Naknek, Alaska (Cape Suwarof) Wind Resource Report

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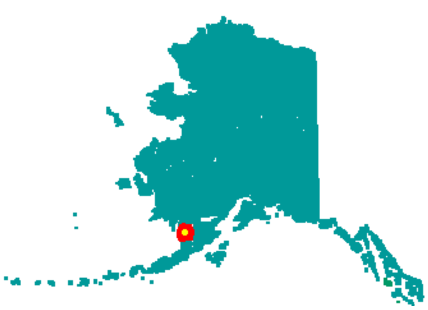
Date of Report: September 16, 2009

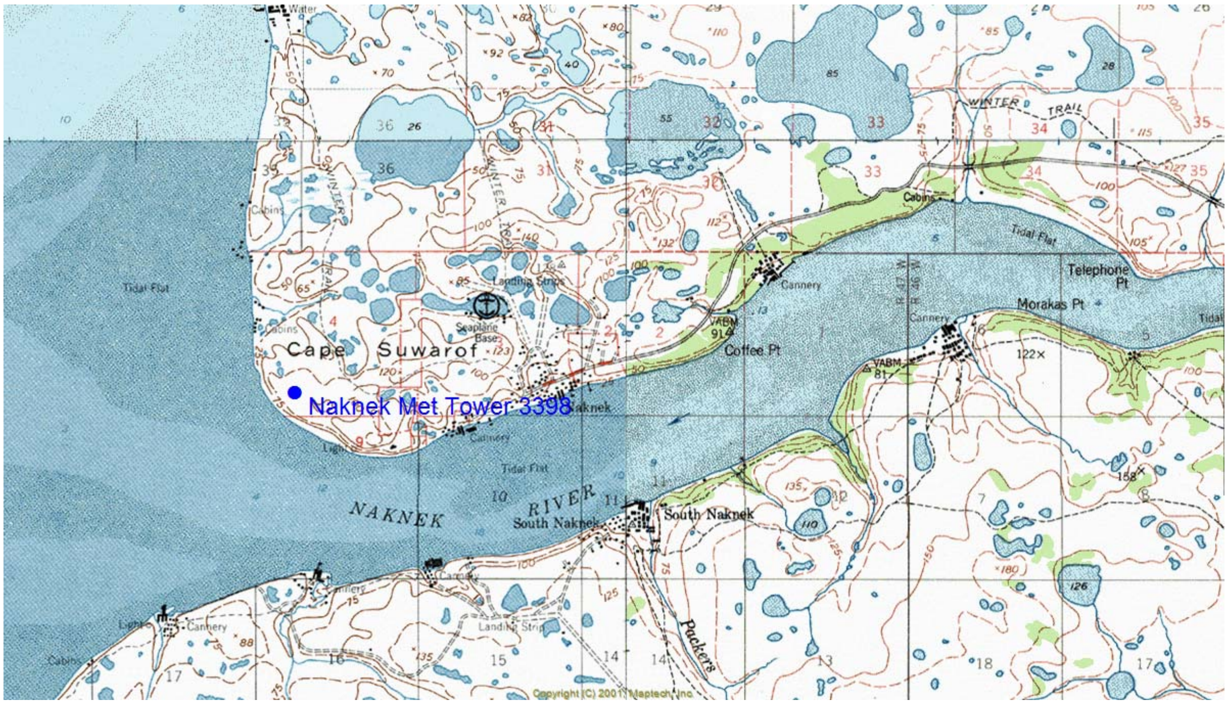
Photo © Doug Vaught



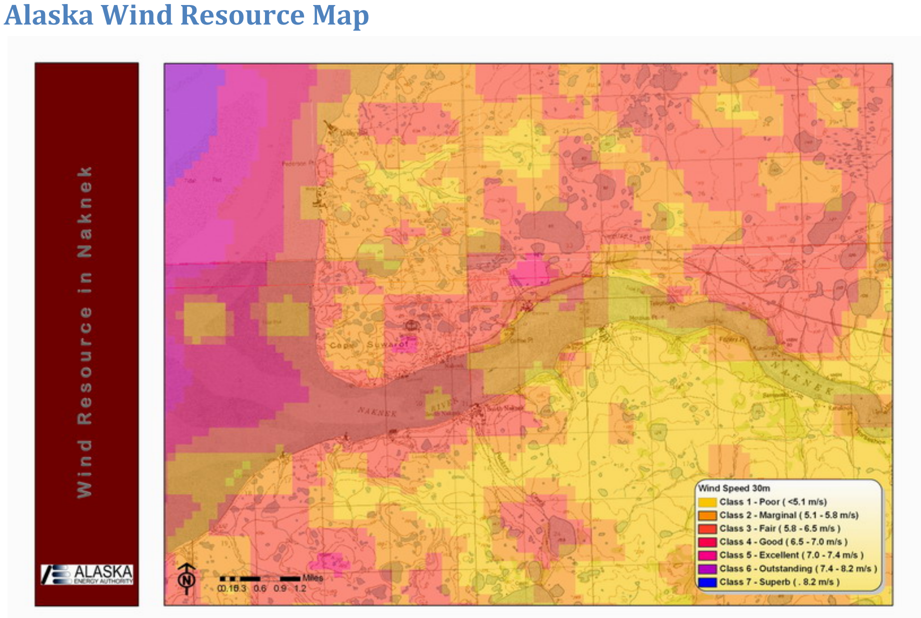
Summary Information

The wind resource at proposed Cape Suwarof wind power site in Naknek shows very good potential for wind energy development as a high Class 4 (near Class 5) wind power class resource with excellent turbulence behavior. Note that the measured wind power class is higher than predicted by the Alaska Wind Resource Map (see below) which forecast a Class 3 resource at the test site.

Test Site Location



Alaska Wind Resource Map



Meteorological Tower Data Synopsis

Wind power class	(High) Class 4 – Good
Wind speed annual average (30 meters)	6.73 m/s
Maximum ten-minute average wind speed	28.2 m/s
Maximum two second wind gust	37.1 m/s
Wind power density (50 meters)	468 W/m^2 (projected)
Wind power density (30 meters)	395 W/m^2 (measured)
IEC 61400-1 3rd edition classification	Class III C-
Weibull distribution parameters	k = 1.93, c = 7.59 m/s
Surface roughness	.0096 m (rough pasture)
Power law exponent	0.128 (moderate wind shear)
1-hr autocorrelation coefficient	0.921
Diurnal pattern strength	0.060
Hour of peak wind speed	18
Frequency of calms (4 m/s threshold)	24%
Mean turbulence intensity (30 meters)	0.104 (excellent)
Data start date	July 20, 2006
Data end date	July 7, 2009

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	ESE
2	NRG #40 anemometer	30 m	0.765	0.35	NNW
3	NRG #40 anemometer	20 m	0.765	0.35	ESE
7	NRG #200P wind vane (up to 9/18/07)	30 m	0.351	110	290° T
8	NRG #200P wind vane (after 10/18/07)	28 m	0.351	205	025° T
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

General Site Information

Site number	3398
Site Description	Site west of the city of Naknek at Cape Suwarof, on a sloping bluff above Naknek Bay
Latitude/longitude	N 58° 43.709’ W 157° 03.496’, WGS 84
Site elevation	30 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter

Measured Wind Speeds

The 30 meter anemometer annual wind speed averages (anemometer A and B) are 6.72 and 6.70 m/s. The 20 meter anemometer annual average wind speed is 6.35 m/s. The maximum recorded wind gust was 37.1 m/s recorded in January, 2009.

