Shaktoolik, Alaska Wind Resource Report

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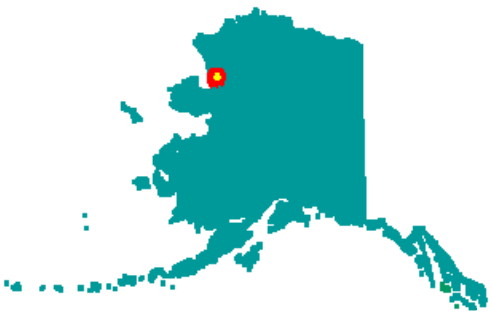
Date of Report: November 3, 2008

Photo © Doug Vaught



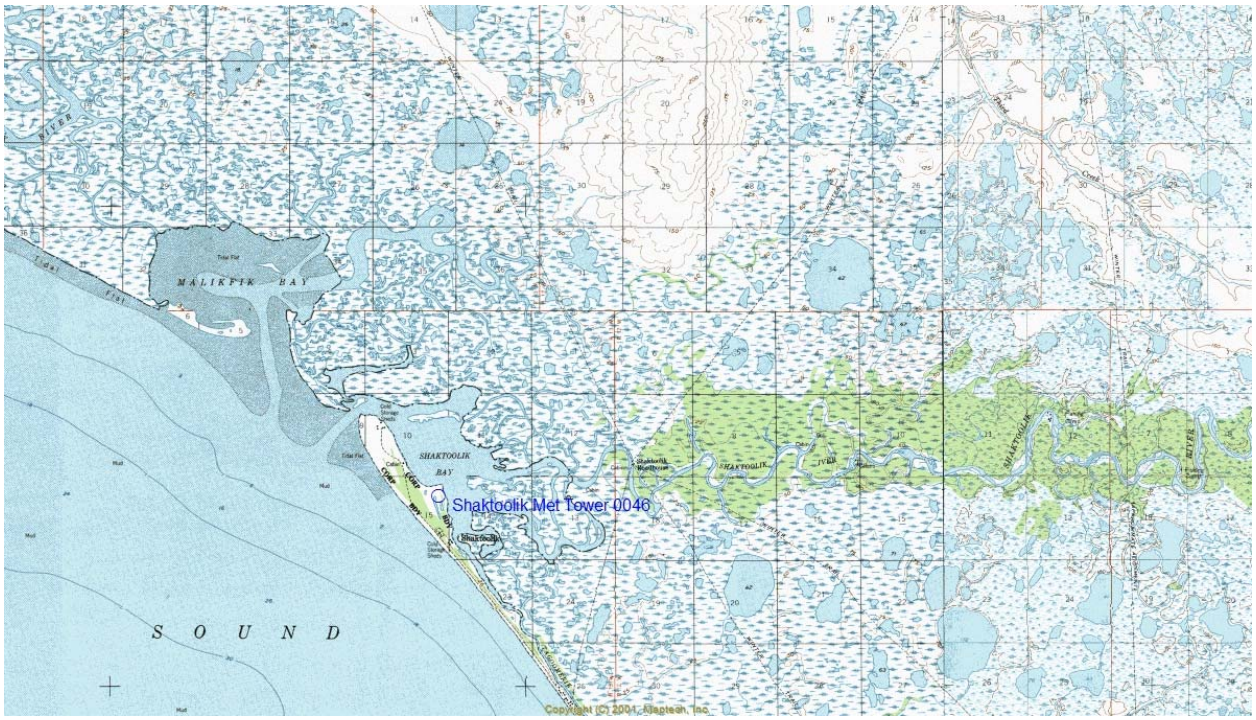
Summary Information

The wind resource in Shaktoolik shows very good potential for wind energy development as a high Class 4 (near Class 5) wind power class resource with excellent turbulence behavior.

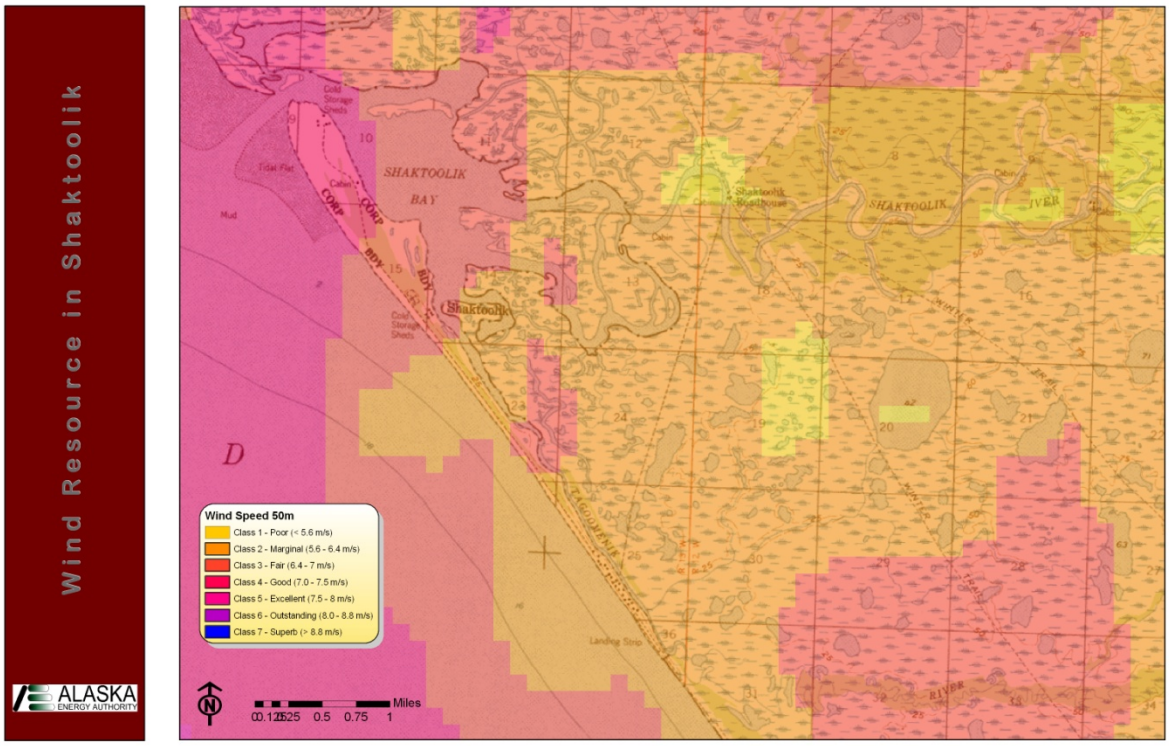
Meteorological Tower Data Synopsis

Wind power class	(High) Class 4 – Good
Wind speed annual average (30 meters)	6.38 m/s
Maximum two second wind gust	30.2 m/s (January 2008)
Wind power density (50 meters)	461 W/m^2 (projected)
Wind power density (30 meters)	370 W/m^2
Weibull distribution parameters	k = 1.85, c = 6.95 m/s
Roughness Class	1.94 (few trees)
Power law exponent	0.143 (moderately low wind shear)
Frequency of calms (4 m/s threshold)	32%
Representative turbulence intensity	0.097 (very low)
IEC61400-1 3rd ed. extreme wind	Class III
IEC61400-1 3rd ed. turbulence	Class C-
Data start date	July 4, 2007
Data end date	July 22, 2008

Test Site Location



Alaska Wind Resource Map



Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	355° T
2	NRG #40 anemometer	30 m	0.765	0.35	270° T
3	NRG #40 anemometer	20 m	0.765	0.35	355° T
7	NRG #200P wind vane	30 m	0.351	265	085° T
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

General Site Information

Site number	0046
Site Description	On the north end of the village's old runway
Latitude/longitude	N 64° 21.921' W 161° 12.186', WGS 84
Site elevation (ASL)	2 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter

Community Profile

Current Population: 214 (2007 DCCED Certified Population)
Pronunciation/Other Names: (shack-TOO-lick)
Incorporation Type: 2nd Class City
Borough Located In: Unorganized
School District: Bering Straits Schools
Regional Native Corporation: Bering Straits Native Corp.

Location

Shaktoolik is located on the east shore of Norton Sound. It lies 125 miles east of Nome and 33 miles north of Unalakleet. The area encompasses 1.1 sq. miles of land and 0.0 sq. miles of water.

