Togiak, Alaska Wind Resource Report

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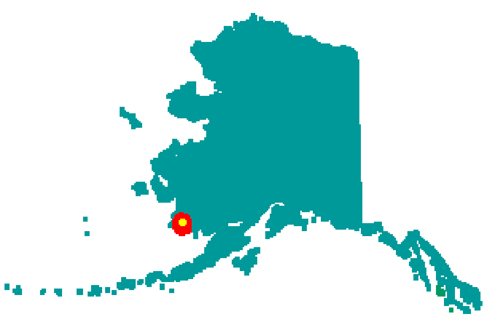
Photo by Doug Vaught



Summary Information

Togiak's winds are possibly lighter than expected given its geographic location on the Bering Sea coast. This may be due to the site location well down on the northeast side of the hill that comprises the Togiak Heights subdivision. Possibly more exposed locations would experience higher wind speeds.

Meteorological Tower Data Synopsis

Wind power class	Class 3 – Fair
Wind speed annual average (30 meters)	5.68 m/s
Maximum wind gust (2 sec avg)	32.9 m/s (April 2005)
Mean wind power density (50 meters)	311 W/m^2 (calculated)
Mean wind power density (30 meters)	256 W/m^2 (measured)
Weibull distribution parameters	k = 1.75, c = 6.40 m/s
Roughness Class	1.11 (fallow field)
Power law exponent	0.151 (moderate wind shear)
Turbulence Intensity	0.104
Data start date	September 11, 2004
Data end date	July 12, 2006

Community Profile

Current Population:	779 (2005 State Demographer est.)
Pronunciation/Other Names:	(TOAG-ee-ack)
Incorporation Type:	2nd Class City
Borough Located In:	Unorganized
School District:	Southwest Region Schools
Regional Native Corporation:	Bristol Bay Native Corporation

Location:

Togiak is located at the head of Togiak Bay, 67 miles west of Dillingham. It lies in Togiak National Wildlife Refuge, and is the gateway to Walrus Island Game Sanctuary. It lies at approximately 59.061940° North Latitude and -160.376390° West Longitude. (Sec. 12, T013S, R067W, Seward Meridian.) Togiak is located in the Bristol Bay Recording District. The area encompasses 45.2 sq. miles of land and 183.3 sq. miles of water.

History:

In 1880, "Old Togiak," or "Togiagamute," was located across the Bay, and had a population of 276. Heavy winter snowfalls made wood-gathering difficult at Old Togiak, so gradually people settled at a new site on the opposite shore, where the task was easier. Many residents of the Yukon-Kuskokwim region migrated south to the Togiak area after the devastating influenza epidemic in 1918-19. A school was established in an old church in 1950. A school building and a National Guard Armory were constructed in 1959. Togiak was flooded in 1964, and many fish racks and stores of gas, fuel oil and stove oil were destroyed. Three or four households left Togiak after the flood and developed the village of Twin Hills upriver. The City government was incorporated in 1969.

Culture:

Togiak is a traditional Yup'ik Eskimo village with a fishing and subsistence lifestyle. The sale, importation or possession of alcohol is banned in the village.

Economy:

Togiak's economic base is primarily commercial salmon, herring, and herring roe-on-kelp fisheries. Two hundred forty-four residents hold commercial fishing permits; fishermen use flat-bottom boats for the shallow waters of Togiak Bay. There is one on-shore fish processor and several floating processing facilities near Togiak. The entire community depends heavily on subsistence activities. Salmon, herring, seal, sea lion, whale and walrus are among the species harvested. A few residents trap.

Facilities:

Water is derived from a well, is treated and stored in a 500,000-gal. tank. The majority of households (125 residences) are connected to the piped water and sewer system installed in 1976; the remaining homes have new individual wells and septic tanks. Thirty-five new HUD housing units were recently completed in the Togiak Heights Subdivision, with a sewage system. In all, 210 homes are fully plumbed, and 14 are not. The water system is 25 to 30 years old and suffers from broken or corroded pipes, valves and service connections. A new landfill was recently completed.

Transportation:

A State-owned 4,400' long by 98' wide lighted gravel airstrip with a 1,200' long by 49' wide crosswind airstrip and navigation aids is available. Scheduled and chartered flights are available from Dillingham. Freight is brought in by air or barge and lightered to shore. There are no docking facilities. Skiffs, autos, ATVs and snowmachines are used for local transportation.

Climate:

Togiak is located in a climatic transition zone, however the arctic climate also affects this region. Average summer temperatures range from 37 to 66; winter temperatures average 4 to 30. Precipitation is 20 to 26 inches annually. Fog and high winds are prevalent during the winter. The Bay is ice-free from June through mid-November.

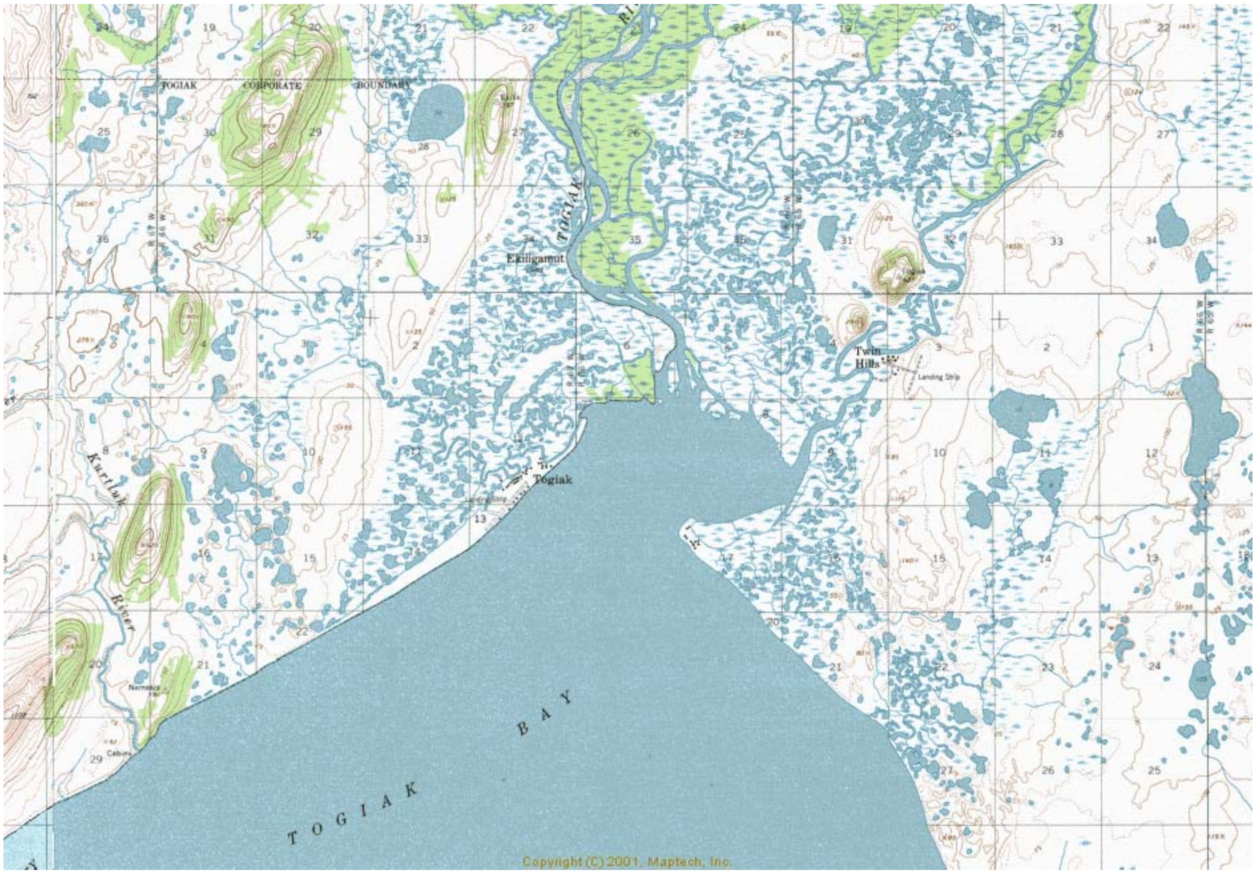
(Above information from State of Alaska Department of Commerce, Community, and Economic Development website, http://www.dced.state.ak.us/)

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	west
2	NRG #40 anemometer	22 m	0.765	0.35	northeast
7	NRG #200P wind vane	30 m	0.351	280	east
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

Site Information and Location

Site number	0010
Site Description	Open tundra, northeast side of Togiak Heights subdivision
Latitude/longitude	N 59° 04.278’; W 160° 25.386’
Site elevation	20 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6-in) diameter


TOGIAK CORPORATE BOUNDARY
TOGIAK
Ekilligamut
Twin Hills
Landing Strip
Togiak
TOGIAK BAY
Copyright (C) 2001, Maptech, Inc.