	30 m A speed					30 m B speed		20 m speed	
Month	Mean (m/s)	Max 10 min. (m/s)	Max gust (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max gust (m/s)	Mean (m/s)	Max gust (m/s)
Jan	7.28	28.2	36.7	1.93	8.22	7.24	37.1	6.73	35.5
Feb	7.53	22.4	28.7	2.18	8.48	7.47	29.1	7.08	28.3
Mar	7.71	23.2	27.1	2.00	8.71	7.71	27.5	7.35	26.0
Apr	7.19	21.3	27.5	1.89	8.09	7.07	27.9	6.85	27.1
May	6.08	26.6	33.6	1.93	6.86	6.14	34.4	5.91	33.6
Jun	5.58	20.5	27.5	2.11	6.30	5.54	28.3	5.36	27.5
Jul	5.98	17.4	22.1	1.99	6.74	5.87	22.9	5.66	21.4

Aug	5.76	19.3	24.0	1.91	6.50	5.77	23.7	5.47	24.0
Sep	6.03	20.3	26.3	1.89	6.79	5.97	27.1	5.72	25.6
Oct	6.93	25.9	33.6	2.12	7.81	6.89	33.6	6.53	32.4
Nov	7.55	20.9	27.9	1.99	8.50	7.60	27.9	7.09	26.8
Dec	7.44	22.6	28.7	1.97	8.38	7.45	29.1	6.95	28.7
Annual	**6.75**	**28.2**	**36.7**	1.93	7.59	6.72	**37.1**	6.39	35.5

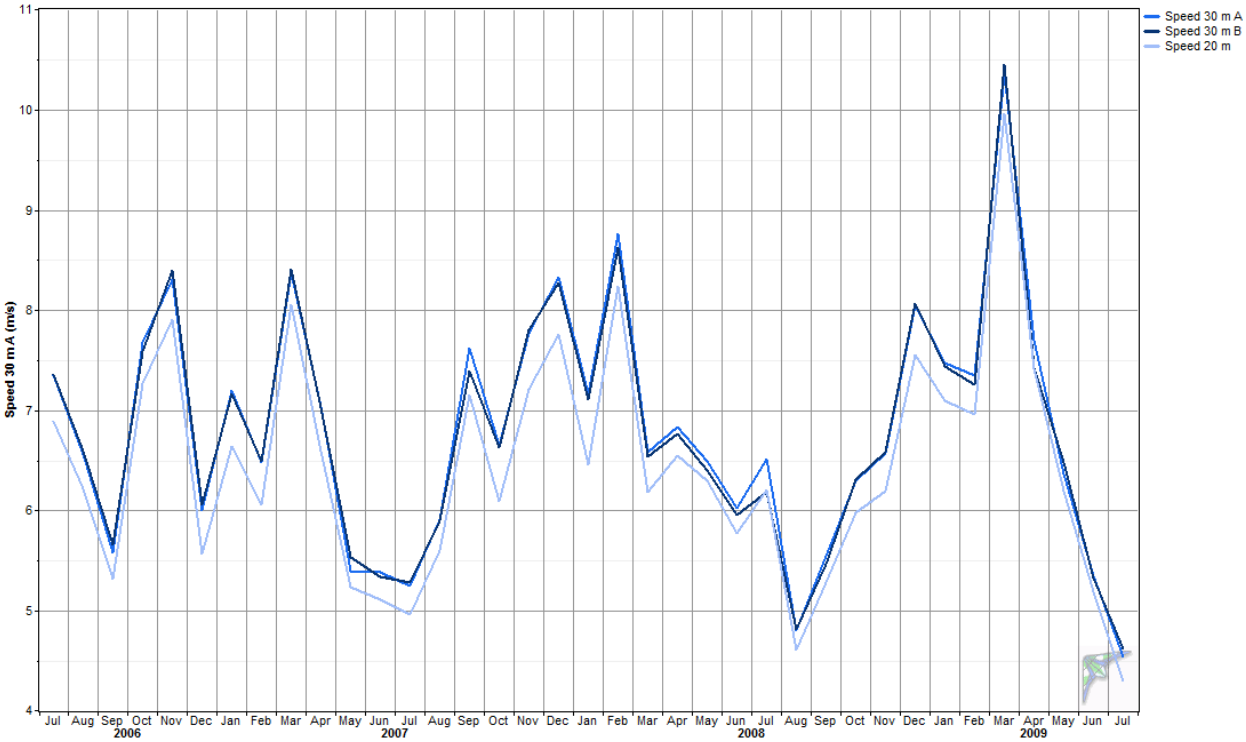
Note: max gust is a two second time average wind speed measurement

Wind Speed Sensor Summary

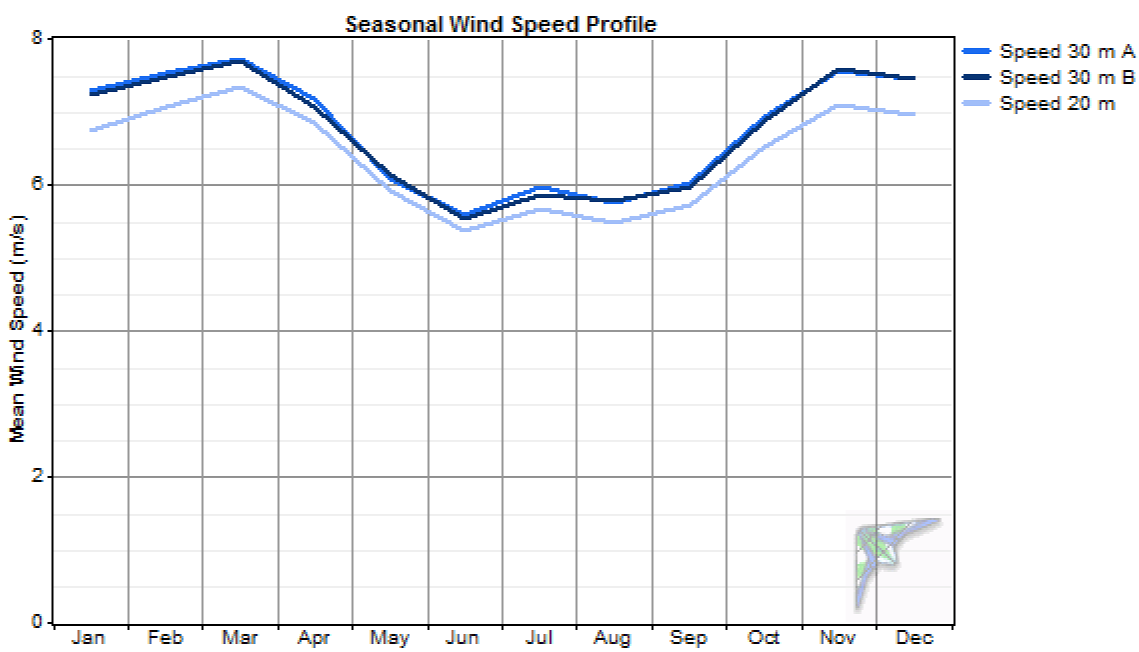
Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30.0	30.0	20.0
Mean wind speed (m/s)	6.73	6.70	6.37
MMM wind speed (m/s)	6.75	6.72	6.39
Median wind speed (m/s)	6.2	6.1	5.8
Min wind speed (m/s)	0.4	0.4	0.4
Max wind speed (m/s)	28.2	28.5	27.0
Weibull k	1.93	1.96	1.93
Weibull c (m/s)	7.59	7.56	7.19
Mean power density (W/m²)	392	383	336
MMM power density (W/m²)	395	386	338
Mean energy content (kWh/m²/yr)	3,434	3,355	2,940
MMM energy content (kWh/m²/yr)	3,460	3,382	2,960
Energy pattern factor	2.0	2.0	2.0
Frequency of calms (%)	24.5	24.3	27.9
1-hr autocorrelation coefficient	0.921	0.92	0.922
Diurnal pattern strength	0.060	0.060	0.063
Hour of peak wind speed	18	18	17

