6-2013

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

Lake Michigan Offshore Wind Assessment Project

Lake Michigan Wind Assessment Project

Data Summary and Analysis

May 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: June 1 through June 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

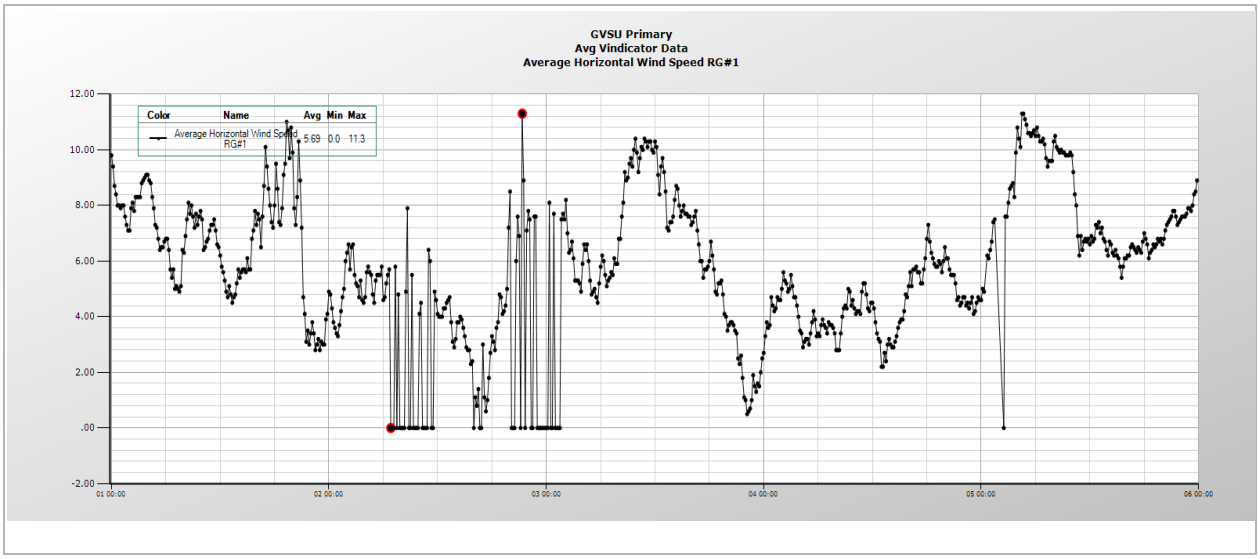
Missing Observations: None

Good Observations: 4320

Notes:

- 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.
- 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.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8.00
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03 00:00
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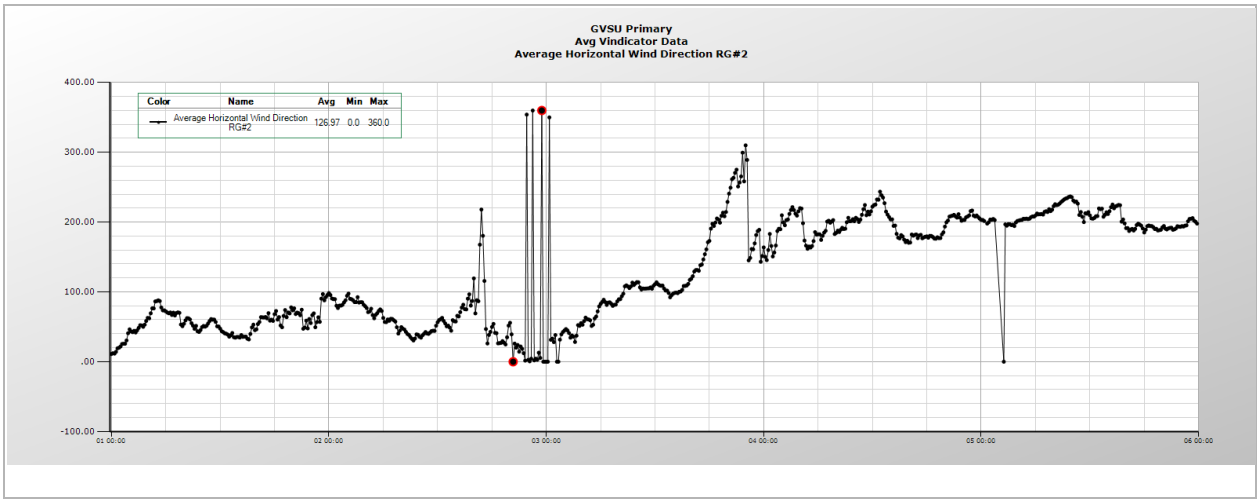
06 00:00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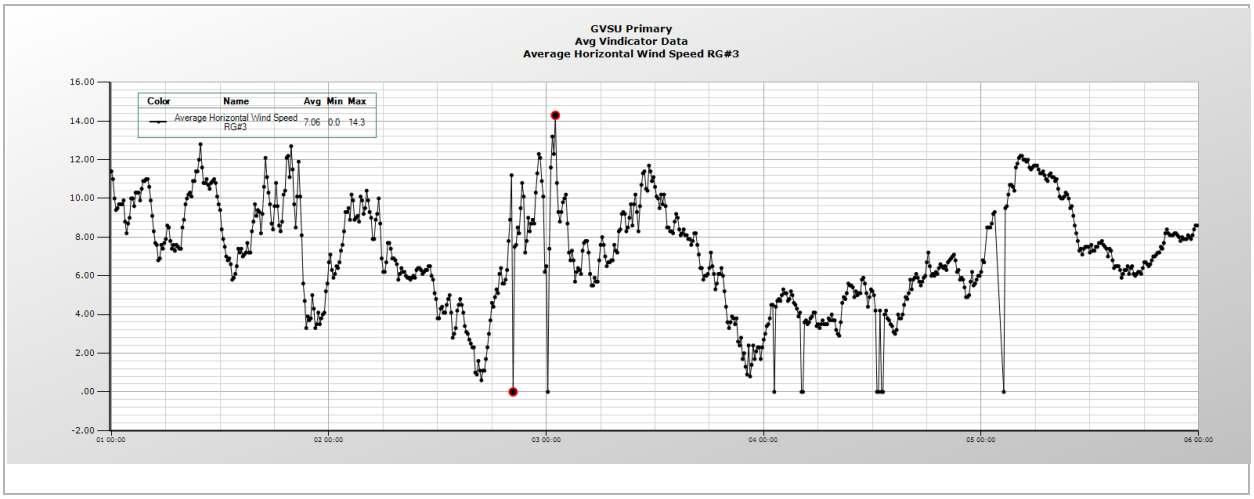
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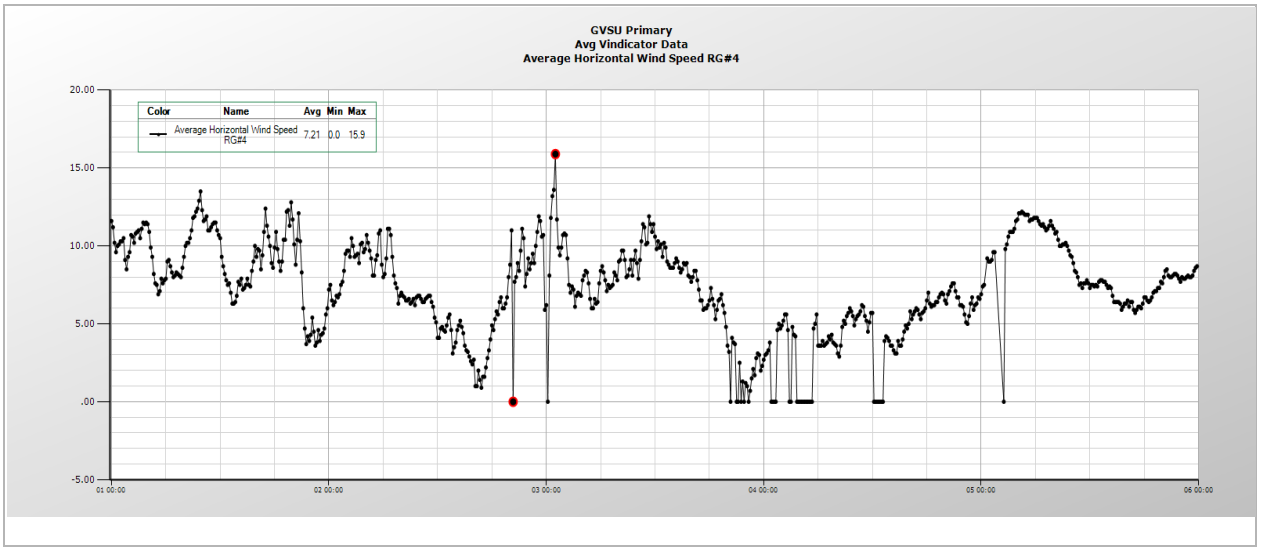