Data Quality Control

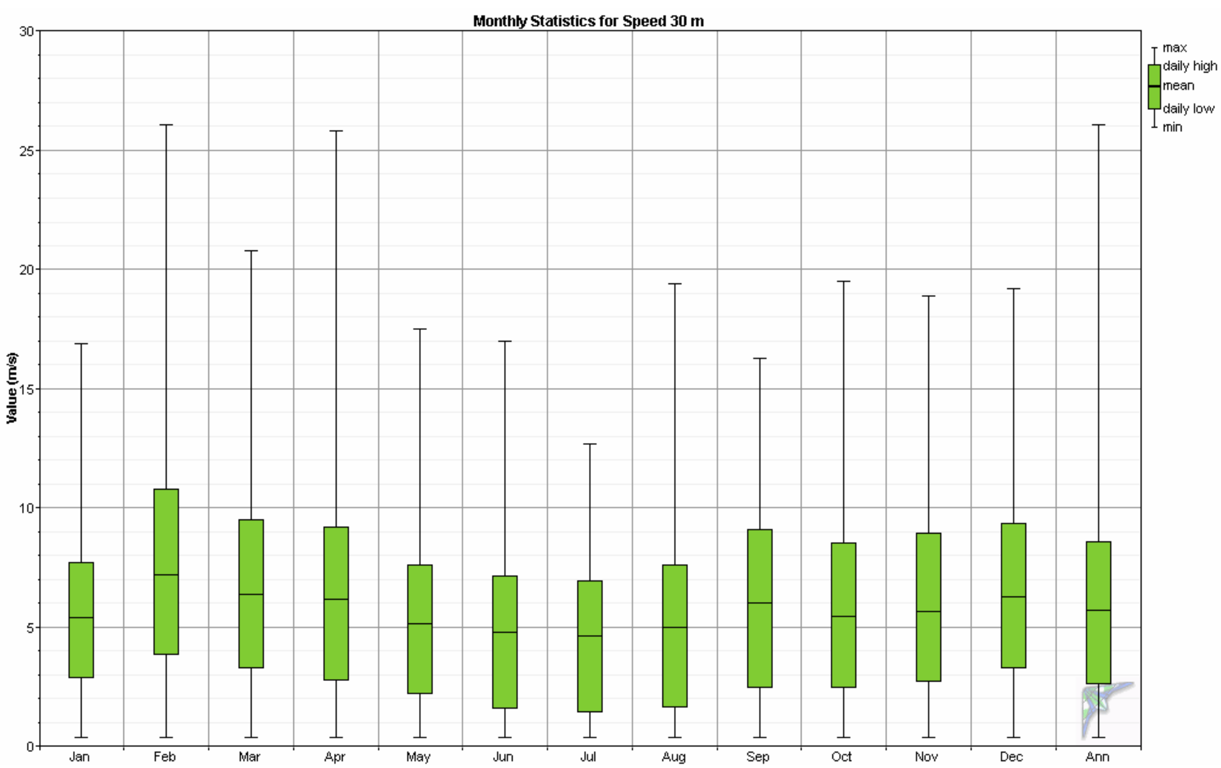
Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 2° C. Note that during the months of March through September little to no data was lost due to icing with some icing loss during the winter months. Because sensor icing was minimal, filtered data was not synthesized and replaced.

		Ch 1 (30 m speed)		Ch 2 (22 m speed)		Ch 7 (wind vane)		Ch 9 (temperature)	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2004	Sep	2,820	100	2,820	100	2,820	100	2,820	100
2004	Oct	4,464	100	4,464	100	4,464	100	4,464	100
2004	Nov	4,182	96.8	4,182	96.8	4,227	97.8	4,320	100
2004	Dec	4,266	95.6	4,182	93.7	2,802	62.8	4,464	100
2005	Jan	4,210	94.3	4,233	94.8	4,002	89.7	4,464	100
2005	Feb	3,910	97.0	3,910	97.0	3,846	95.4	4,032	100
2005	Mar	4,446	100	4,446	100	4,345	97.3	4,446	100
2005	Apr	4,320	100	4,320	100	4,320	100	4,320	100
2005	May	4,464	100	4,464	100	4,464	100	4,464	100
2005	Jun	4,320	100	4,320	100	4,320	100	4,320	100
2005	Jul	4,464	100	4,464	100	4,464	100	4,464	100
2005	Aug	4,464	100	4,464	100	4,464	100	4,464	100
2005	Sep	4,320	100	4,320	100	4,320	100	4,320	100
2005	Oct	4,382	98.2	4,464	100	4,317	96.7	4,464	100
2005	Nov	4,320	100	4,320	100	4,320	100	4,320	100
2005	Dec	4,101	91.9	3,774	84.5	3,659	82.0	4,464	100
2006	Jan	4,405	98.7	4,405	98.7	4,464	100	4,464	100
2006	Feb	3,932	97.5	3,932	97.5	4,032	100	4,032	100
2006	Mar	4,382	98.2	4,464	100	4,417	98.9	4,464	100
2006	Apr	4,320	100	4,320	100	4,320	100	4,320	100
2006	May	4,464	100	4,464	100	4,464	100	4,464	100
2006	Jun	4,320	100	4,320	100	4,320	100	4,320	100
2006	Jul	1,638	100	1,638	100	1,638	100	1,638	100
All data		94,914	98.5	94,690	98.3	92,809	96.3	96,312	100

Measured Wind Speeds

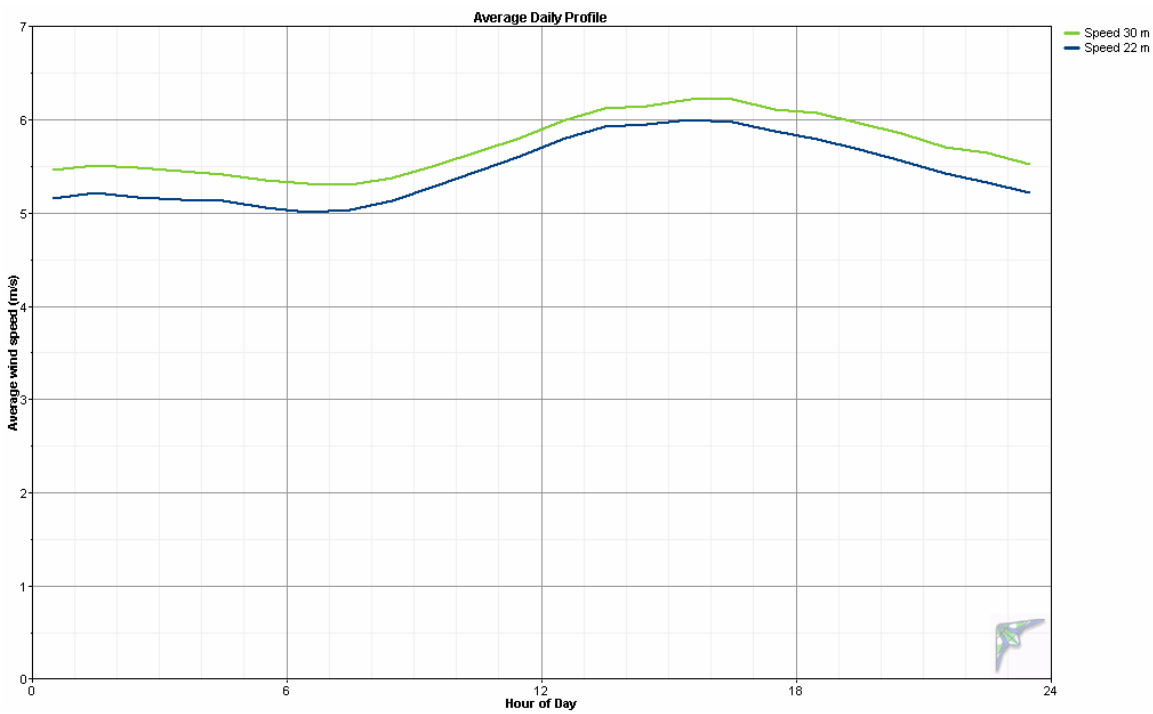
The 30 meter anemometer annual wind speed average for the reporting period is 5.68 m/s and the 22 meter anemometer wind speed average is 5.42 m/s.

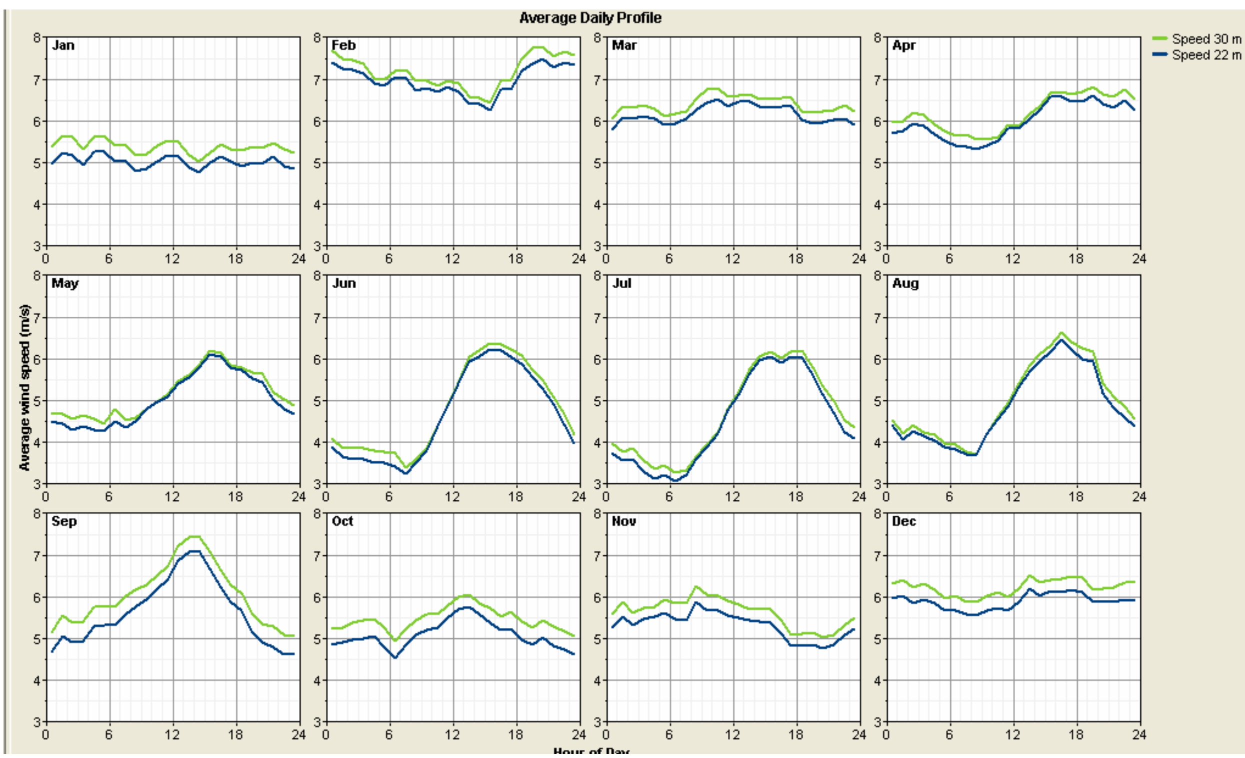
	30 m speed (Ch 1)					22 m speed (Ch 2)		
Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)
Jan	5.39	16.9	2.77	2.003	6.07	5.02	16.2	2.68
Feb	7.21	26.1	4.34	1.697	8.06	6.95	25.3	4.45
Mar	6.41	20.8	3.63	1.792	7.18	6.16	19.2	3.49
Apr	6.18	25.8	3.70	1.651	6.86	5.99	24.8	3.59
May	5.16	17.5	2.79	1.873	5.78	5.01	17.4	2.74
Jun	4.80	17.0	2.70	1.799	5.37	4.62	16.4	2.62
Jul	4.65	12.7	2.47	1.880	5.20	4.49	12.3	2.37
Aug	4.99	19.4	2.92	1.718	5.58	4.86	18.4	2.69
Sep	6.05	16.3	3.08	2.017	6.80	5.63	15.5	2.97
Oct	5.48	19.5	3.36	1.652	6.12	5.09	18.8	3.16
Nov	5.67	18.9	3.50	1.604	6.30	5.35	18.7	3.43
Dec	6.28	19.2	3.07	2.115	7.06	5.87	18.5	3.00
Annual	**5.68**	26.1	3.33	1.745	6.41	**5.42**	25.3	3.25



