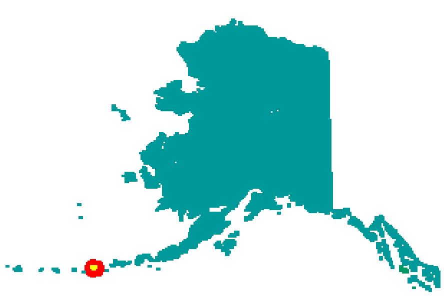
Nikolski, Alaska Wind Resource Report

Report written by: Douglas Vaught, P.E., V3 Energy LLC, Eagle River, AK
Date of report: March 27, 2007

Photo by Mia Devine, Alaska Energy Authority



Summary Information

Nikolski has superb potential for wind power development with Class 7 wind power density, moderate wind shear, bi-directional winds and low turbulence.

Meteorological Tower Data Synopsis

Wind power class (measured to date)	Class 7 – Superb
Average wind speed (30 meters)	9.01 m/s (at 30 meters)
Maximum wind gust (2 sec average)	40.9 m/s, 1/24/07, 12 p.m.
Mean wind power density (50 meters)	1,118 W/m^2 (predicted by calculation)
Mean wind power density (30 meters)	881 W/m^2 (measured)
Roughness Class	1.77 (few trees)
Power law exponent	0.174 (moderate wind shear)
Turbulence Intensity (30 meters)	0.108
Data start date	December 11, 2005
Most recent data date	March 13, 2007

Community Profile

Current Population:	31 (2005 State Demographer est.)
Pronunciation/Other Names:	(nih-COAL-skee)
Incorporation Type:	Unincorporated
Borough Located In:	Unorganized
School District:	Aleutian Region Schools
Regional Native Corporation:	Aleut Corporation

Location:

Nikolski is located on Nikolski Bay, off the southwest end of Umnak Island, one of the Fox Islands. It lies 116 air miles west of Unalaska, and 900 air miles from Anchorage. It lies at approximately 52.938060° North Latitude and -168.867780° West Longitude. (Sec. 04, T084S, R136W, Seward Meridian.) Nikolski is located in the Aleutian Islands Recording District. The area encompasses 132.1 sq. miles of land and 0.7 sq. miles of water.

History:

Nikolski is reputed by some to be the oldest continuously-occupied community in the world. Archaeological evidence from Ananiuliak Island, on the north side of Nikolski Bay, dates as far back as 8,500 years ago. The Chaluka archaeological site, in the village of Nikolski, indicates 4,000 years of virtually continuous occupation. People were living in Nikloski before the pyramids were built, the Mayan calendar was invented, or the Chinese language was written. In 1834, it was the site of sea otter hunting, and was recorded by the Russians as "Recheshnoe," which means "river." In 1920, a boom in fox farming occurred here. The Unangan became affluent enough to purchase a relatively large boat, the "Umnak Native," which was wrecked in 1933. A sheep ranch was established in 1926 as part of the Aleutian Livestock Company. In June 1942, when the Japanese attacked Unalaska and seized Attu and Kiska, residents were evacuated to the Ketchikan area. Locals were allowed to return in 1944, but the exposure to the outside world brought about many changes in the traditional lifestyle and community attitudes. In the 1950s, the Air Force constructed a White Alice radar communication site here, which provided some jobs. It was abandoned in late 1977.

Culture:
Residents are known as Unangan, and Aleut is spoken in three-quarters of all homes. Subsistence activities, sheep and cattle raising, and fishing-related employment sustain the community.

Economy:
Most residents support themselves by working outside the village at crab canneries and on processing ships. The lack of a harbor and dock has limited fisheries-related activities. The village is interested in developing a small value-added fish processing plant and a sport fishing lodge to attract former residents who left Nikolski for economic reasons. A sport-fishing charter boat was recently purchased by APICDA. Sheep, cattle and horses graze over much of the island. Income is supplemented by subsistence activities, which provide a substantial part of the villagers' diets. Salmon, halibut, seals and ducks are utilized.

Facilities:
The twelve occupied homes in Nikolski are connected to a piped water system and individual septic tanks. All homes are fully plumbed. The Council provides septic pumping services. The village has requested funds to develop a treated water supply.

Transportation:
Nikolski has a 3,500' unlighted gravel runway which provides passenger, mail and cargo service. The airstrip is owned by the U.S. Air Force. It has no landing or port facilities for ships. Barges deliver cargo once or twice a year. Goods and passengers are lightered three miles to the beach.

Climate:
Nikolski lies in the maritime climate zone. Temperatures range from 11 to 65 degrees Fahrenheit. Snowfall averages 41 inches; total precipitation is 21 inches. Strong winds are frequent during the winter and fog during the summer, which limits accessibility.

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

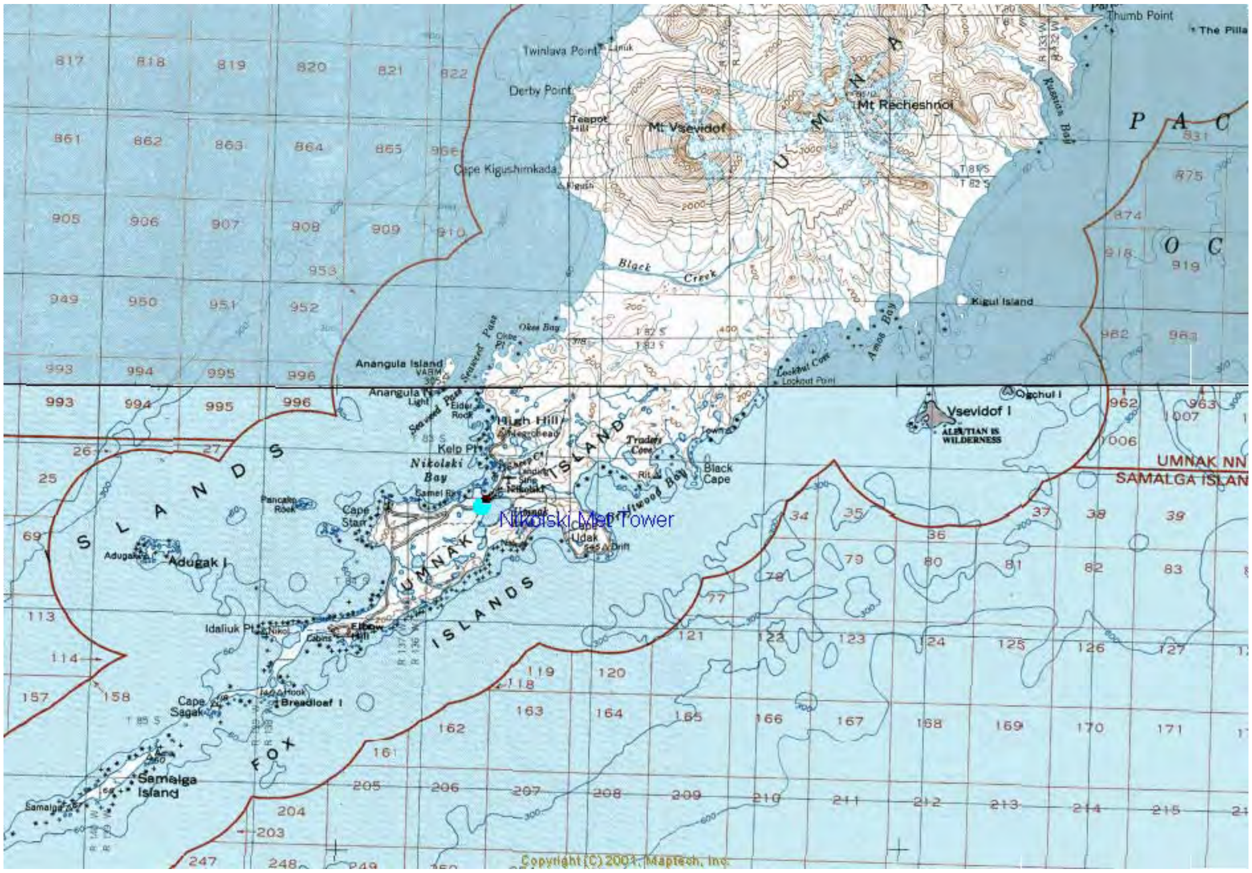
Met Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m (A)	0.765	0.35	North (0°)
2	NRG #40 anemometer	30 m (B)	0.765	0.35	South (170°)
3	NRG #40 anemometer	20 m	0.765	0.35	South (170°)
7	NRG #200P wind vane	27 m	0.351	270	East (90°)
9	NRG #110S Temp C	2 m	0.138	-86.383	N/A

Site Information

Site number	4061
Site Description	On a hill overlooking Umnak Lake, immediately southwest of the village
Latitude/longitude	N 052° 56.025'; W 168° 52.239'
Site elevation	27 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter Tall Tower, 152 mm (6 in) diameter

Site Location Maps



Data Quality Control Summary

Data was filtered to remove presumed icing events that yield false zero wind speed data. A small amount of January 2006 anemometer data was removed because of apparent icing that did not affect the wind vane. A more substantial data problem is the temperature sensor which had a very strange data output in October and early November 2006, but then returned to seemingly normal operation until February 2007 when it apparently quit working. For this wind resource report, data was not synthesized to replace data lost due to icing or the faulty temperature sensor.

		Ch 1, 30 m (A)		Ch 2, 30 m (B)		Ch 3, 20 m	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2005	Dec	3,024	100	3,024	100	3,024	100
2006	Jan	4,429	99.2	4,429	99.2	4,429	99.2
2006	Feb	4,032	100	4,032	100	4,032	100
2006	Mar	4,464	100	4,464	100	4,464	100
2006	Apr	4,320	100	4,320	100	4,320	100
2006	May	4,464	100	4,464	100	4,464	100
2006	Jun	4,320	100	4,320	100	4,320	100
2006	Jul	4,464	100	4,464	100	4,464	100
2006	Aug	4,464	100	4,464	100	4,464	100
2006	Sep	4,320	100	4,320	100	4,320	100
2006	Oct	4,464	100	4,464	100	4,464	100
2006	Nov	4,320	100	4,320	100	4,320	100
2006	Dec	4,464	100	4,464	100	4,464	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	1,812	100	1,812	100	1,812	100
All data		65,857	99.9	65,857	99.9	65,857	99.9

