Alaska Wind Power Site 10 Wind Resource Report

Rev. 1, 2/4/08

Photo: David Lappi

Summary Information

Site 10 (also referred to as Coal Mine Road Site 10) exhibits some unusual wind power characteristics. Although the wind power density calculates as a solid Class 6 (Outstanding) wind resource, the mean annual wind speed is in a range one would expect from a Class 2 (Marginal) wind resource. Some reasons for this discrepancy will be addressed in this report, but in brief the

distribution of winds at this site is unusually broad, with a very large percentage of calm winds but also a not insignificant percentage of very strong winds. Because wind turbines cannot operate in exceptionally strong winds, the gains of wind power on the high end will not entirely mitigate the frequent calms at the low end. But, other wind resource factors at Site 10, such as low turbulence intensity and astonishing wind directionality, are quite promising for wind power development.

One should exercise caution in evaluating Site 10 when using standard wind site description tools such as mean wind speed, power density and wind power class. The characteristics of this site warrant a close look at predicted turbine performance to accurately compare Site 10 with other sites, either in the immediate area or in other locations. It is likely that utility-scale wind turbines at Site 10 would produce power outputs and capacity factors that one would expect from a Class 4 wind resource if the wind distribution were more normal.

Note that this evaluation is based on thirteen months of data. In February and March, 2007, very cold and very calm conditions persisted for several weeks which significantly influenced the mean wind speed calculations. It is entirely possible that mid-winter 2008 will see different climate characteristics and not such a long period of calm wind conditions. If so, the difference between mean wind speed and wind power density may narrow in the context of predicting wind power class.

Meteorological Tower Data Synopsis

Wind power class	Class 6 - Outstanding
Mean annual wind speed (48 meters)	5.84 m/s
Maximum wind speed (10 min. avg)	31.9 m/s
Maximum wind speed (2 sec. gust)	40.5 m/s
Mean wind power density (50 meters)	681 W/m^2
Weibull distribution parameters	k = 0.892, c = 5.61 m/s
Turbulence intensity (48 m)	0.123 (all sectors, 4 m/s calm threshold)
Roughness class	0.62 (description: snow surface)
Power law exponent	0.111 (moderately low wind shear)
Data start date	December 30, 2006
Data end date	February 1, 2008

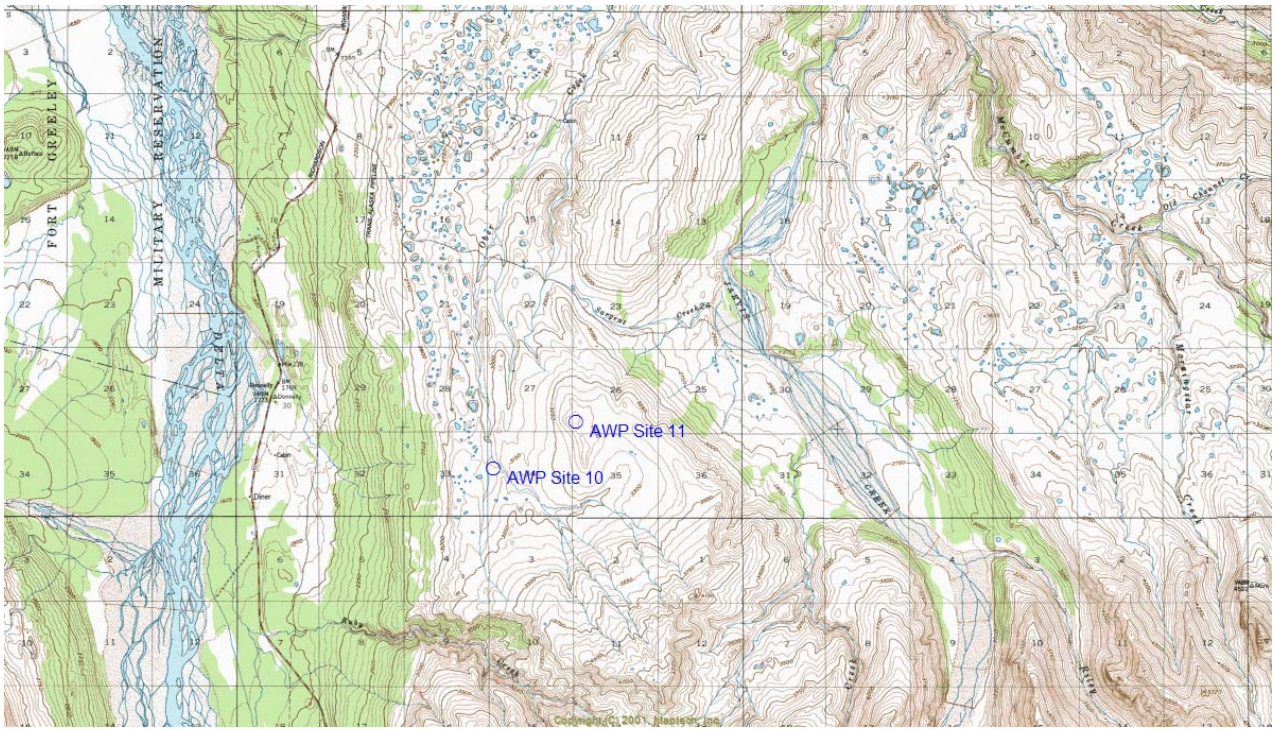
Meteorological Tower Site Information

Site number	0010
Site description	Coal Mine Road Site 10
Site elevation	936 meters AMSL
Lat/long	N 63° 39.560’; W 145° 48.107’
Datalogger type	NRG Symphonie
Tower type	NRG 50-meter tall tower, 8-inch diameter

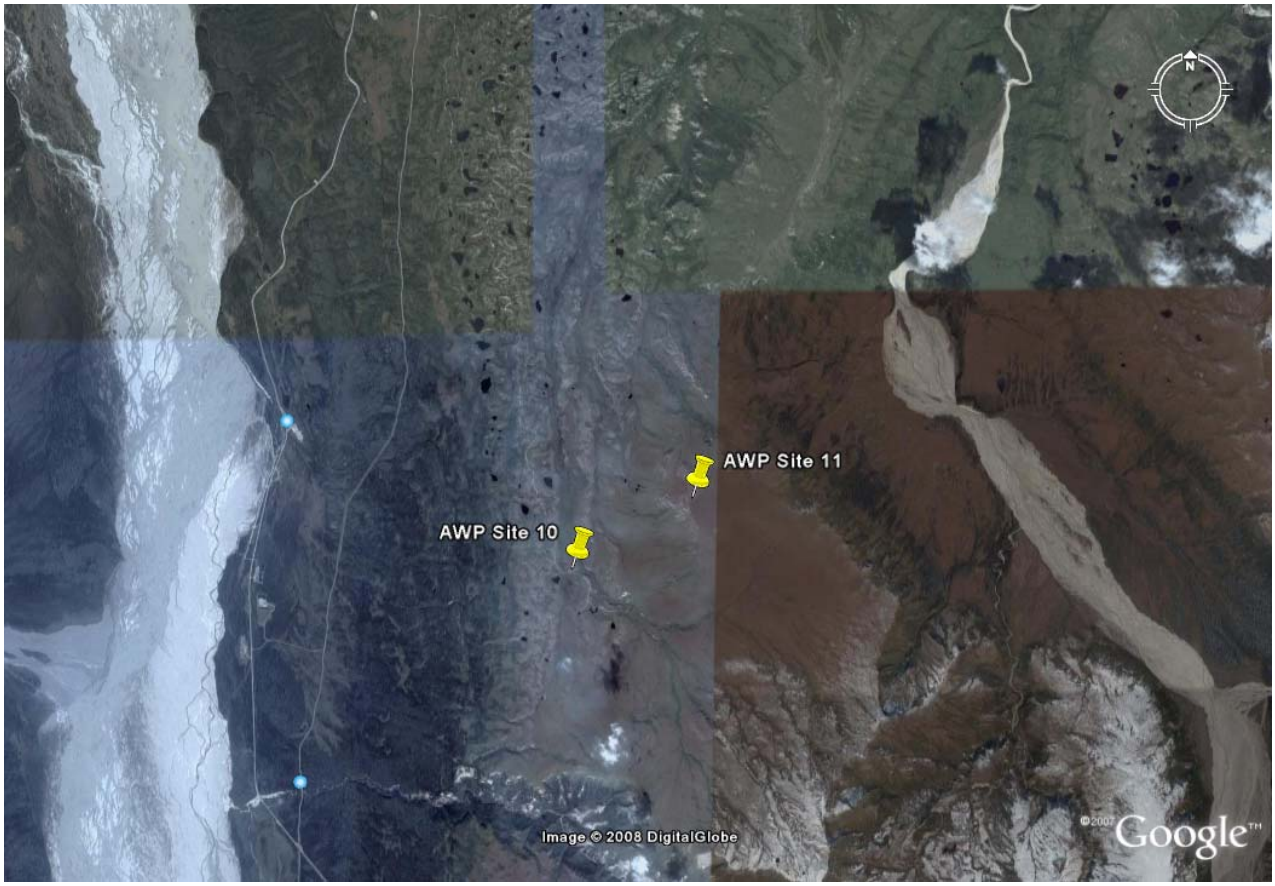
Met Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Sensor Orientation
1 (A)	NRG #40 anemometer	47.4 m	0.765	0.35	SE
2 (B)	NRG #40 anemometer	47.4 m	0.765	0.35	SW
3	NRG #40 anemometer	40.6 m	0.765	0.35	SE
4	NRG #40 anemometer	27.5 m	0.765	0.35	SE
7	NRG #200P wind vane	48 m	0.351	180	S
8	NRG #200P wind vane	40 m	0.551	175	S
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A
10	Voltage	N/A	0.021	0	N/A

Topographic Map Location



Google Earth Site Image



Quality Control

Data recovery from Site 10 was excellent with 96 percent recovered anemometer data, 98 percent recovered wind vane data and 99 percent recovered temperature data. Besides data lost to icing (addressed below), data files are missing for January 25, 48 and 30, 2008 as well as several brief data gaps of not more than a few hours each.

Some recovered data was not usable due to sensor icing events and these compromised data were removed prior to analysis. For anemometers, icing events are identified by zero speed output, non-variant standard deviation and the temperature near or below freezing. For wind vanes, icing events are identified by an unusually steady wind direction combined with non-variant standard deviation and a near or below freezing temperature. Typically, anemometers and wind vane are ice affected simultaneously, but not always.