Daily Wind Profile

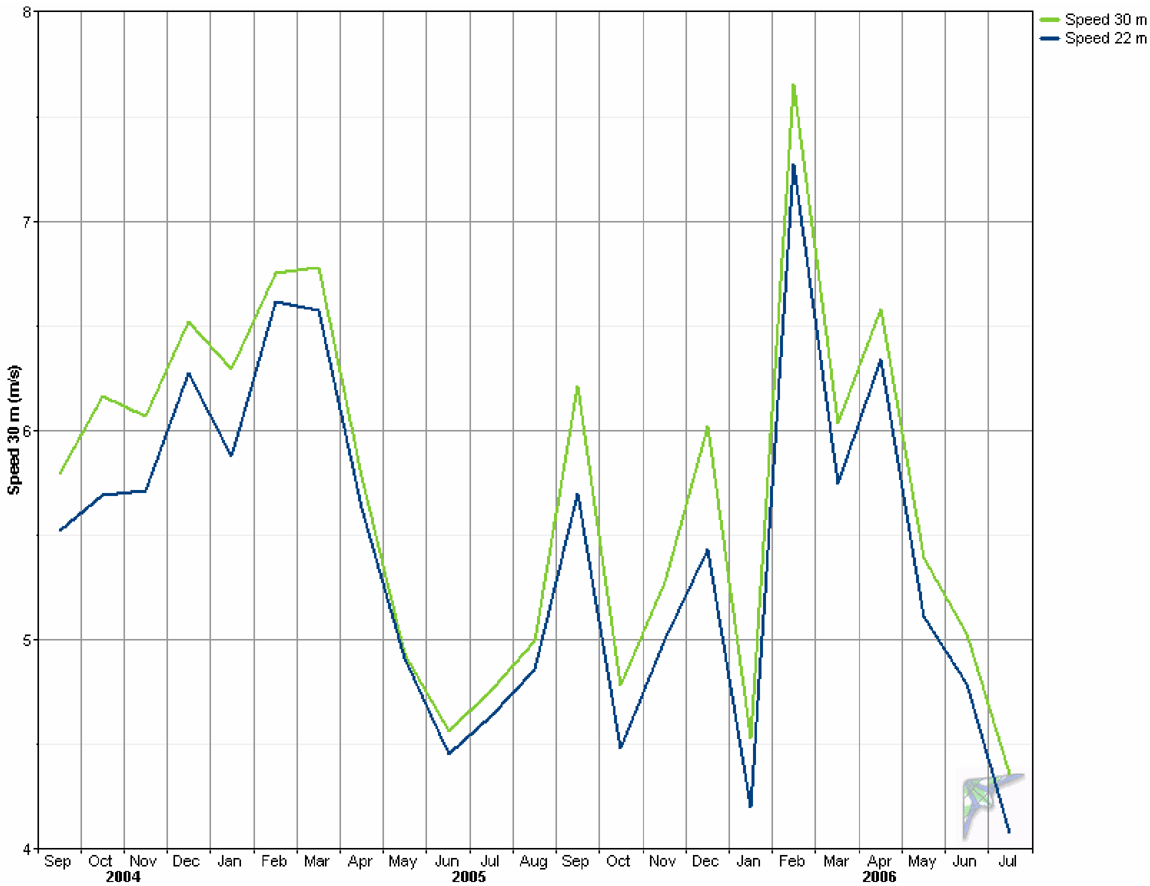
The daily wind profile indicates a strong daily variation of wind speeds with the lowest wind speeds occurring in the morning hours of 6 to 8 a.m. and the highest wind speeds of the day occur during the afternoon and early evening hours of 2 to 6 p.m.

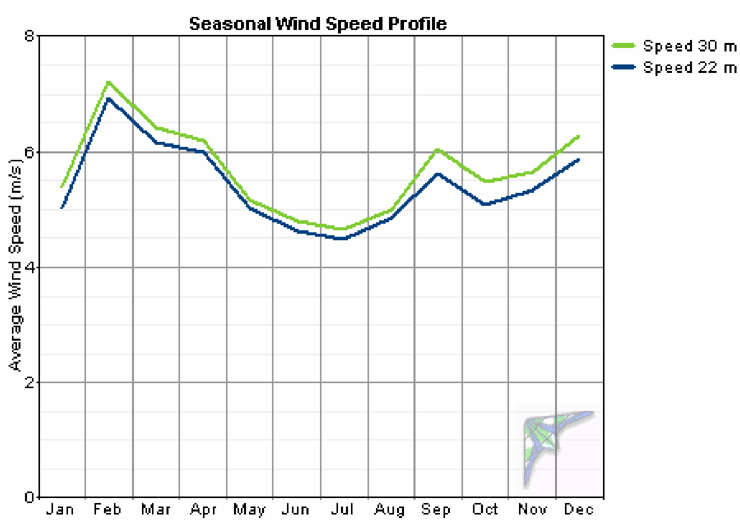




Time Series of Wind Speed Monthly Averages

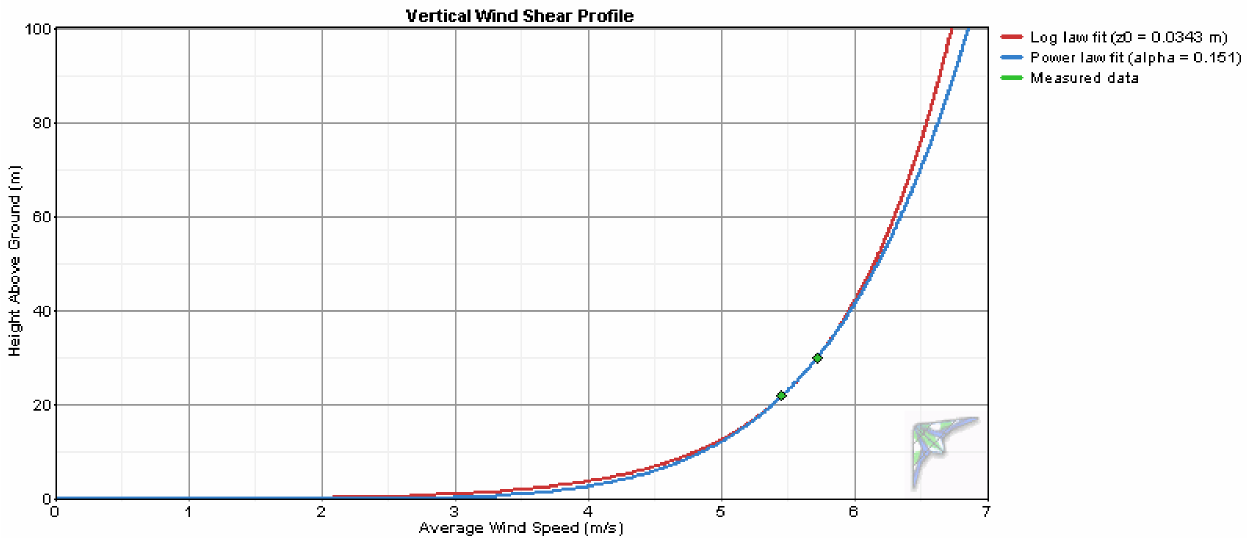
As expected, the highest winds occurred during the fall through spring months with relatively light winds during the late spring and summer months of May through August. Note that the measured winds in January 2006 were unusually low. This was due to a high pressure system that brought extremely cold temperatures and low winds throughout much of Alaska during this month.