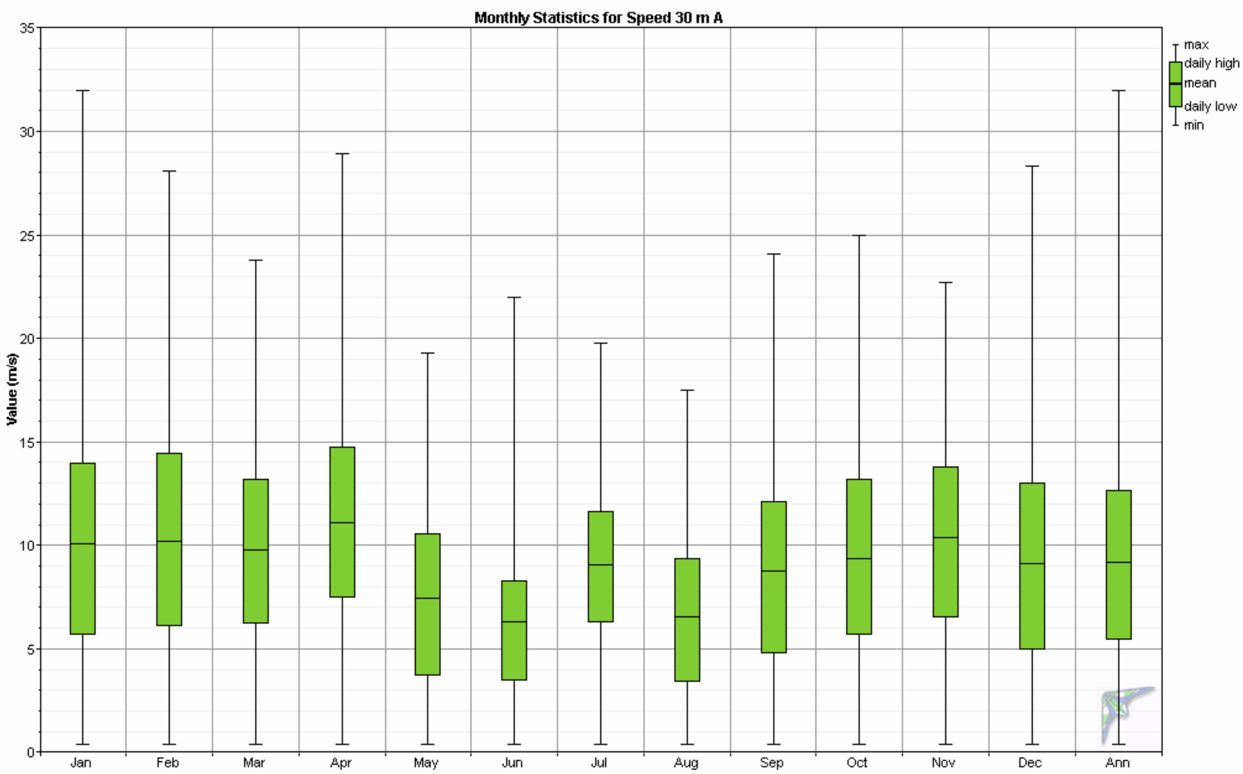
		Ch 7, vane		Ch 9, temperature	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2005	Dec	3,024	100	3,024	100
2006	Jan	4,464	100	4,464	100
2006	Feb	4,032	100	4,032	100
2006	Mar	4,464	100	4,464	100
2006	Apr	4,320	100	4,320	100
2006	May	4,464	100	4,464	100
2006	Jun	4,320	100	4,320	100
2006	Jul	4,464	100	4,464	100
2006	Aug	4,464	100	4,464	100
2006	Sep	4,320	100	4,320	100
2006	Oct	4,464	100	1,707	38.2
2006	Nov	4,320	100	4,127	95.5
2006	Dec	4,464	100	4,464	100
2007	Jan	4,464	100	4,455	99.8
2007	Feb	4,032	100	559	13.9
2007	Mar	1,812	100	0	0
All data		65,892	100	57,648	87.5

Measured Wind Speeds

The 30 meter (A) anemometer wind speed average for the reporting period is 9.01 m/s, the 30 meter (B) anemometer wind speed average is 8.98 m/s, and the 20 meter anemometer wind speed average is 8.37 m/s. Note that the maximum wind speed data represent ten-minute average wind speed measurements.

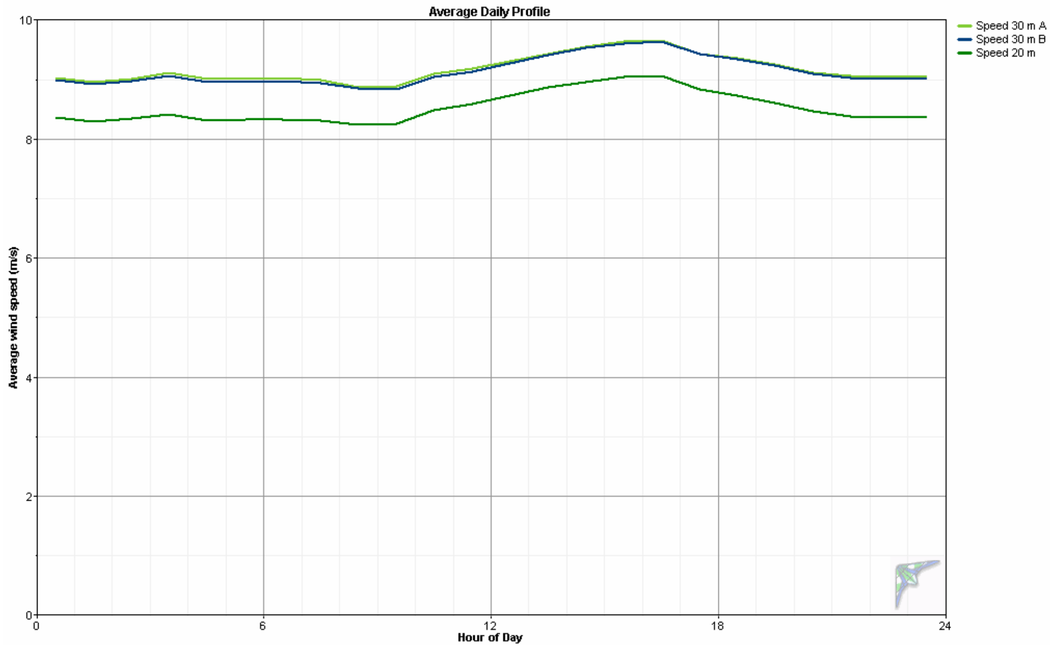
Wind Speed Summary

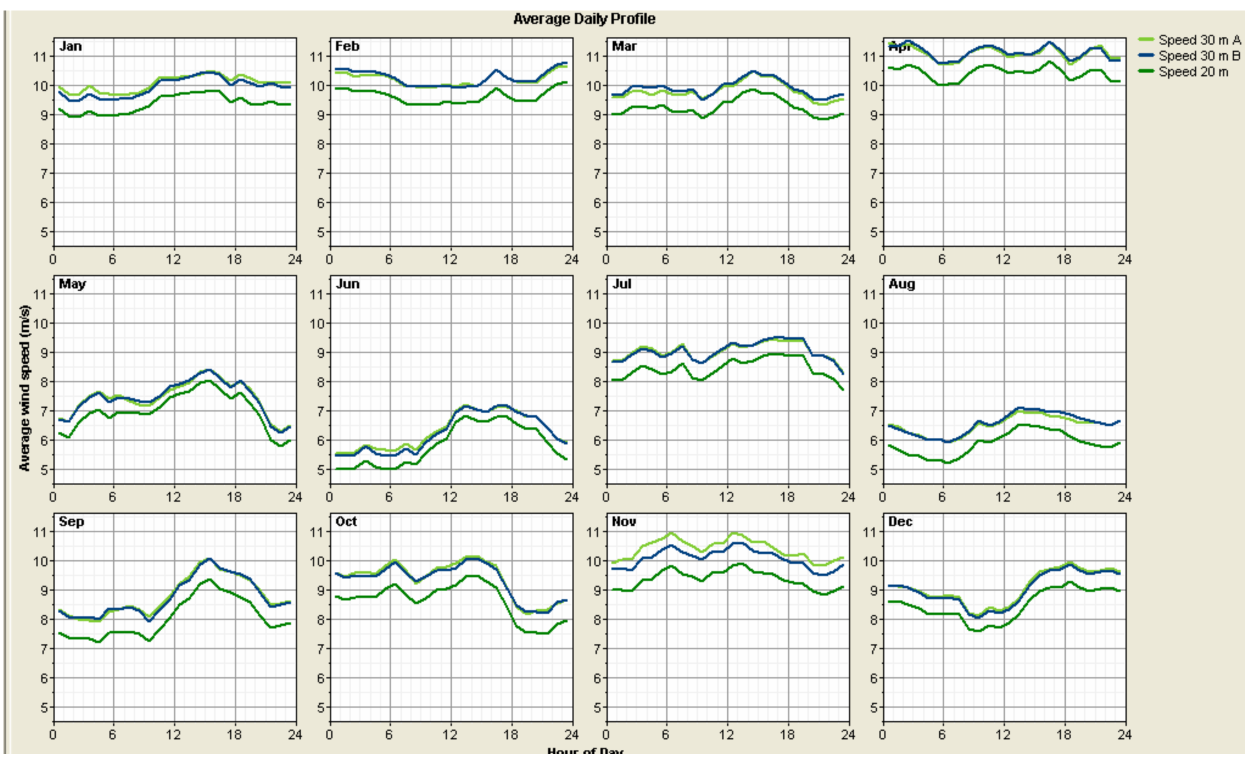
	30 m (A) speed		30 m (B) speed		20 m speed	
Month	Mean (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)
Jan	10.06	32.0	9.93	32.1	9.36	30.8
Feb	10.21	28.1	10.26	27.8	9.63	27.0
Mar	9.81	23.8	9.90	24.1	9.25	23.0
Apr	11.10	28.9	11.13	29.4	10.43	27.2
May	7.45	19.3	7.45	19.9	7.00	18.7
Jun	6.32	22.0	6.26	22.2	5.84	20.8
Jul	9.04	19.8	9.03	20.0	8.45	18.9
Aug	6.52	17.5	6.57	17.9	5.90	16.6
Sep	8.78	24.1	8.75	24.3	8.03	22.9
Oct	9.38	25.0	9.32	25.3	8.64	23.6
Nov	10.39	22.7	10.08	22.9	9.37	21.9
Dec	9.10	28.3	9.04	28.3	8.49	27.1
Annual	**9.01**	32.0	**8.98**	32.1	**8.37**	30.8



Daily wind profile

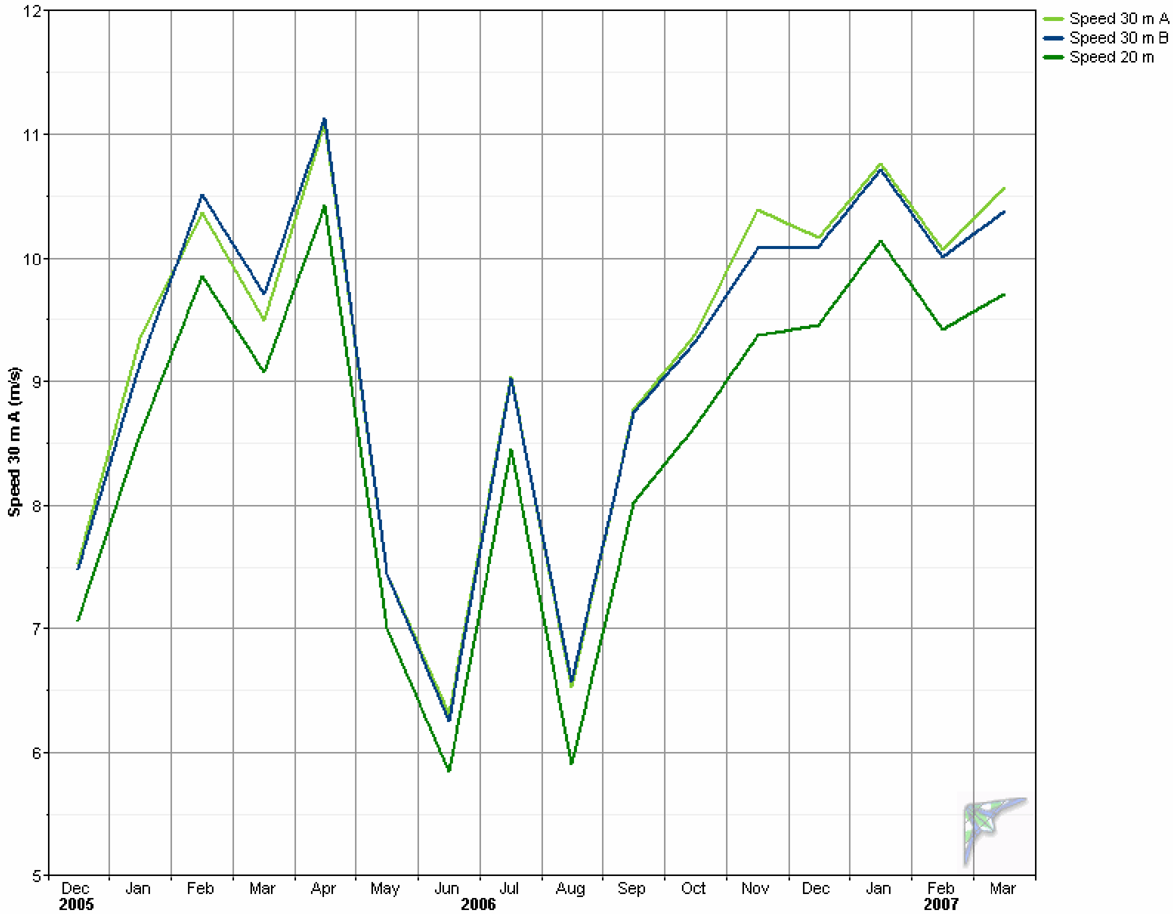
The daily wind profile indicates that the lowest wind speeds of the day occur in the night and morning hours of 9 p.m. to 9 a.m. and the highest wind speeds of the day occur during the late morning, afternoon and evening hours of 9 a.m. to 9 p.m. The daily variation of wind speed is quite minimal on an annual basis, but as shown below, more pronounced on a monthly basis.