MMM = mean of monthly means

Monthly Time Series of Wind Speed

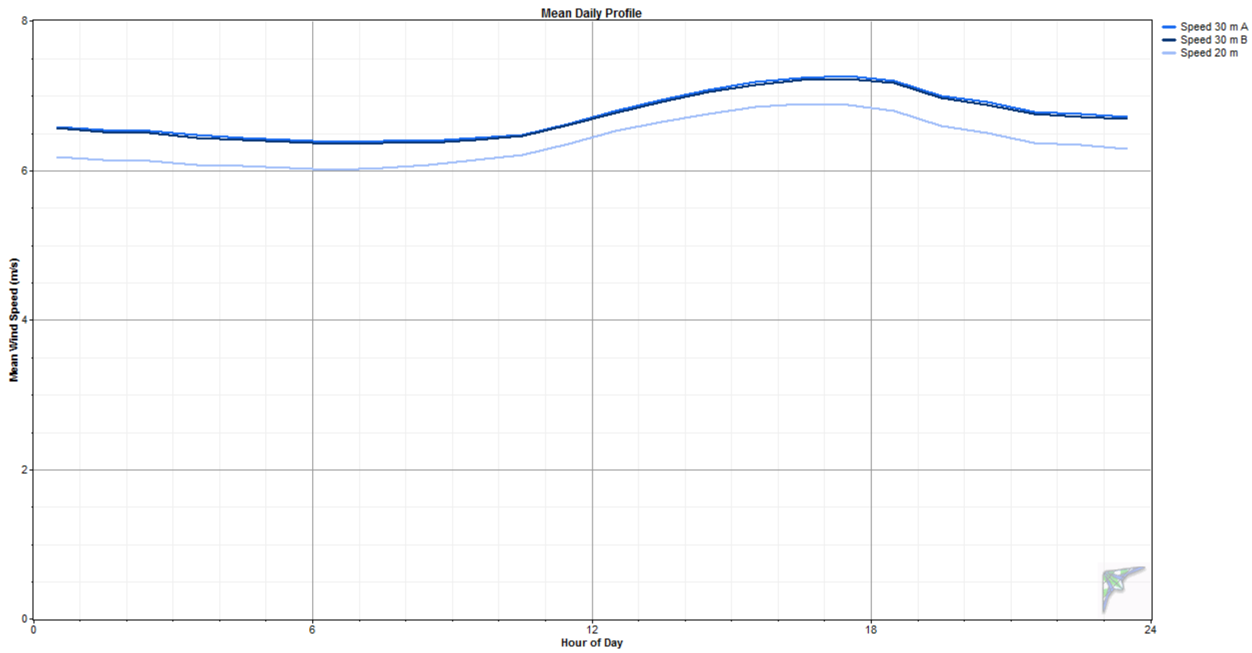


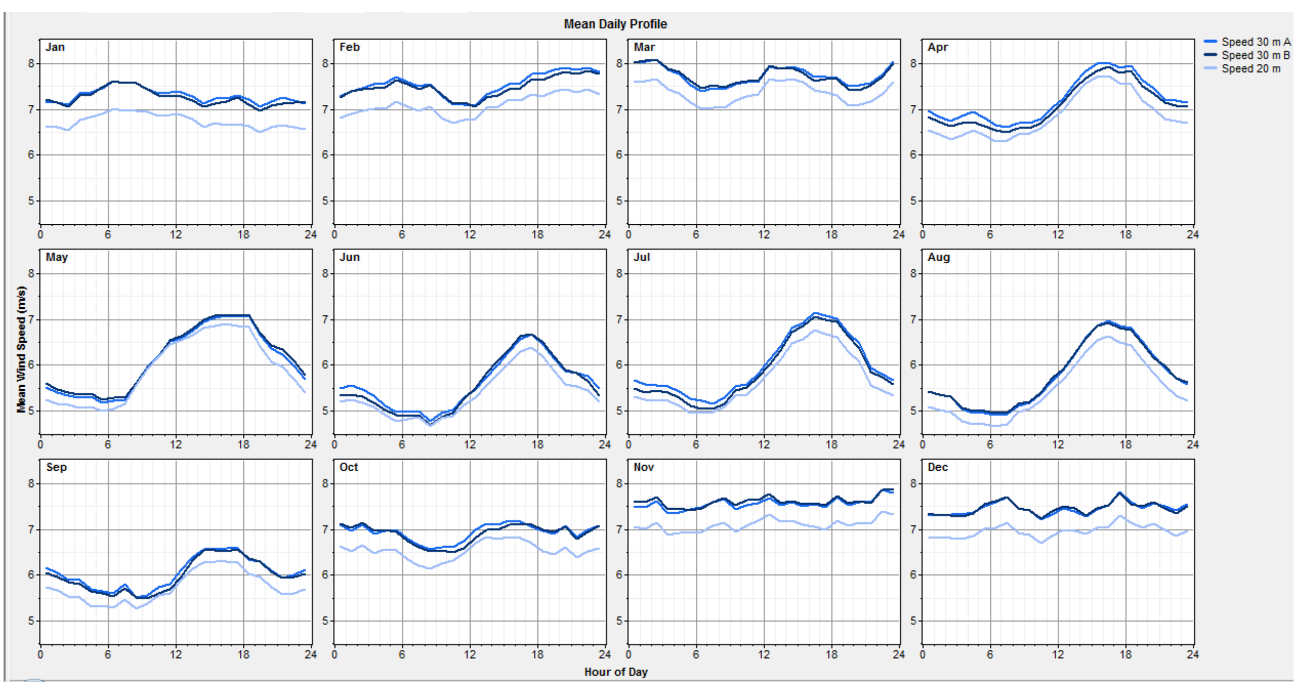
Seasonal Wind Profile



Daily Wind Profile

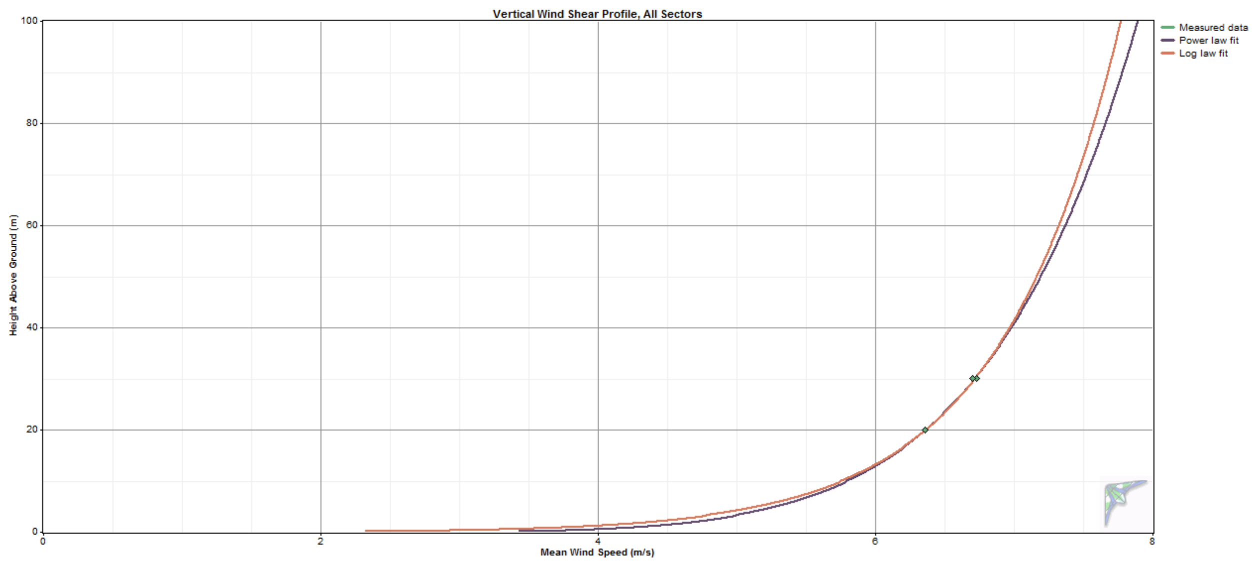
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 4 to 7 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 3 to 6 p.m. The daily variation of wind speed is minimal on an annual basis but more pronounced on a monthly basis.

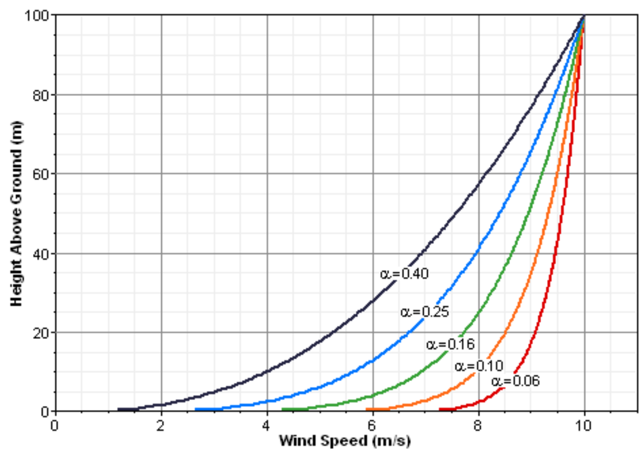




Wind Shear

The power law exponent was calculated at 0.128 with wind speeds filtered to include only those greater than 4 m/s, the cut-in speed for most turbines, indicating moderately low wind shear at the Cape Suwarof met tower site. The practical application of this data is that a higher turbine tower height may be desirable as there will be a worthwhile marginal gain in wind speed and hence power recovery with additional height. A tower height/power recovery/construction cost tradeoff study is advisable.