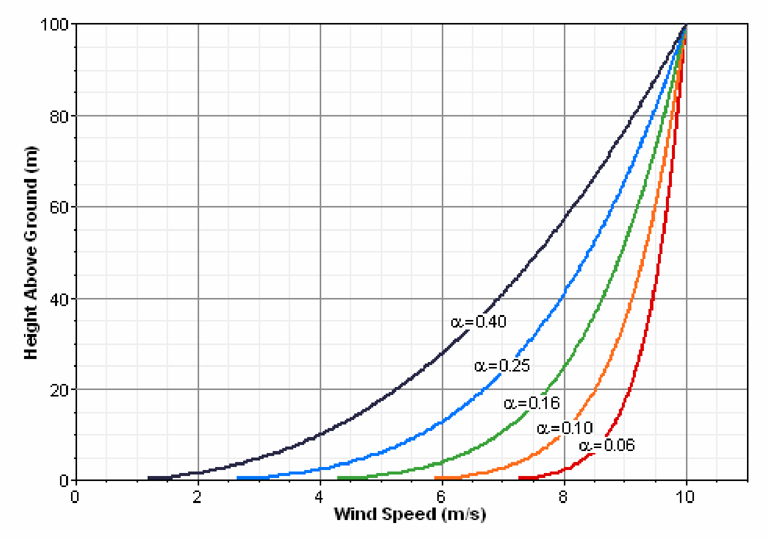


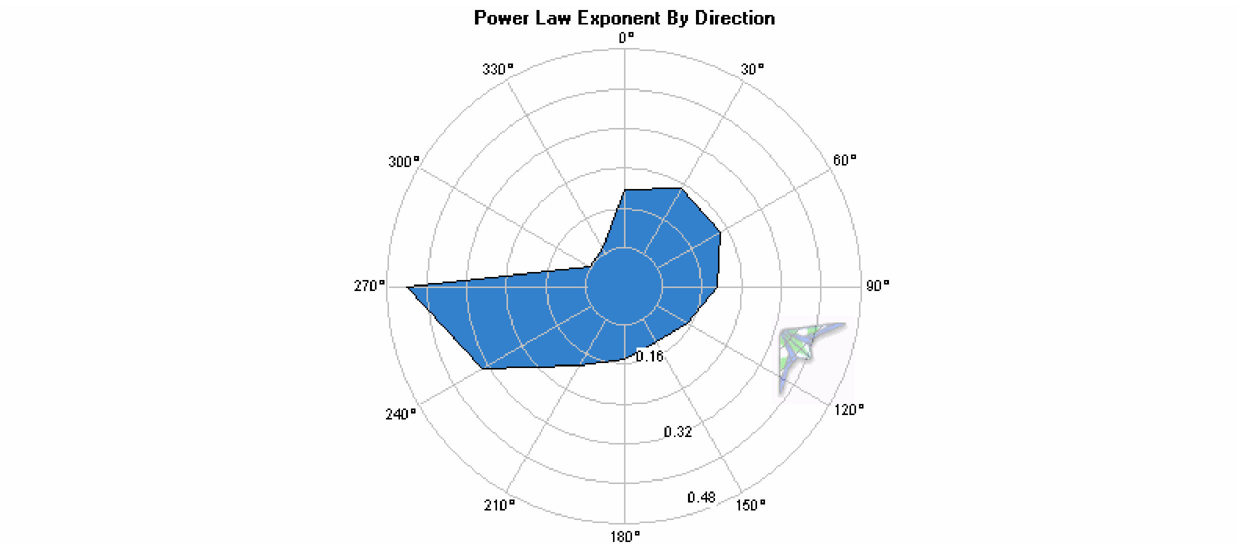


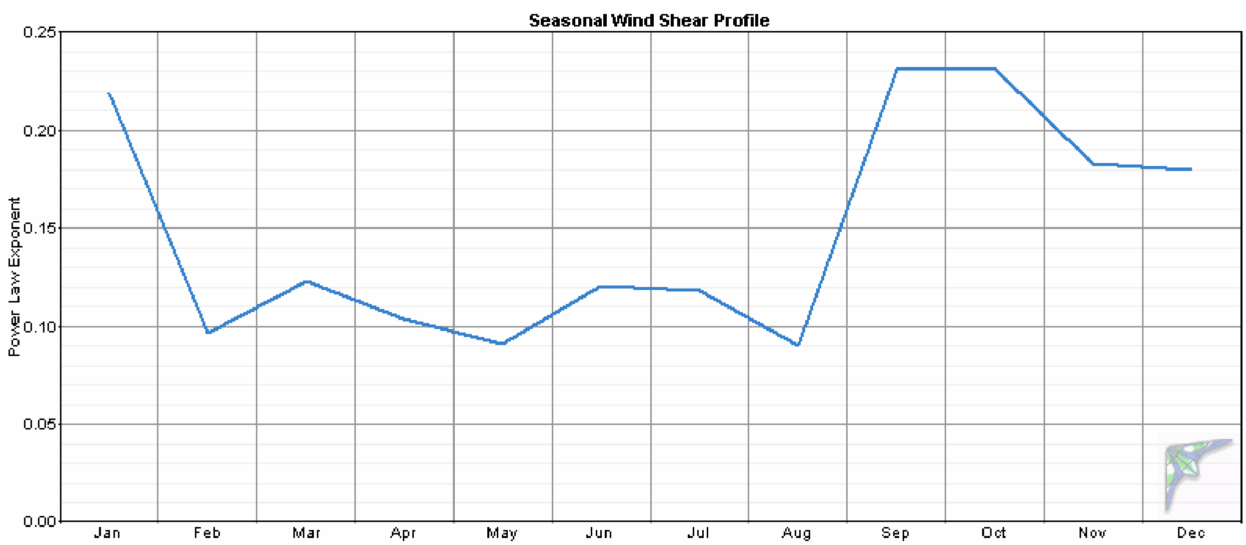
Wind Shear Profile

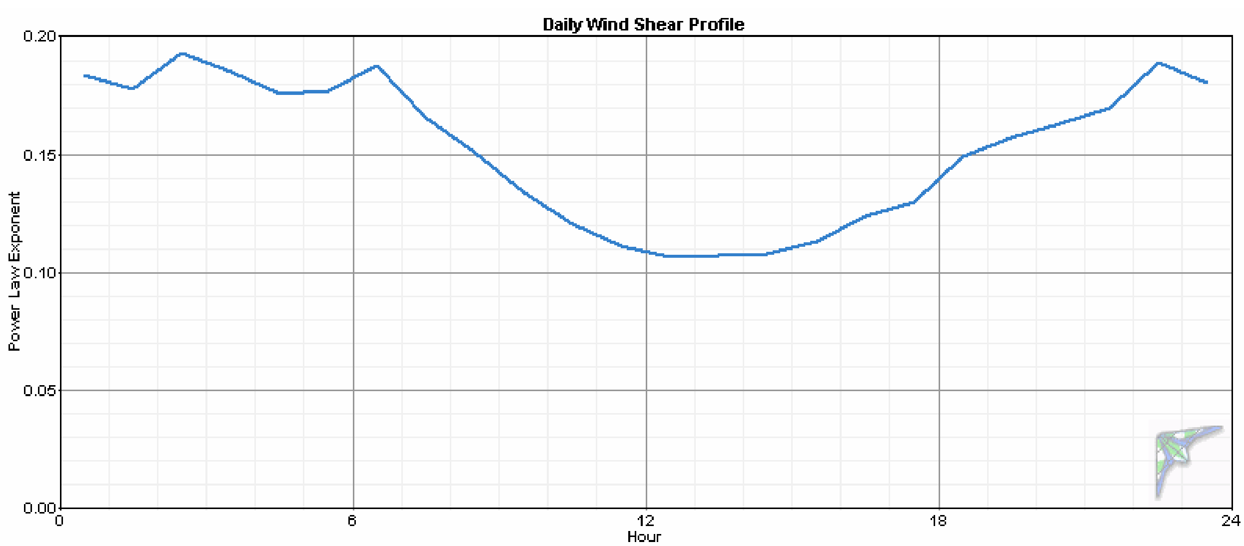
The average power law exponent was calculated at 0.154, indicating moderate wind shear at the Togiak met tower test site, with the seasonal wind shear variation shown below. The practical application of this information is that a higher turbine tower height is advantageous as there is an appreciable marginal gain in average wind speed with height. However, a tower height/power recovery/construction cost tradeoff study would be advisable should a wind power project be initiated.





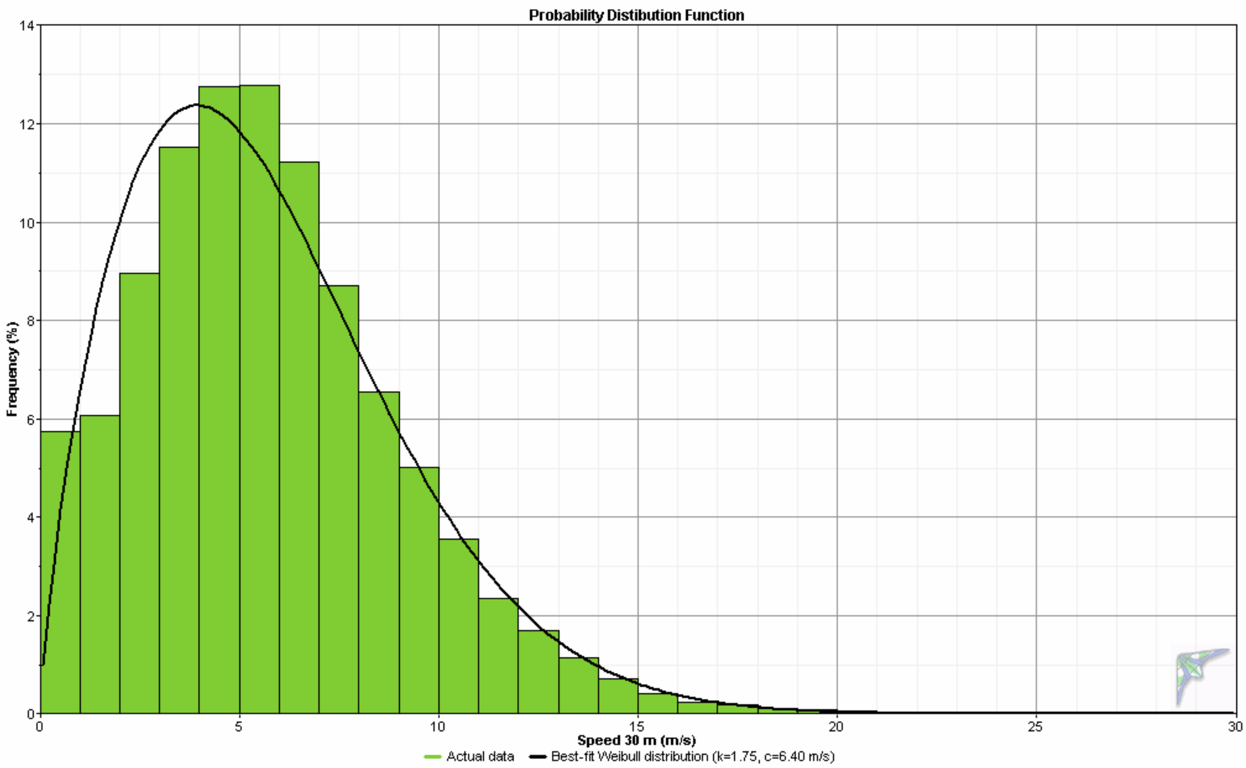

Power Law Exponent By Direction
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0.16
0.32
0.48

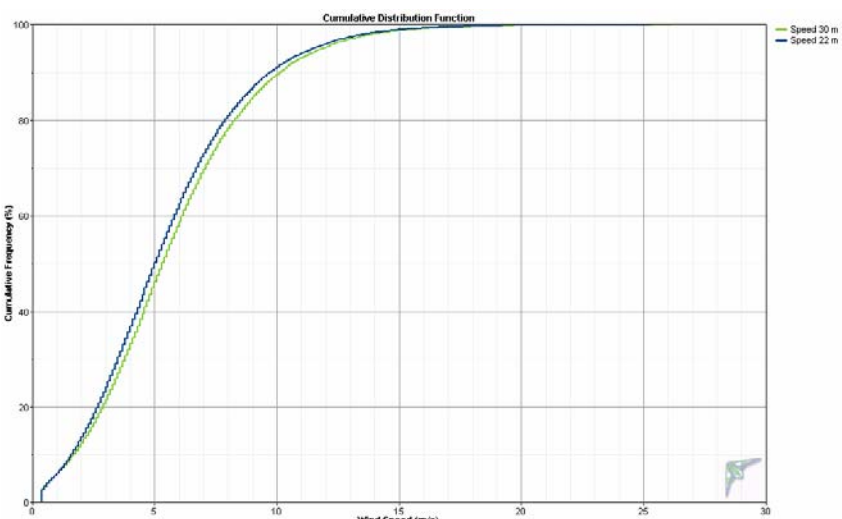

Seasonal Wind Shear Profile
Power Law Exponent
0.25
0.20
0.15
0.10
0.05
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


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 = 1.75 (indicates a low distribution of wind speeds) and c = 6.40 m/s (scale factor for the Weibull distribution).