		48 m A anem		48 m B anem		40 m anem		28 m anem	
Year	Month	Recovery Records	Mean Rate (%)	Recovery Records	Mean Rate (%)	Recovery Records	Mean Rate (%)	Recovery Records	Mean Rate (%)
2006	Dec	288	100	288	100	288	100	288	100
2007	Jan	4,164	93.3	4,164	93.3	4,164	93.3	4,164	93.3
2007	Feb	4,032	100	4,032	100	4,032	100	4,032	100
2007	Mar	4,464	100	4,464	100	4,464	100	4,464	100
2007	Apr	4,320	100	4,320	100	4,320	100	4,320	100
2007	May	4,464	100	4,464	100	4,464	100	4,464	100
2007	Jun	4,320	100	4,320	100	4,320	100	4,320	100
2007	Jul	4,464	100	4,464	100	4,464	100	4,464	100
2007	Aug	4,440	99.5	4,440	99.5	4,440	99.5	4,440	99.5
2007	Sep	4,090	94.7	4,090	94.7	4,090	94.7	4,090	94.7
2007	Oct	4,464	100	4,464	100	4,464	100	4,464	100
2007	Nov	4,040	93.5	4,040	93.5	4,040	93.5	4,040	93.5
2007	Dec	4,187	93.8	4,187	93.8	4,187	93.8	4,187	93.8
2008	Jan	3,310	74.1	3,310	74.1	3,072	68.8	3,310	74.1
2008	Feb	72	100	72	100	72	100	72	100
All data		55,119	96.1	55,119	96.1	54,881	95.6	55,119	96.1

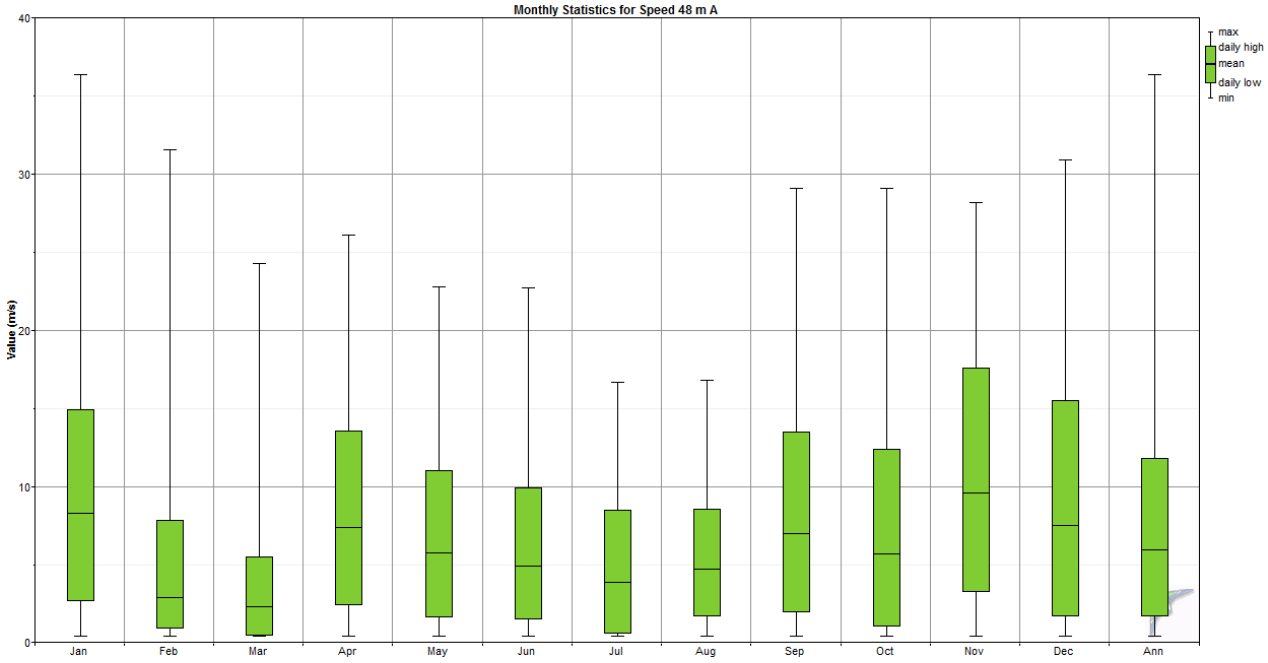
		48 m vane		40 m vane		Temp	
Year	Month	Recovery Records	Mean Rate (%)	Recovery Records	Mean Rate (%)	Recovery Records	Mean Rate (%)
2006	Dec	288	100	288	100	288	100
2007	Jan	4,464	100	4,464	100	4,464	100
2007	Feb	4,032	100	4,032	100	4,032	100
2007	Mar	4,464	100	4,464	100	4,464	100
2007	Apr	4,320	100	4,320	100	4,320	100
2007	May	4,464	100	4,464	100	4,464	100
2007	Jun	4,320	100	4,320	100	4,320	100

2007	Jul	4,464	100	4,464	100	4,464	100
2007	Aug	4,440	99.5	4,440	99.5	4,440	99.5
2007	Sep	4,320	100	4,320	100	4,320	100
2007	Oct	4,464	100	4,464	100	4,464	100
2007	Nov	4,071	94.2	4,073	94.3	4,272	98.9
2007	Dec	4,464	100	4,464	100	4,464	100
2008	Jan	3,387	75.9	3,877	86.9	3,960	88.7
2008	Feb	72	100	72	100	72	100
All data		56,034	97.6	56,526	98.5	56,808	99.0

Measured Wind Speeds

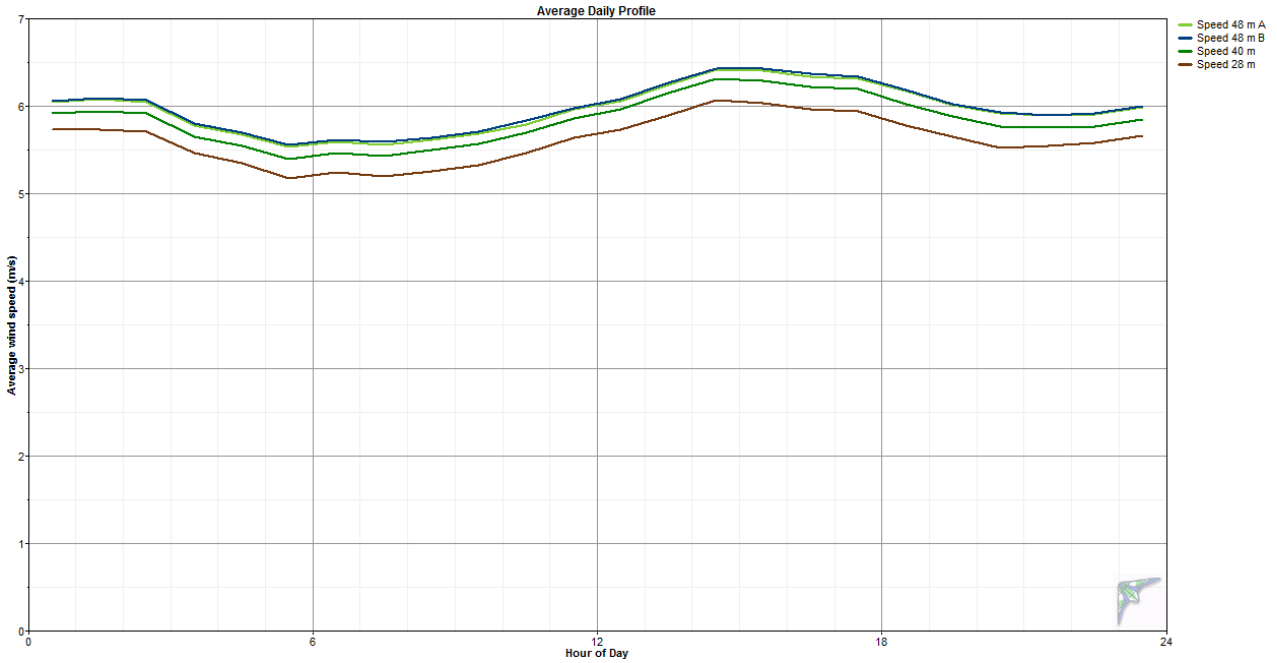
The annual average wind speed is 5.84 m/s and 5.86 m/s respectively for the 48 meter A and B anemometers. Note that maximum (max) wind data are 10 minute averages; two-second gust data for the 48 meter A anemometer are shown in the adjacent column.

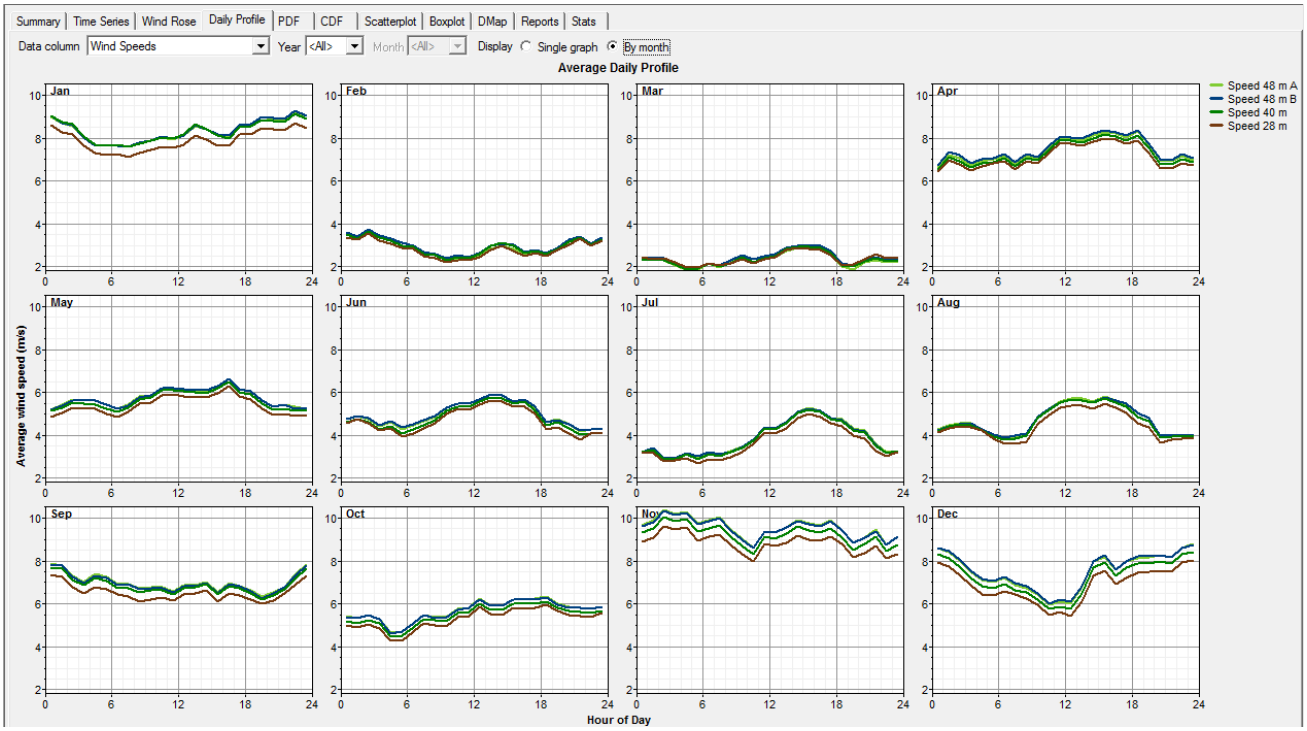
	48 m A anemometer						40 m anem.		28 m anem.	
Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k -	Weibull c (m/s)	Mean (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)
Jan	8.31	31.9	40.5	8.609	0.795	7.341	8.29	31.0	7.83	30.2
Feb	2.90	31.6	38.2	4.777	0.778	2.397	2.93	30.6	2.83	29.4
Mar	2.31	24.3	29.1	3.383	2.056	4.213	2.35	23.7	2.37	22.9
Apr	7.41	26.1	36.7	6.295	1.047	7.541	7.29	25.6	7.13	25.1
May	5.75	22.8	27.9	4.757	1.170	6.072	5.63	22.0	5.39	21.1
Jun	4.94	22.7	29.8	4.207	1.236	5.312	4.79	21.9	4.66	21.0
Jul	3.85	16.7	20.6	3.187	1.240	4.136	3.79	16.2	3.61	15.9
Aug	4.73	16.8	21.4	4.185	1.089	4.885	4.65	16.3	4.47	15.7
Sep	6.99	29.1	34.4	6.692	0.978	6.920	6.84	28.3	6.51	27.1
Oct	5.68	29.1	37.1	6.600	0.816	5.046	5.47	28.2	5.28	27.0
Nov	9.56	28.2	37.8	6.946	1.142	9.969	9.23	27.3	8.84	25.9
Dec	7.53	30.9	40.1	7.661	0.871	7.026	7.25	30.0	6.90	29.1
Annual	**5.84**	31.9	40.5	6.394	0.892	5.609	**5.72**	31.0	**5.49**	30.2