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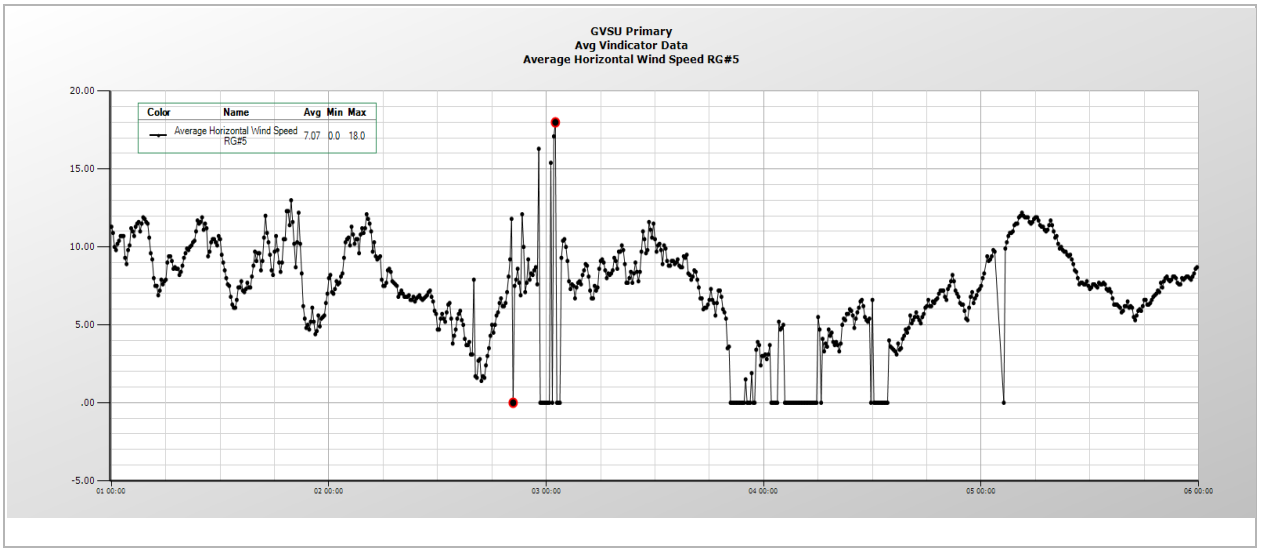
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Average Horizontal Wind Speed RG#5 7.07 0.0 18.0
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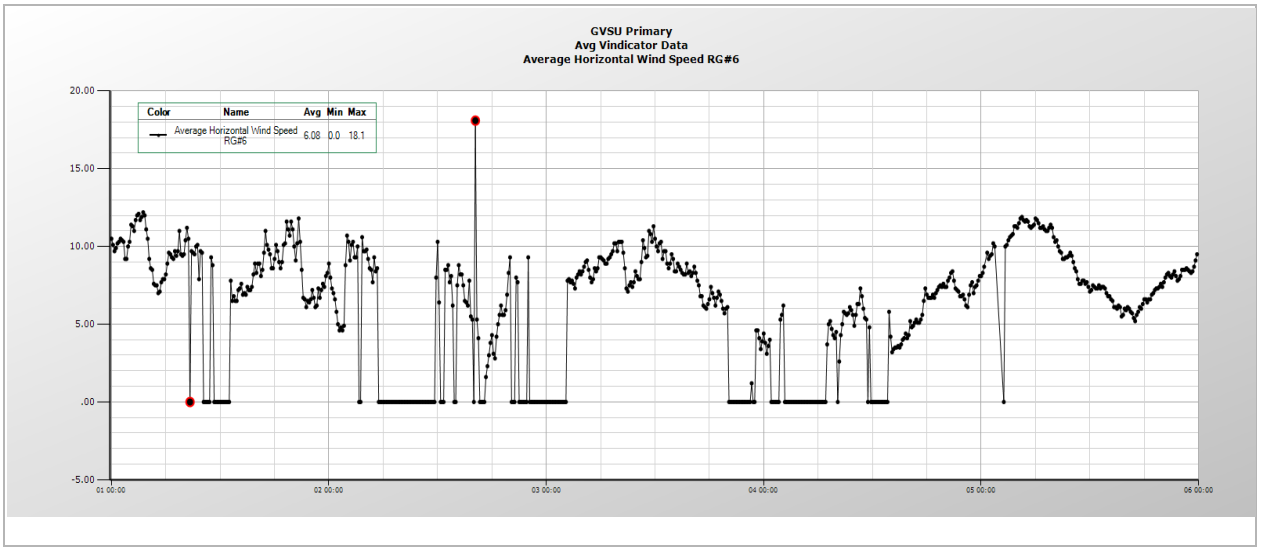
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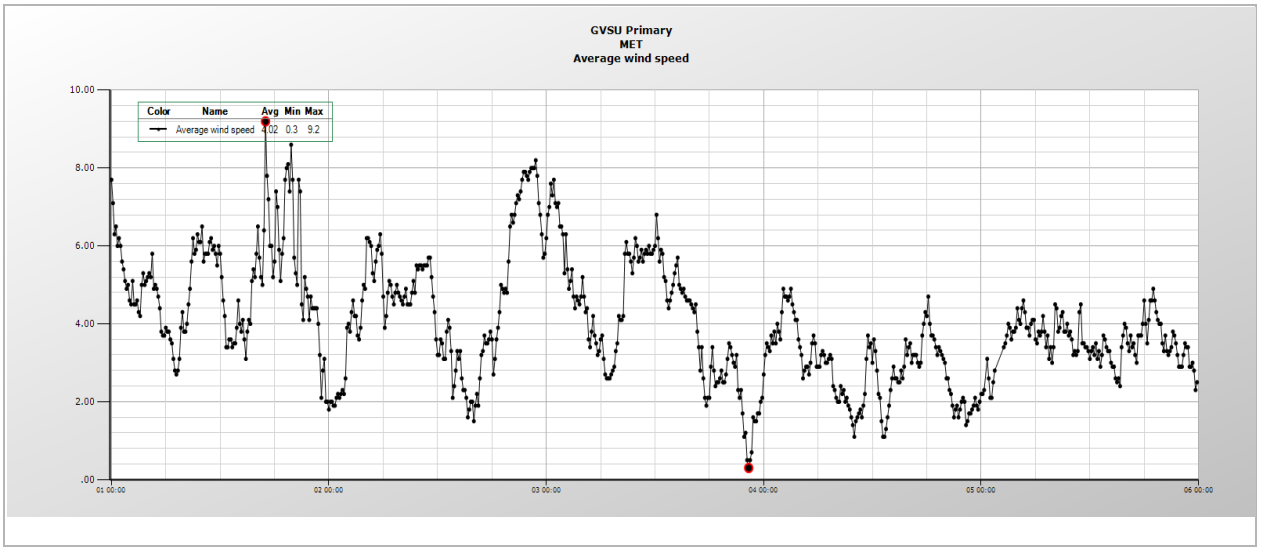
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Color Name Avg Min Max
Average wind speed 4.02 0.3 9.2