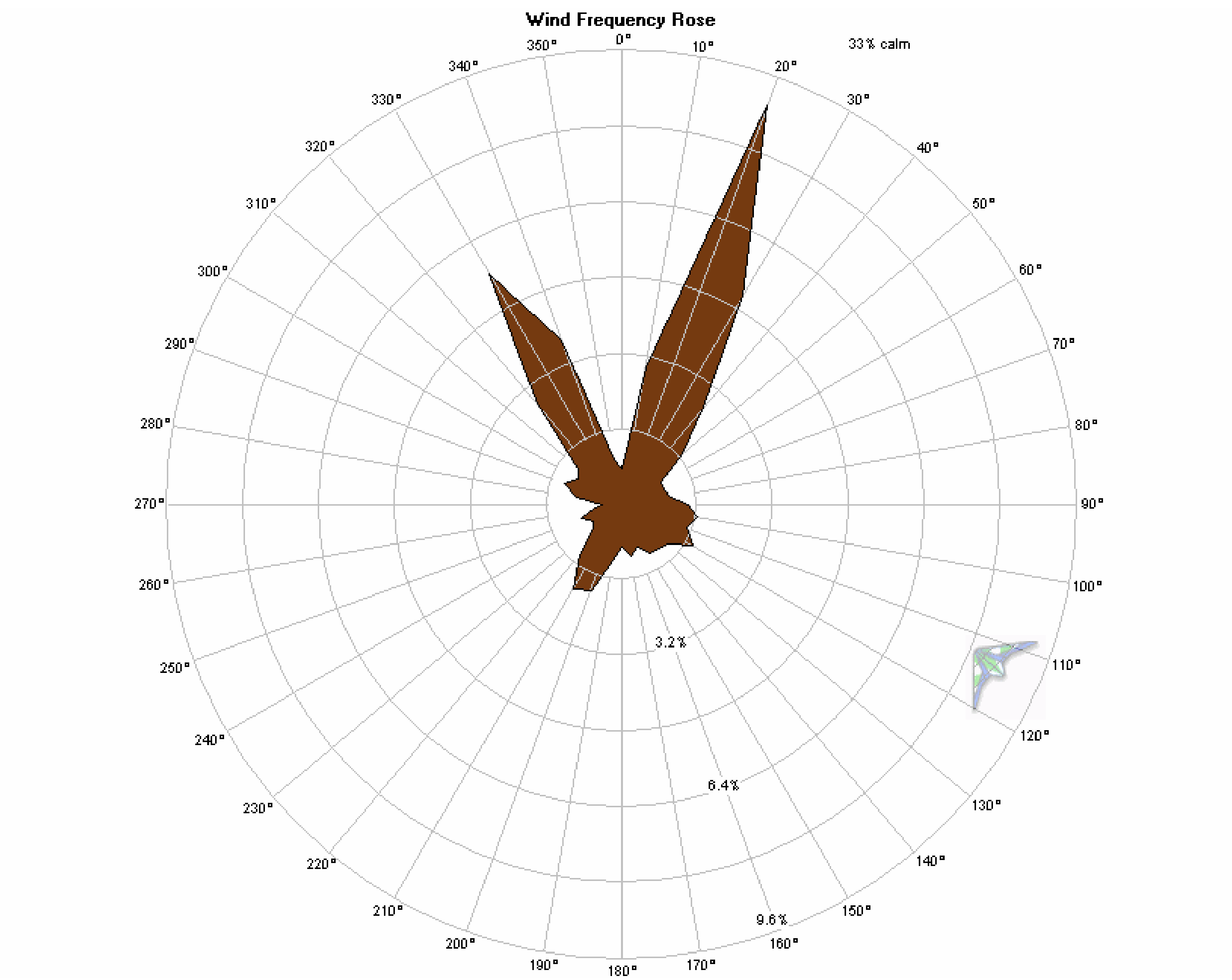


Wind Roses

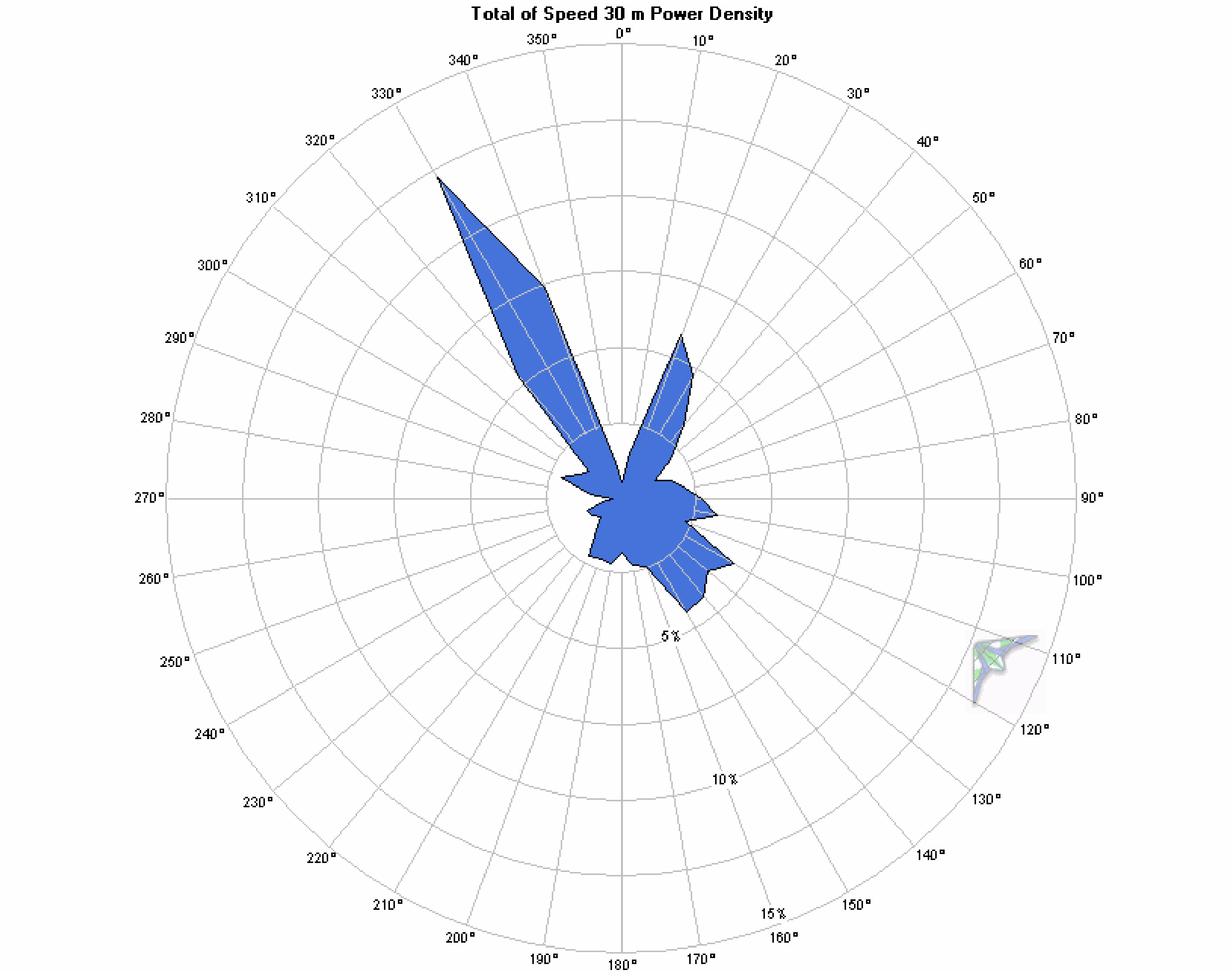
Togiak's winds are strongly bi-directional with the most frequent winds from the north-northwest and north-northeast, and lesser occurring winds from the southeast and south-southwest. This data observation, however, changes somewhat upon consideration of the power density rose (second wind rose). As one can see, the power producing winds are primarily north-northwest and southeast. The NNE winds, although, frequent, are primarily low speed and hence low power. The practical application of this information is that multiple turbines must be spaced in a east-to-west alignment to minimize power loss to downwind machines.

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 Togiak experiences calm conditions thirty-three percent of the time (see wind frequency rose below).