History

Shaktoolik was the first and southernmost Malemiut settlement on Norton Sound, occupied as early as 1839. Twelve miles northeast, on Cape Denbigh, is "Iyatayet," a site that is 6,000 to 8,000 years old. Reindeer herds were managed in the Shaktoolik area around 1905. The village was originally located six miles up the Shaktoolik River, and moved to the mouth of the River in 1933. This site was prone to severe storms and winds, however, and the village relocated to its present, more sheltered location in 1967. The City was incorporated in 1969.

Culture

It is a Malemiut Eskimo village with a fishing and subsistence lifestyle. The sale or importation of alcohol is banned in the village.

Economy

The Shaktoolik economy is based on subsistence, supplemented by part-time wage earnings. Thirty-three residents hold commercial fishing permits. Development of a new fish processing facility is a village priority. Reindeer herding also provides income and meat. Fish, crab, moose, beluga whale, caribou, seal, rabbit, geese, cranes, ducks, ptarmigan, berries, greens and roots are also primary food sources.

Facilities

Water is pumped three miles from the Togoomenik River to the pumphouse, where it is treated and stored in a 848,000-gallon insulated tank adjacent to the washeteria. A piped water and sewage collection system serves most homes. Seventy-five percent of households have complete plumbing and kitchen facilities. The school is connected to City water, and has received funding to develop a sewage treatment system to serve the entire community. The City burns refuse in an incinerator. The landfill needs to be relocated as the current site is not permitted.

Transportation

Shaktoolik is primarily accessible by air and sea. A State-owned 4,000' long by 75' wide gravel airstrip is available. The Alex Sookiayak Memorial Airstrip allows for regular service from Nome. Summer travel is by 4-wheel ATV, motorbike, truck and boat; winter travel is by snowmachine and dog team. Cargo is barged to Nome, and then lightered to shore. The community has no docking facilities.

Climate

Shaktoolik has a subarctic climate with maritime influences when Norton Sound is ice-free, usually from May to October. Summer temperatures average 47 to 62 F; winter temperatures average -4 to 11 F. Extremes from -50 to 87 F have been recorded. Average annual precipitation is 14 inches, including 43 inches of snowfall.

(Above information from State of Alaska Department of Commerce, Community, and Economic Development website, www.dced.state.ak.us)

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 also removed. In general, data recovery from the Shaktoolik met tower was excellent with no significant icing events during the one year data collection period.

		Ch 1, 30m A		Ch 2, 30 m B		Ch 3, 20 m	
Year	Month	Records	Recovery Rate, %	Records	Recovery Rate, %	Records	Recovery Rate, %
2007	Jul	4,032	100.0	4,032	100.0	4,032	100.0
2007	Aug	4,464	100.0	4,464	100.0	4,464	100.0
2007	Sep	4,320	100.0	4,320	100.0	4,320	100.0
2007	Oct	4,464	100.0	4,464	100.0	4,464	100.0
2007	Nov	3,987	92.3	3,987	92.3	3,823	88.5
2007	Dec	4,464	100.0	4,464	100.0	4,464	100.0
2008	Jan	4,464	100.0	4,464	100.0	4,464	100.0
2008	Feb	4,176	100.0	4,176	100.0	4,176	100.0
2008	Mar	4,427	99.2	4,464	100.0	4,427	99.2
2008	Apr	4,320	100.0	4,320	100.0	4,320	100.0
2008	May	4,464	100.0	4,464	100.0	4,464	100.0
2008	Jun	4,320	100.0	4,320	100.0	4,320	100.0
2008	Jul	3,078	100.0	3,078	100.0	3,078	100.0
All data		54,980	99.3	55,017	99.4	54,816	99.0

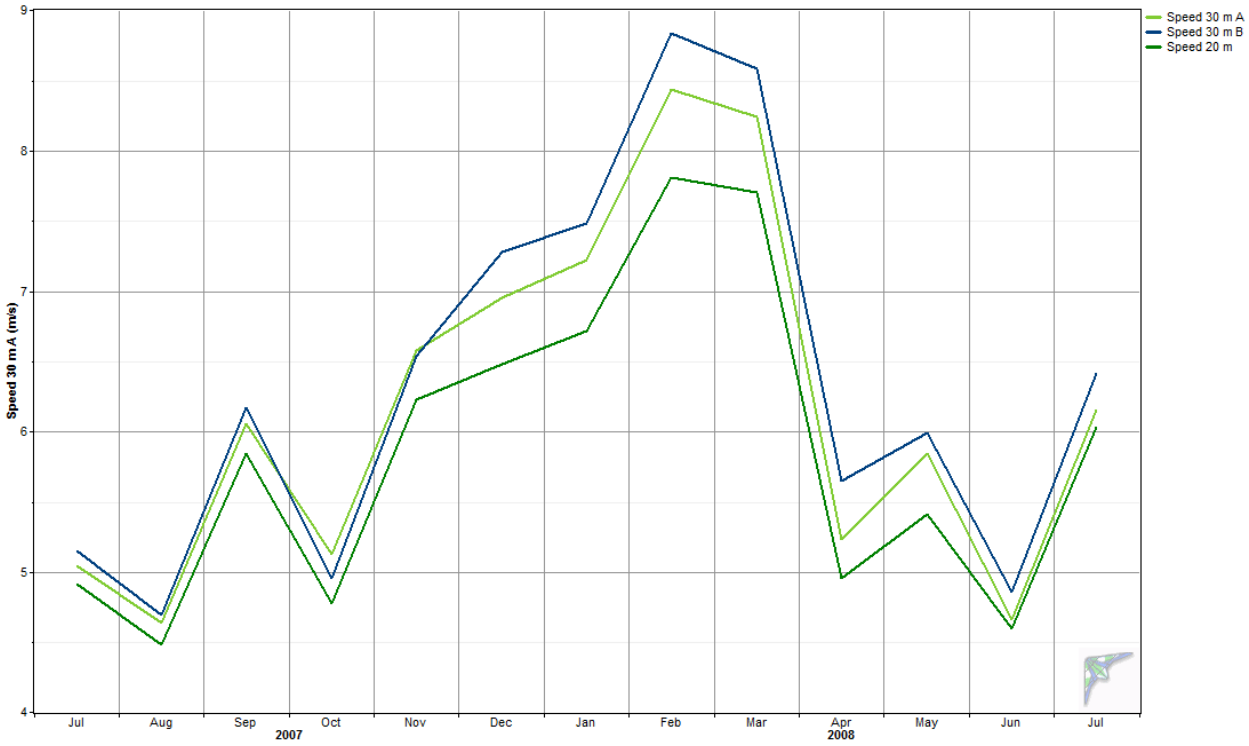
		Ch 7, vane		Ch 9, temperature	
Year	Month	Records	Recovery Rate, %	Records	Recovery Rate, %
2007	Jul	4,032	100.0	4,032	100.0
2007	Aug	4,464	100.0	4,464	100.0
2007	Sep	4,320	100.0	4,320	100.0
2007	Oct	4,464	100.0	4,464	100.0

2007	Nov	3,736	86.5	4,320	100.0
2007	Dec	4,319	96.8	4,464	100.0
2008	Jan	4,366	97.8	4,464	100.0
2008	Feb	3,925	94.0	4,176	100.0
2008	Mar	4,464	100.0	4,464	100.0
2008	Apr	4,320	100.0	4,320	100.0
2008	May	4,464	100.0	4,464	100.0
2008	Jun	4,320	100.0	4,320	100.0
2008	Jul	3,078	100.0	3,078	100.0
All data		54,272	98.1	55,350	100.0