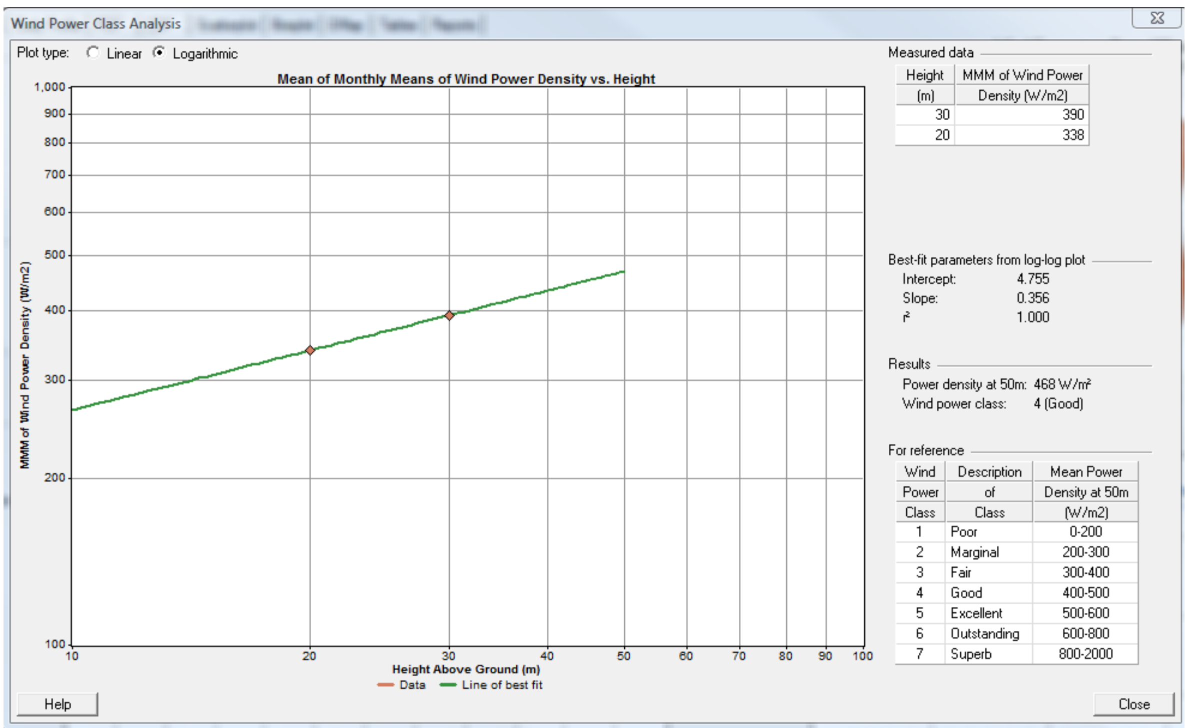


Wind Power Density

Another view of wind shear is wind power density by height above ground level. 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 multiplying ½ times the air density times the wind speed cubed for each time step. The equation is P/A = ½*ρ*U^3. The time step values are averaged to produce an overall wind power density.

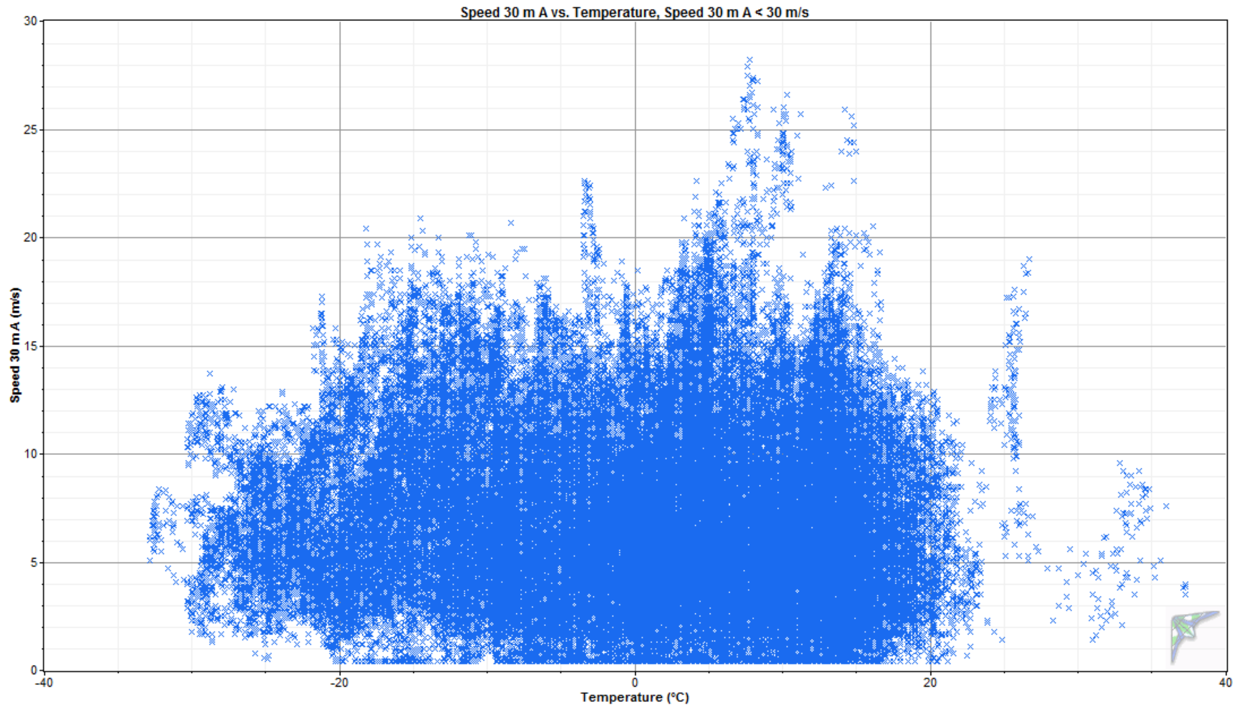
The wind power density at 50 meters elevation is a wind industry standard method of comparing and evaluating sites. If the anemometer measurement heights are at other than 50 meters, the wind analysis software uses the power law exponent derived from the two (or more) measurement heights to extrapolate up or down.

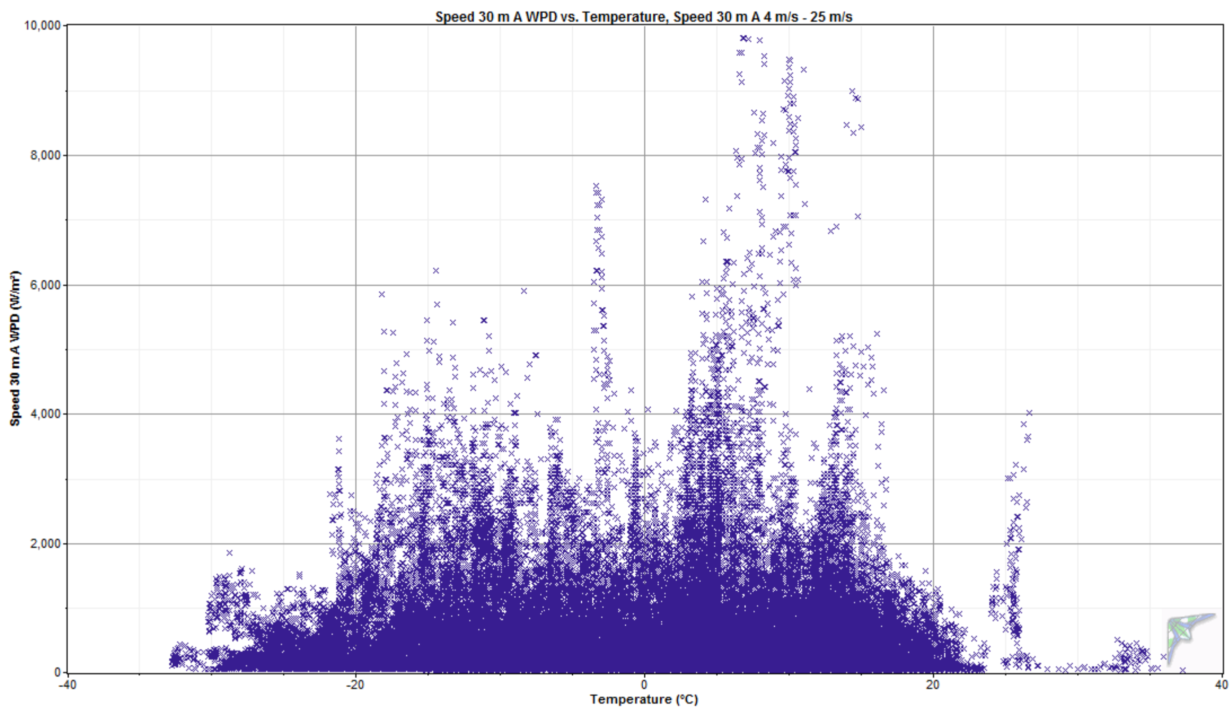
As can be seen in the figure below, power density and hence potential turbine power production increases substantially with turbine hub height at Naknek's Cape Suwarof, as is true at most sites. Note that the measured power densities in the figure below differ from those reported in the data summary table on page 2 of this report. The figure below uses all collected data (July 2006 through July 2009) while in the summary table these data are presented as annual averages.