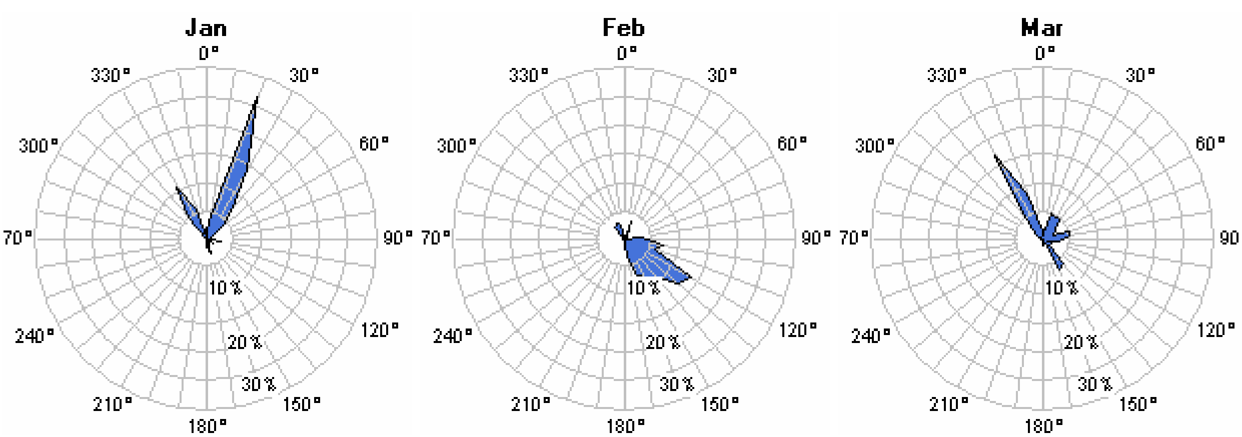
Wind frequency rose (30 meters)

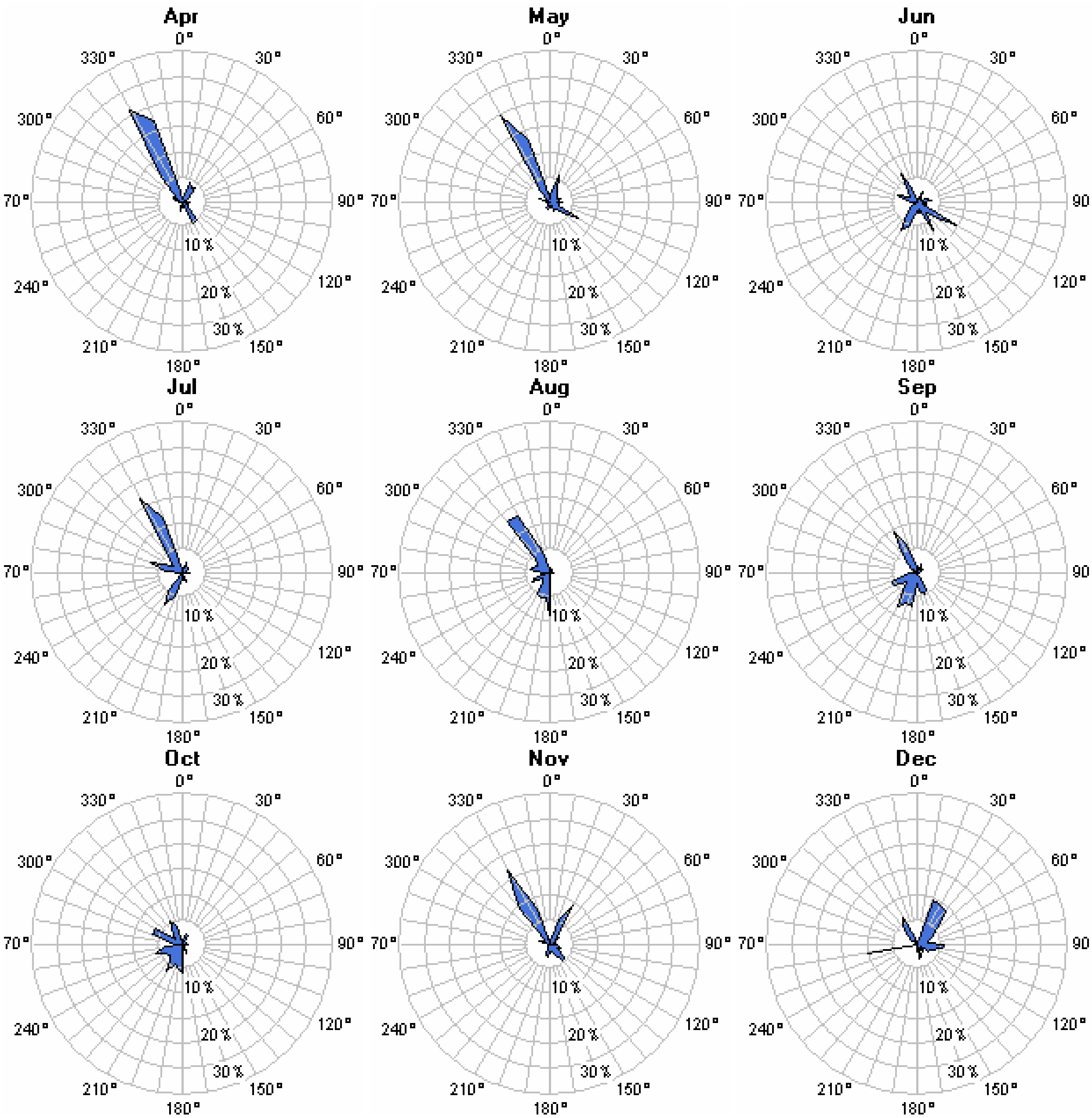


Power Density Rose (30 meters)



Wind Power Density Rose by Month (30 meters), scale is common

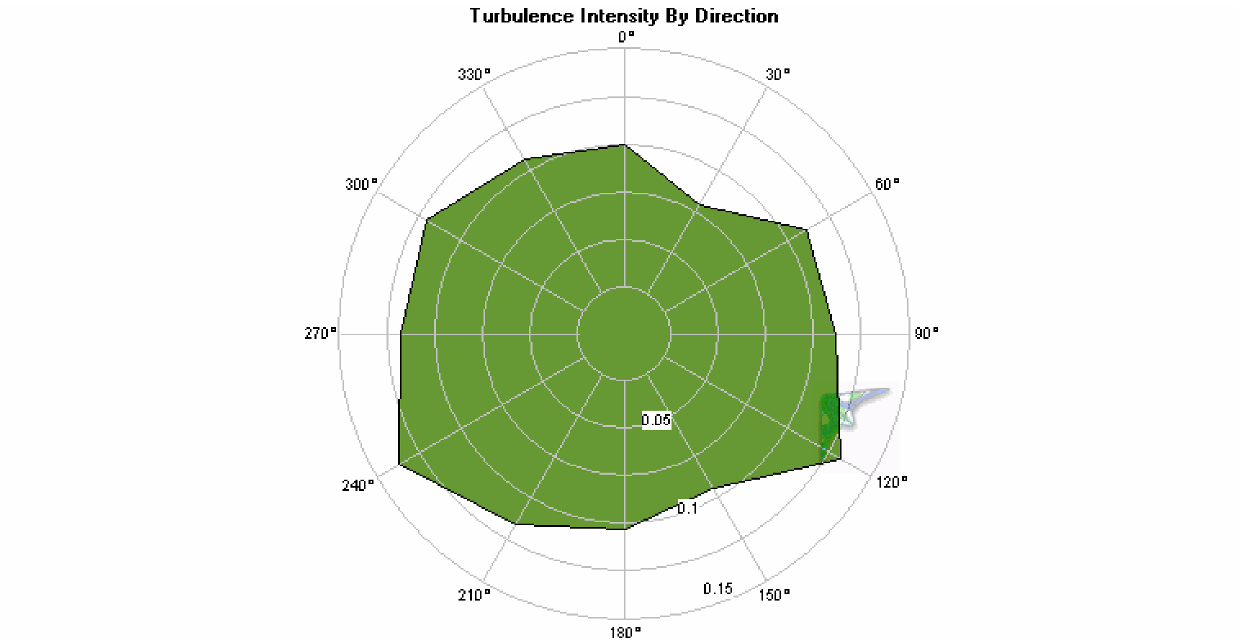



Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0°
30°
60°
90°
120°
150°
180°
210°
240°
70°
300°
330°
10 %
20 %
30 %

Turbulence Intensity

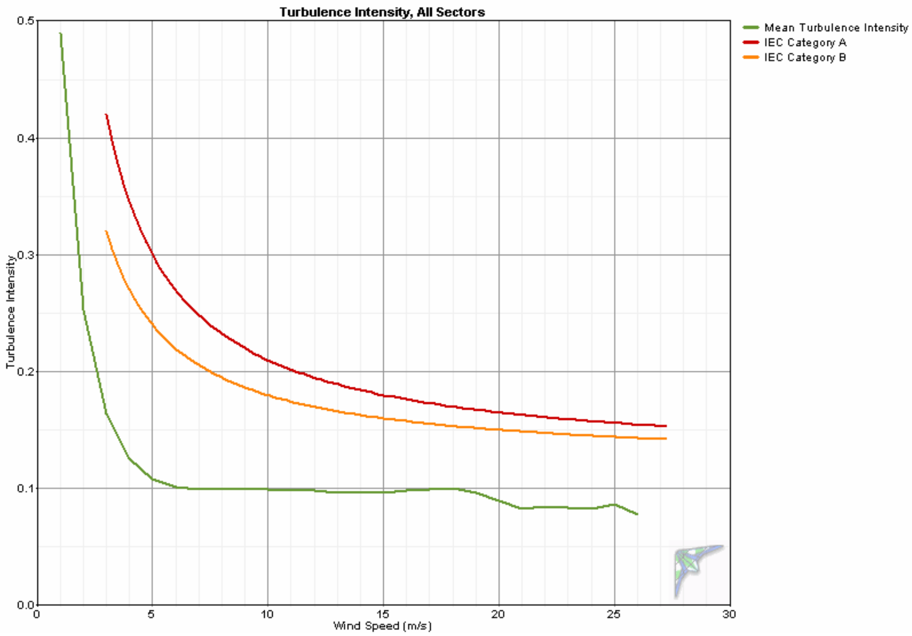
The turbulence intensity is acceptable for the most frequent wind directions, with mean turbulence intensity at 30 meters of 0.104 (threshold wind speed is 4 m/s), indicating acceptable turbulence for wind power development. The relatively high turbulence intensity to the southwest is not important as winds rarely blow from this sector, but the relatively high turbulence intensity to the southeast likely is due to gusty storm winds from this sector.