Measured Wind Speeds

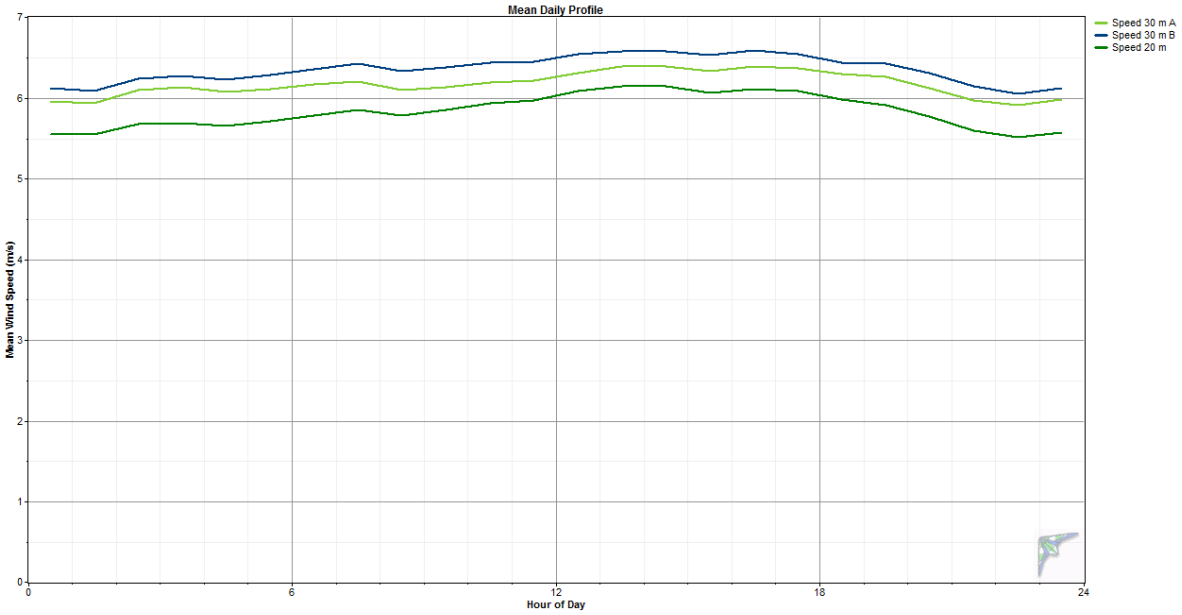
The 30 meter anemometer annual wind speed averages (anemometer A and B) for the reporting period are 6.21 and 6.39 m/s. The 20 meter anemometer annual average wind speed is 5.87 m/s. The maximum recorded wind gust was 30.2 m/s, recorded in January 2008.

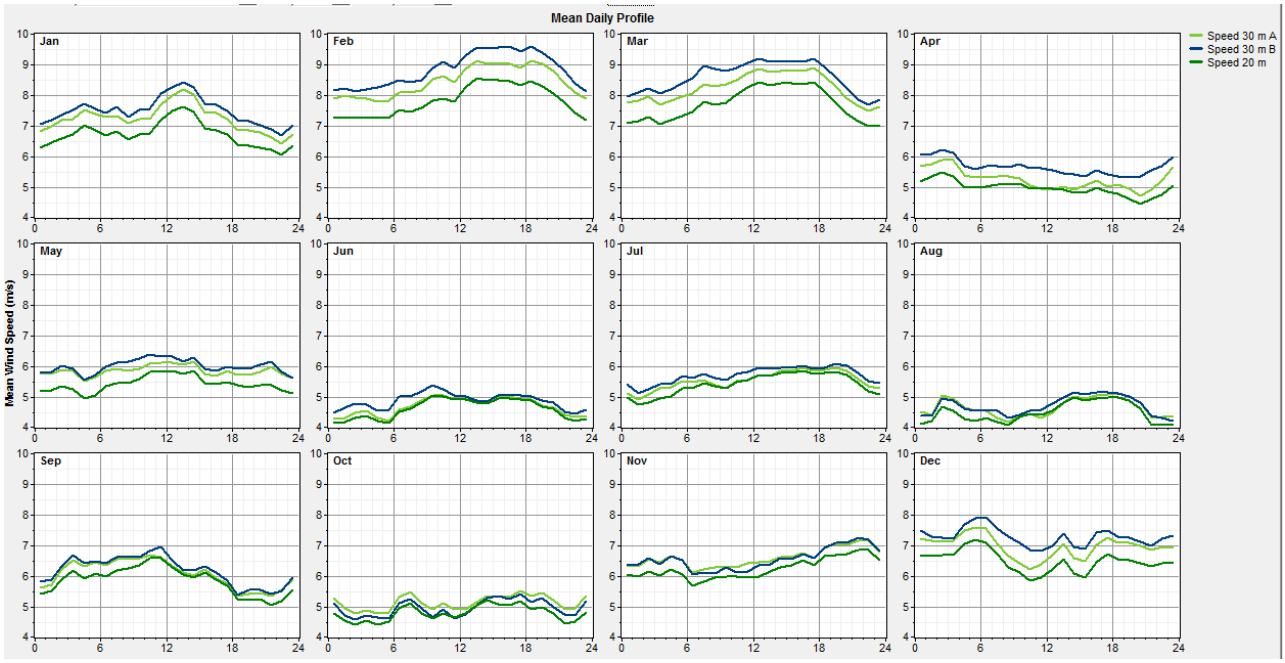
	30 m A speed						30 m B speed		20 m speed	
Month	Mean (m/s)	Max 10 min. (m/s)	Max gust (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max gust (m/s)	Mean (m/s)	Max gust (m/s)
Jan	7.22	25.1	30.2	4.28	1.78	8.14	7.48	29.8	6.71	29.8
Feb	8.44	17.8	21.0	4.05	2.22	9.53	8.83	21.8	7.81	20.6
Mar	8.24	21.4	25.2	3.96	2.18	9.28	8.58	24.0	7.71	24.0
Apr	5.23	13.8	17.6	2.78	1.94	5.89	5.65	16.8	4.95	16.8
May	5.84	14.9	17.6	2.98	2.06	6.60	5.99	18.3	5.41	16.8
Jun	4.66	13.6	16.1	2.22	2.19	5.25	4.86	16.4	4.60	16.4
Jul	5.53	14.9	17.9	2.35	2.51	6.22	5.69	17.9	5.40	16.4
Aug	4.64	13.0	16.1	2.43	1.98	5.23	4.70	16.4	4.48	16.4
Sep	6.06	17.7	21.8	3.35	1.87	6.82	6.17	21.8	5.84	21.8
Oct	5.12	15.9	18.7	3.07	1.76	5.77	4.95	19.1	4.78	18.7
Nov	6.58	23.4	29.1	4.03	1.69	7.37	6.54	29.1	6.23	27.9
Dec	6.95	17.7	21.4	3.41	2.17	7.86	7.28	21.8	6.48	21.8
Annual	**6.21**	**25.1**	**30.2**	3.48	1.85	6.95	**6.39**	**29.8**	**5.87**	**29.8**



Daily wind profile

The daily wind profile indicates that the lowest wind speeds of the day occur in the nighttime hours of 10 p.m. to 2 a.m. and the highest wind speeds of the day occur during the afternoon hours of 12 to 6 p.m. The daily variation of wind speed is minimal on an annual basis but more pronounced on a monthly basis with the highest variation during the winter months.





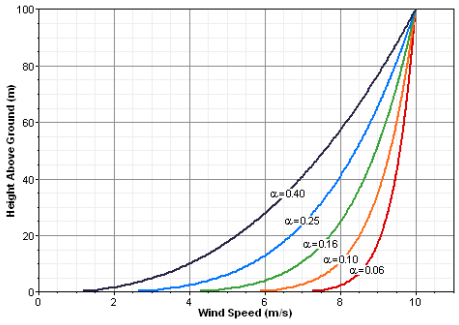
Extreme Winds

Although the data collection period was quite brief at only thirteen months, an extreme wind calculation modified to use monthly extreme wind data instead of annual extreme wind data yielded a 50 year extreme wind gust estimate of 36.0 m/s. This results in an IEC 61400-1 edition 3 classification of Class III winds (lowest of three standard classifications) for this site.