An observation of some interest is to compare by scatter plot the power density and, separately, the mean wind speed to temperature. As one can see below, the power producing winds (winds greater than 4 m/s, the typical wind turbine cut-in speed) are present through all temperature ranges, even as low as -30° C. For this reason, it will be important that a turbine for Naknek is capable of cold climate operation, with a minimum operating temperature at least -30° C.

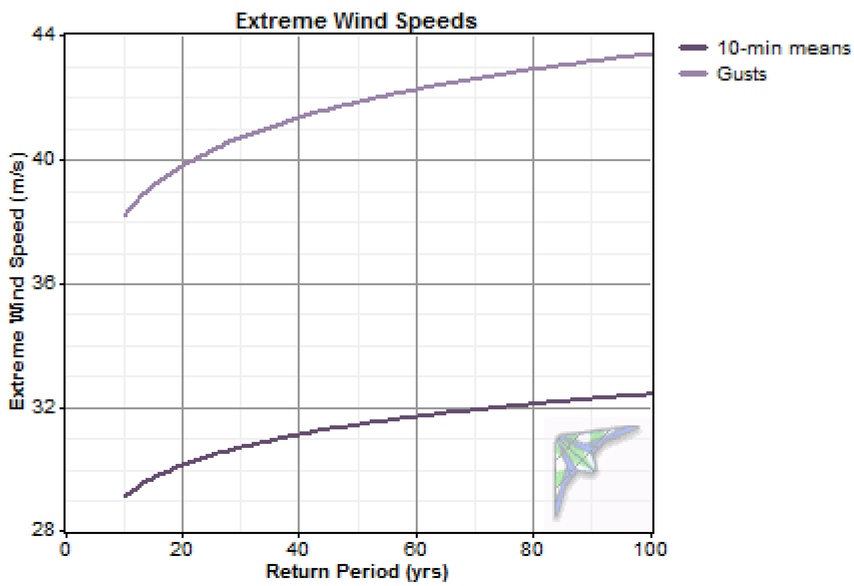
Scatterplots





Extreme Wind Analysis

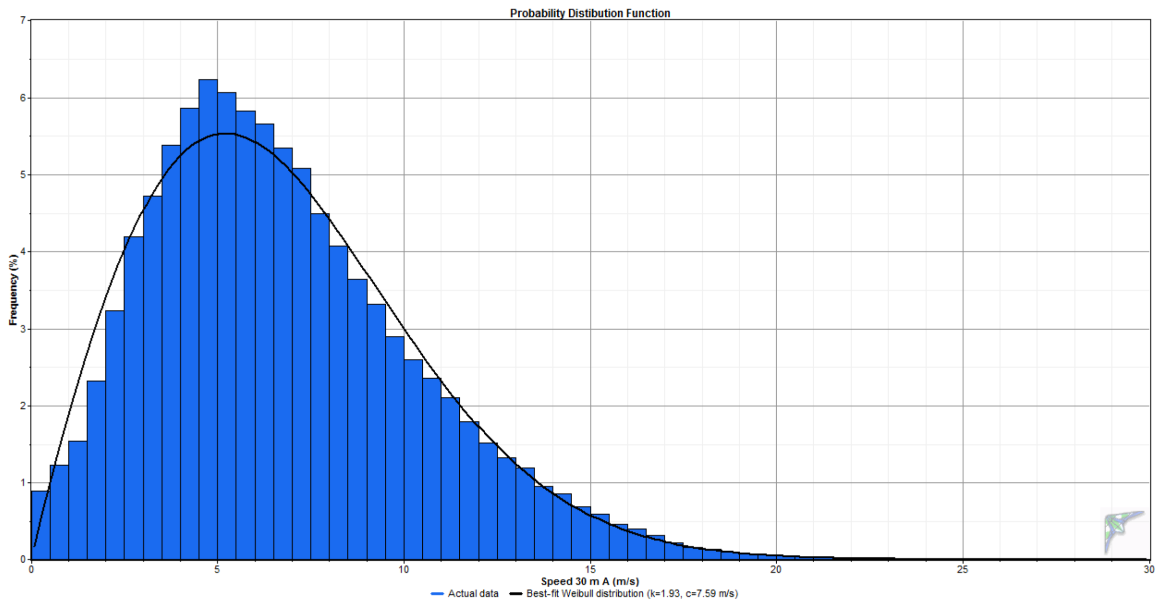
Using a Gumbel distribution, one can predict the probability of winds exceeded a certain value within a defined period of time. Another way to consider the analysis though is by the concept of return period. In other words, in a defined period of time, typically 50 years, one can determine the maximum wind speed likely to occur. This is important when selecting a wind turbine as manufacturers classify their turbines by IEC standards of Class (see IEC 61400-1, edition 3). At the Naknek test site, using data collected to date, the maximum predicted 50 year wind speed (ten minute average) at 30 meters is 31.4 m/s while the maximum predicted 50 year wind gust (two second average) at 30 meters is 41.8 m/s. This qualifies the site as IEC (International Electrotechnical Commission) Class III, the lowest and most common extreme wind designation. Note below for reference the graph of the return period for 10-minute average wind speed.

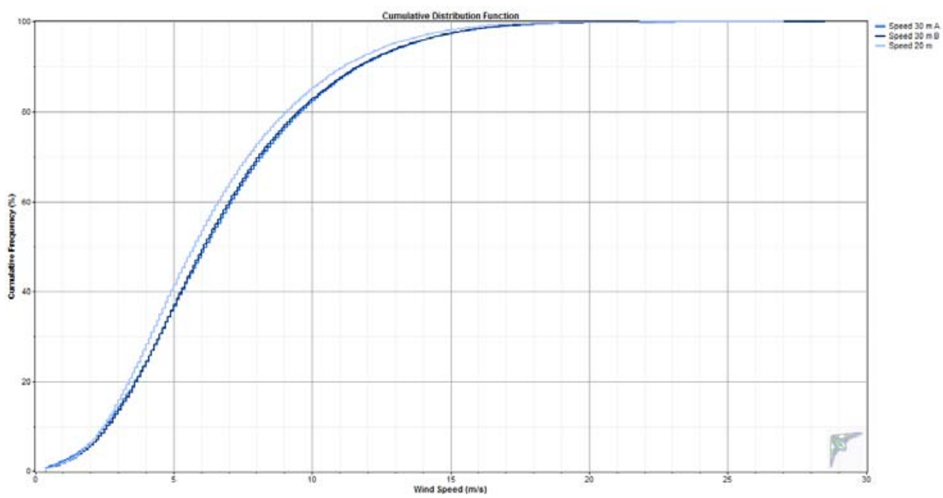


Probability Distribution Function

The probability distribution function provides a visual indication of measured wind speeds in one meter per second "bins". Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s, known as the "cut-in" wind speed. The black line in the graph is a best fit Weibull distribution. At the 30 meter level, Weibull parameters are k = 1.93 and c = 7.59 m/s ("k" is the shape factor and "c" is the scale factor) for the data period. This shape factor is indicative of a normal wind distribution for wind power sites.