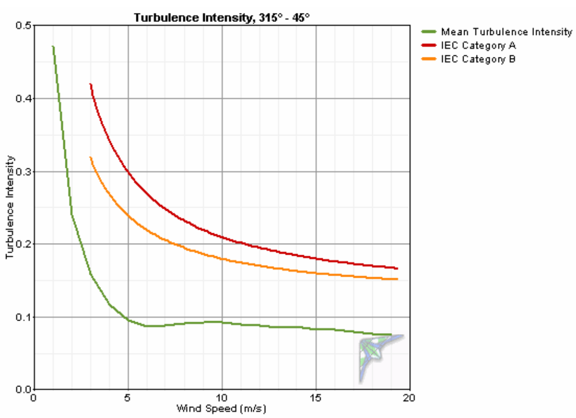
Turbulence Intensity Rose – 30 meter vane, 30 meter anemometer

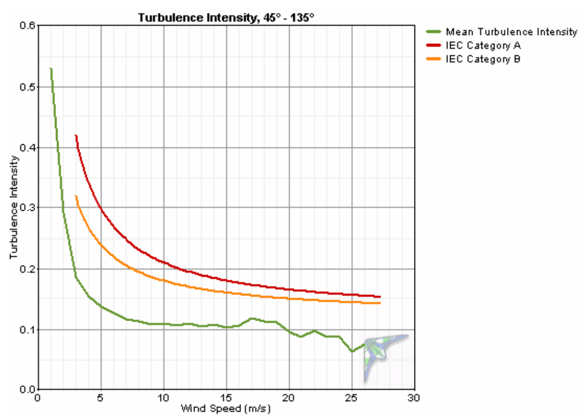


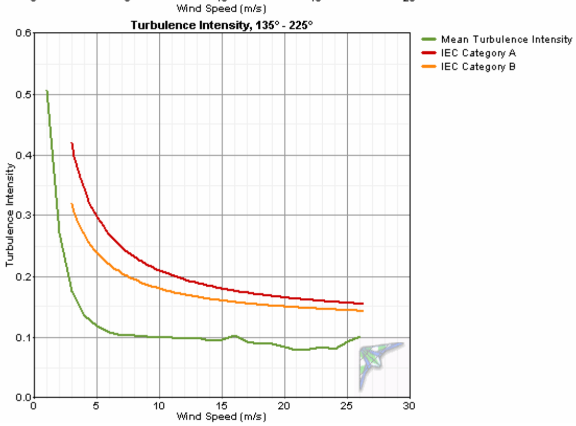
IEC Turbulence Intensity Standards

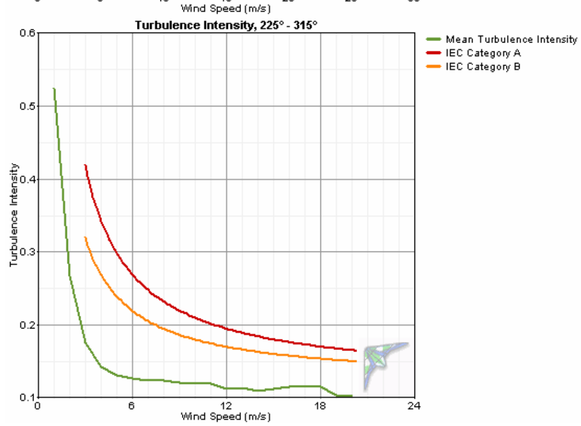
As shown below, the Togiak project test site meets International Electrotechnical Commission (IEC) turbulence intensity Category A and Category B standards.


Turbulence Intensity, All Sectors
Turbulence Intensity
Wind Speed (m/s)
Mean Turbulence Intensity
IEC Category A
IEC Category B


Turbulence Intensity, 315° - 45°
Turbulence Intensity
Wind Speed (m/s)
Mean Turbulence Intensity
IEC Category A
IEC Category B


Turbulence Intensity, 45° - 135°
Turbulence Intensity
Wind Speed (m/s)
Mean Turbulence Intensity
IEC Category A
IEC Category B


Turbulence Intensity, 135° - 225°
Turbulence Intensity
Wind Speed (m/s)
Mean Turbulence Intensity
IEC Category A
IEC Category B


Turbulence Intensity, 225° - 315°
Turbulence Intensity
Wind Speed (m/s)
Mean Turbulence Intensity
IEC Category A
IEC Category B

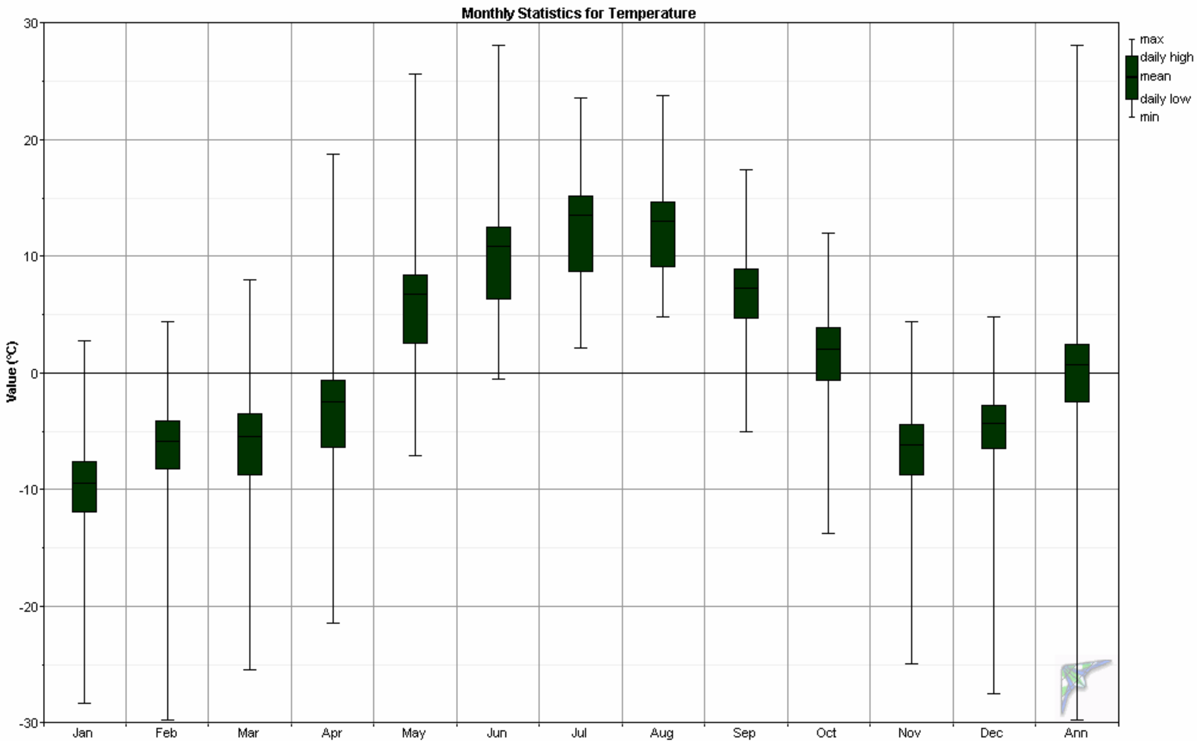
Turbulence Table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints 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	5222	0.452	0.502	0.179	0.680
2	1.5	2.5	7029	0.502	0.259	0.138	0.397
3	2.5	3.5	9555	0.490	0.167	0.086	0.253
4	3.5	4.5	11827	0.504	0.128	0.064	0.192
5	4.5	5.5	12450	0.540	0.109	0.054	0.163
6	5.5	6.5	11408	0.605	0.102	0.047	0.149
7	6.5	7.5	9602	0.695	0.100	0.041	0.142
8	7.5	8.5	7100	0.807	0.102	0.037	0.139
9	8.5	9.5	5620	0.900	0.101	0.034	0.135
10	9.5	10.5	4041	1.002	0.101	0.033	0.134
11	10.5	11.5	2711	1.083	0.099	0.032	0.131
12	11.5	12.5	1924	1.176	0.099	0.031	0.129
13	12.5	13.5	1324	1.252	0.097	0.027	0.124
14	13.5	14.5	863	1.346	0.097	0.028	0.125
15	14.5	15.5	540	1.435	0.096	0.030	0.126
16	15.5	16.5	295	1.567	0.098	0.029	0.127
17	16.5	17.5	212	1.678	0.099	0.030	0.129
18	17.5	18.5	137	1.791	0.100	0.032	0.132
19	18.5	19.5	75	1.817	0.096	0.024	0.120
20	19.5	20.5	70	1.779	0.089	0.019	0.108
21	20.5	21.5	42	1.736	0.083	0.014	0.097
22	21.5	22.5	35	1.863	0.085	0.014	0.099
23	22.5	23.5	19	1.911	0.084	0.012	0.096
24	23.5	24.5	7	1.971	0.082	0.013	0.095
25	24.5	25.5	5	2.160	0.086	0.014	0.100
26	25.5	26.5	8	2.025	0.078	0.011	0.090
27	26.5	27.5	0	2.025	0.078	0.011	0.090

Air Temperature and Density

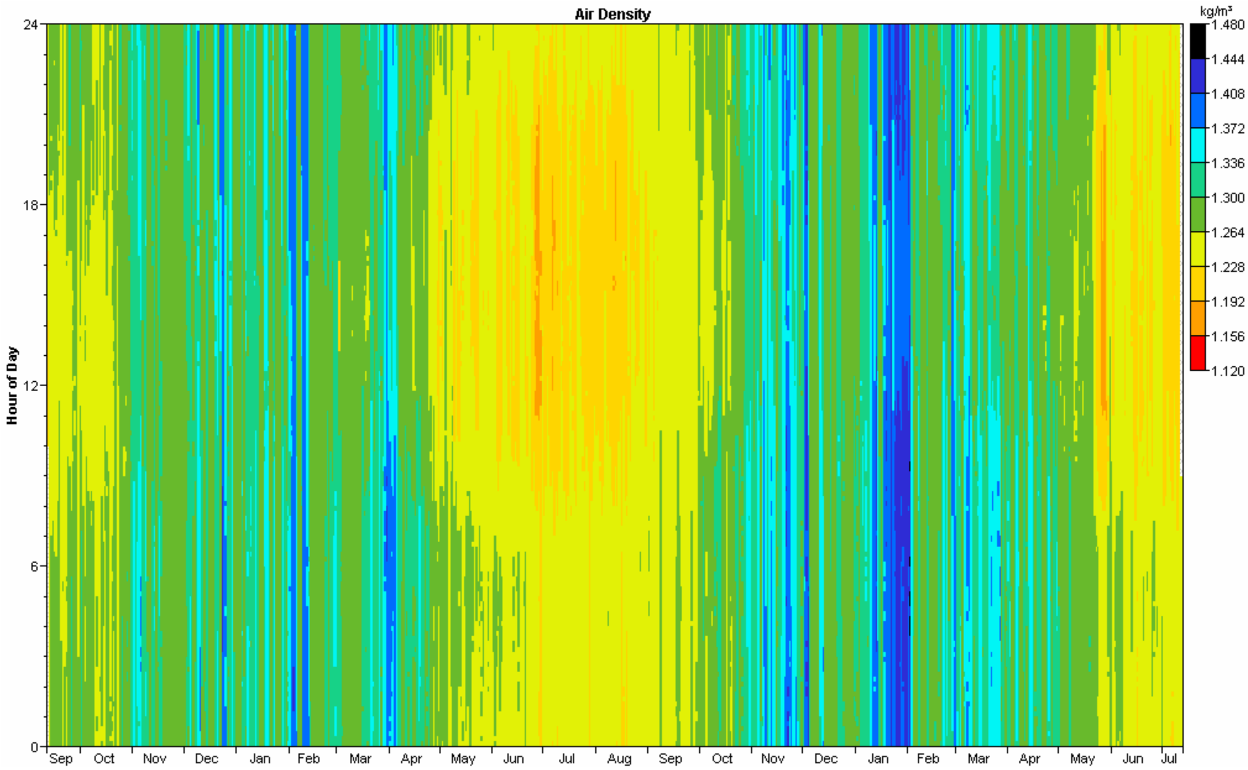
Over the reporting period, Togiak had an average temperature of 1.6° C. The minimum recorded temperature during the measurement period was -29.7° C and the maximum temperature was 28.1° C, indicating a cool temperate environment for wind turbine operations. Consequent to Togiak's cool temperatures, the average air density of 1.283 kg/m^3 is five percent higher than the standard air density of 1.223 kg/m^3 (at 14.8° C temperature and 101.1 kPa pressure at 20 meters elevation). Density variance from standard is accounted for in the turbine performance predictions.