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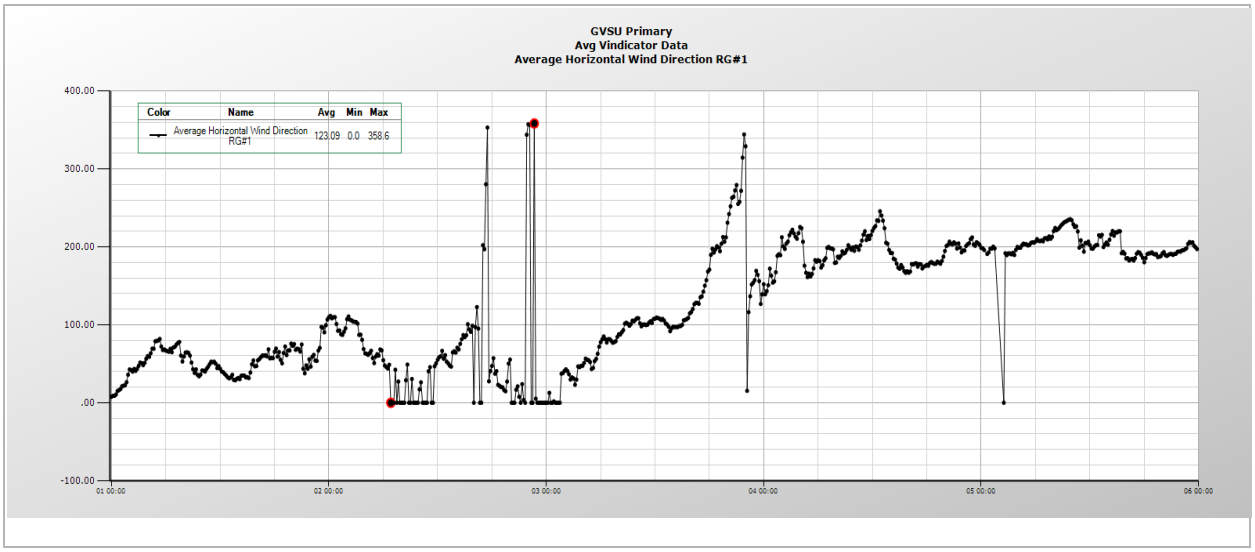
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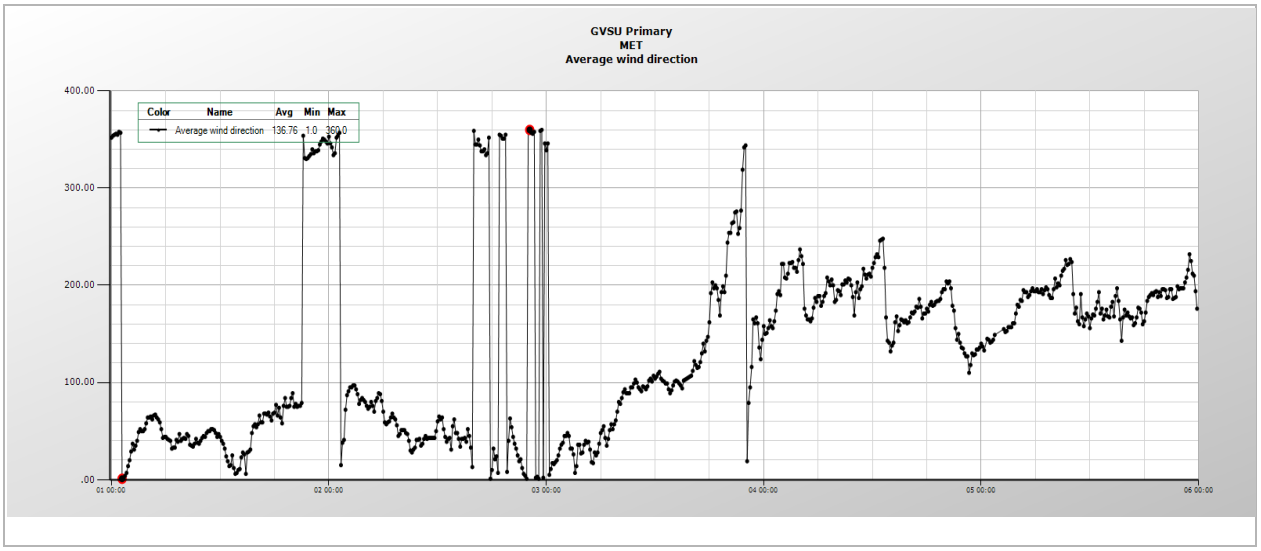
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Average wind direction
Color Name Avg Min Max
Average wind direction 136.76 1.0 360.0
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200.00
100.00
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01 00:00
02 00:00
03 00:00
04 00:00
05 00:00
06 00:00