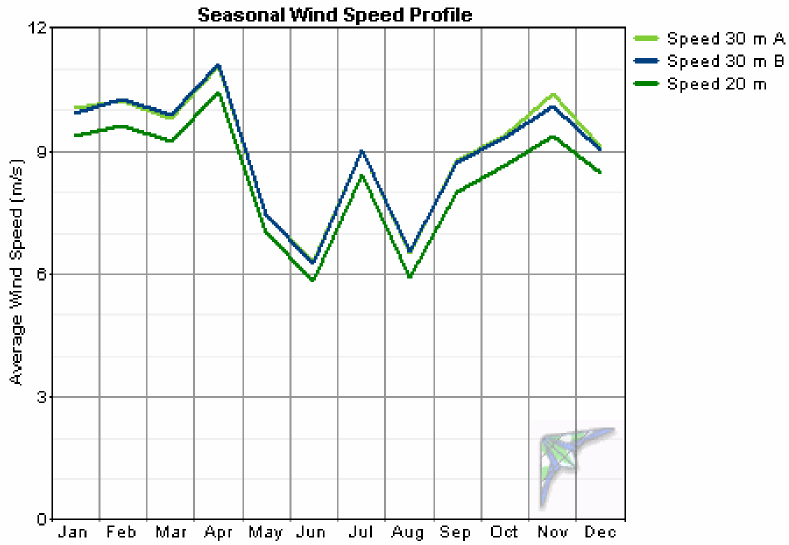




Time Series of Wind Speed Monthly Averages

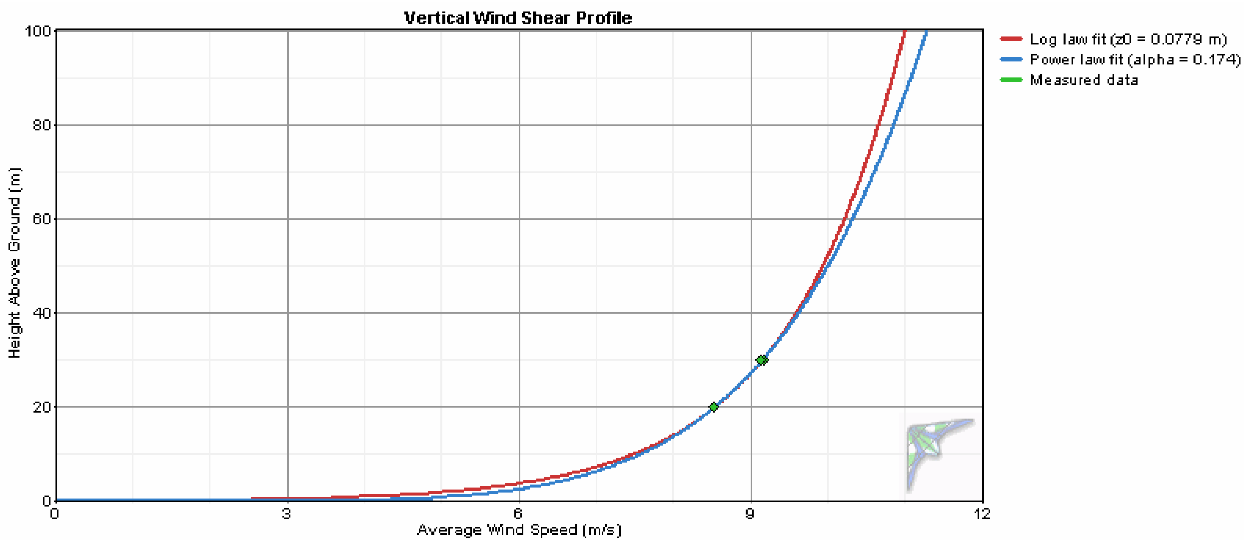
As expected, the highest winds occurred during the fall through spring months with lighter, but still very strong, winds during in May through September. Note that measured winds during winter 2006/2007 are about equivalent to the winter 2005/2006 winds.

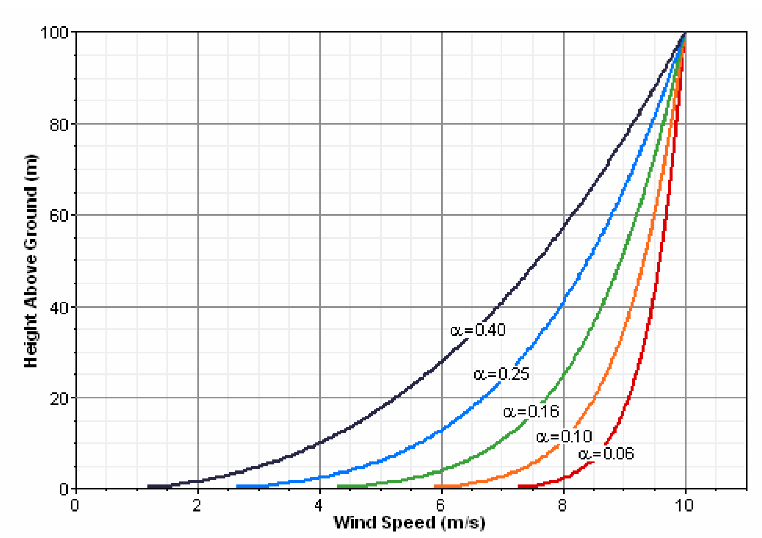


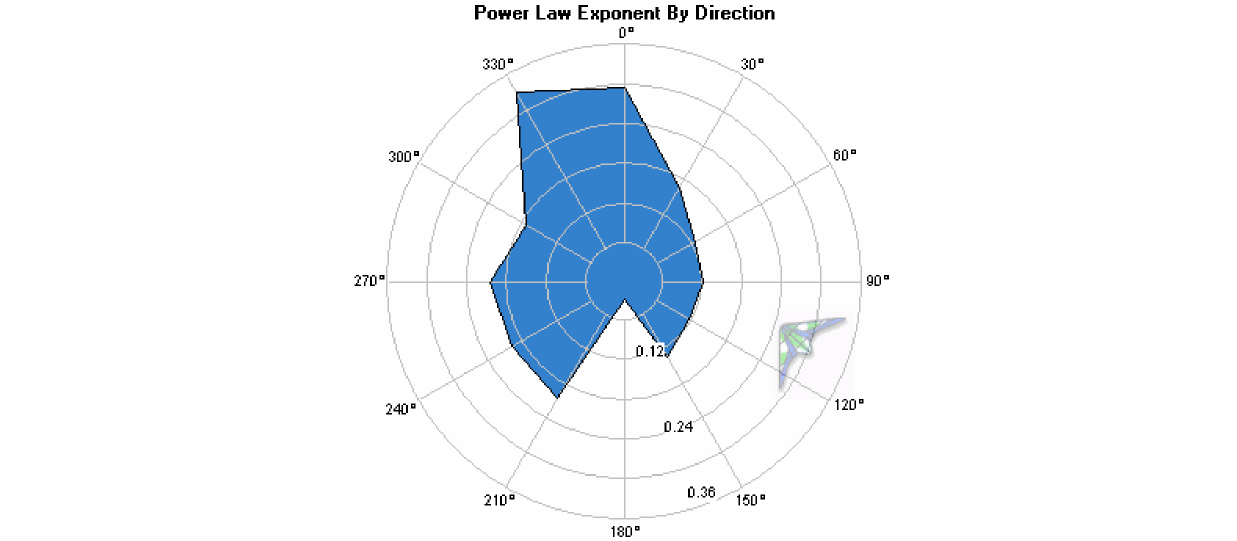


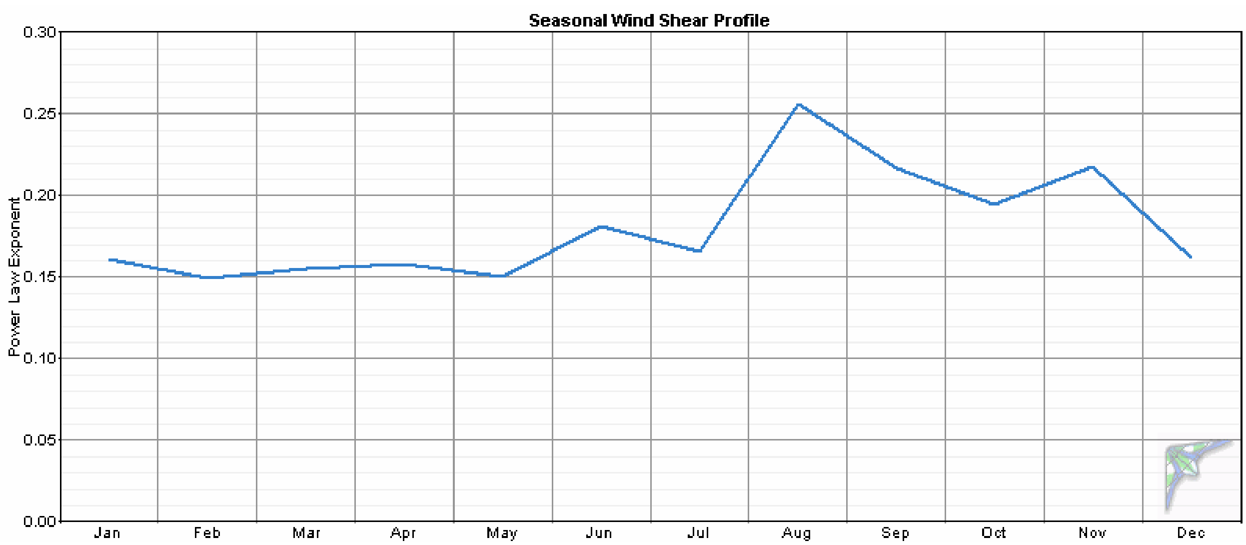
Wind Shear Profile

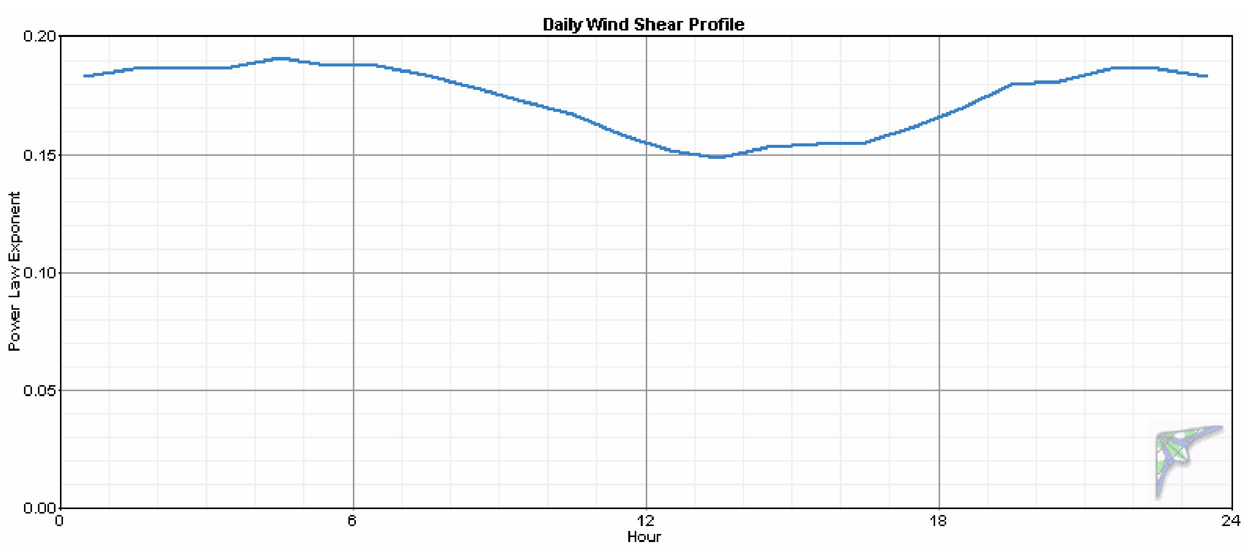
The average power law exponent was calculated at 0.174, indicating moderate wind shear at the Nikolski test site. The practical application of this information is that a higher turbine tower height would yield a desirable marginal gain in average wind speed with height, but the wind resource in Nikolski is so exceptionally strong that lower tower heights are advisable for reasons of cost and foundation engineering considerations. Other figures below show the variability of wind shear by direction and seasonal and daily variability.