Daily Wind Profile

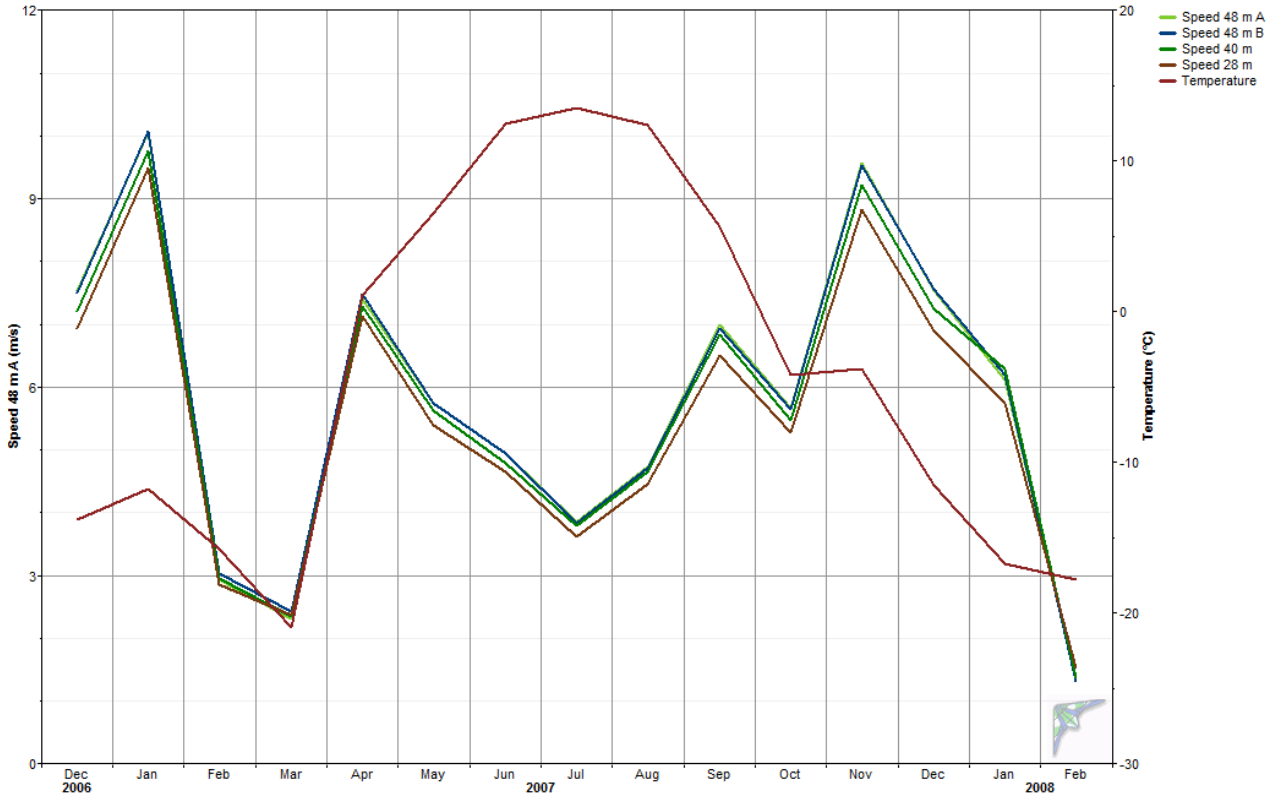
The daily wind profile indicates that, on an annual basis, the lowest wind speeds of the day occur in the morning hours of 4 to 8 a.m. and the highest wind speeds of the day occur during the afternoon hours of 1 to 5 p.m. Daily wind profiles by month exhibit more variability and different patterns of high and low wind diurnal variation.





Time Series of Wind Speed Monthly Averages

Winter winds are generally higher than summer winds at Site 10; however, in February and March of 2007, very cold and very stable air resulted in a prolonged period of mostly calm winds. But, winter weather conditions often exhibit considerable variability from year-to-year and this pattern may not repeat in 2008.

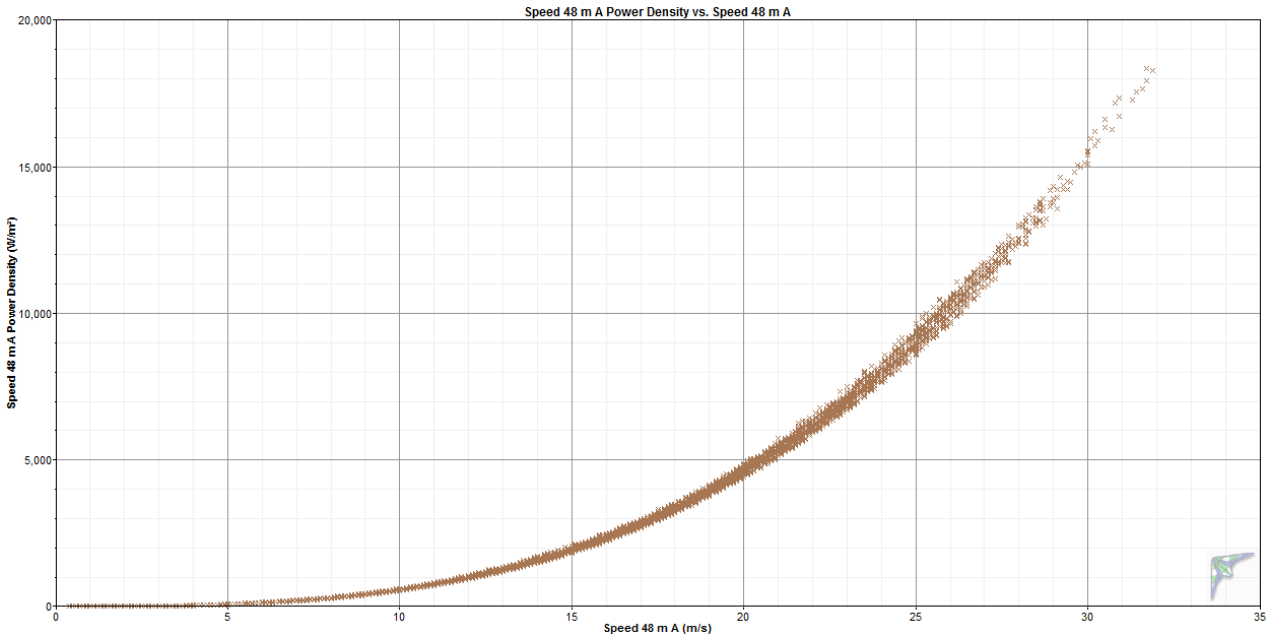


Wind Power Density

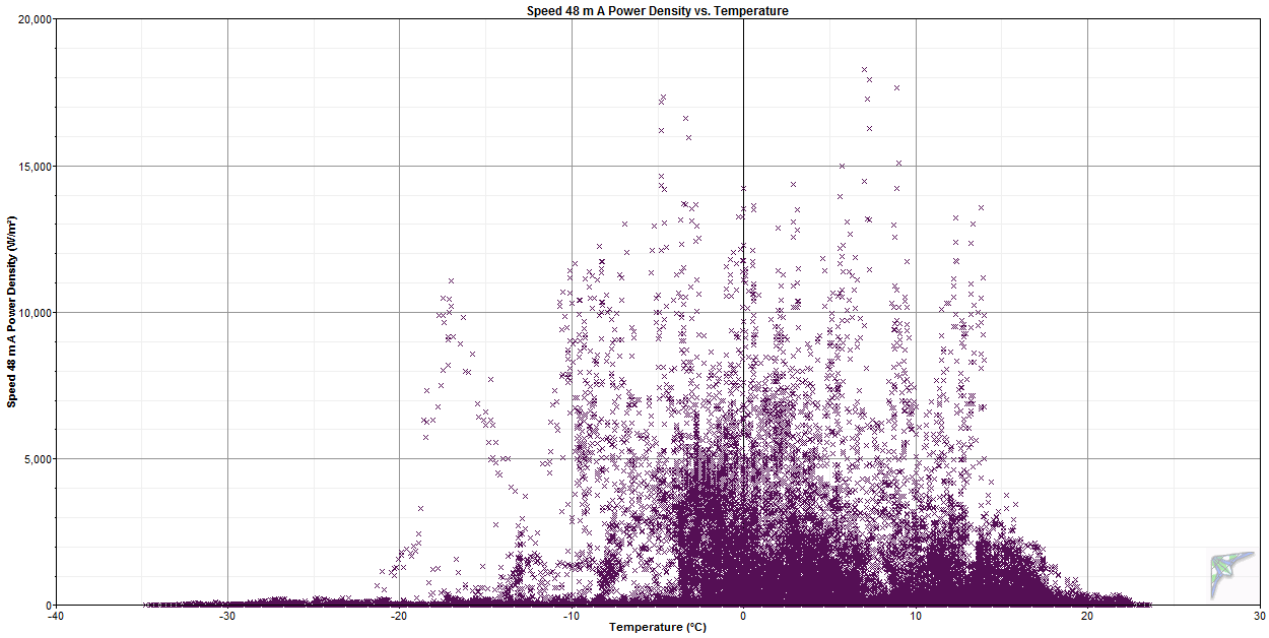
The wind power density is defined as the power per unit area of the wind with units of Watts per square meter. It is calculated by ½ times the air density times the wind speed cubed for each time step. The equation is: $P/A = ½*\rho*U^3$. The time step values are averaged to generate an overall wind power density.