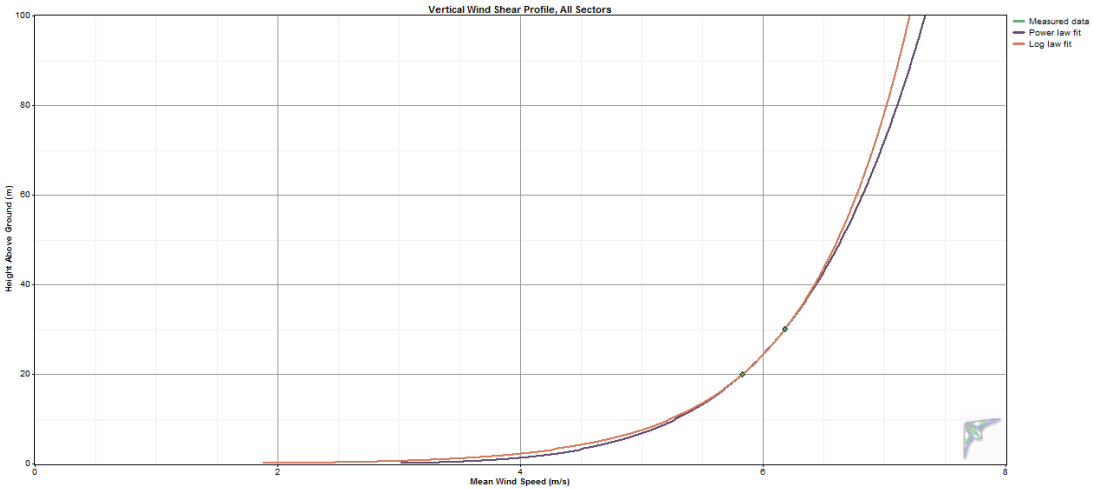
RETURN PERIOD SPEED:		Average Gust Factor	1.18
Shaktoolik	RETURN YR	10 min average, m/s	3 sec gust, m/s
30 meter	2	22.6	26.8
	10	26.6	31.4
	15	27.5	32.6
	30	29.2	34.6
	50	30.4	36.0
	100	32.1	38.0

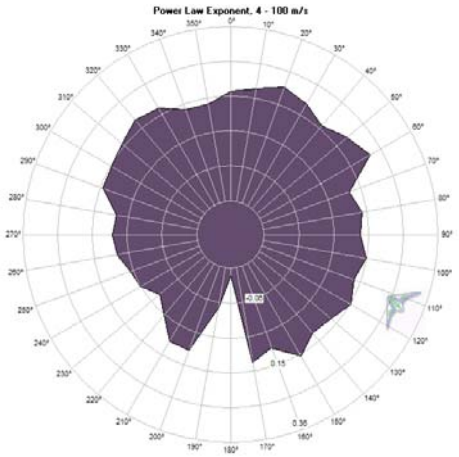
Wind Shear

The power law exponent was calculated at 0.143 when considering only the two north-facing anemometers (channels 1 and 3), indicating moderately-low shear at the Shaktoolik met tower site (see graph to the right). In a seasonal view, the wind shear is highest during the windier winter months and lowest during summer, as one would expect. The practical



application of this data is that a higher turbine tower height is 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.



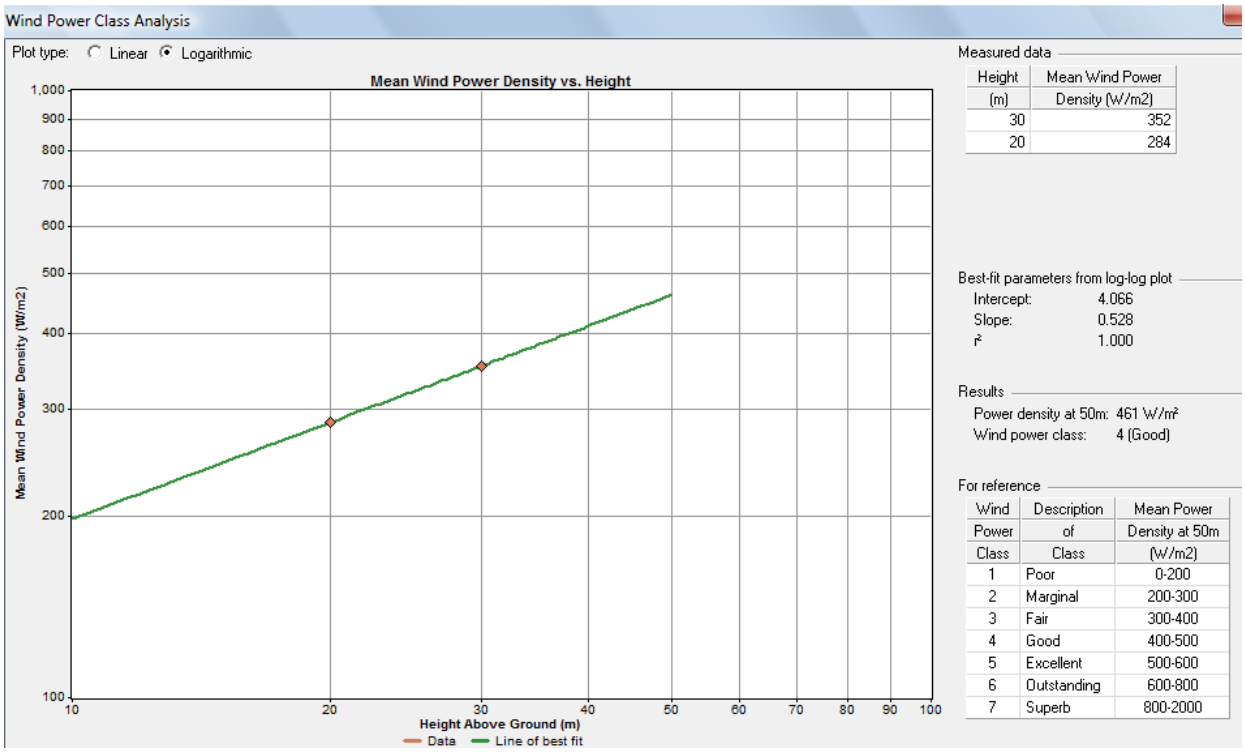


Wind Power Density

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 $P/A = ½*\rho*U^3$. The time step values are averaged to produce an overall wind power density.

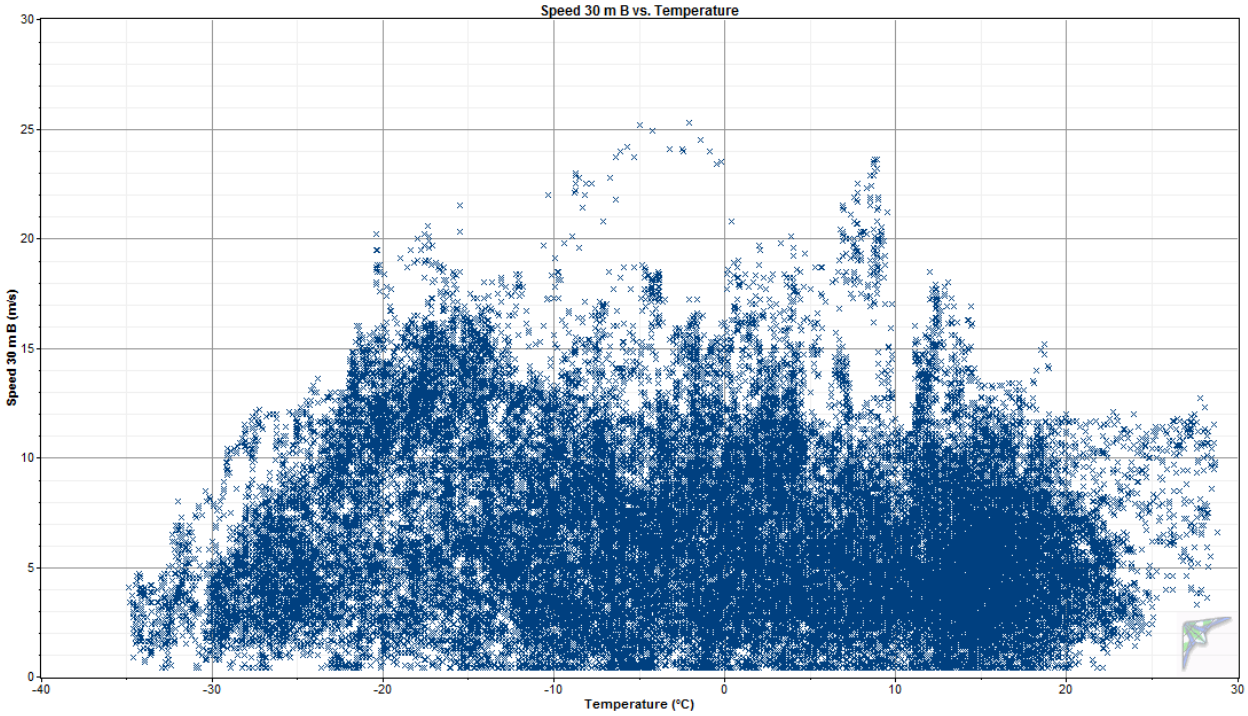
The wind power density at 50 meters elevation is a wind industry standard method of comparing and evaluating sites. If the anemometer measurement heights are at other than 50 meters, the wind analysis software uses the power law exponent derived from the two (or more) measurement heights to extrapolate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