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.	4318	3642	4008	4109	4106	3758	2917
% of Total (4320)	100	84.3	92.8	95.1	95	87	67.5
Average	4.2	6.7	7.1	7.5	7.6	7.6	8
Std. Dev.	2.2	3.7	4.0	4.2	4.3	4.2	3.7
Coeff. of Variation	0.52	0.55	0.56	0.56	0.57	0.55	0.46
Minimum	0.0	0.5	0.3	0.3	0.2	0.3	0.3
Quartile 1	2.6	4.1	4.1	4.4	4.4	4.3	5.3
Median	3.8	5.9	6.1	6.5	6.7	6.8	7.3
Quartile 3	5.2	8.6	9.2	9.8	10	10	10.3
Maximum	14.2	22.2	27.1	24.7	24.9	23	20.5
99% CI– Lower Bound	4.1	6.5	6.9	7.3	7.4	7.4	7.8
99% CI Upper Bound	4.3	6.9	7.3	7.7	7.8	7.8	8.2

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	53.4	23.4	22.7	21.3	20.1	21.1	12.5
4-8	39.8	46.2	43.3	40.4	39.9	39.2	44.1
8-12	6.2	19.4	20.2	22.6	23.5	23	26.7
12-16	0.6	9.2	9.4	10	10.8	0	13.6
16-20	0	1.7	4.1	4.8	4.8	16.2	3.1
20-24	0	0	0.3	0.8	0.9	0.5	0.1
24-28	0	0	0	0	0	0	0
28-32	0	0	0	0	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)	14.2	5.5
45 – 90 (NE)	9.1	5.3
90 – 135 (SE)	12.9	6.5
135 – 180 (SSE)	10.6	5.6
180 – 225 (SSW)	24.2	8.7
225 – 270 (SW)	7.7	6.0
270 – 315 (NW)	4.8	4.7
315 – 360 (NNW)	16.6	7.5