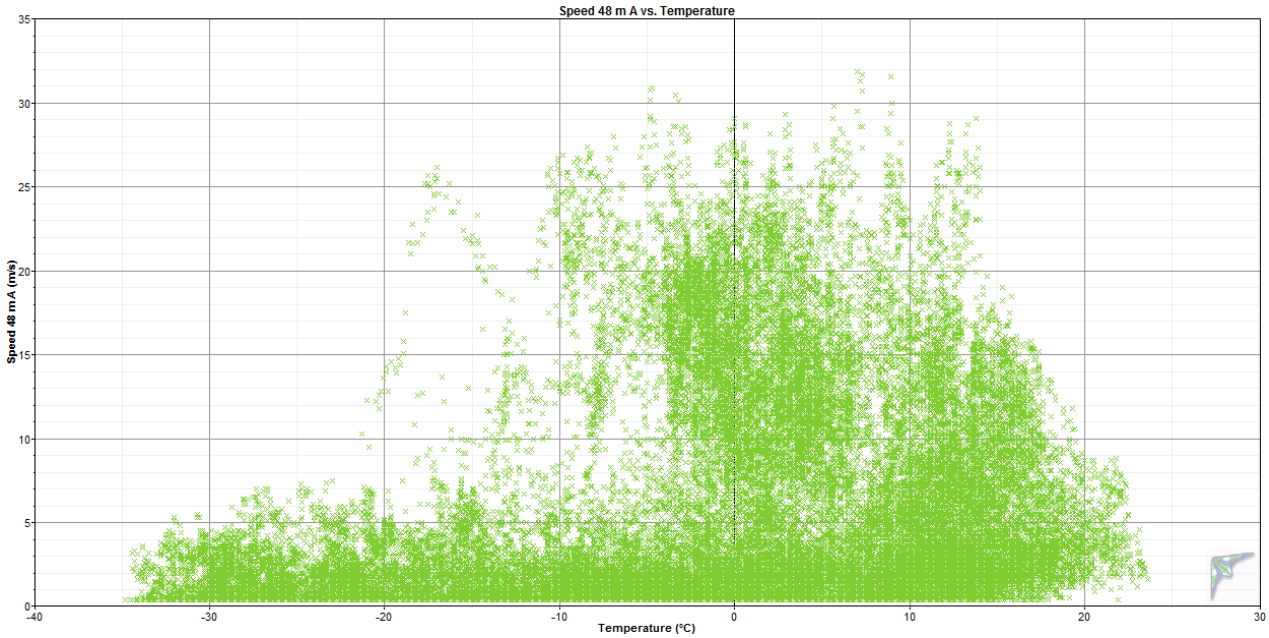
A wind industry standard method of comparing and evaluating sites is by the wind power density at 50 meters. If the anemometer measurement heights are other than 50 meters, the wind analysis software extrapolates up or down using the power law exponent value calculated for wind shear.

The power density at Site 10 is calculated at 681 W/m^2 at 50 meters, categorizing it as a Class 6 (outstanding) wind resource. This is an unusual situation though because the 48 meter wind mean annual wind speed is 5.84 m/s, which, if the Weibull parameters were more normal (see later in this report), would predict a Class 2 (marginal) wind resource. This is due to the very odd nature of the winds at this site: majority calm winds (< 4 m/s) and then a not insignificant fraction of very high winds, some well over 25 m/s. Because the power density is dependent on the wind speed cubed, a relatively small percentage of very high winds (see below) can skew the power density high and hence the wind classification if the Weibull distribution is unusual, which at Site 10 it is.



An observation also of some interest is to compare in a scatter plot the power density and, separately, the mean wind speed to temperature (below). As one can see, the power producing winds (winds greater than 4 m/s, the typical wind turbine cut-in speed) are primarily evident when the temperature is above approximately -3° C.

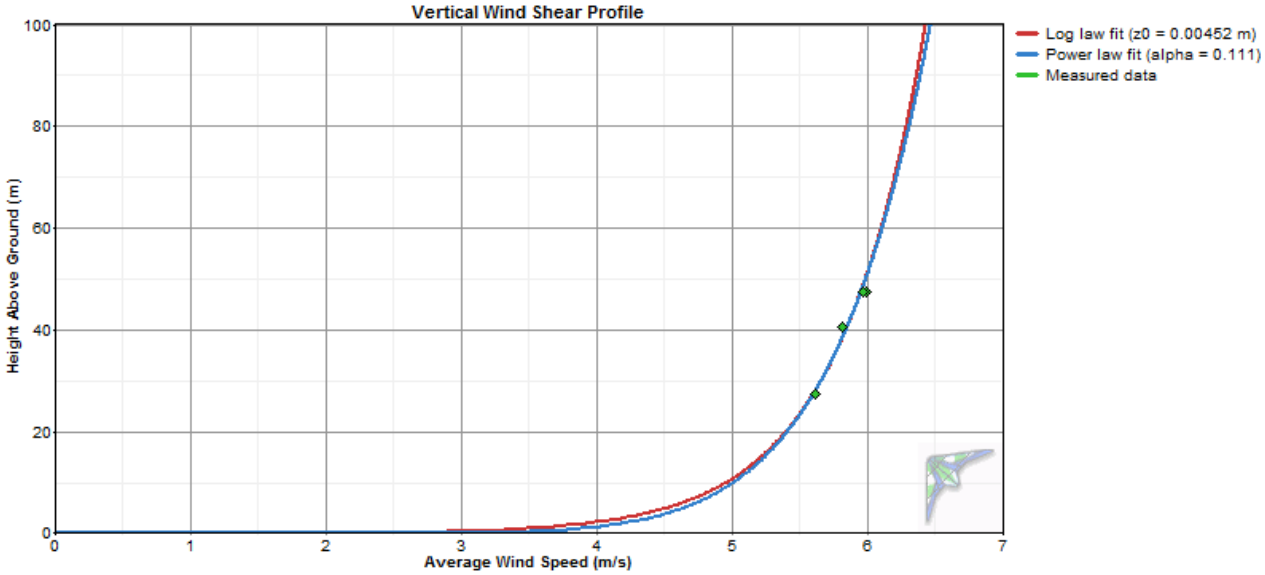

Speed 48 m A Power Density vs. Temperature
Speed 48 m A Power Density (W/m²)
20,000
15,000
10,000
5,000
0
-40
-30
-20
-10
0
10
20
30
Temperature (°C)

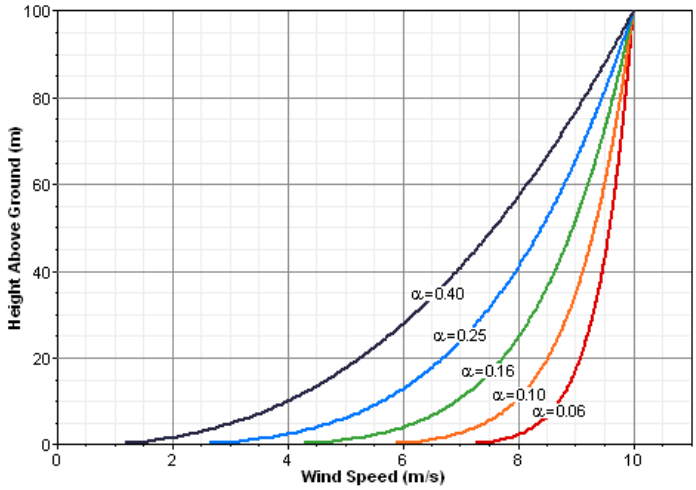

Speed 48 m A vs. Temperature
Speed 48 m A (m/s)
35
30
25
20
15
10
5
0
-40
-30
-20
-10
0
10
20
30
Temperature (°C)

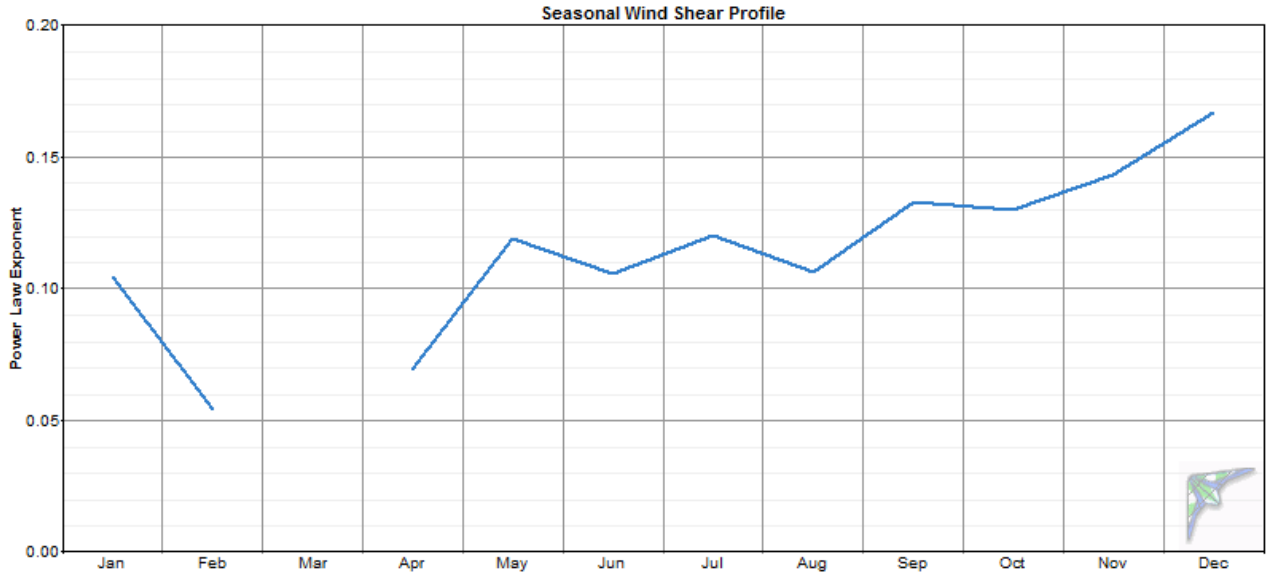
Wind Shear Profile

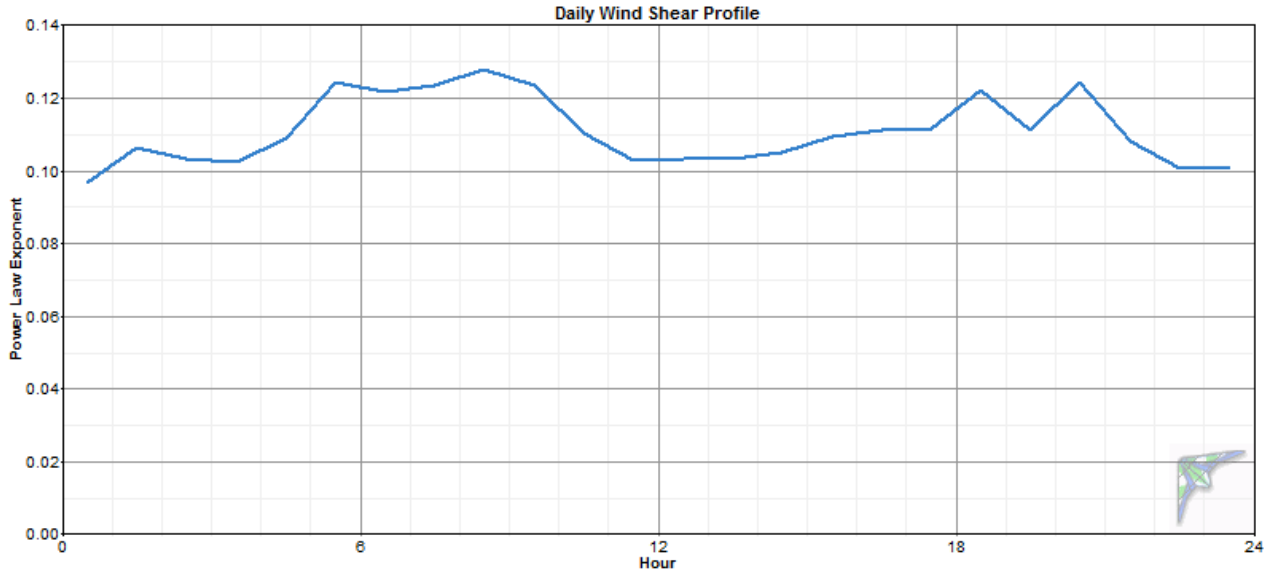
The annual average power law exponent was calculated at 0.111, indicating moderately low wind shear at the site. The practical application of this information is that a lower wind turbine tower height is possible, but there is enough marginal gain in average wind speed with height to warrant considering higher tower heights. A tower height/power recovery/construction cost tradeoff study is advisable prior to project development.