The PDF information is shown visually in another manner in the second graph, the Cumulative Distribution Function. In this view, one can see that about 25 percent of winds (at 30 meters) are less than 4 m/s, the standard cut-in speed of most turbines and essentially 100 percent of the winds are less than 25 m/s, the standard high wind cut-out speed for most turbines.



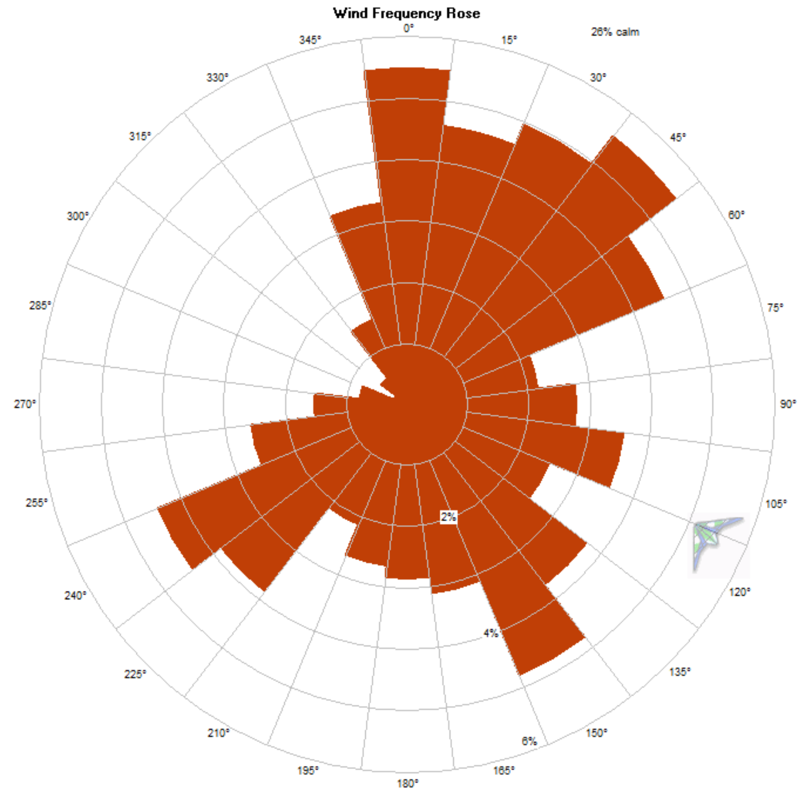


Wind Roses

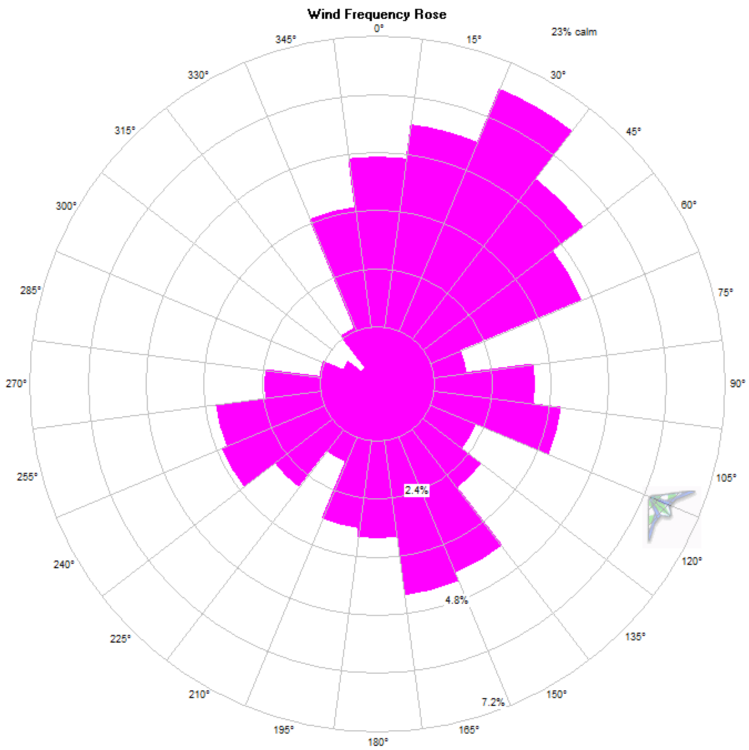
Naknek winds are multi-directional with the wind frequency rose indicating frequent north, northeast, southeast and southwest winds. This observation is reinforced with reference to the mean value and total value power density roses below. Power producing winds are chiefly north-northeast and south-east with secondary power winds from the east and west. The practical application of this information is that a site should be selected with adequate freedom from ground interference to the north-northeast and southeast directions and if more than one turbine is installed, the turbines should be adequately spaced apart to prevent downwind shadowing and turbulence problems between the turbines.

Note also that a wind threshold of 4 m/s was selected for the definition of calm winds. This wind speed represents the cut-in wind speed of most wind turbines. By this definition, Naknek experienced approximately 25 percent calm conditions during the measurement period (see wind frequency roses below).