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 (2867/4320 = 66.4%)

Statistic	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
Average	7.1	7.6	7.9	8.1	8.1	8.0
Std. Dev.	3.8	4.1	4.2	4.2	4.1	3.7
Coeff. of Variation	0.54	0.54	0.53	0.52	0.51	0.46
Minimum	0.5	0.3	0.4	0.4	0.3	0.3
Quartile 1	4.3	4.6	4.7	4.8	4.8	5.3
Median	6.2	6.7	7.1	7.3	7.4	7.3
Quartile 3	9.1	9.9	10.5	10.7	10.7	10.3
Maximum	18.9	20.9	21.2	22	22	20.5
99% CI– Lower Bound	6.9	7.4	7.7	7.9	7.9	7.8
99% CI Upper Bound	7.3	7.8	8.1	8.3	8.3	8.2

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

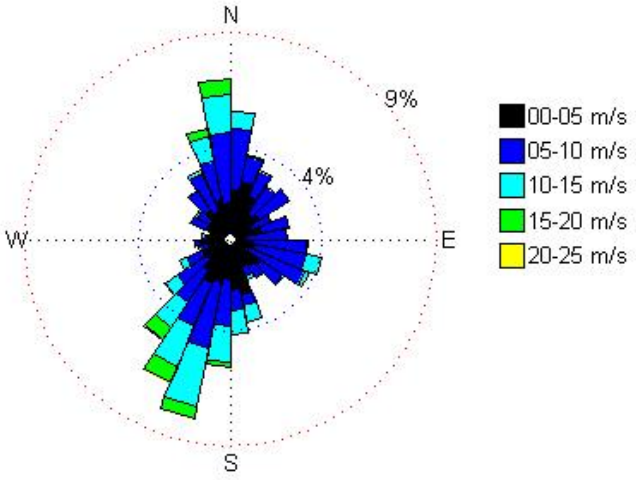
Statistic	175m – 150m	150m-125m	125m-105m	105m-90m	90m-75m
Good Obs.	2915	3753	4069	3982	3625
% of Total (4896)	67.5	86.9	94.2	92.2	83.9
Average	-0.071	0.003	0.12	0.34	0.50
99% CI– Lower Bound	-0.12	-0.02	0.10	0.31	0.47
99% CI Upper Bound	-0.02	0.02	0.14	0.36	0.52

Table 6 shows the energy generated for each range gate. 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.

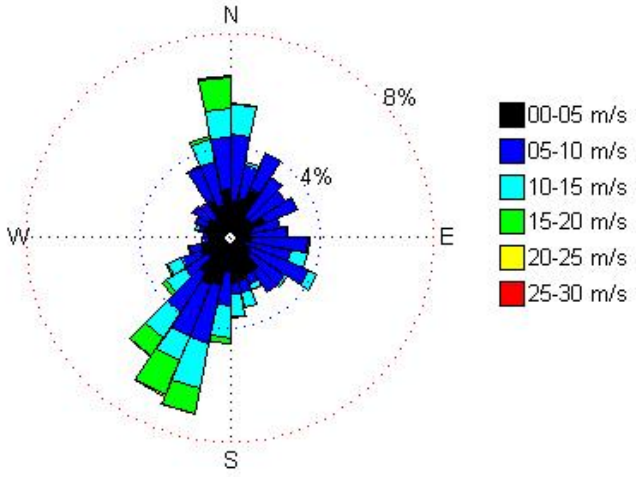
Table 6: Energy (kWh/time unit) by Range Gate

Range Gate	Average Power (MW)	Average Daily Energy (MWh)
1	0.282	6.77
2	0.303	7.28
3	0.333	8.00
4	0.344	8.25
5	0.347	8.33
6	0.386	9.27
Buoy Cup	0.152	3.65