Also shown are seasonal and daily wind shear profiles which indicate some variability, although likely not significant from a project planning point of view.






Seasonal Wind Shear Profile
Power Law Exponent
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

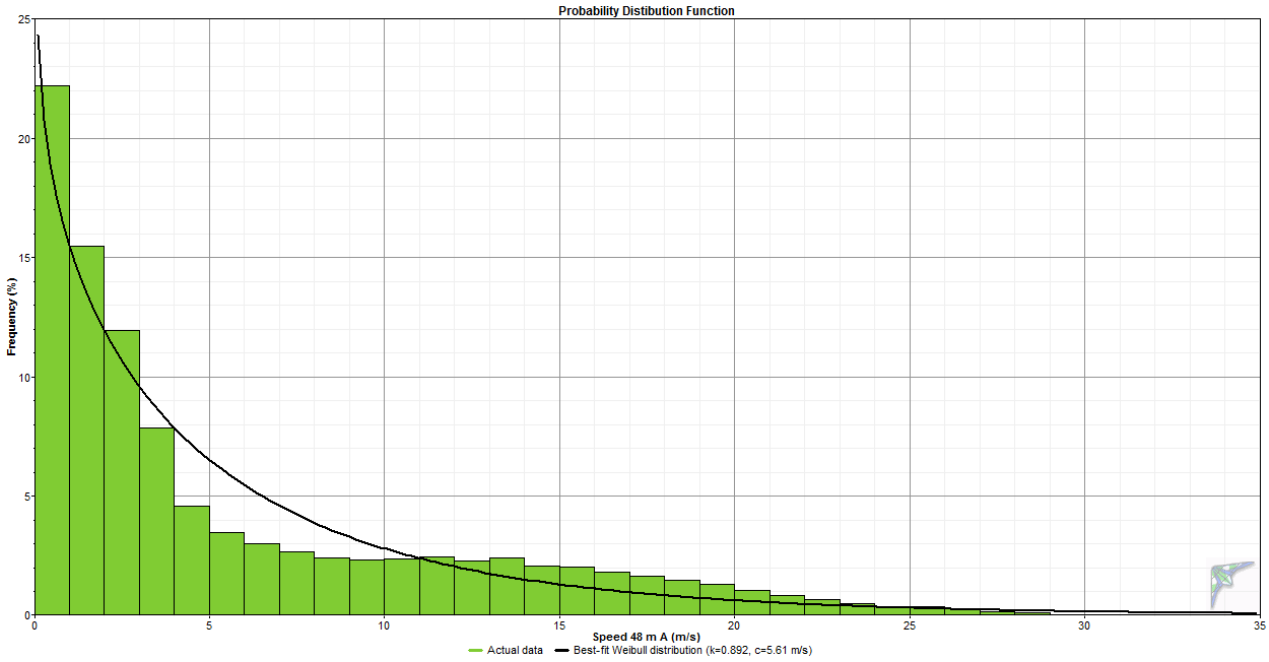

Daily Wind Shear Profile
Power Law Exponent
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
6
12
18
24
Hour

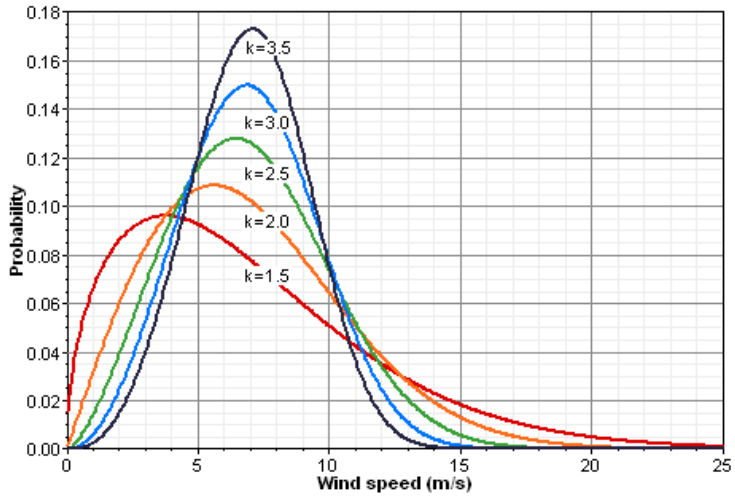
Probability Distribution Function

The probability distribution function indicates the probability that a variable will return a value "x", in the case of wind speed this means the frequency that the speed falls within 1 m/s bins, as shown in the histogram below. Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s, also known as the "cut-in" speed. Also note that most turbines have a cutout speed of 25 m/s.

The black line in the graph is a best fit Weibull distribution. At the 48 meter level, Weibull parameters are k = 0.892 and c = 5.61 m/s (scale factor for the Weibull distribution). Weibull k is the shape factor of the Weibull distribution, indicating the breadth of the distribution as shown below. Low k values indicate broad distributions of wind speeds.

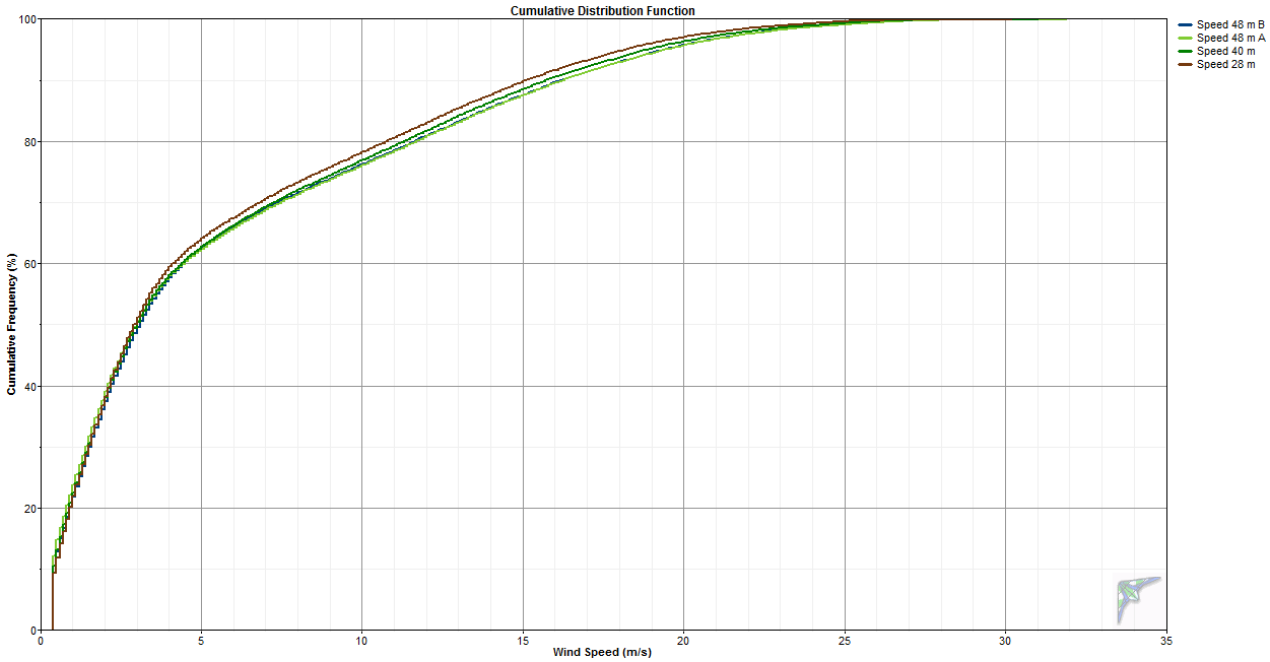
Site 10 is unusual in that it has an extremely low Weibull k. A typical site might have a Weibull k value in the range of 1.5 to 2.5. The Weibull k helps explain the curious nature of this site: although the mean annual wind speed is not particularly high, the power density is. This is because there is a high frequency of calm winds (wind less than 4 m/s) *and* a relatively high frequency (given the moderate annual mean wind speed) of high to very high winds as well.





Cumulative Distribution Function

The cumulative distribution function represents another way to understand the probability distribution function. Note that approximately 57 percent of the measured winds were less than 4 m/s, the cut-in speed of most turbines, and approximately 98 percent of winds are less than 25 m/s, the cutout speed of most turbines; hence the time frequency of wind speeds suitable for power production is approximately 41 percent.



