1	8.5	8.7	8.9	9.0
Minimum	3.8	4.0	4.1	4.2	4.3	4.1
Quartile 1	0.51	0.49	0.48	0.48	0.48	0.46
Median	0.8	0.8	0.9	1.0	0.7	0.9
Quartile 3	5.0	5.4	5.6	5.7	5.8	6.3
Maximum	6.7	7.4	7.9	8.2	8.4	8.4
99% CI- Lower Bound	9.2	10.1	10.7	11.0	11.2	10.9
99% CI Upper Bound	19.7	20.8	21.6	22.1	22.7	23.9

Table 5 shows the 99% confidence intervals for the mean difference in average wind speed between adjacent range gates for example between the range gates centered at 175 meters and 150 meters. The difference is higher range gate – lower range gate. The confidence intervals are computed using the paired t method. An observation time is included in the difference if the number of observations for each of the two range gates was at least 300.

Table 5: Horizontal Wind Speed – Average Difference by Pairs of Adjacent Range Gates

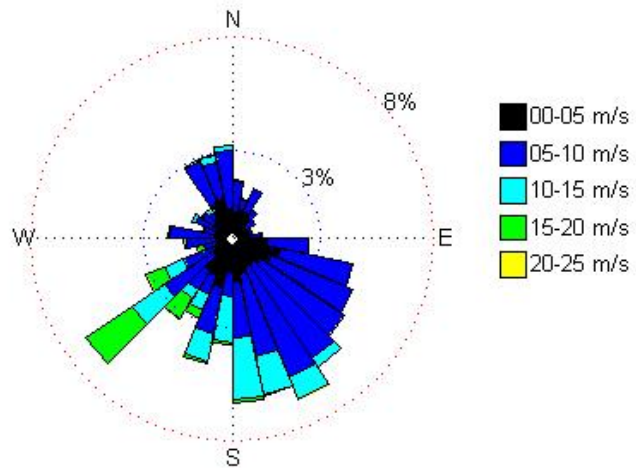
Statistic	175m – 150m	150m- 125m	125m- 105m	105m- 90m	90m- 75m
Good Obs.	2616	3847	4094	3540	2886
% of Total (4320)	60.6	89.1	94.8	81.9	66.8
Average	0.14	0.14	0.28	0.48	0.56
99% CI– Lower Bound	0.10	0.13	0.27	0.46	0.53
99% CI Upper Bound	0.17	0.16	0.30	0.49	0.58

Table 6 shows the energy generated for each range gate both when all data are considered as in Table 1 and the subset of times when every range gate had a good observation as in Table 4. The amount of energy generated depends on the turbine employed in this case the Gamesa Elioca G58 850kW. The energy estimate was computed assuming that the turbine will always face the wind.

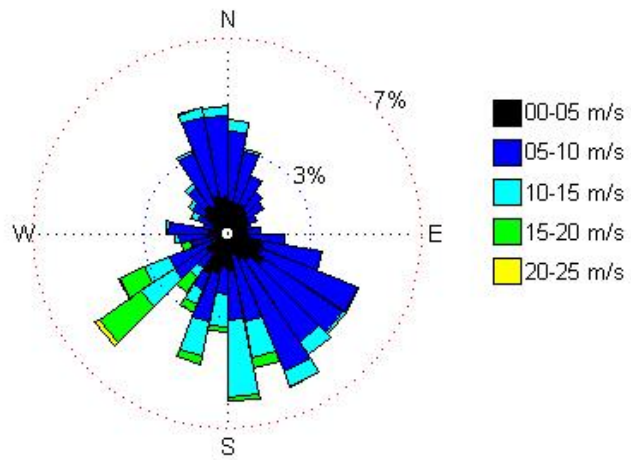
Table 6: Energy (kWh/time unit) by Range Gate

Range Gate	All data		Every Range Gate with Good Obs.	
	Average Power (MW)	Average Daily Energy (MWh)	Average Power (MW)	Average Daily Energy (MWh)
1	0.31	7.43	0.33	7.93
2	0.33	7.94	0.38	9.11
3	0.36	8.61	0.34	9.91
4	0.39	9.26	0.41	10.32
5	0.40	9.51	0.43	10.59
6	0.46	10.91	0.44	10.75
Buoy Cup	0.18	4.38	0.33	7.93

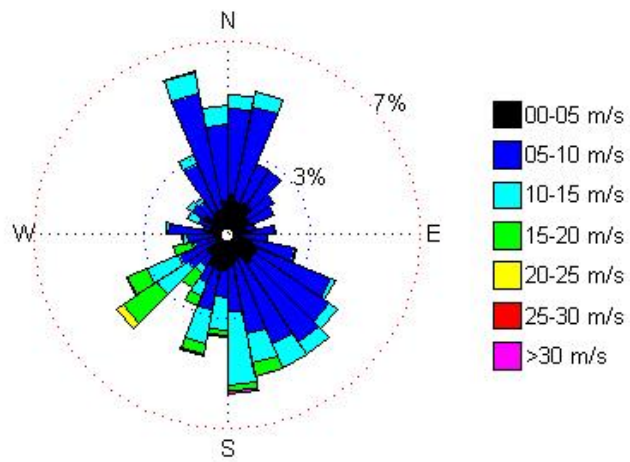
The wind rose graphs show the wind speed by direction as well as the percent of time the wind was blowing in each direction.