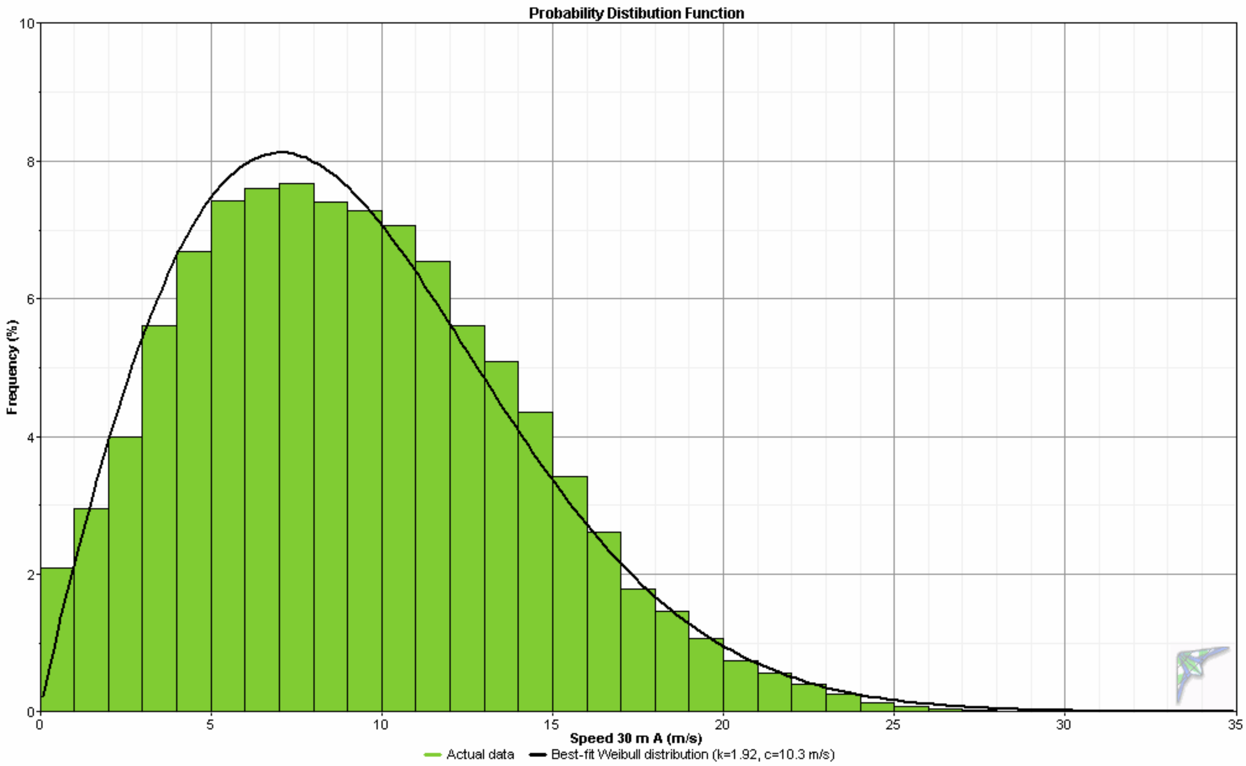

Power Law Exponent By Direction
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0.12
0.24
0.36

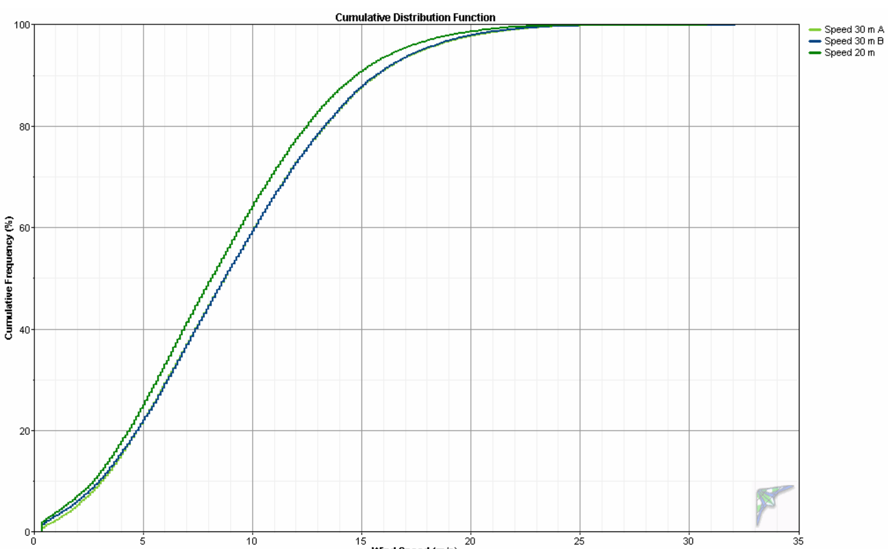

Seasonal Wind Shear Profile
Power Law Exponent
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daily Wind Shear Profile
Power Law Exponent
0.20
0.15
0.10
0.05
0.00
0
6
12
18
24
Hour

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, also 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 = 1.92 (indicates a broad distribution of wind speeds) and c = 10.3 m/s (scale factor for the Weibull distribution) for the measurement period of 121/11/2005 to 3/13/2007. At 20 meters, k = 1.85 and c = 9.56 m/s for the same measurement period.