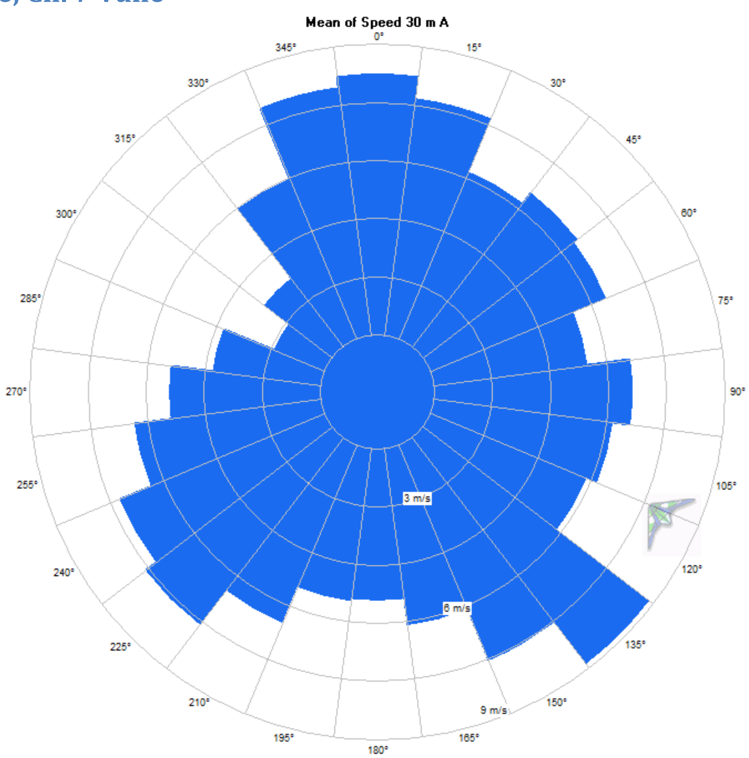
Wind Frequency Rose, Ch. 7 Vane



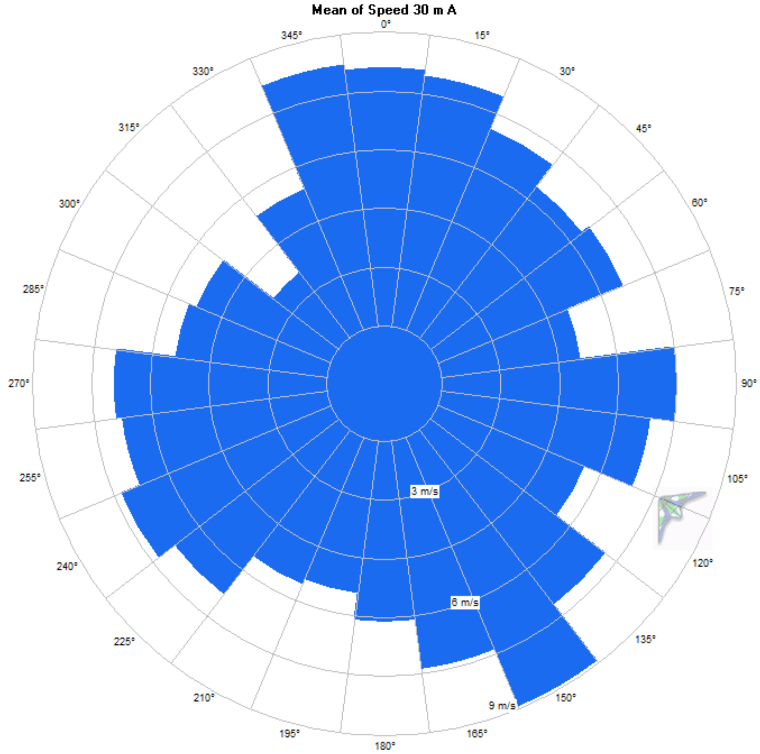
Wind Frequency Rose, Ch. 8 Vane



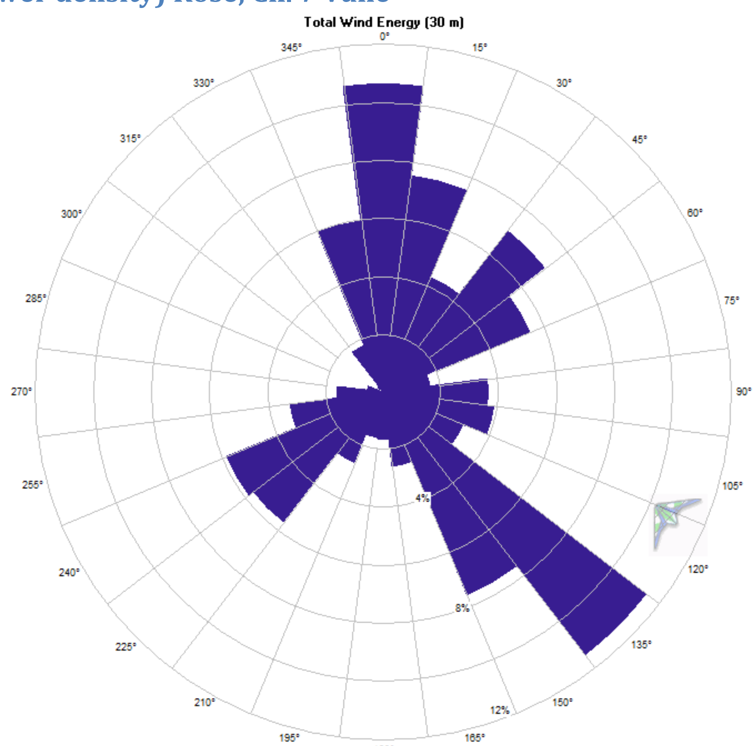
Mean Value Rose, Ch. 7 Vane



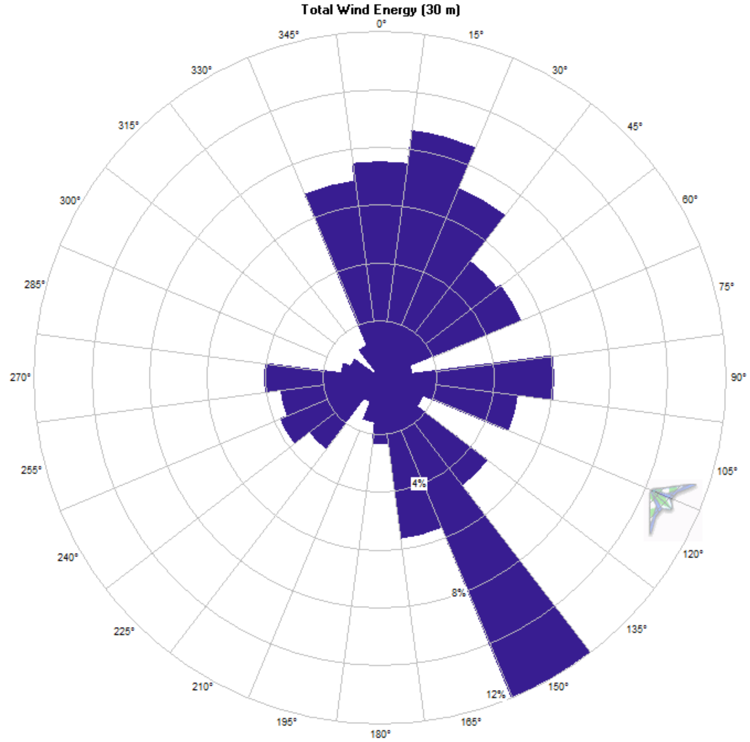
Mean Value Rose, Ch. 8 Vane



Total Value (power density) Rose, Ch. 7 Vane



Total Value (power density) Rose, Ch. 8 Vane



Turbulence Intensity

The turbulence intensity is acceptable with a mean turbulence intensity of 0.104 and a representative turbulence intensity of 0.130 at 15 m/s wind speed, indicating quite smooth air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 3rd Edition (2005) turbulence category C, which is the lowest defined category.