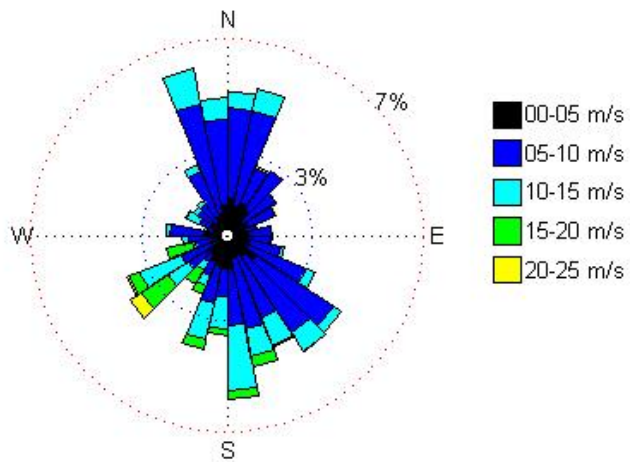
Range Gate 1: Average Wind Speed and Percent Time by Direction



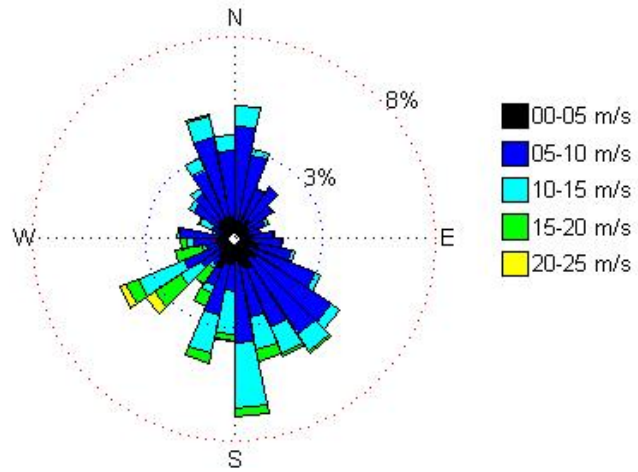
Range Gate 2: Average Wind Speed and Percent Time by Direction



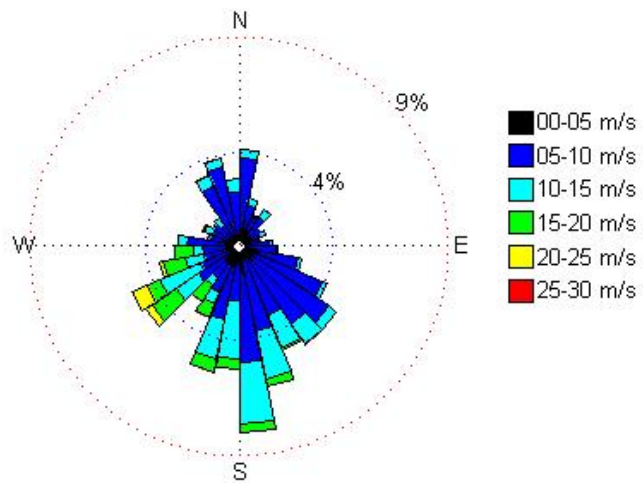
Range Gate 3: Average Wind Speed and Percent Time by Direction



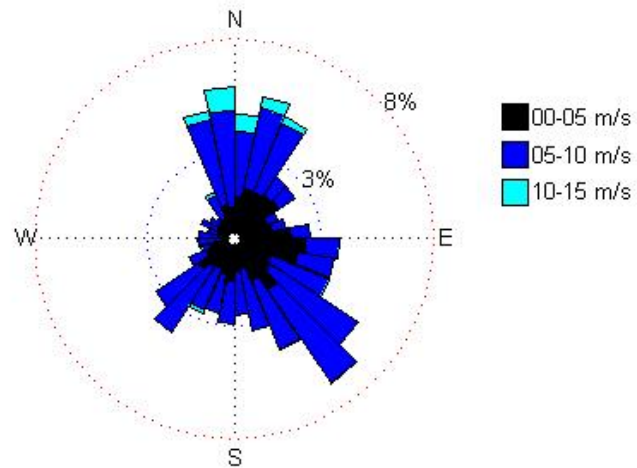
Range Gate 4: Average Wind Speed and Percent Time by Direction