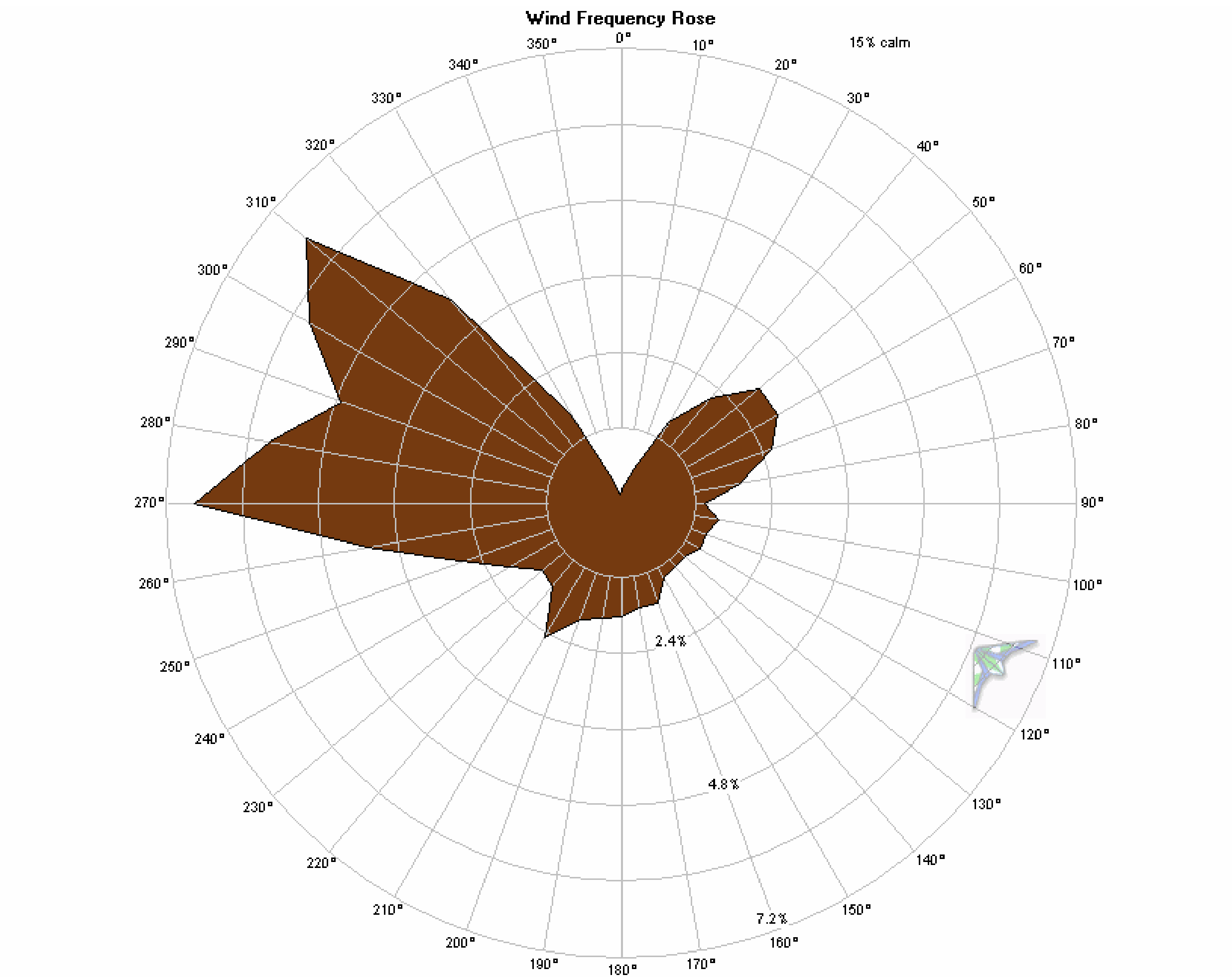




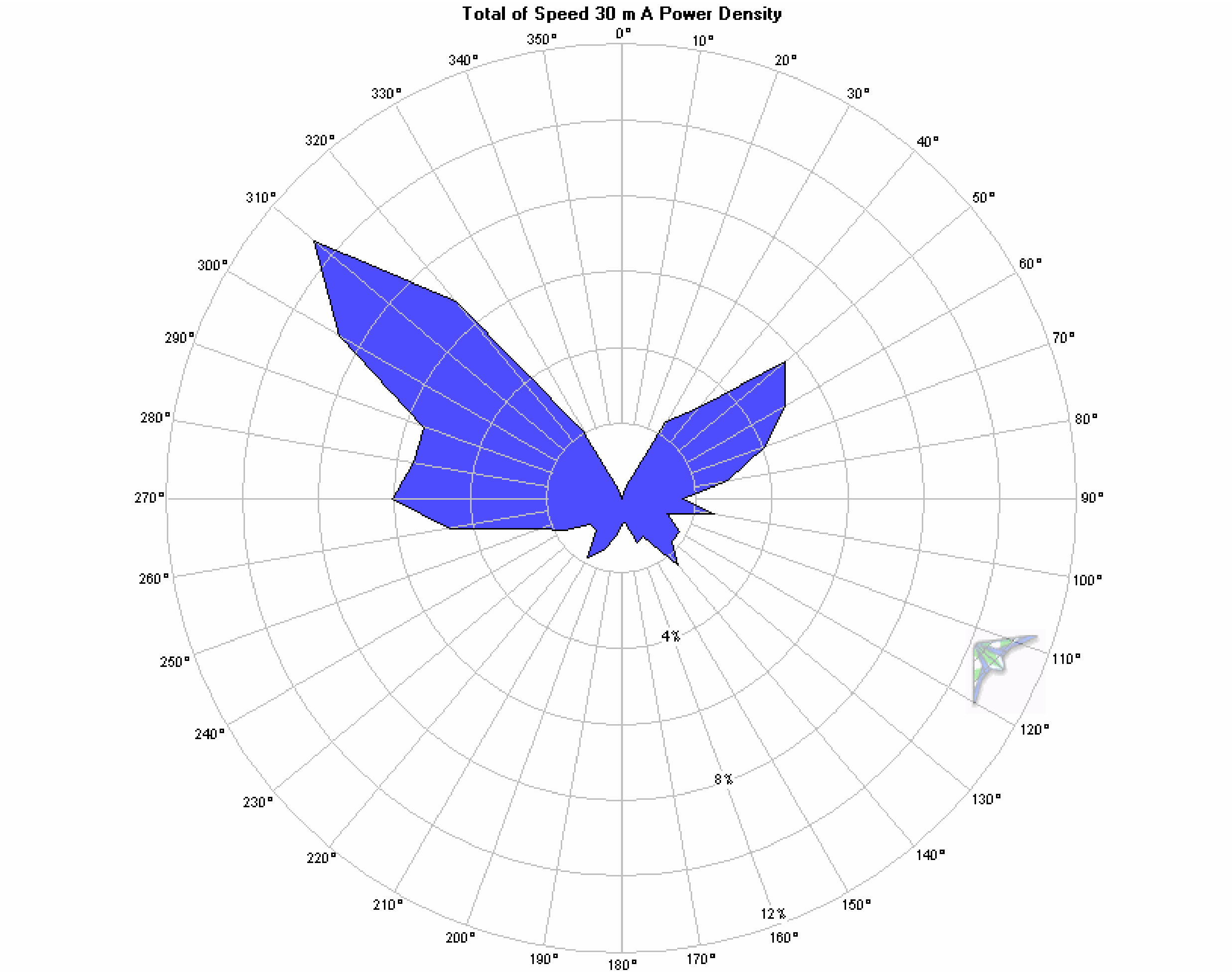
Wind Roses

Nikolski's winds are strongly bi-directional. The wind frequency rose indicates predominately north to northwest winds with a lesser component of northeast winds. This data observation is even stronger when one considers the power density rose (second wind rose). As one can see, the power producing winds are primarily northwest with lesser components of west and north-east. The practical application of this information is that multiple turbines should be spaced to avoid downwind effects from north to northwest and northeast sectors.

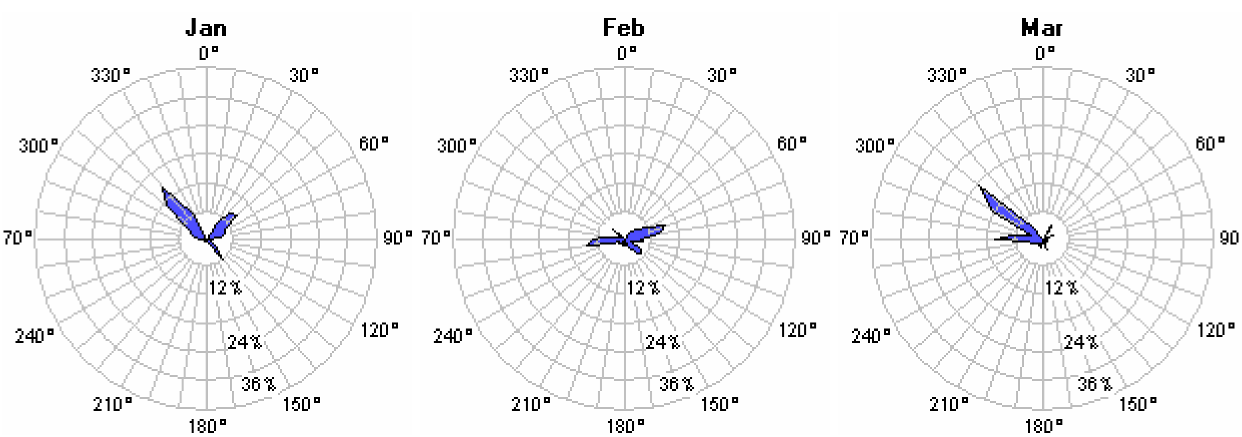
Wind frequency rose (30 meters)

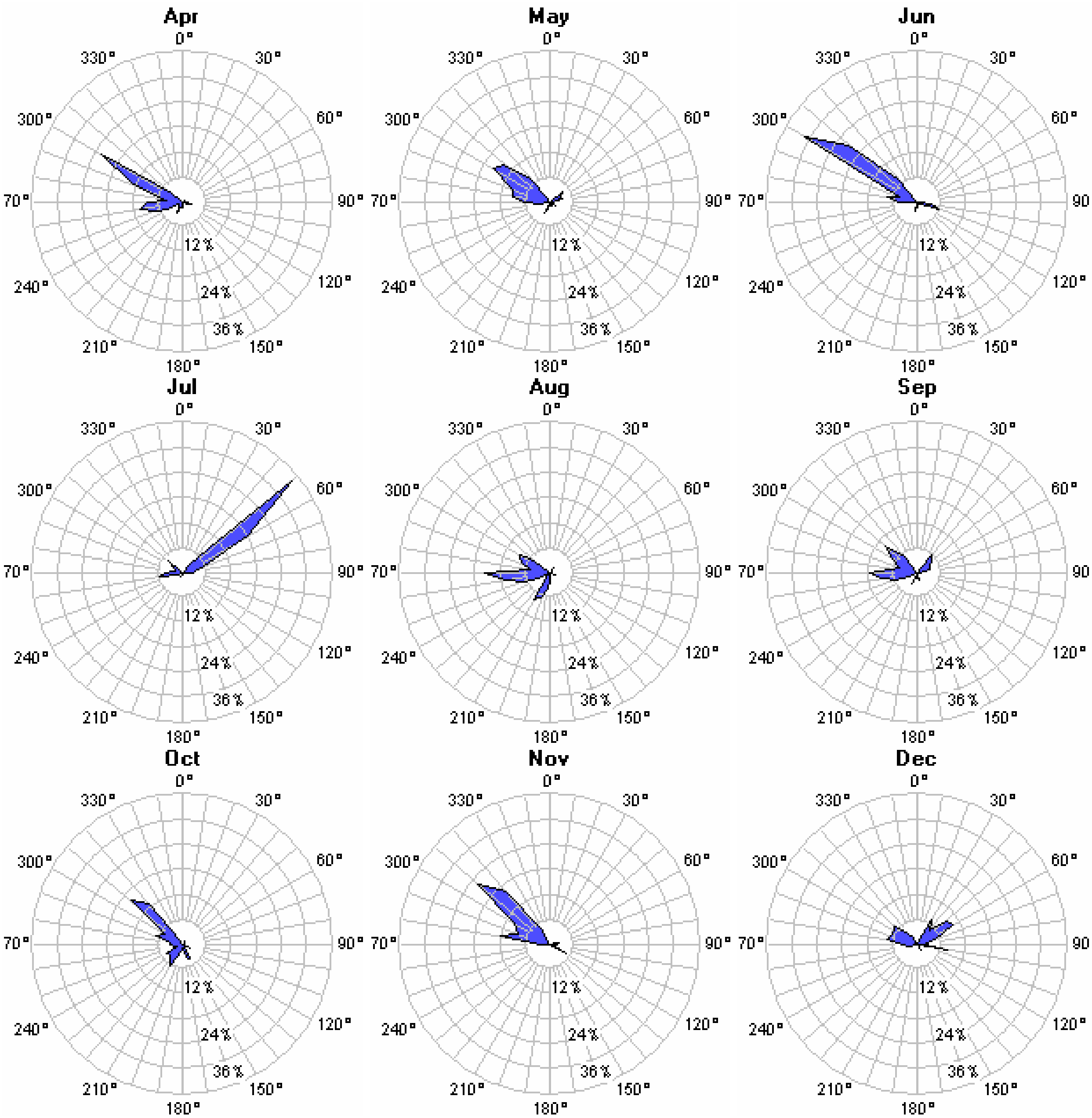


Power density rose (30 meters)



Wind Power Density Rose by Month (30 meters); note that scale is common

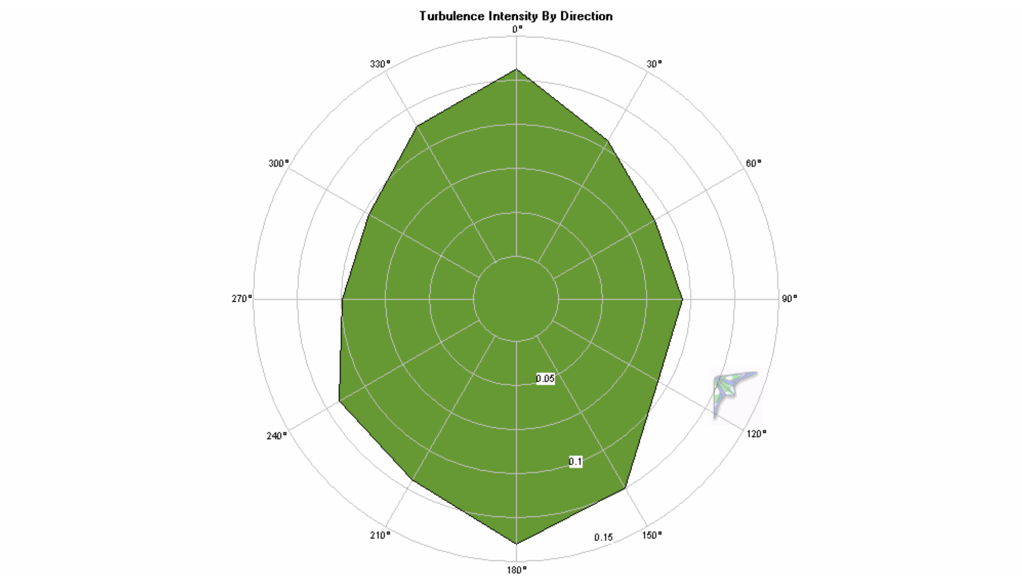



Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0°
30°
60°
90°
120°
150°
180°
210°
240°
70°
300°
330°
12%
24%
36%

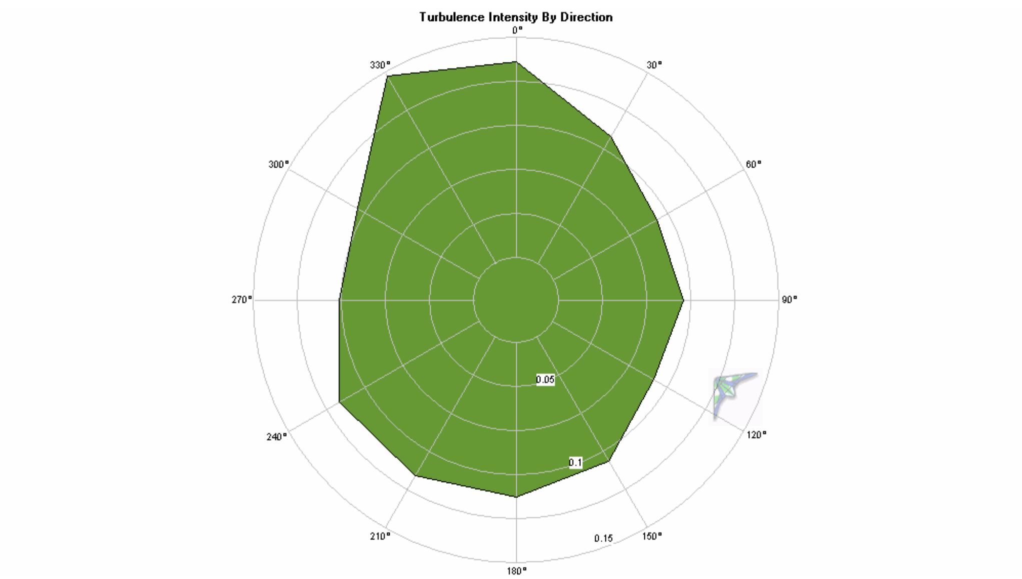
Turbulence Intensity

The Nikolski test site turbulence intensity is quite acceptable with a mean of 0.106 (A channel) and 0.108 (B channel) at 30 meters. The higher turbulence in the north and south quadrants in the A channel is inconsequential as the wind rarely blows from these directions. The higher turbulence intensity to the north-northwest in B channel can be attributed to the placement of the sensor facing south; northwesterly winds must flow around the tower before reaching the sensor and hence appear more turbulent than is the case. Note that turbulence intensity is calculated for each time step as the standard deviation of the wind speed divided by the mean of the wind speed.