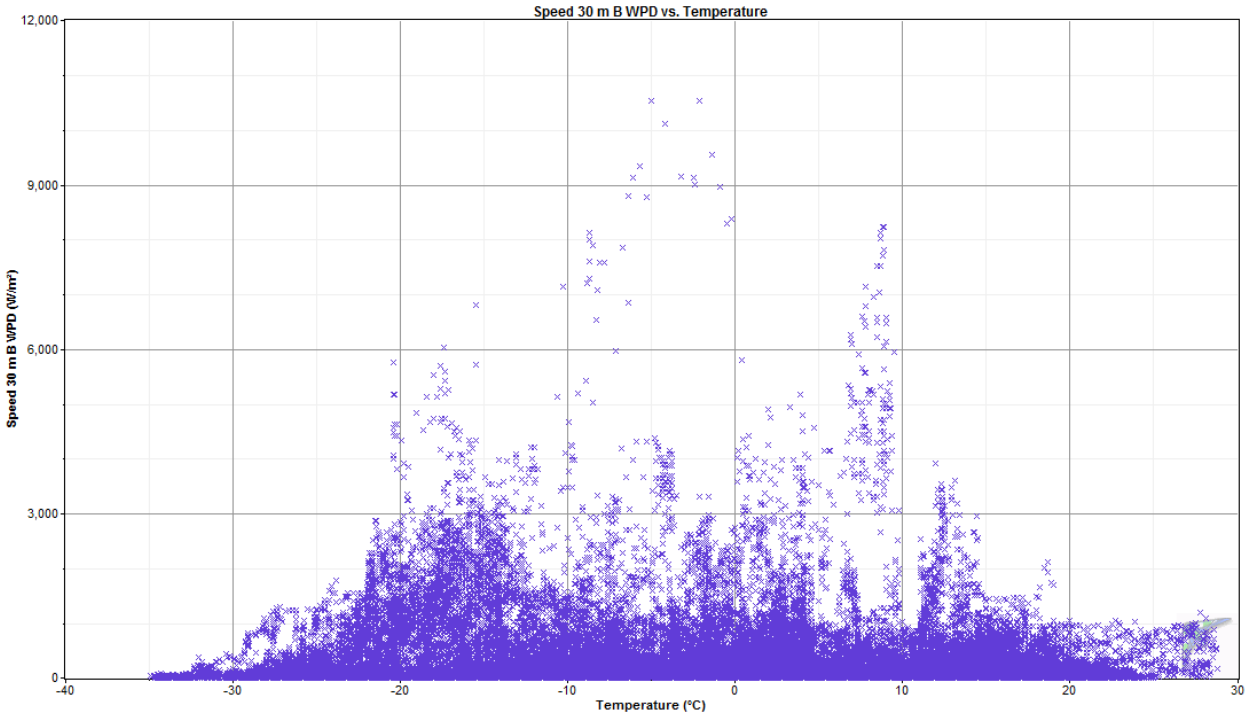
As can be seen in the figure below, power density and hence potential turbine power production increases substantially with turbine hub height in Shaktoolik, as is true at most sites. Note that the measured power densities in the figure below differ from those reported in the data summary table on page 2 of this report. The figure below uses all collected data (early July 2007 through late July 2008) while in the summary table these data are presented as annual averages.



An observation of interest is to compare by scatter plot the mean wind speed to temperature and power density to temperature. As one can see, 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 -25° C.

For this reason, it will be important when selecting a turbine for Shaktoolik to ensure that it is capable of operation in extreme cold, with a minimum operating temperature of -30° C or colder.

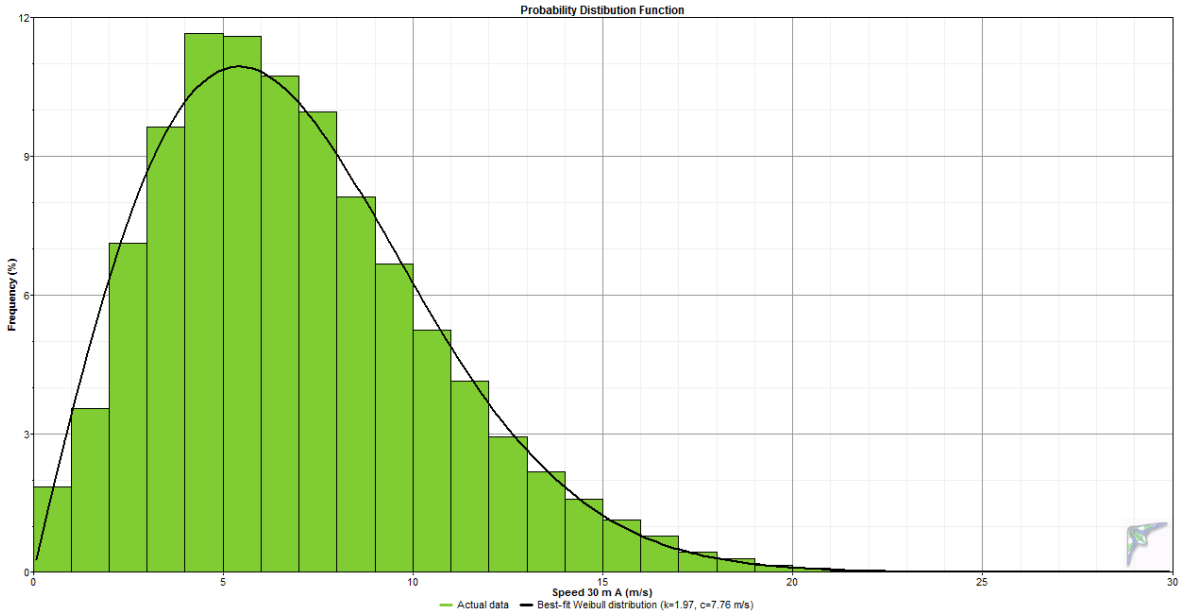


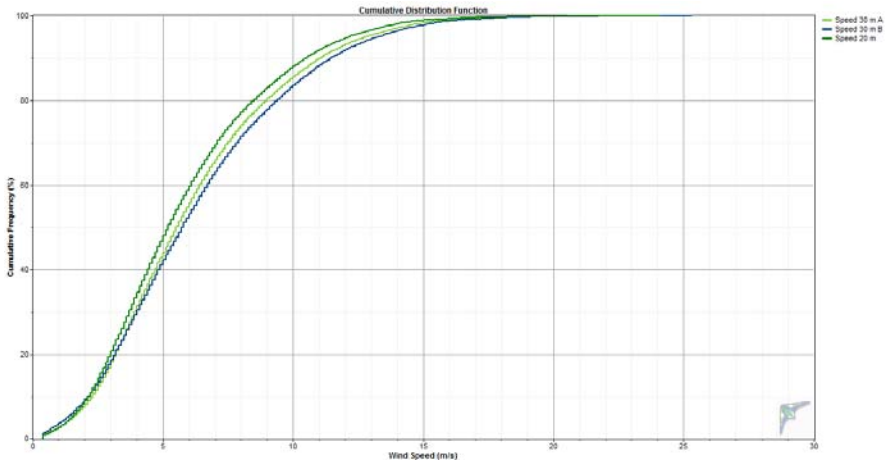


Probability Distribution Function

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 = 1.97 and c = 7.76 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 30 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 wind turbines.