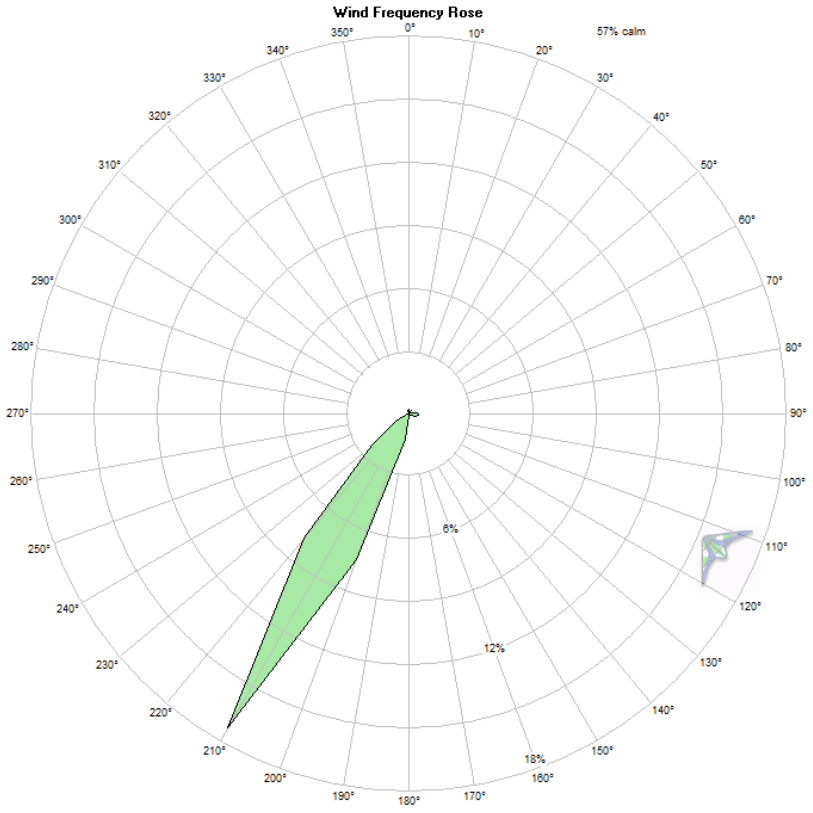
Wind Roses

Site 10 winds are extraordinarily directional; the 48 m height wind frequency rose indicates only SSW winds centered on 210° T with a very, very minor contribution of winds from other directions. Note that the 40 m wind rose indicates the same SSW winds, but centered on 200° T, indicating that the offset of one (or both) of the wind vanes is off slightly.

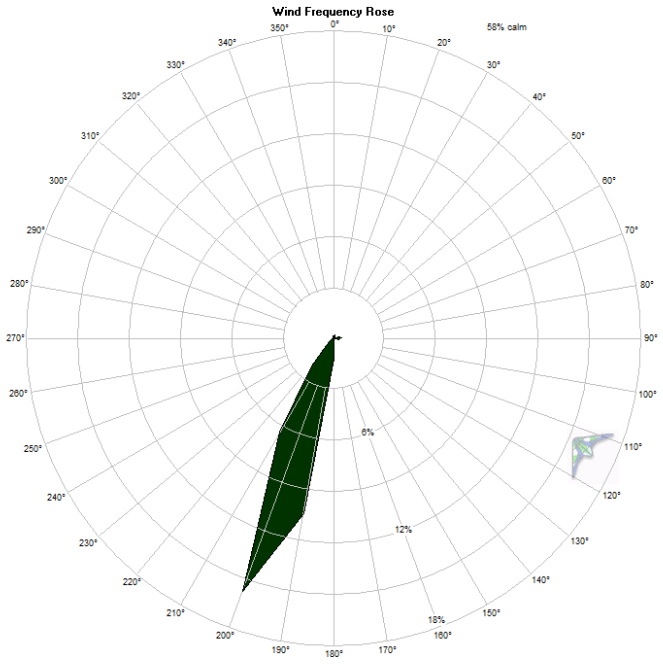
The observation of wind directionality is reinforced with reference to the power density rose. Power producing winds are only SSW at Site 10. Even on a monthly basis (see below), there is no wind direction variability.

Although quite unusual, the practical application of these highly directional winds is that multiple turbines can be arranged with a very tight spacing perpendicular to 210° T (or 200° T). Of course one would want to avoid placing turbines in columns parallel to 210° T unless they were spaced very far apart.

Wind frequency rose (48 meters)

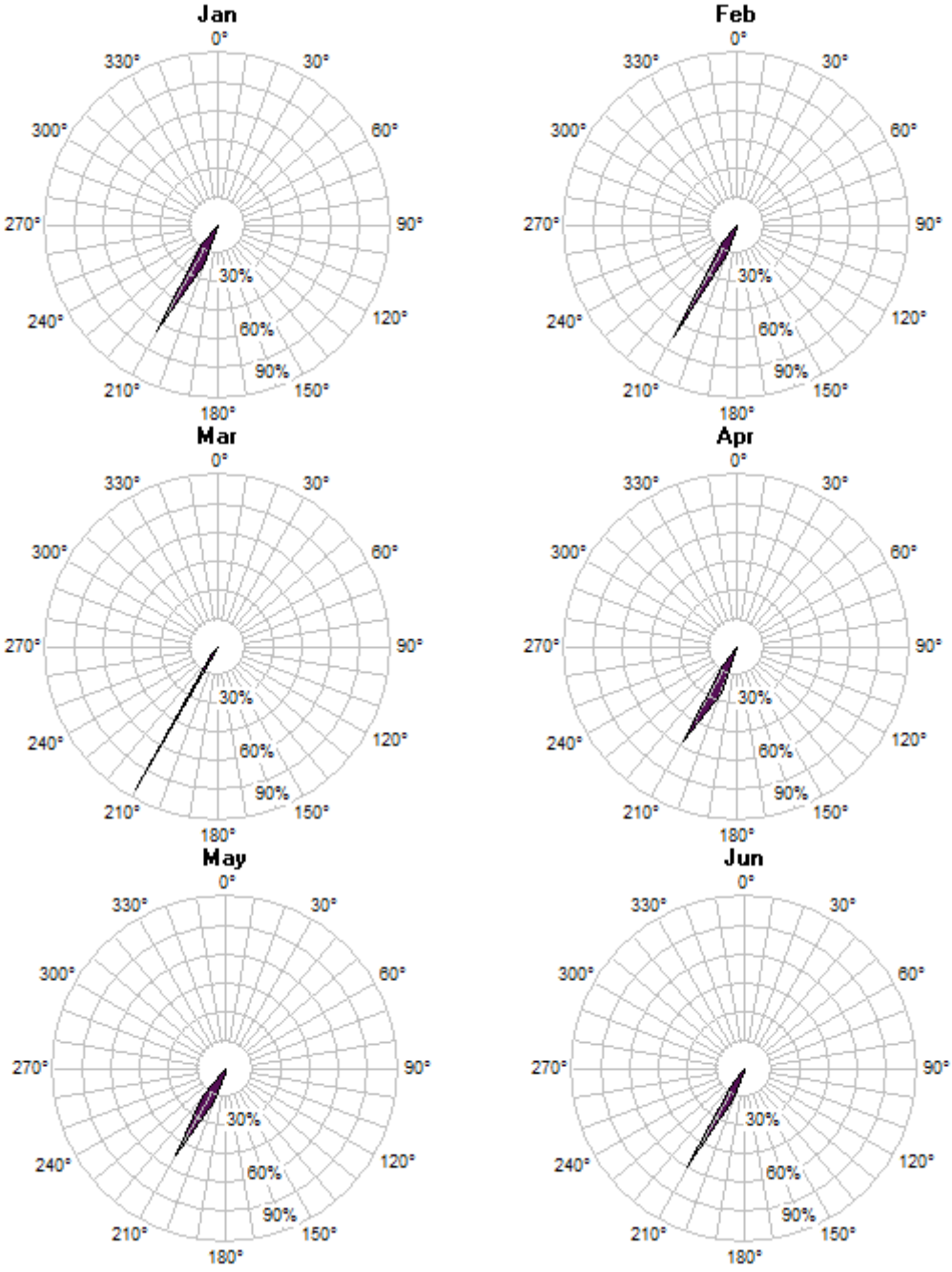


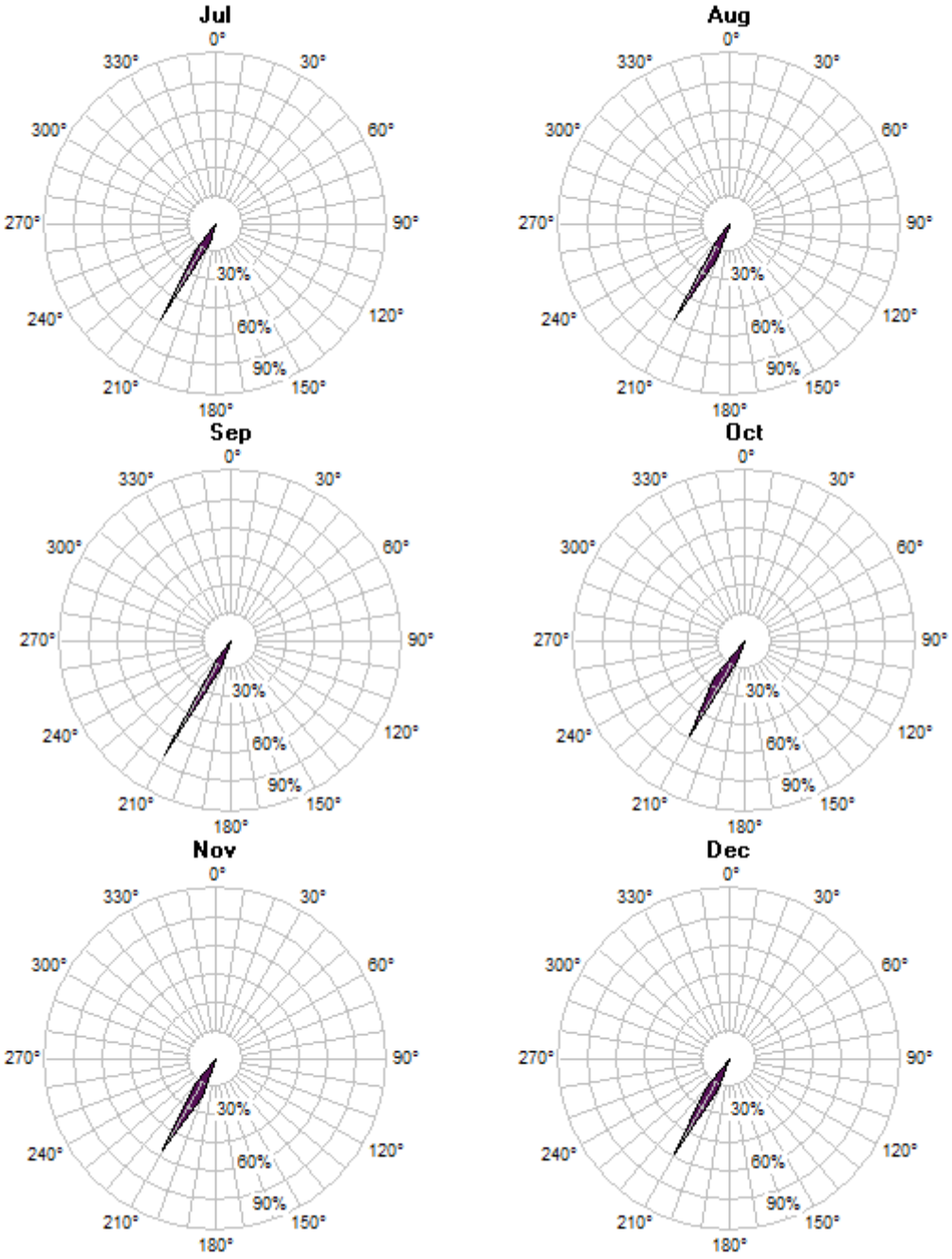
Wind frequency rose (40 meters)



Power density rose (48 meters)

Wind Power Density Rose by Month (scale is common)




Jul
Aug
Sep
Oct
Nov
Dec
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
30%
60%
90%

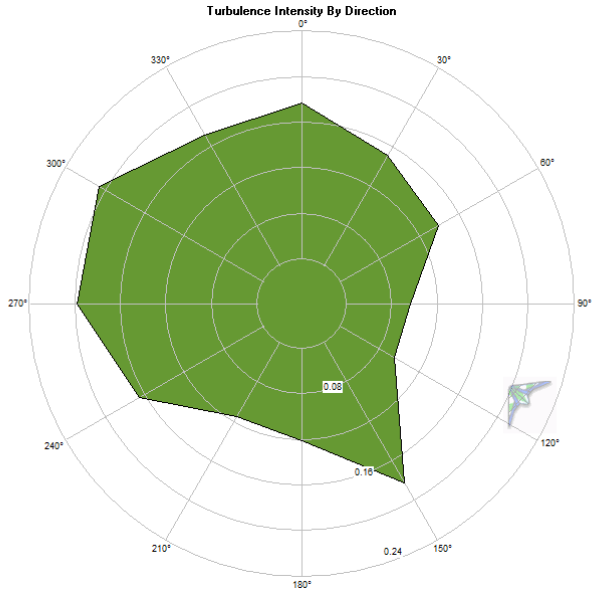
Turbulence Intensity

Turbulence intensity is a dimensionless number defined as standard deviation of the wind speed within a time step divided by the mean wind speed within that time step.