30 meter vane – 30 meter (A) Turbulence Intensity (Mean = 0.106)



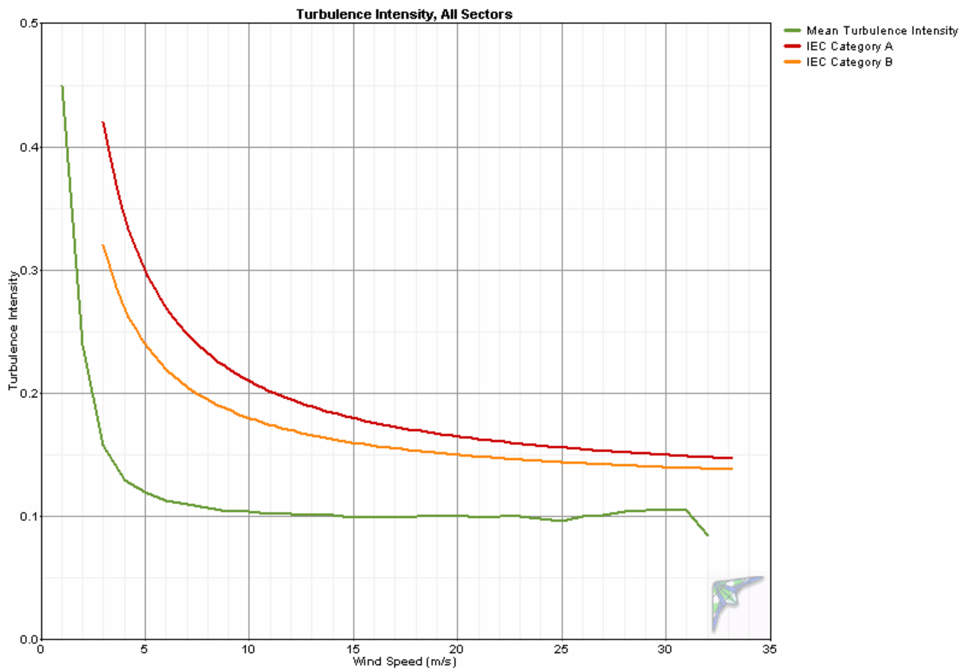
30 meter vane – 30 meter (B) Turbulence Intensity (Mean = 0.108)

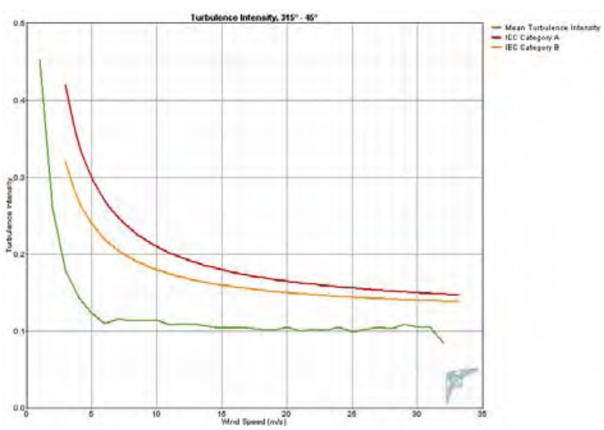


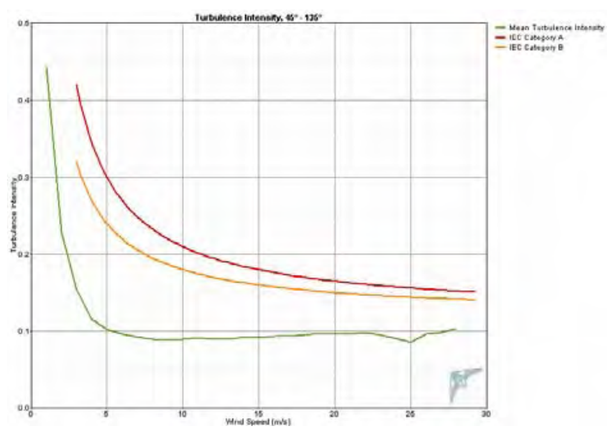
International Energy Agency turbulence standard comparisons

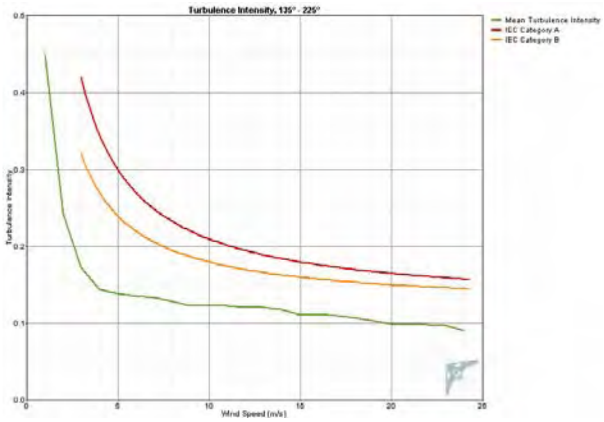
As indicated, turbulence is within International Energy Agency (IEA) Category A and B standards for all wind directions and at all measured wind speeds.

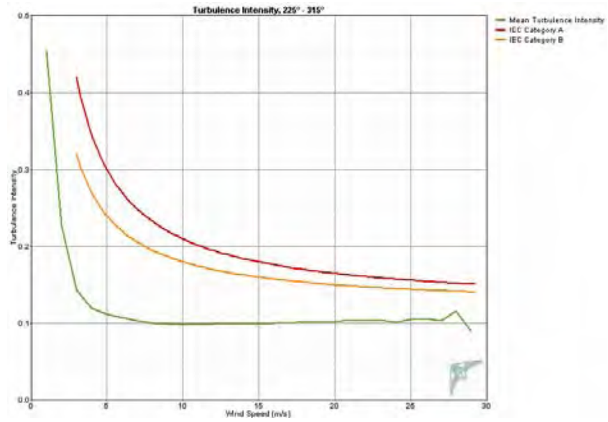
30 meter vane – 30 meter (A) speed











Turbulence Tables

30 m A speed - 27 m vane, 4 m/s threshold wind speed, 12/11/05 to 3/13/07

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records In Bin	Standard Deviation of Wind Speed (m/s)	Mean Turbulence Intensity	Standard Deviation of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	394	0.425	0.454	0.163	0.618
2	1.5	2.5	825	0.442	0.228	0.109	0.337
3	2.5	3.5	1307	0.423	0.143	0.069	0.213
4	3.5	4.5	1664	0.472	0.120	0.046	0.165
5	4.5	5.5	1723	0.556	0.112	0.042	0.155
6	5.5	6.5	2203	0.637	0.107	0.037	0.144
7	6.5	7.5	2481	0.715	0.103	0.032	0.135
8	7.5	8.5	2413	0.799	0.101	0.032	0.133
9	8.5	9.5	2313	0.890	0.099	0.029	0.128
10	9.5	10.5	2501	0.983	0.099	0.027	0.125
11	10.5	11.5	2261	1.077	0.099	0.026	0.124
12	11.5	12.5	1967	1.183	0.099	0.023	0.123
13	12.5	13.5	1688	1.286	0.099	0.020	0.119
14	13.5	14.5	1576	1.392	0.100	0.020	0.120
15	14.5	15.5	1248	1.482	0.099	0.020	0.120
16	15.5	16.5	958	1.598	0.100	0.020	0.120
17	16.5	17.5	758	1.696	0.100	0.020	0.120
18	17.5	18.5	543	1.828	0.102	0.022	0.124
19	18.5	19.5	412	1.913	0.101	0.021	0.122
20	19.5	20.5	253	2.040	0.102	0.021	0.123
21	20.5	21.5	117	2.181	0.104	0.020	0.125
22	21.5	22.5	103	2.265	0.103	0.016	0.120
23	22.5	23.5	87	2.405	0.105	0.015	0.120
24	23.5	24.5	41	2.439	0.102	0.015	0.117
25	24.5	25.5	22	2.627	0.106	0.017	0.123
26	25.5	26.5	6	2.767	0.106	0.012	0.118
27	26.5	27.5	1	2.800	0.104	0.000	0.104
28	27.5	28.5	1	3.200	0.116	0.000	0.116
29	28.5	29.5	1	2.600	0.090	0.000	0.090

30 m B speed - 27 m vane, 4 m/s threshold wind speed, 12/11/05 to 3/13/07

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records In Bin	Standard Deviation of Wind Speed (m/s)	Mean Turbulence Intensity	Standard Deviation of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	541	0.463	0.496	0.165	0.661
2	1.5	2.5	823	0.498	0.258	0.112	0.370
3	2.5	3.5	1197	0.472	0.159	0.073	0.232
4	3.5	4.5	1576	0.497	0.126	0.050	0.177
5	4.5	5.5	1696	0.578	0.116	0.045	0.162
6	5.5	6.5	2115	0.655	0.110	0.038	0.148
7	6.5	7.5	2444	0.735	0.106	0.032	0.137
8	7.5	8.5	2455	0.822	0.104	0.034	0.137
9	8.5	9.5	2253	0.917	0.102	0.029	0.132
10	9.5	10.5	2437	1.018	0.102	0.027	0.129
11	10.5	11.5	2261	1.124	0.103	0.027	0.130
12	11.5	12.5	1955	1.225	0.103	0.023	0.125
13	12.5	13.5	1727	1.357	0.105	0.022	0.127
14	13.5	14.5	1609	1.470	0.105	0.020	0.125
15	14.5	15.5	1309	1.576	0.106	0.021	0.126
16	15.5	16.5	902	1.677	0.105	0.020	0.125
17	16.5	17.5	790	1.761	0.104	0.019	0.123
18	17.5	18.5	555	1.917	0.107	0.022	0.128
19	18.5	19.5	439	1.991	0.105	0.021	0.126
20	19.5	20.5	273	2.115	0.106	0.021	0.127
21	20.5	21.5	146	2.265	0.108	0.019	0.128
22	21.5	22.5	98	2.349	0.107	0.016	0.123
23	22.5	23.5	79	2.491	0.108	0.017	0.125
24	23.5	24.5	42	2.550	0.107	0.013	0.119
25	24.5	25.5	21	2.748	0.111	0.015	0.126
26	25.5	26.5	9	2.856	0.110	0.019	0.129
27	26.5	27.5	2	2.750	0.102	0.001	0.104
28	27.5	28.5	1	3.300	0.119	0.000	0.119
29	28.5	29.5	1	2.600	0.088	0.000	0.088
30	29.5	30.5	0	2.600	0.088	0.000	0.088