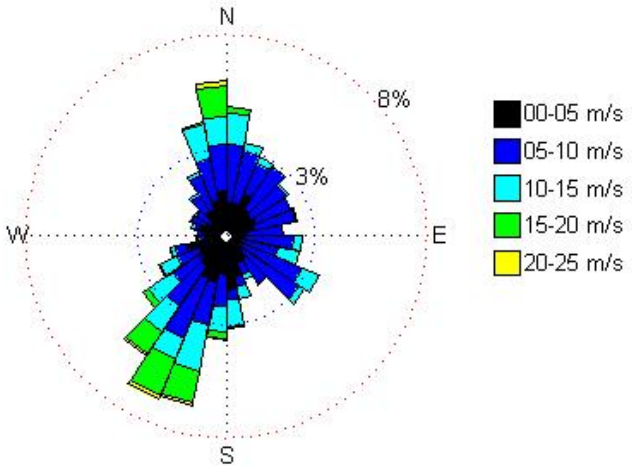
The wind rose graphs show the wind speed by direction as well as the percent of time the wind was blowing in each direction.



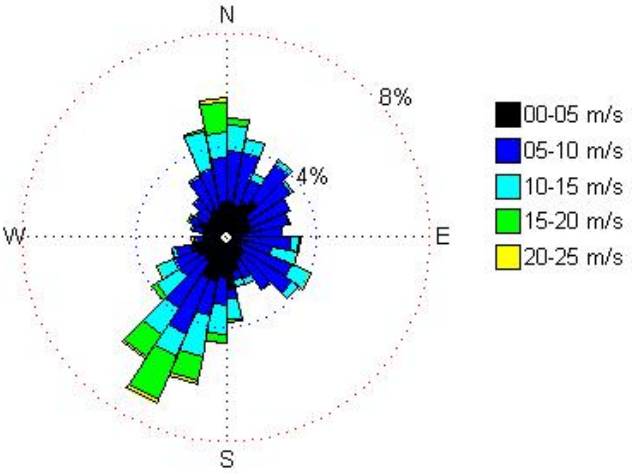
Range Gate 1: Average Wind Speed and Percent Time by Direction



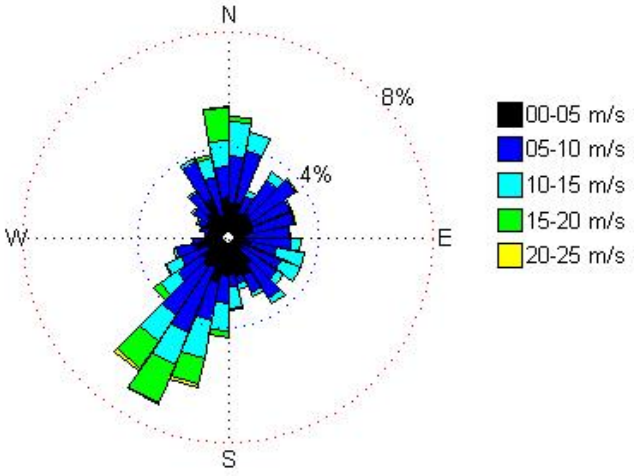
Range Gate 2: Average Wind Speed and Percent Time by Direction



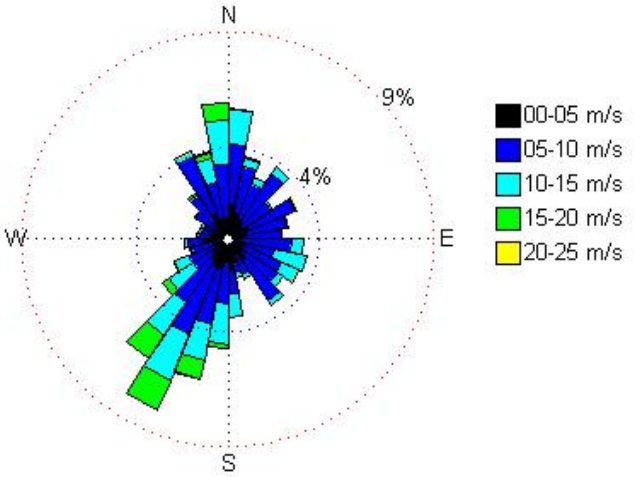
Range Gate 3: Average Wind Speed and Percent Time by Direction