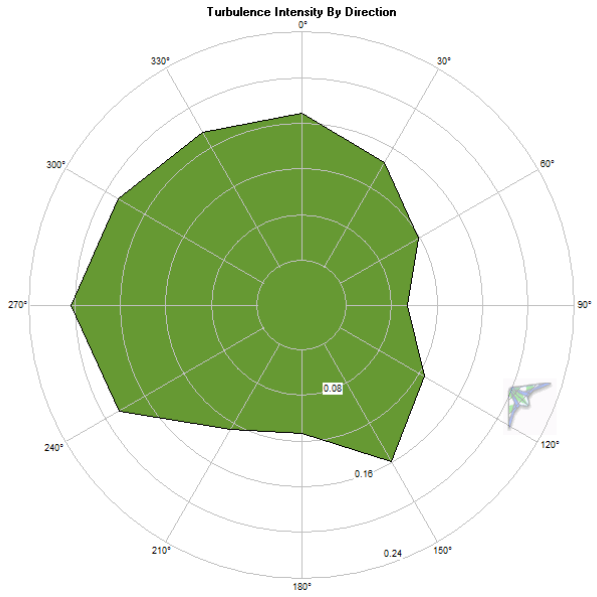
Turbulence intensity at Site 10 is acceptable, with a mean turbulence intensity of 0.123 (48 meter vane and 48 m A anemometer) indicating relatively smooth air. Because the winds at Site 10 are almost completely SSW, the mean turbulence intensity from that sector (195° T to 225° T) is promising 0.115, indicating again relatively smooth air for wind turbine operations. Note that the turbulence intensities are calculated with a threshold wind speed of 4 m/s. Winds less than 4 m/s are not important from a turbulence perspective as this is below turbine cut-in speeds.

Note below that the turbulence intensity roses indicate high turbulence intensities in some wind sectors. Because the power producing winds are entirely SSW, the turbulence intensity value from that the SSW sector is the only one of any real interest.

48 meter turbulence intensity (48 m A anemometer – 48 m vane)

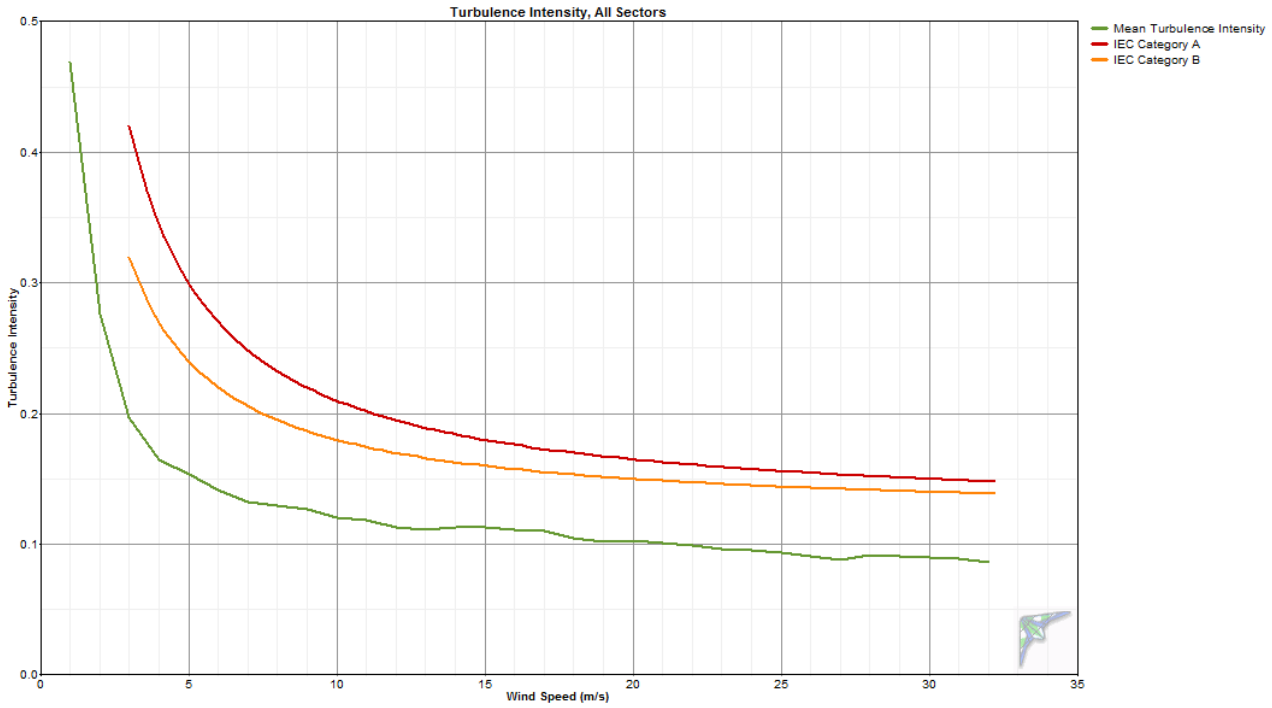


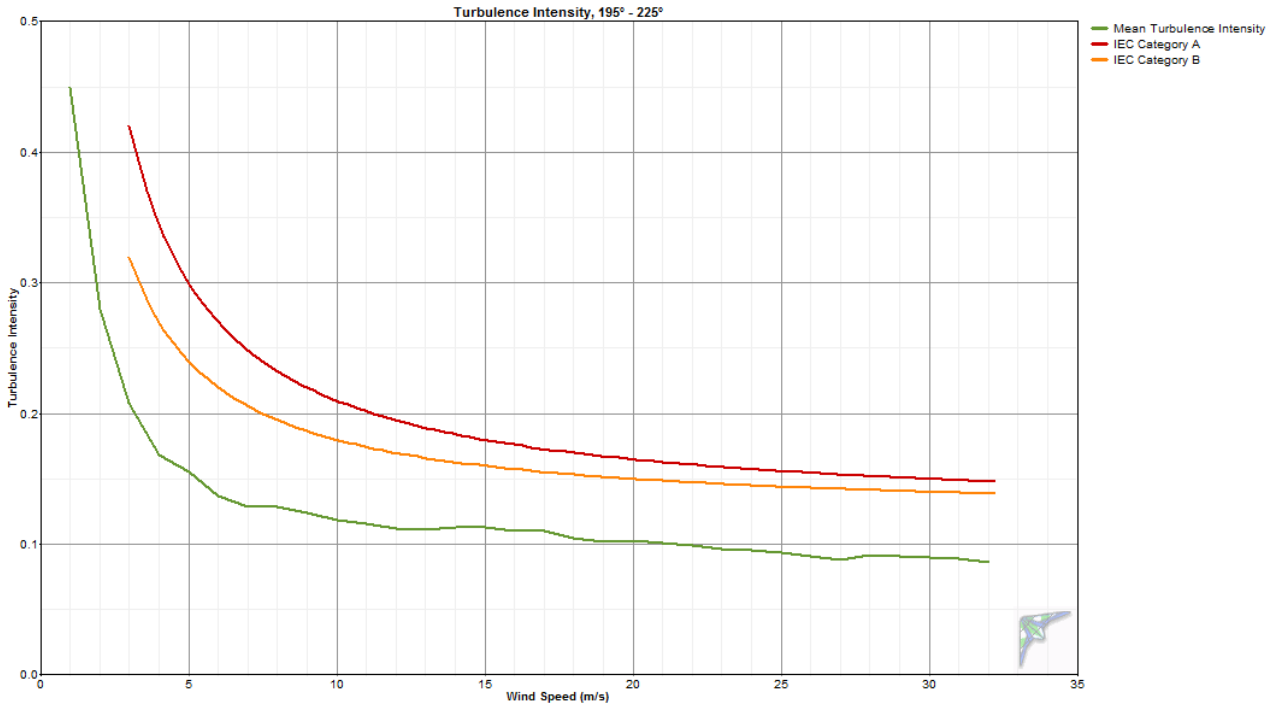
40 meter turbulence intensity (40 m anemometer – 40 m vane)



IEC Turbulence Intensity Standards

As indicated below, turbulence at Site 10 is well within International Electrotechnical Commission (IEC) Category A and B standards at all measured wind speeds for all sectors and more importantly, for the SSW sector of the power-producing winds. Note: the IEC is a global organization based in Switzerland that prepares and publishes international standards for all electrical, electronic and related technologies. These serve as a basis for national standardization and as references when drafting international tenders and contracts (this description from the IEC website www.iec.ch).