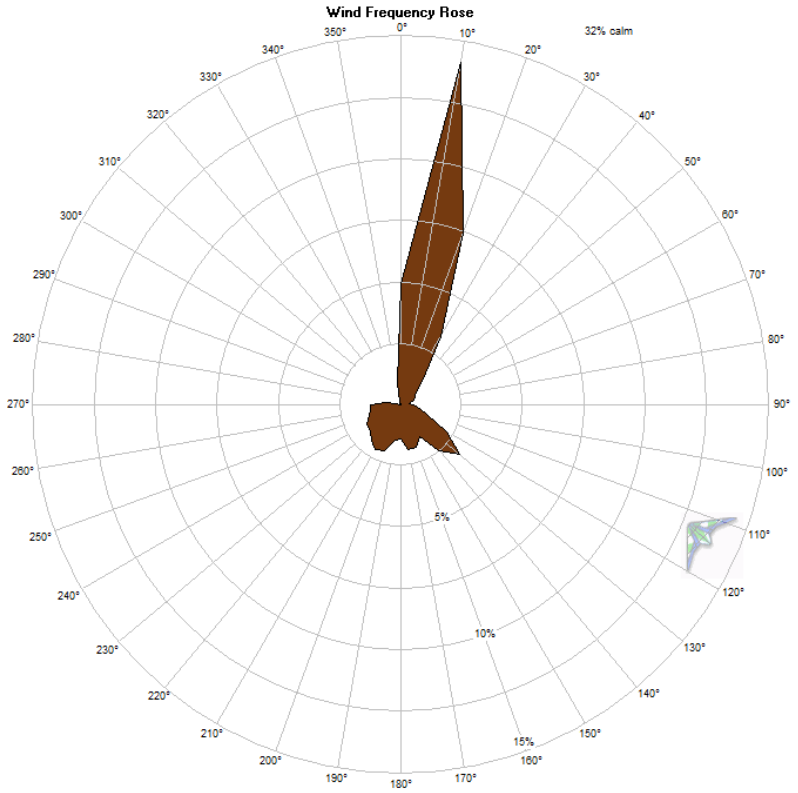


Wind Roses

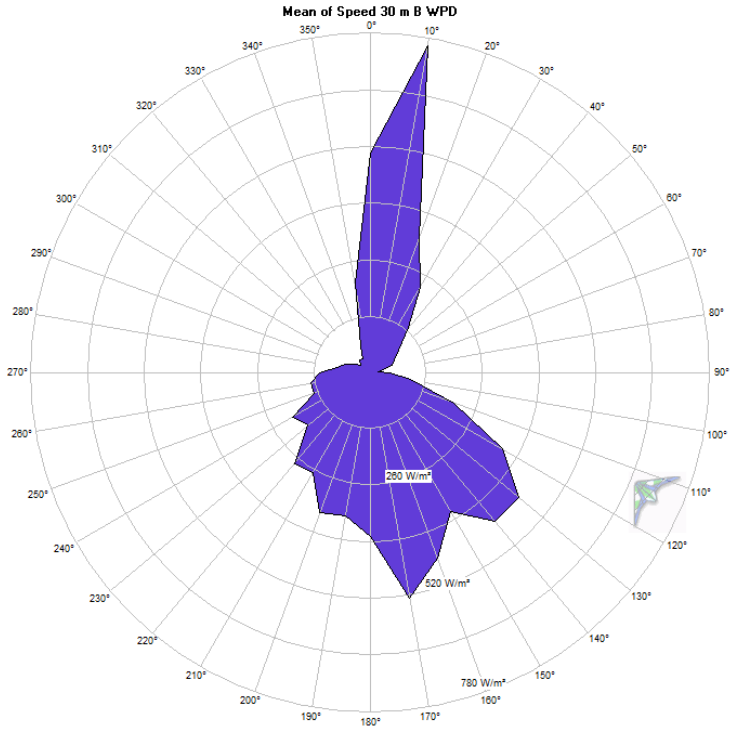
Shaktoolik's winds are highly directional with northerly winds predominating. Occasional southeasterly to westerly winds occur and as one can see in the mean value wind rose, these winds are quite strong, but in the larger view of the annual wind density rose, the power-producing winds over the course of a year are strongly directional at or near 010° T. 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, Shaktoolik experienced 32 percent calm conditions during the measurement period (see wind frequency rose below).

The practical application of this information is that multiple wind turbines can be arranged in a relatively tight east-west alignment, perhaps as close as three rotor diameters from hub to hub. This could present some practical difficulties in Shaktoolik as the old runway, an ideal construction surface, is oriented NNE/SSW. Hence, only one turbine could likely be placed on the old runway; additional turbines would need to be located on the adjacent tundra.

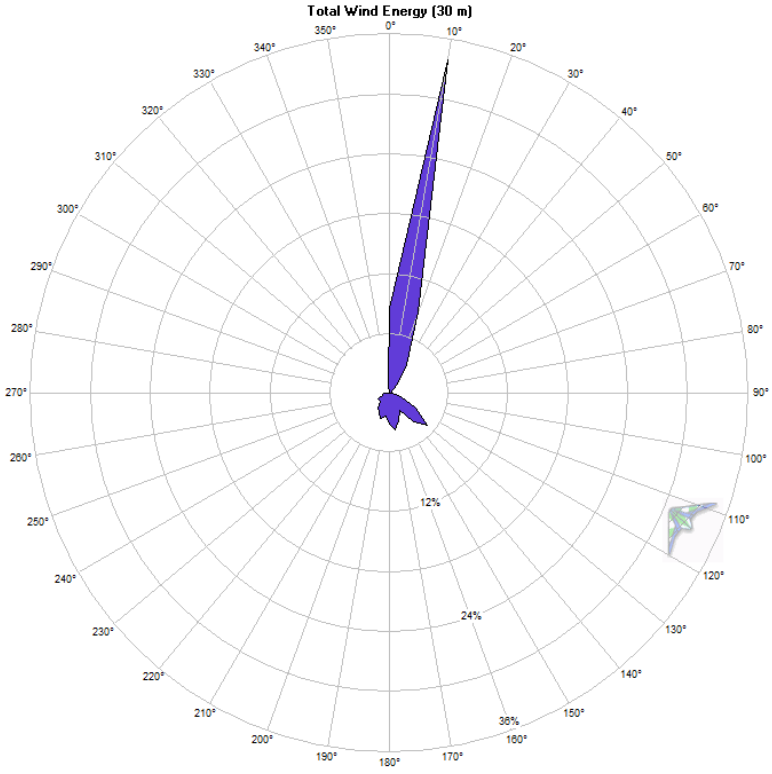
Wind Frequency Rose



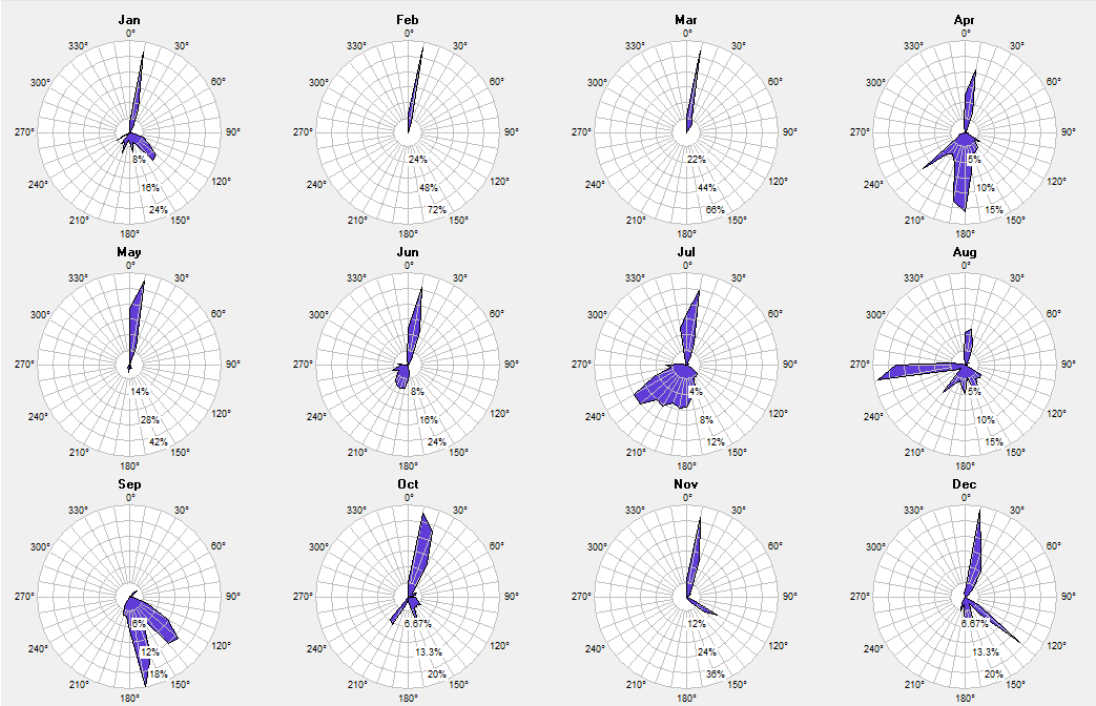
Mean Value (power density) rose by direction