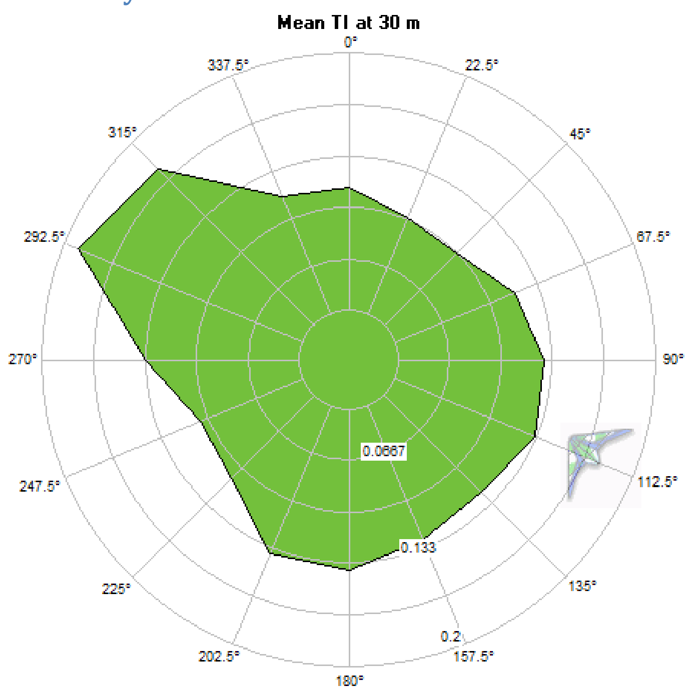
Turbulence Table

Turbulence Intensity (TI) Table, 30 m A speed, 7/20/06 to 7/07/09

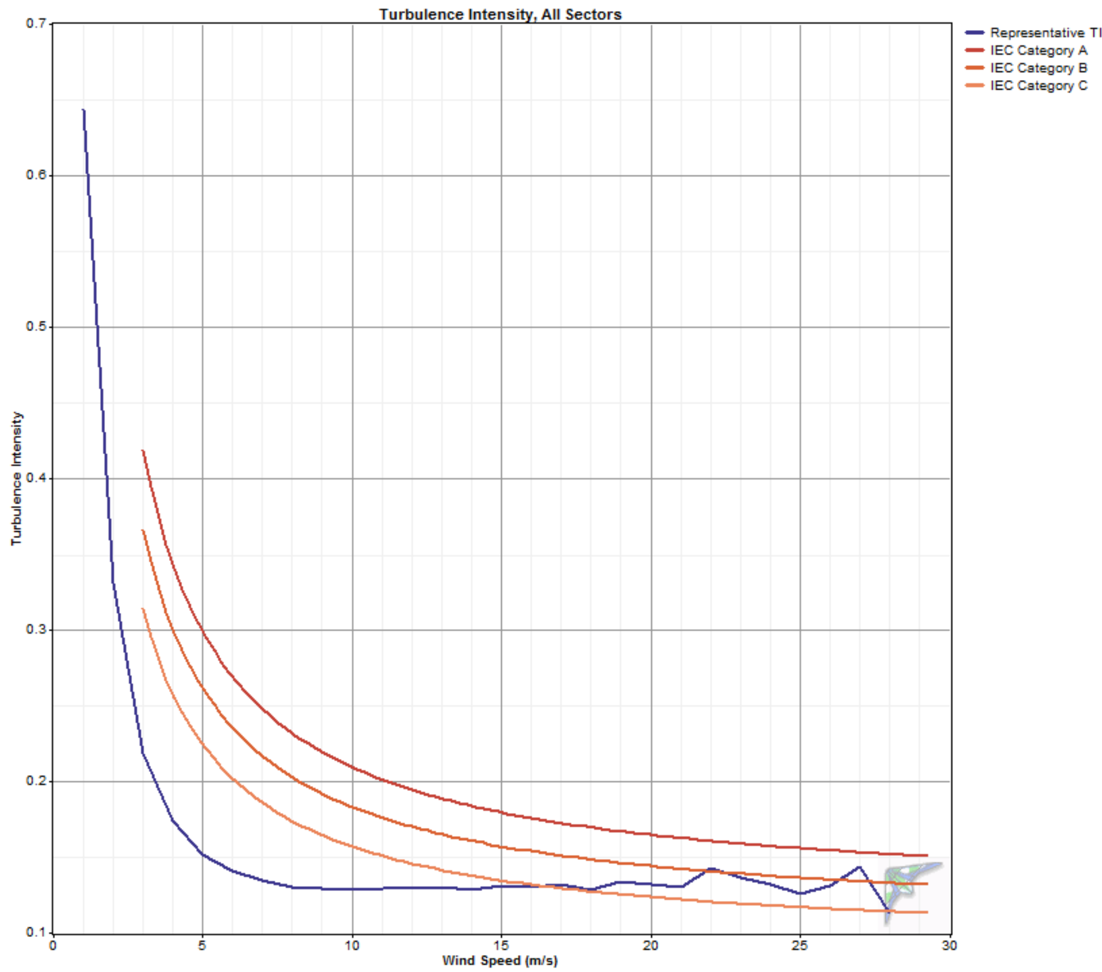
Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records In Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	0.5	1.5	3,877	0.430	0.165	0.641	1.444
2	1.5	2.5	7,857	0.208	0.098	0.333	1.000
3	2.5	3.5	13,039	0.142	0.060	0.218	0.697
4	3.5	4.5	16,514	0.116	0.046	0.175	0.667
5	4.5	5.5	18,032	0.104	0.038	0.153	0.574
6	5.5	6.5	16,859	0.098	0.034	0.142	0.419
7	6.5	7.5	15,038	0.096	0.031	0.135	0.370
8	7.5	8.5	12,479	0.095	0.028	0.131	0.383

9	8.5	9.5	10,039	0.096	0.026	0.130	0.348
10	9.5	10.5	7,991	0.097	0.025	0.128	0.284
11	10.5	11.5	6,377	0.099	0.023	0.129	0.292
12	11.5	12.5	4,669	0.100	0.022	0.129	0.269
13	12.5	13.5	3,553	0.102	0.022	0.130	0.267
14	13.5	14.5	2,573	0.102	0.021	0.128	0.209
15	14.5	15.5	1,816	0.104	0.021	0.130	0.203
16	15.5	16.5	1,233	0.105	0.020	0.131	0.226
17	16.5	17.5	792	0.106	0.019	0.131	0.237
18	17.5	18.5	485	0.105	0.018	0.127	0.171
19	18.5	19.5	277	0.106	0.020	0.132	0.205
20	19.5	20.5	196	0.105	0.019	0.129	0.159
21	20.5	21.5	103	0.105	0.017	0.127	0.168
22	21.5	22.5	55	0.106	0.024	0.138	0.193
23	22.5	23.5	35	0.111	0.019	0.136	0.147
24	23.5	24.5	34	0.113	0.015	0.132	0.148
25	24.5	25.5	25	0.112	0.011	0.126	0.135
26	25.5	26.5	19	0.114	0.014	0.132	0.141
27	26.5	27.5	9	0.124	0.016	0.144	0.151
28	27.5	28.5	3	0.107	0.005	0.113	0.113
29	28.5	29.5	-				

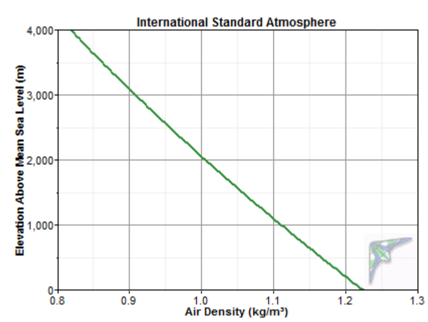
30-meter Turbulence Intensity Rose



IEC 3rd Edition Turbulence Category Graph



Air Temperature and Density



During the study period, the Cape Suwarof test site recorded an average temperature of 2.2° C. The minimum recorded temperature during the measurement period was -32.8° C and the maximum temperature was 29.0° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations.

Consequent to Naknek's cool temperatures, the average air density of 1.274 kg/m^3 is over four percent higher than the standard air density of 1.222 kg/m^3 (14.8° C and 100.9 kPa standard temperature and pressure at 30 m elevation), indicating that Naknek has denser air than the standard air density used to calculate turbine power curves (note that all turbine power curves are calculate at a sea level standard of 15° C and 101.3 kPa pressure).

Month	Temperature Mean (°C)	Temperature Min (°C)	Temperature Max (°C)	Air Density Mean (kg/m³)	Air Density Min (kg/m³)	Air Density Max (kg/m³)
Jan	-10.4	-32.8	11.4	1.330	1.221	1.463
Feb	-8.3	-29.1	8.8	1.318	1.221	1.441
Mar	-7.4	-22.5	8.0	1.296	1.221	1.403
Apr	1.7	-14.2	15.9	1.280	1.217	1.358
May	7.7	-2.9	21.7	1.252	1.193	1.301
Jun	11.1	2.3	29.0	1.236	1.164	1.277
Jul	13.3	6.6	24.9	1.227	1.180	1.257
Aug	13.9	4.8	23.4	1.225	1.186	1.265
Sep	11.1	1.7	20.4	1.235	1.198	1.279
Oct	2.9	-16.6	15.0	1.264	1.220	1.371
Nov	-4.3	-23.4	10.6	1.309	1.239	1.408
Dec	-6.1	-25.5	9.7	1.318	1.243	1.420
Annual	**2.2**	-32.8	29.0	**1.274**	1.164	1.463

Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 3 °C. Other obvious icing event data not meeting these criteria were filtered manually.

Note that the met tower collapsed on September 18, 2007 due to a guy wire anchor that failed. Fortunately, the tower fell straight over and sustained only minor damage. On October 18, 2007, the met tower was reinstalled at the same location with new sensors. The new wind vane was connected to Channel 8 because of anomaly with Channel 7 after the tower collapse.

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 m A	m/s	30 m	155,952	145,266	93.2
Speed 30 m A SD	m/s		155,952	145,266	93.2
Speed 30 m A Max	m/s		155,952	147,367	94.5
Speed 30 m A Min	m/s		155,952	147,367	94.5
Speed 30 m B	m/s	30 m	155,952	145,189	93.1
Speed 30 m B SD	m/s		155,952	145,189	93.1
Speed 30 m B Max	m/s		155,952	147,367	94.5
Speed 30 m B Min	m/s		155,952	147,367	94.5
Speed 20 m	m/s	20 m	155,952	145,680	93.4
Speed 20 m SD	m/s		155,952	145,680	93.4
Speed 20 m Max	m/s		155,952	147,367	94.5

Speed 20 m Min	m/s		155,952	147,367	94.5
Direction 30 m	°	30 m	155,952	62,963	40.4
Direction 30 m SD	°		155,952	62,963	40.4
Direction 30 m Max	°		155,952	63,940	41.0
Direction 30 m Min	°		155,952	63,940	41.0
Direction 28 m	°	28 m	155,952	85,003	54.5
Direction 28 m SD	°		155,952	81,767	52.4
Direction 28 m Max	°		155,952	85,279	54.7
Direction 28 m Min	°		155,952	92,419	59.3
Temperature	°C		155,952	143,756	92.2
Temperature SD	°C		155,952	143,772	92.2
Temperature Max	°C		155,952	143,301	91.9
Temperature Min	°C		155,952	143,748	92.2