Turbulence Table

48 m A anemometer, 12/30/06 to 2/1/08

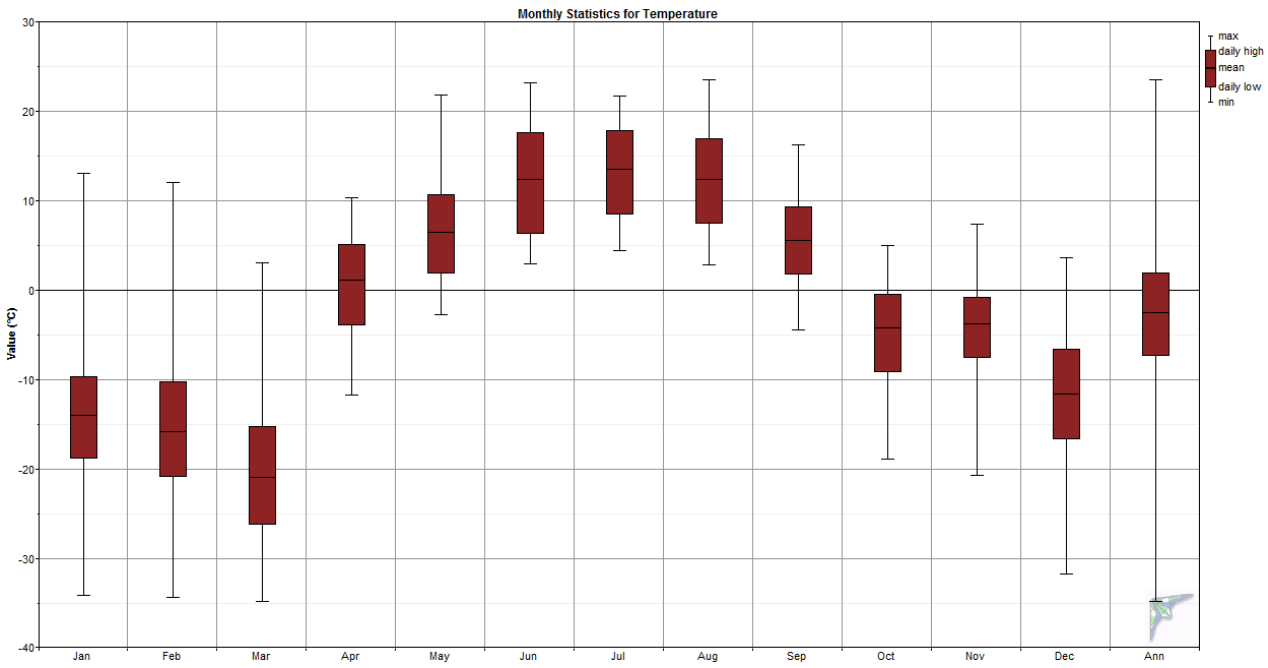
Bin Midpt. (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Std. Dev. of Wind Speed (m/s)	Mean Turbulence Intensity	Std. Dev. of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	9859	0.395	0.451	0.162	0.613
2	1.5	2.5	7915	0.494	0.261	0.129	0.390
3	2.5	3.5	5803	0.538	0.186	0.096	0.281
4	3.5	4.5	3628	0.598	0.154	0.089	0.243
5	4.5	5.5	2347	0.710	0.144	0.075	0.219
6	5.5	6.5	1790	0.819	0.138	0.064	0.202
7	6.5	7.5	1487	0.932	0.134	0.055	0.190
8	7.5	8.5	1363	1.047	0.132	0.050	0.181
9	8.5	9.5	1283	1.147	0.128	0.047	0.175
10	9.5	10.5	1281	1.236	0.124	0.044	0.168
11	10.5	11.5	1274	1.323	0.121	0.042	0.163
12	11.5	12.5	1318	1.375	0.115	0.037	0.152
13	12.5	13.5	1293	1.471	0.113	0.036	0.149
14	13.5	14.5	1212	1.600	0.115	0.033	0.148
15	14.5	15.5	1105	1.720	0.115	0.031	0.146
16	15.5	16.5	1084	1.782	0.112	0.028	0.140
17	16.5	17.5	932	1.881	0.111	0.029	0.140

18	17.5	18.5	812	1.909	0.106	0.026	0.132
19	18.5	19.5	797	1.965	0.104	0.026	0.130
20	19.5	20.5	638	2.050	0.103	0.024	0.127
21	20.5	21.5	507	2.128	0.102	0.024	0.126
22	21.5	22.5	393	2.221	0.101	0.024	0.125
23	22.5	23.5	348	2.247	0.098	0.023	0.121
24	23.5	24.5	219	2.349	0.098	0.023	0.121
25	24.5	25.5	205	2.434	0.098	0.021	0.119
26	25.5	26.5	189	2.395	0.092	0.018	0.110
27	26.5	27.5	105	2.509	0.093	0.021	0.114
28	27.5	28.5	55	2.536	0.091	0.019	0.109
29	28.5	29.5	31	2.497	0.086	0.013	0.099
30	29.5	30.5	14	2.521	0.084	0.019	0.103
31	30.5	31.5	6	2.883	0.093	0.007	0.100
32	31.5	32.5	4	2.525	0.080	0.011	0.091

Air Temperature and Density

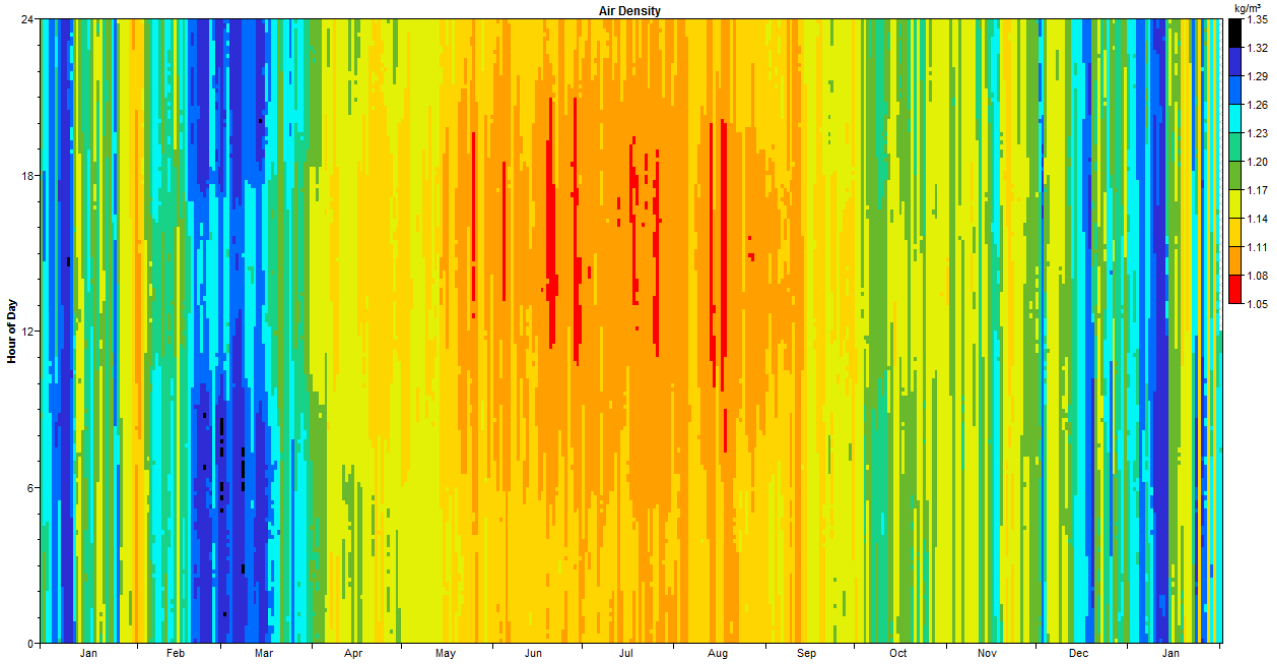
An annual average temperature of -1.5° C was measured at Site 10. The minimum temperature during the measurement period was -34.8° C and the maximum temperature was 23.6° C, indicating a wide variability of ambient operating environment important to wind turbine operations. Consequent to Site 10's cool temperatures, the average air density of 1.165 kg/m^3 is approximately four percent higher than the standard air density of 1.1186 kg/m^3 (at 8.9° C temperature and 90.6 kPa pressure at an elevation of 936 meters).

	Temperature			Air Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-14.1	-34.1	13.1	1.215	1.103	1.321
Feb	-15.8	-34.4	12.1	1.229	1.107	1.322
Mar	-20.9	-34.8	3.1	1.253	1.143	1.325
Apr	1.1	-11.7	10.4	1.152	1.113	1.208
May	6.5	-2.7	21.9	1.129	1.070	1.167
Jun	12.5	3.0	23.2	1.106	1.065	1.143
Jul	13.5	4.5	21.8	1.102	1.070	1.137
Aug	12.4	2.8	23.6	1.106	1.064	1.144
Sep	5.6	-4.4	16.3	1.133	1.091	1.175
Oct	-4.2	-18.9	5.0	1.174	1.135	1.242
Nov	-3.8	-20.7	7.4	1.172	1.119	1.251
Dec	-11.6	-31.7	3.7	1.209	1.140	1.308
Annual	**-1.5**	-34.8	23.6	**1.165**	1.064	1.325



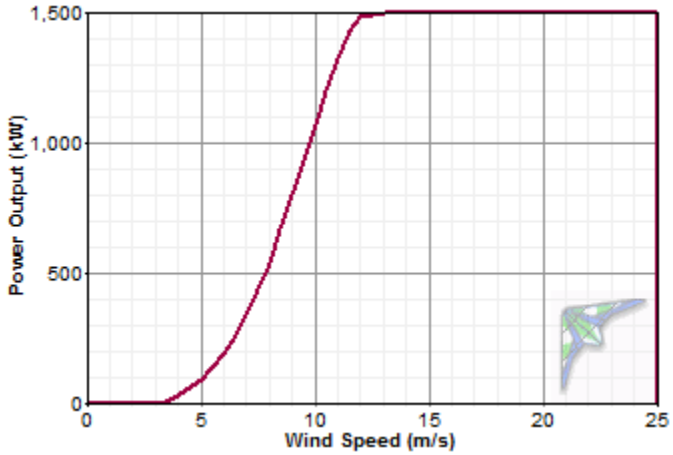
Air Density DMap

This DMap is a visual indication of the seasonal and daily variations in air density (and temperature). Air densities higher than standard (STP at sea level) will yield higher turbine power than predicted by turbine power curves, while density lower than standard will yield lower turbine power than predicted.



Sample Turbine Performance

For general information, predicted annual performance of a General Electric 1.5sle turbine is shown below. This turbine was selected because of its widespread use throughout the United States in grid-connected applications. The 1.5sle is rated at 1500 kW maximum output and is available at several hub heights, although 80 meters is the most common. For this analysis, an 80 meter hub height with 97 percent turbine availability (typical for utility applications) was assumed. Note below the turbine power curve. Also note that this prediction does not account for some turbine operational issues at return to operation after high wind speed cut-out which will lower performance slightly from the below predicated performance. Additional information regarding this turbine can be found at www.gepower.com.



GE 1.5sle, 97% availability, 80 m hub height, annual performance

Month	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Average Net Energy Output (kWh)	Average Net Capacity Factor (%)
Jan	8.75	51.0	29.1	513	381,875	34.2
Feb	3.12	76.1	7.2	148	99,748	9.9
Mar	2.48	75.8	3.5	71.4	53,106	4.8
Apr	7.81	36.9	23.7	592	426,478	39.5
May	6.10	38.6	10.4	414	307,747	27.6
Jun	5.23	43.6	7.6	303	217,915	20.2
Jul	4.07	51.9	2.4	184	136,643	12.2
Aug	5.06	49.1	7.8	324	241,207	21.6
Sep	7.45	44.2	20.0	490	352,608	32.6
Oct	6.01	57.6	17.2	390	289,936	26.0
Nov	10.19	28.6	38.2	800	576,202	53.4
Dec	8.00	48.3	28.1	504	374,839	33.6
Annual	6.19	50.1	16.3	399	3,491,110	26.3