Total value (power density) rose



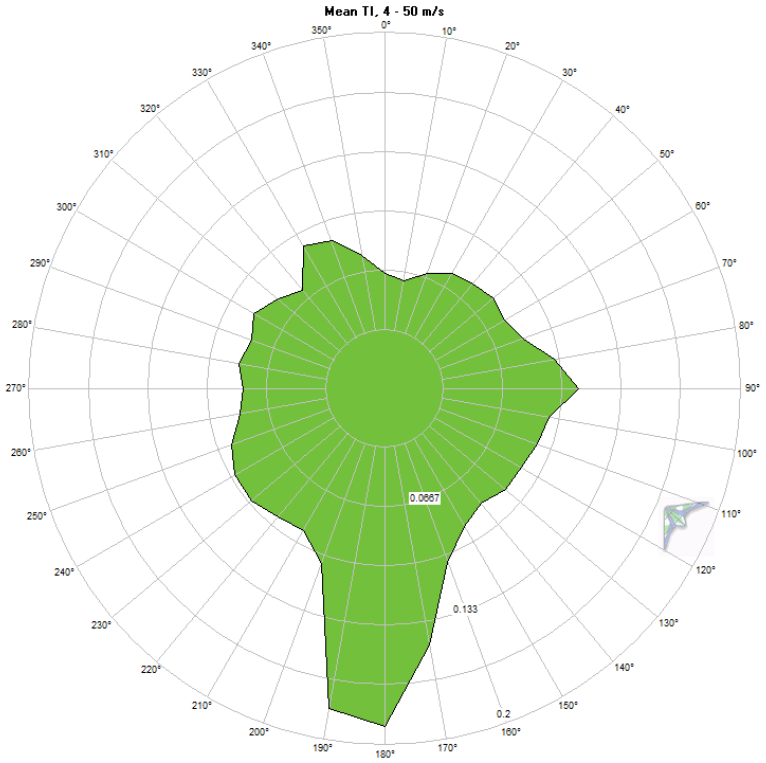
Wind power density roses by month; scale is not common



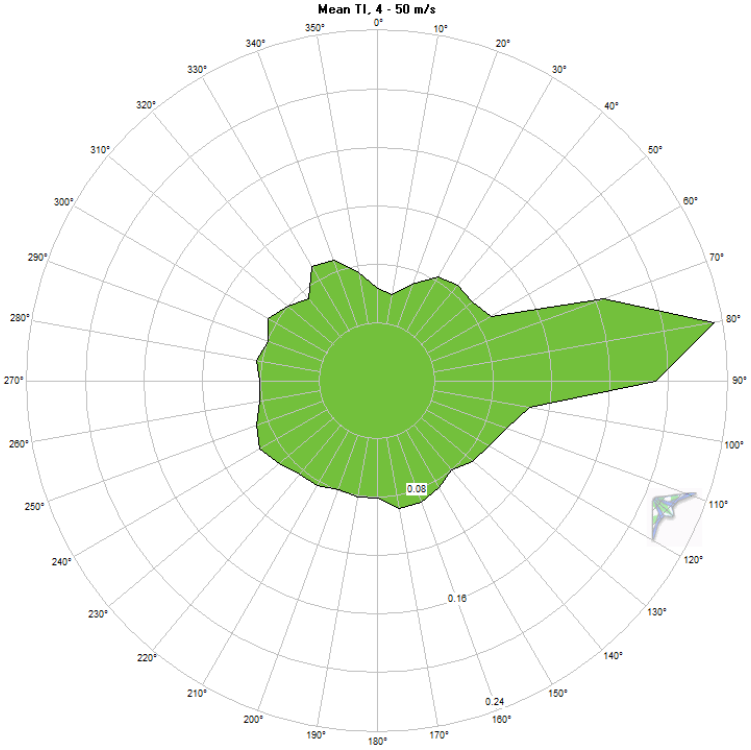
Turbulence Intensity

The turbulence intensity is acceptable with representative turbulence intensity at 15 m/s of 0.097 (30 m A anemometer) and 0.087 (30 m B anemometer) during the data period, indicating quite smooth air for wind turbine operations and classifying as an IEC61400-1 ed. 3 Class C- site. Note that the high turbulence to the south from the A anemometer and to the east for the B anemometer are artifacts of the location of the respective anemometer on the met tower. Winds from the direction opposite the orientation of a sensor on the met tower must flow past the met tower itself, inducing high turbulence. For this reason, one can consider the true turbulence rose for Shaktoolik as a combination of the 30m A and 30m B roses, discounting the south and east turbulence spikes.

30-meter (A) Turbulence Intensity, (north-facing anemometer)



30-meter (B) Turbulence Intensity, (west-facing anemometer)



Turbulence Table

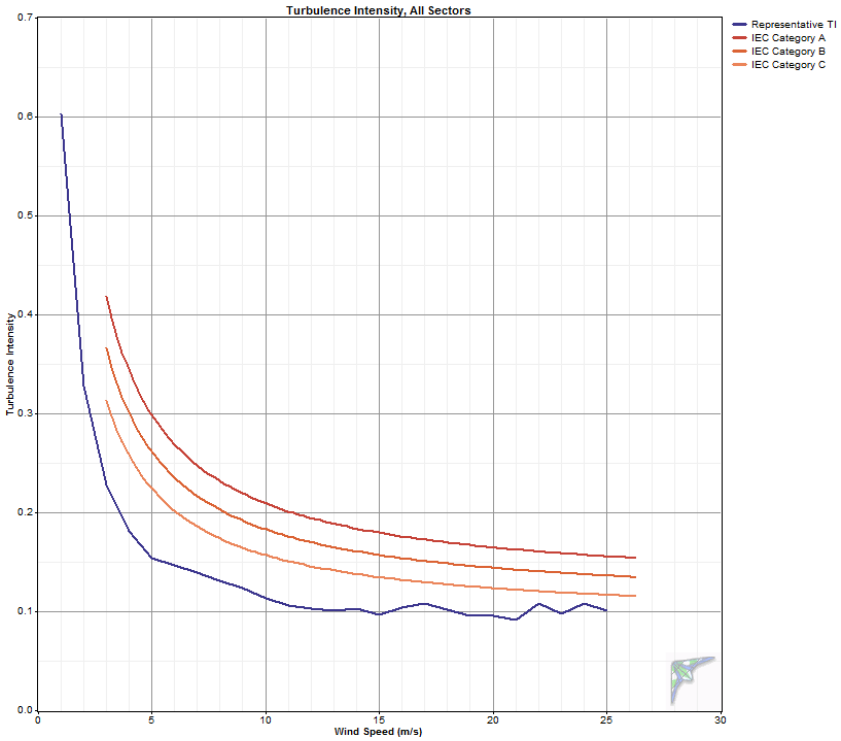
Turbulence Intensity Table, 30 m A speed, 30 m vane, 7/4/07 to 7/22/08