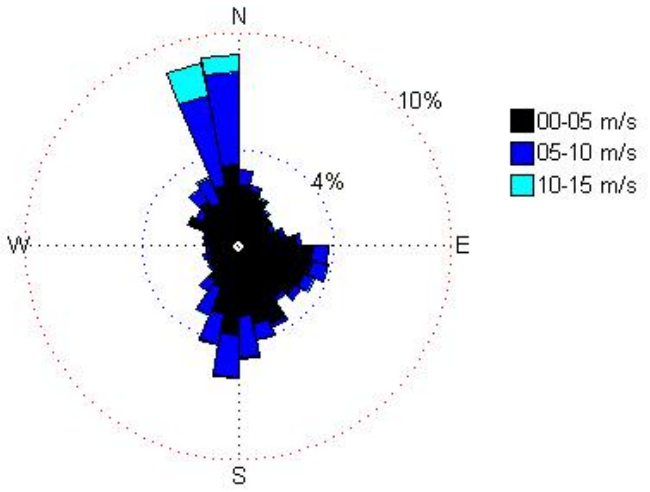
Range Gate 4: Average Wind Speed and Percent Time by Direction



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 90% of the time the wind speed on the buoy deck is 8m/s or less. For heights 75m and above, this is true about 55%-70% of the time.
2. The average wind speed increases notably from 75m to 90m as well as from 90m to 105m, slowly or not at all from 105m to 150m, and drops slights from 150m to 175m as shown in table 4. Each difference, except from 125m to 150m, is statistically significant ($\alpha = 0.01$) as shown in table 5. These data are inconsistent with the idea that power generation potential increases with turbine height. Instead the data suggest that a turbine height between 105m and 150m, perhaps closer to 105m than 150m, would provide a good balance between power generation and cost. This idea 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 SE through SSW, about 48% of the time as shown in table 3. In addition, the wind is from the NNW or NNE about 31% 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	4257	4277	4274	4152	2602	1207
% of Total (4320)	100	98.5	99.0	98.9	96.1	60.2	27.9
Average	5.1	9.7	9.9	10	9.9	11.2	11.3
2013							
Good Obs.	4318	3642	4008	4109	4106	3758	2917
% of Total (4320)	100	84.3	92.8	95.1	95.0	87.0	67.5
Average	4.2	6.7	7.1	7.5	7.6	7.6	8.0
Compare							
Average Difference	0.90	3.0	2.8	2.5	2.3	3.6	3.3
Pooled Std. Dev.	2.3	4.4	4.5	4.6	4.7	4.6	3.8
99% CI– Lower Bound	0.78	2.7	2.5	2.2	2.0	3.3	3.0
99% CI Upper Bound	1.0	3.3	3.1	2.8	2.6	3.9	3.6

Notes:

1. The average wind speed at heights 75m through 175m is greater at the mid-lake plateau in 2012 than near to the shore in 2013. All results are statistically significant ($\alpha = 0.01$).
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 April - May 2013 and June 2013 Data

In this section, the data collected from April 28 through May 31 are compared with the data collected from June 1 through June 30. The results are shown in table 8. Homogeneity of variance is assumed.

Table 8: Comparison of Monthly Data: May versus June

Statistic	N001S007 P006 Cup Anemometer	N001S009 P083 75m	N001S009 P084 90m	N001S009 P085 105m	N001S009 P086 125m	N001S009 P087 150m	N001S009 P088 175m
May							
Good Obs.	4894	4012	4333	4696	4705	4432	3711
% of Total (4896)	100	81.9	88.5	95.9	96.1	90.5	75.8
Average	5.0	8.6	9	9	9.2	9.3	9.4
June							
Good Obs.	4318	3642	4008	4109	4106	3758	2917
% of Total (4320)	100	84.3	92.8	95.1	95.0	87.0	67.5
Average	4.2	6.7	7.1	7.5	7.6	7.6	8.0
Compare							
Average Difference	-0.80	-1.9	-1.9	-1.5	-1.6	-1.7	-1.4
Pooled Std. Dev.	2.4	4.3	4.5	4.7	4.8	4.8	4.7
99% CI– Lower Bound	-0.93	-2.2	-2.2	-1.8	-1.9	-2.0	-1.7
99% CI Upper Bound	-0.67	-1.6	-1.6	-1.2	-1.3	-1.4	-1.1

Notes:

1. The average wind speed at heights 75m through 175m is greater May than in June. All results are statistically significant ($\alpha = 0.01$).
2. The average wind speed is greater in May than in June on the buoy deck. This result is statistically significant ($\alpha = 0.01$).
3. In addition, there appears to be a shift of wind direction from May to June. In June, the wind direction is from the SE to SSW about 10% of the time less than in May.