Range Gate 5: Average Wind Speed and Percent Time by Direction



Range Gate 6: Average Wind Speed and Percent Time by Direction



Buoy Cup Anemometer: Average Wind Speed and Percent Time by Direction

Notes:

1. The average wind speed at 75m and above is notably more than the average wind speed on the buoy deck. This conclusion is supported by the statistics in table 1, particularly the average and the median. Further, the data in table 2 show that over 85% of the time the wind speed on the buoy deck is 8m/s or less. For heights 75m and above, this is true about 45%-65% of the time.
2. The average wind speed increases as the range gate height increases as shown in table 4. Each difference between adjacent in range gate height pairs is statistically significant ($\alpha = 0.01$) as shown in table 5. This is consistent with the average daily energy values shown in table 6.
3. The highest frequency of wind direction as well as wind speed is SSE through SSW, about 55% of the time as shown in table 3. In addition, the wind is from the NNW or NNE about 18% of the time.

Part II – Comparison of 2013 Data and 2012 Data

In this section, the data collected from June 1 through June 30, 2012 at the mid-lake plateau (4320.510N, 8707.206W) are compared to data from the same days collected in 2013 as described above. The results are shown in table 7. Homogeneity of variance is assumed. Note that two variables are confounded regarding the comparison:

- Location (mid-lake plateau versus near Muskegon)
- Year (2012 versus 2013)

Table 7: Comparison of 2012 and 2013 Data

Statistic	N001S007 P006 Cup Anemometer	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
2012							
Good Obs.	4320	3829	4112	4120	3773	2543	1176
% of Total (4320)	100	88.6	95.2	95.4	87.3	58.9	27.2
Average	6.9	7.7	8.1	8.2	8	8.0	8.2
2013							
Good Obs.	4320	2898	3541	4131	4237	3850	2616
% of Total (4320)	100	67.1	82.0	95.6	98.1	89.1	60.6
Average	5.7	7.2	7.5	7.9	8.1	8.3	9.0
Compare							
Average Difference	1.2	0.50	0.60	0.30	-0.10	-0.30	-0.80
Pooled Std. Dev.	2.6	3.9	3.9	4.0	3.9	4.1	4.2
99% CI- Lower Bound	1.1	0.26	0.37	0.073	-0.32	-0.57	-1.2
99% CI Upper Bound	1.3	0.74	0.83	0.53	0.12	-0.030	-0.42

Notes:

1. The average wind speed at heights 75, 90m, and 105m is higher at the mid-lake plateau in 2012 than near to the shore in 2013. There is no statistically significant difference in average wind speed at heights 125m, 150m and 175m. For all results $\alpha = 0.01$.
2. The average wind speed is greater at the mid-lake plateau in 2012 than near to shore in 2013 on the buoy deck. This result is statistically significant ($\alpha = 0.01$).

Part III – Comparison of August 2013 Data and September 2013 Data

In this section, the data collected in from August 1 through August 31 are compared with the data collected from September 1 through September 30. The results are shown in table 8. Homogeneity of variance is assumed.

Table 8: Comparison of Monthly Data: August versus September

Statistic	N001S007 P006 Cup Anemometer	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
August							
Good Obs.	4367	3348	3747	4106	4113	3917	2722
% of Total (4320)	97.8	75.0	83.9	92.0	92.1	87.7	61.0
Average	4.2	7.0	6.7	6.9	7.1	7.2	7.7
Sept.							
Good Obs.	4320	2898	3541	4131	4237	3850	2616
% of Total (4320)	100	67.1	82	95.6	98.1	89.1	60.6
Average	5.7	7.2	7.5	7.9	8.1	8.3	9.0
Compare							
Average Difference	-1.5	-0.2	-0.8	-1.0	-1.0	-1.1	-1.3
Pooled Std. Dev.	2.1	5.0	3.9	4.2	4.0	4.1	4.0
99% CI- Lower Bound	-1.6	-0.53	-1.0	-1.2	-1.2	-1.3	-1.6
99% CI Upper Bound	-1.4	0.13	-0.56	-0.76	-0.77	-0.86	-1.0

Notes:

1. The average wind speed at heights 90m, 105m, 125m, 150m, and 175m is greater in September than in August. There is no statistically significant difference in the average wind speed at 75m. All results are statistically significant ($\alpha = 0.01$).
2. The average wind speed is greater in September than in August on the buoy deck. This result is statistically significant ($\alpha = 0.01$).
3. In addition, there appears to be a slight shift of wind direction from July to August. In August, the wind direction is from SSE through SW about 60% of the time. In September, the wind was from this direction about 55% of the time.