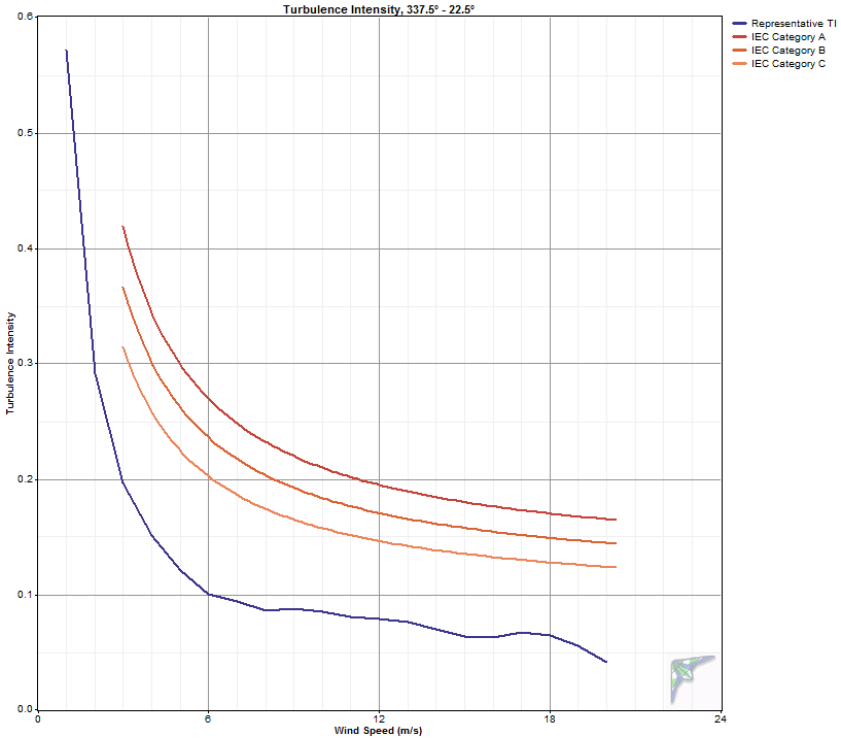
Bin	Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	1	0.5	1.5	1956	0.385	0.170	0.603	1.091
2	2	1.5	2.5	3776	0.197	0.103	0.328	0.882
3	3	2.5	3.5	6597	0.135	0.072	0.228	0.923
4	4	3.5	4.5	7283	0.108	0.057	0.181	0.816
5	5	4.5	5.5	6767	0.095	0.047	0.155	0.528
6	6	5.5	6.5	6153	0.090	0.045	0.147	0.589
7	7	6.5	7.5	5145	0.086	0.041	0.139	0.431
8	8	7.5	8.5	4029	0.082	0.039	0.132	0.387
9	9	8.5	9.5	3145	0.079	0.035	0.124	0.337
10	10	9.5	10.5	2677	0.075	0.030	0.113	0.357
11	11	10.5	11.5	2184	0.072	0.027	0.106	0.252
12	12	11.5	12.5	1584	0.071	0.025	0.103	0.237
13	13	12.5	13.5	1051	0.070	0.024	0.101	0.217
14	14	13.5	14.5	803	0.068	0.027	0.103	0.184
15	15	14.5	15.5	592	0.064	0.026	0.097	0.221
16	16	15.5	16.5	258	0.071	0.026	0.105	0.149
17	17	16.5	17.5	156	0.075	0.026	0.108	0.188
18	18	17.5	18.5	97	0.074	0.022	0.102	0.154
19	19	18.5	19.5	76	0.074	0.017	0.096	0.128
20	20	19.5	20.5	48	0.075	0.017	0.096	0.116
21	21	20.5	21.5	17	0.072	0.016	0.092	0.096
22	22	21.5	22.5	26	0.085	0.018	0.108	0.149
23	23	22.5	23.5	11	0.079	0.015	0.098	0.123
24	24	23.5	24.5	7	0.091	0.014	0.108	0.114
25	25	24.5	25.5	2	0.092	0.007	0.101	0.097
26	26	25.5	26.5	0				

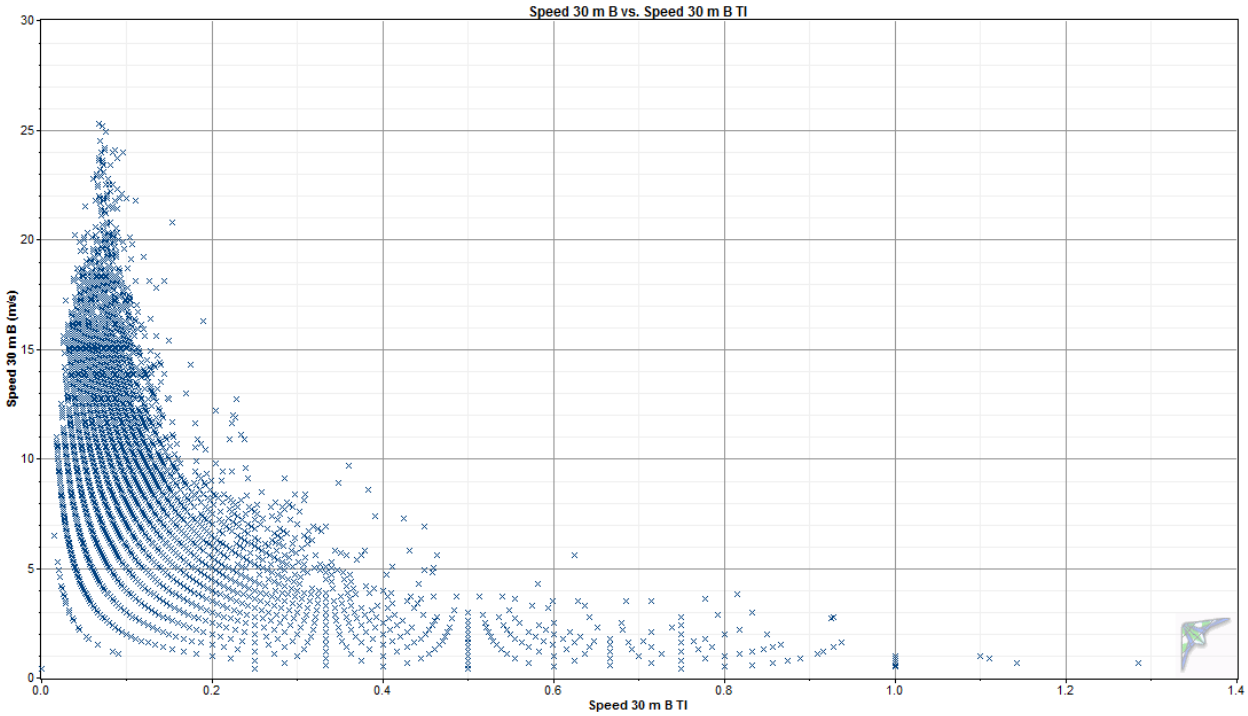
Turbulence Intensity Graphics

As one can see below, turbulence at the Shaktoolik met tower site is well below International Electro-technical Commission (IEC) Class A, B, and C criteria at all measured wind speeds, including isolation of the data to the north to north-northeast wind direction sector. The first scatterplot graphs below shows that for virtually all higher wind speeds – those exceeding 10 m/s – the turbulence intensity is less the 0.2 and mostly less than 0.15. Only at low wind speeds does one see higher turbulence intensities. This higher turbulence is not important however as turbines don't operate below 4 m/s wind speeds and at

low operating range wind speeds the mechanical loads are low and hence relatively high turbulence is a minor concern.



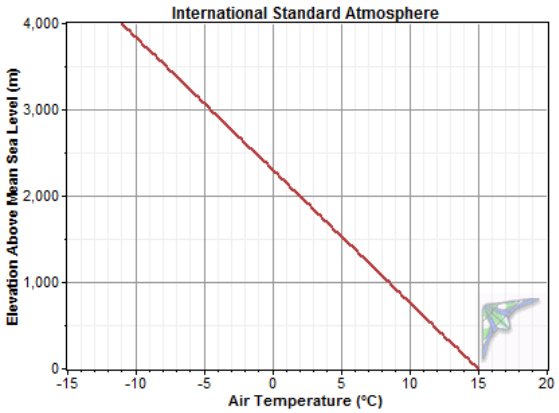




Air Temperature and Density

Over the reporting period, Shaktoolik had an average temperature of -0.6° C. The minimum recorded temperature during the measurement period was -35.1° C and the maximum temperature was 29.3° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations.

Consequent to Shaktoolik's cool temperatures, the average air density of 1.298 kg/m^3 is six percent higher than the standard air density of 1.225 kg/m^3 (15.0° C and 100.3 kPa standard temperature and pressure at 2 m elevation), indicating that Shaktoolik has denser air than the standard air density used to calculate turbine power curves (power curves are calculate at a sea level standard of 15° C and 101.3 kPa pressure). This density variance from standard *is* accounted for in turbine performance predicted by Windographer wind analysis software.



Month	Temperature			Air Density		
	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-16.7	-35.1	6.0	1.378	1.264	1.481
Feb	-18.8	-30.4	4.3	1.388	1.273	1.453
Mar	-11.0	-26.2	6.0	1.347	1.266	1.427
Apr	-6.0	-26.8	15.7	1.321	1.224	1.430
May	5.1	-13.2	19.7	1.268	1.208	1.357
Jun	12.0	4.5	23.2	1.237	1.191	1.270
Jul	16.6	6.0	29.3	1.218	1.168	1.264
Aug	16.4	7.3	25.3	1.219	1.183	1.258
Sep	11.2	1.4	20.2	1.241	1.205	1.285
Oct	-0.7	-12.4	9.6	1.295	1.249	1.352
Nov	-4.8	-24.0	10.3	1.316	1.247	1.415
Dec	-10.1	-30.6	10.3	1.343	1.246	1.453
Annual	**-0.6**	-35.1	29.3	**1.298**	1.168	1.481