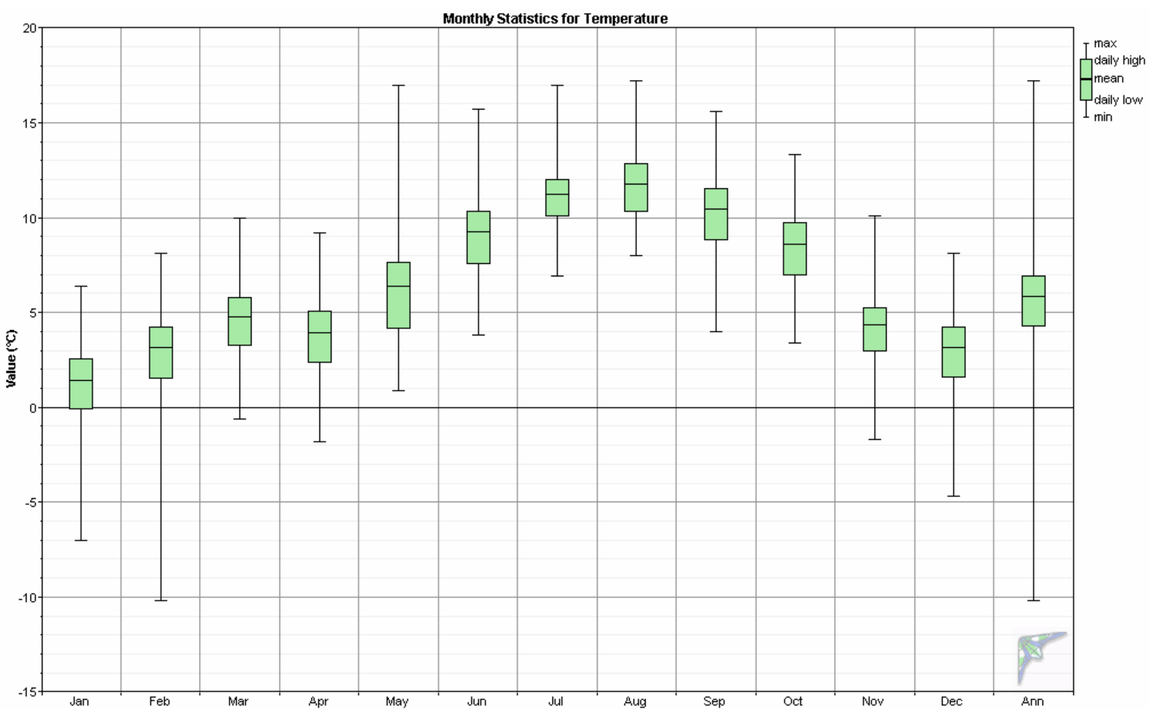
20 m speed - 27 m vane, 4 m/s threshold wind speed, 12/11/05 to 3/13/07

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records In Bin	Standard Deviation of Wind Speed (m/s)	Mean Turbulence Intensity	Standard Deviation of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	605	0.463	0.498	0.170	0.668
2	1.5	2.5	889	0.504	0.260	0.116	0.376
3	2.5	3.5	1448	0.501	0.169	0.072	0.241
4	3.5	4.5	1736	0.559	0.142	0.054	0.196
5	4.5	5.5	2204	0.666	0.134	0.042	0.176
6	5.5	6.5	2583	0.779	0.130	0.033	0.164
7	6.5	7.5	2585	0.884	0.127	0.032	0.159
8	7.5	8.5	2437	0.994	0.125	0.030	0.155
9	8.5	9.5	2493	1.107	0.123	0.025	0.149
10	9.5	10.5	2433	1.218	0.123	0.025	0.148
11	10.5	11.5	2171	1.326	0.121	0.024	0.145
12	11.5	12.5	1803	1.460	0.122	0.022	0.145
13	12.5	13.5	1696	1.592	0.123	0.020	0.143
14	13.5	14.5	1285	1.712	0.123	0.021	0.144
15	14.5	15.5	959	1.811	0.121	0.020	0.141
16	15.5	16.5	771	1.888	0.119	0.021	0.139
17	16.5	17.5	599	2.014	0.119	0.022	0.141
18	17.5	18.5	409	2.104	0.117	0.022	0.139
19	18.5	19.5	234	2.204	0.117	0.020	0.137
20	19.5	20.5	131	2.377	0.120	0.019	0.138
21	20.5	21.5	101	2.464	0.118	0.018	0.136
22	21.5	22.5	71	2.600	0.119	0.013	0.132
23	22.5	23.5	39	2.762	0.121	0.017	0.137
24	23.5	24.5	13	2.723	0.114	0.012	0.127
25	24.5	25.5	4	2.950	0.119	0.010	0.129
26	25.5	26.5	1	3.300	0.127	0.000	0.127
27	26.5	27.5	1	3.300	0.121	0.000	0.121
28	27.5	28.5	0	3.300	0.121	0.000	0.121

Air Temperature and Density

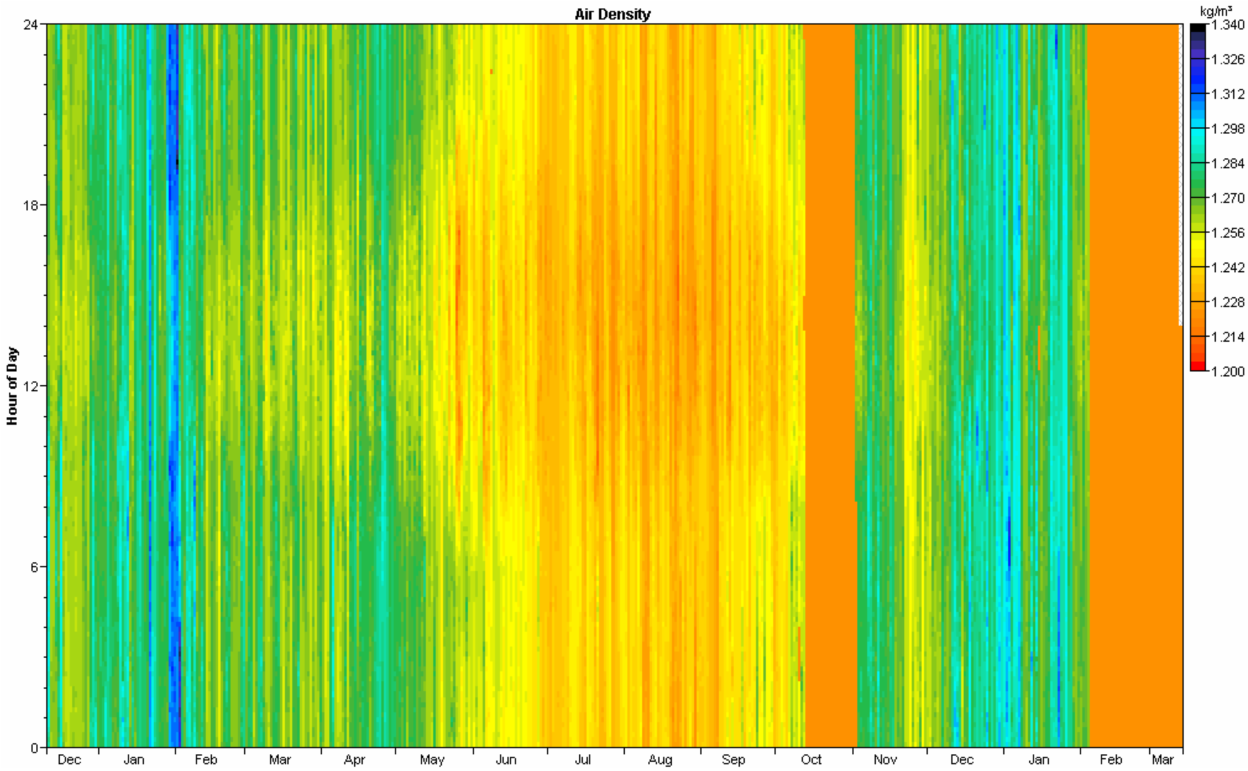
Over the reporting period, Nikolski had an average temperature of 6.5° C, although note that the temperature sensor began to fail in October 2006 and completely failed in February 2007. The minimum recorded temperature during the measurement period was -10.2° C and the maximum temperature was 17.2° C, indicating a cool temperate operating environment for wind turbine operations. Consequent to Nikolski's cool temperatures, the average air density of 1.253 kg/m^3 is 2.5 percent higher than the standard air density of 1.222 kg/m^3 (at 14.8° C and 100.9 kPa) at the test site elevation of 27 meters. Density variance from standard is accounted for in turbine performance predictions.

	Temperature				Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Std. Dev. (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	1.4	-7.0	6.4	2.59	1.281	1.221	1.322
Feb	3.2	-10.2	8.1	2.68	1.251	1.221	1.338
Mar	4.8	-0.6	10.0	1.58	1.253	1.221	1.291
Apr	4.0	-1.8	9.2	2.08	1.269	1.246	1.296
May	6.4	0.9	17.0	2.39	1.258	1.212	1.284
Jun	9.3	3.8	15.7	1.80	1.246	1.218	1.270
Jul	11.2	6.9	17.0	1.39	1.237	1.212	1.256
Aug	11.8	8.0	17.2	1.50	1.235	1.211	1.251
Sep	10.5	4.0	15.6	1.80	1.240	1.218	1.269
Oct	8.6	3.4	13.3	1.75	1.232	1.221	1.272
Nov	4.4	-1.7	10.1	2.24	1.266	1.221	1.296
Dec	3.2	-4.7	8.1	2.46	1.273	1.251	1.310
Annual	6.5	-10.2	17.2	4.17	1.253	1.211	1.338



Air Density DMap

The DMap is a visual indication of the daily and seasonal variations of air density (and hence temperature). Air densities higher than standard will yield higher turbine power than predicted by turbine power curves (which are calibrated for a sea level temperature of 15° C, air pressure of 101.3 kPa, and air density of 1.225 kg/m^3), while densities lower than standard will yield lower turbine power than predicted by the power curves. Orange bands in October 2006 and February and March 2007 indicated compromised temperature data. For these time periods, a standard temperature and air density are assumed.



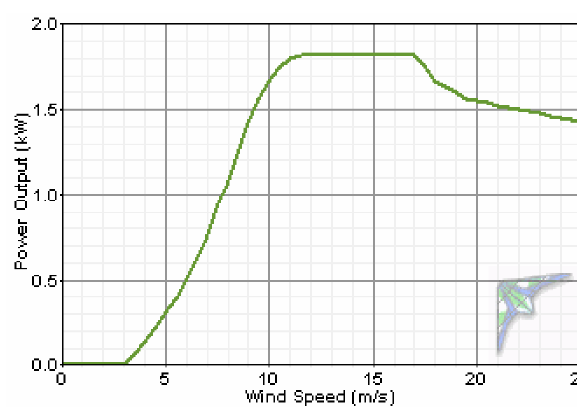
Turbine Performance Predictions

The turbine performance predictions noted below are based on 100 percent and 89 percent turbine availabilities. The 100 percent data is for use as a baseline of comparison, but it is realistic to expect ten percent or more of losses or downtime for wind turbines located in a small, remote community such as Nikolski.

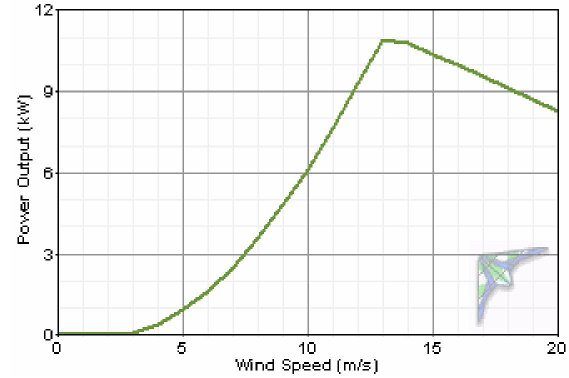
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m^3 at sea level with standard temperature and pressure. However, the predictions of power production are density compensated by multiplying the standard density power output by the ratio of the measured air density to standard air density, accounting for the site elevation.

A number of smaller village-scale grid-connected turbines are profiled in this report for comparison purposes. These turbines were selected because they have market availability and they are deemed to be within a suitable range for consideration of wind power development in a village the size of Nikolski.

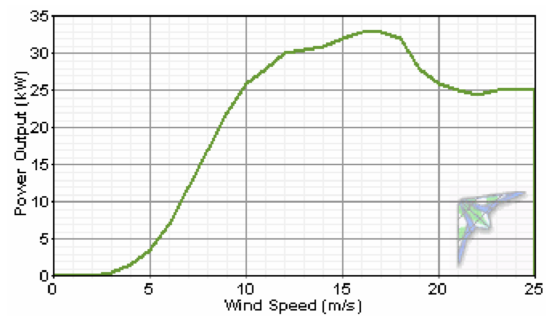
Southwest Skystream 3.7: 1.8 kW rated power output, 3.7 meter rotor diameter, stall-controlled. Available tower heights: 10.7 and 33.5 meters. Additional information is available at www.skystreamenergy.com.



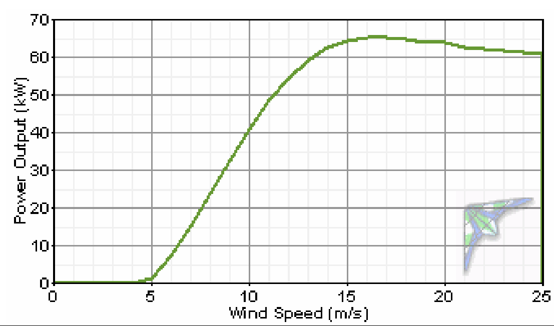
Bergey Excel-S: 10 kW rated power output, 6.7 meter rotor diameter, stall-controlled. Available tower heights: 18, 24, 30, 37 and 43 meters. Additional information is available at www.bergey.com.



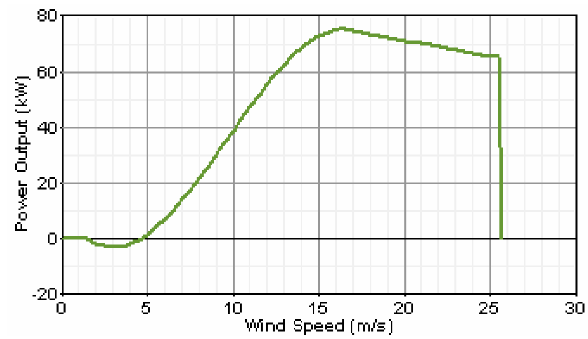
Fuhrländer FL30: 30 kW rated power output, 13 meter rotor, stall-controlled (power curve provided by Lorax Energy, LLC). Available tower heights: 26 and 30 meters. Additional information is available at http://www.fuhrlaender.de/ and http://www.lorax-energy.com/.



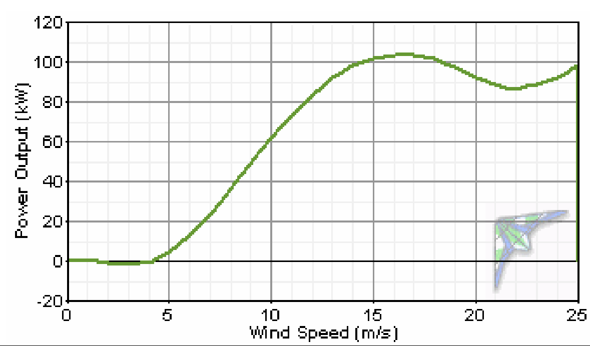
Entegrity eW-15: 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Available tower heights: 25 and 31 meters. Additional information is available at http://www.entegritywind.com/.



Vestas V15: 75 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Powercorp Alaska LLC). Available tower heights: 25, 31 and 34 meters. Additional information is available at http://www.pcorpalaska.com/.



Northwind 100/19: 100 kW rated power output, 19 meter rotor, stall-controlled (power curve provided by Northern Power Systems). Available tower heights: 25 and 32 meters. Additional information is available at http://www.northernpower.com/.



Turbine Power Output Comparison (100% turbine availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Annual Net Energy Output (kWh/yr)	Average Net Capacity Factor (%)
Southwest Skystream 3.7	10.7	7.72	13.9	22.7	0.92	8,059	51.2
Bergey Excel-S	24	8.82	8.3	15.1	4.63	40,508	46.3
Fuhrländer FL30	26	8.94	6.6	5.8	17.5	153,522	53.2
Entegrity eW-15 60 Hz	25	8.88	16.3	11.5	29.9	261,556	46.0
Vestas V15	25	8.88	20.1	6.6	30.3	264,644	40.4
Northern Power NW 100/19	25	8.88	16.3	8.1	42.3	369,639	42.3

Capacity Factor <20%
Capacity Factor >20%, <30%
Capacity Factor >30%, <40%
Capacity Factor >40%, <50%
Capacity Factor >50%

Assumed turbine losses for predictions of average power output, annual energy output, and average capacity factor:

Downtime (%)	0
Array (%)	0
Icing/soiling (%)	0
Other (%)	0
Total (%)	0

Turbine Power Output Comparison (89% availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Net Power Output (kW)	Annual Net Energy Output (kWh/yr)	Average Net Capacity Factor (%)
Southwest Skystream 3.7	10.7	7.72	13.9	22.7	0.82	7,198	45.7
Bergey Excel-S	24	8.82	8.3	15.1	4.14	36,182	41.4
Fuhrländer FL30	26	8.94	6.6	5.8	15.66	137,126	47.5
Entegrity eW-15 60 Hz	25	8.88	16.3	11.5	26.71	233,622	41.1
Vestas V15	25	8.88	20.1	6.6	27.03	236,380	36.0
Northern Power NW 100/20	25	8.88	16.3	8.1	37.76	330,162	37.8

Capacity Factor <20%
Capacity Factor >20%, <30%
Capacity Factor >30%, <40%
Capacity Factor >40%, <50%
Capacity Factor >50%

Assumed turbine losses for predictions of average power output, annual energy output, and average capacity factor:

Downtime (%)	7	
Array (%)	0	
Icing/soiling (%)	2	
Other (%)	2	
Total (%)	10.68	(factors are multiplicative)

Annual Fuel Cost Avoided for Energy Generated by Wind Turbine vs. Diesel Generator

Turbine	Annual Energy Output (kW-hr/yr)	Fuel Quantity Avoided (gallons)	Fuel Price (USD/gallon) $1.75	$2.00	$2.25	$2.50	$2.75	$3.00	$3.25	Turbine Hub Height (m)
Southwest Skystream 3.7	7,198	600	$1,050	$1,200	$1,350	$1,500	$1,650	$1,800	$1,950	10.7
Bergey Excel-S	36,182	3,015	$5,277	$6,030	$6,784	$7,538	$8,292	$9,045	$9,799	24
Fuhrländer FL30	137,126	11,427	$19,998	$22,854	$25,711	$28,568	$31,425	$34,281	$37,138	26
Entegrity eW-15 60 Hz	233,622	19,468	$34,070	$38,937	$43,804	$48,671	$53,538	$58,405	$63,273	25
Vestas V15	236,380	19,698	$34,472	$39,397	$44,321	$49,246	$54,170	$59,095	$64,020	25
Northern Power NW 100/20	330,162	27,513	$48,149	$55,027	$61,905	$68,784	$75,662	$82,540	$89,419	25

Notes:

1. Nikolski electrical energy production efficiency assumed to be 12.0 kW-hr/gal
2. Assumes **89**% wind turbine availability with no diversion of power to a thermal or other dump load
3. Assumes linear diesel generator fuel efficiency (i.e., 1:1 tradeoff of wind turbine kW-hr to diesel genset kW-hr)

Temperature Conversion Chart °C to °F

°C	°F	°C	°F	°C	°F
-40	-40	-10	14	20	68
-39	-38.2	-9	15.8	21	69.8
-38	-36.4	-8	17.6	22	71.6
-37	-34.6	-7	19.4	23	73.4
-36	-32.8	-6	21.2	24	75.2
-35	-31	-5	23	25	77
-34	29.2	-4	24.8	26	78.8
-33	-27.4	-3	26.6	27	80.6
-32	-25.6	-2	28.4	28	82.4
-31	-23.8	-1	30.2	29	84.2
-30	-22	0	32	30	86
-29	-20.2	1	33.8	31	87.8
-28	-18.4	2	35.6	32	89.6
-27	-16.6	3	37.4	33	91.4
-26	-14.8	4	39.2	34	93.2
-25	-13	5	41	35	95
-24	-11.2	6	42.8	36	96.8
-23	-9.4	7	44.6	37	98.6
-22	-7.6	8	46.4	38	100.4
-21	-5.8	9	48.2	39	102.2
-20	-4	10	50	40	104
-19	-2.2	11	51.8	41	105.8
-18	-0.4	12	53.6	42	107.6
-17	1.4	13	55.4	43	109.4
-16	3.2	14	57.2	44	111.2
-15	5	15	59	45	113
-14	6.8	16	60.8	46	114.8
-13	8.6	17	62.6	47	116.6
-12	10.4	18	64.4	48	118.4
-11	12.2	19	66.2	49	120.2

Wind Speed Conversion Chart m/s to mph

m/s	mph	m/s	mph	m/s	mph
0.5	1.1	10.5	23.5	20.5	45.9
1.0	2.2	11.0	24.6	21.0	47.0
1.5	3.4	11.5	25.7	21.5	48.1
2.0	4.5	12.0	26.8	22.0	49.2
2.5	5.6	12.5	28.0	22.5	50.3
3.0	6.7	13.0	29.1	23.0	51.4
3.5	7.8	13.5	30.2	23.5	52.6
4.0	8.9	14.0	31.3	24.0	53.7
4.5	10.1	14.5	32.4	24.5	54.8
5.0	11.2	15.0	33.6	25.0	55.9
5.5	12.3	15.5	34.7	25.5	57.0
6.0	13.4	16.0	35.8	26.0	58.2
6.5	14.5	16.5	36.9	26.5	59.3
7.0	15.7	17.0	38.0	27.0	60.4
7.5	16.8	17.5	39.1	27.5	61.5
8.0	17.9	18.0	40.3	28.0	62.6
8.5	19.0	18.5	41.4	28.5	63.8
9.0	20.1	19.0	42.5	29.0	64.9
9.5	21.3	19.5	43.6	29.5	66.0
10.0	22.4	20.0	44.7	30.0	67.1

Distance Conversion m to ft

m	ft	m	ft
5	16	35	115
10	33	40	131
15	49	45	148
20	66	50	164
25	82	55	180
30	98	60	197

Selected definitions (courtesy of Windographer® software by Mistaya Engineering Inc.)

Wind Power Class

The wind power class is a number indicating the average energy content of the wind resource. Wind power classes are based on the average wind power density at 50 meters above ground, according to the following table. Source: Wind Energy Resource Atlas of the United States (http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html)

Wind Power Class	Description	Power Density at 50m (W/m^2)
1	Poor	0-200
2	Marginal	200-300
3	Fair	300-400
4	Good	400-500
5	Excellent	500-600
6	Outstanding	600-800
7	Superb	800-2000

Windographer classifies any wind resource with an average wind power density above 2000 W/m^2 as class 8.

Probability Distribution Function

The probability distribution function f(x) gives the probability that a variable will take on the value x. It is often expressed using a frequency histogram, which gives the frequency with which the variable falls within certain ranges or bins.

Wind Turbine Power Regulation

All wind turbines employ some method of limiting power output at high wind speeds to avoid damage to mechanical or electrical subsystems. Most wind turbines employ either stall control or pitch control to regulate power output.

A stall-controlled turbine typically has blades that are fixed in place, and are designed to experience aerodynamic stall at very high wind speeds. Aerodynamic stall dramatically reduces the torque produced by the blades, and therefore the power produced by the turbine.

On a pitch-controlled turbine, a controller adjusts the angle (pitch) of the blades to best match the wind speed. At very high wind speeds the controller increasingly feathers the blades out of the wind to limit the power output.