	Temperature (Ch 9)				Air Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Std. Dev. (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-9.5	-28.3	2.8	8.489	1.337	1.276	1.438
Feb	-5.8	-29.7	4.4	7.756	1.318	1.268	1.446
Mar	-5.4	-25.4	8.0	6.391	1.315	1.222	1.421
Apr	-2.5	-21.4	18.8	6.200	1.301	1.206	1.398
May	6.8	-7.1	25.6	5.539	1.258	1.178	1.323
Jun	10.9	-0.5	28.1	4.328	1.240	1.169	1.291
Jul	13.5	2.2	23.6	3.824	1.228	1.186	1.279
Aug	13.0	4.8	23.8	3.584	1.230	1.186	1.267
Sep	7.3	-5.0	17.4	3.571	1.256	1.212	1.313
Oct	2.1	-13.7	12.0	4.825	1.279	1.235	1.357
Nov	-6.2	-24.9	4.4	6.671	1.319	1.268	1.418
Dec	-4.4	-27.5	4.8	6.619	1.310	1.267	1.433
Annual	**1.6**	-29.7	28.1	9.680	**1.283**	1.169	1.446



Air Density DMap

The DMap below 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 predicated by the turbine power curves, while densities lower than average will yield lower turbine power than predicted. Density variance from standard is accounted for in the turbine performance predictions.



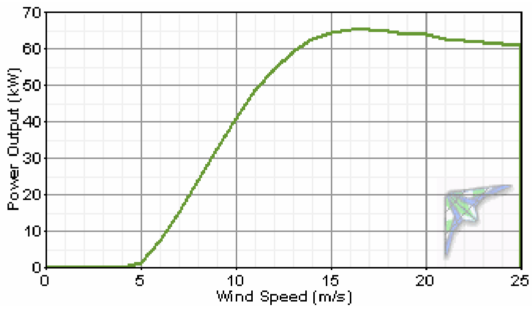
Wind Turbine Performance

The turbine performance predictions noted below are based on 100% and 90% turbine availabilities. It is realistic to expect five to ten percent downtime for maintenance, repairs and/or other outages should be expected.

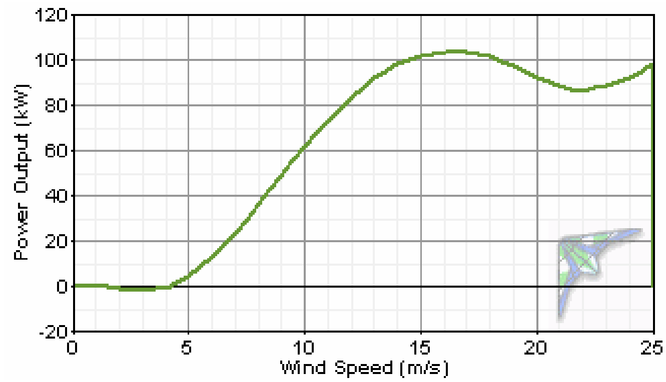
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m^3 at 15° C temperature and 101.3 kPa at sea level; 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.

A number of smaller village-scale grid-connected turbines are profiled belong 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 Togiak.

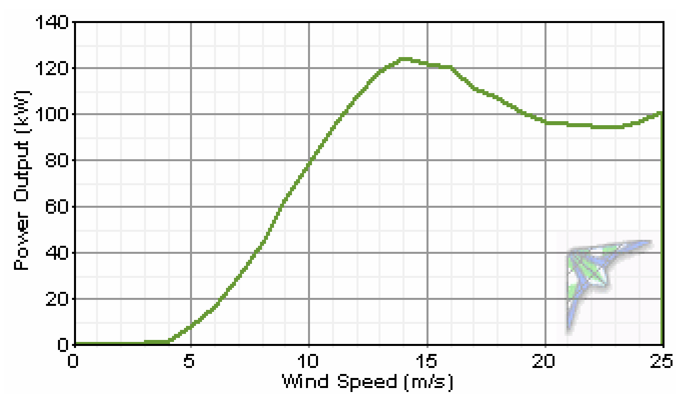
Entegrity eW-15: 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Additional information is available at http://www.entegritywind.com/.



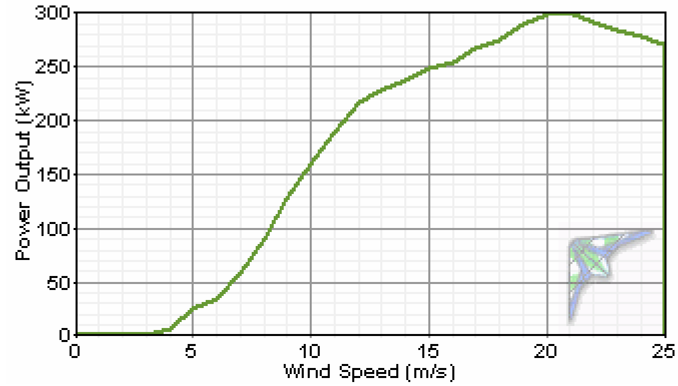
Northwind 100/19 and 100/20: 100 kW rated power output, 19 meter rotor and 20 meter rotor (19 meter rotor blades with 0.6 meter blade root extensions added) models, stall-controlled (power curve provided by Northern Power Systems). Additional information is available at http://www.northernpower.com/.



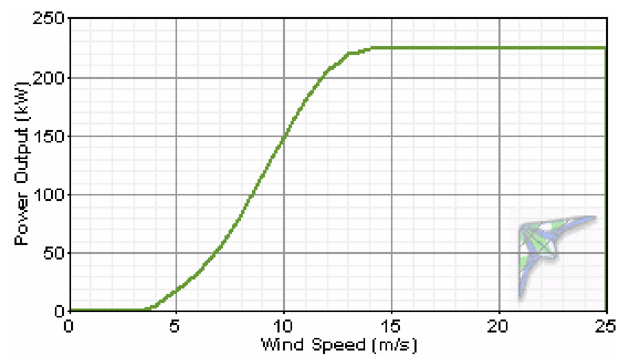
Fuhrländer FL100: 100 kW rated output (125 kW max output), 21 meter rotor, stall-controlled, 35 meter hub height (power curve provided by lorax-energy.com). Additional information is available at http://www.fuhrlaender.de/ and http://www.lorax-energy.com/.



Fuhrländer FL250: 250 kW rated output (300 kW max output), 29.5 meter rotor, stall-controlled, 42-meter hub height (power curve provided by lorax-energy.com). Additional information is available at http://www.fuhrlaender.de/ and http://www.lorax-energy.com/.



Vestas V27: 225 kW rated power output, 27 meter rotor, pitch-controlled (power curve provided by Alaska Energy Authority)



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 Power Output (kW)	Annual Energy Output (kWh/yr)	Average Capacity Factor (%)
Entegrity eW-15 60 Hz	25	5.57	34.84	2.0	12.7	110,956	19.5
Entegrity eW-15 60 Hz	31	5.71	33.14	2.3	13.6	119,008	20.9
Northern Power NW 100/19	25	5.57	34.83	1.2	17.6	153,937	17.6
Northern Power NW 100/19	32	5.74	33.00	1.4	19.1	166,982	19.1
Northern Power NW 100/20	25	5.57	34.82	1.8	18.6	163,255	18.6
Northern Power NW 100/20	32	5.74	33.00	2.1	20.2	177,034	20.2
Fuhrländer FL100	35	5.83	12.63	2.5	28.6	250,930	22.9
Fuhrländer FL250	42	6.00	12.33	0.3	63.3	554,717	21.1
Vestas V27	32	5.74	16.56	1.4	51.6	451,821	22.9
Vestas V27	42	6.00	15.71	1.8	56.8	497,155	25.2

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

Note: Calculated for the data period 9/11/04 to 7/12/06

Turbine Power Output Comparison (90% Turbine Availability)

Turbine	Hub Height (m)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Power Output (kW)	Annual Energy Output (kWh/yr)	Average Capacity Factor (%)
Entegrity eW-15 60 Hz	25	5.57	34.84	2.0	12.7	99,860	17.6
Entegrity eW-15 60 Hz	31	5.71	33.14	2.3	13.6	107,107	18.8
Northern Power NW 100/19	25	5.57	34.83	1.2	17.6	138,543	15.8
Northern Power NW 100/19	32	5.74	33.00	1.4	19.1	150,284	17.2
Northern Power NW 100/20	25	5.57	34.82	1.8	18.6	146,930	16.7
Northern Power NW 100/20	32	5.74	33.00	2.1	20.2	159,331	18.2
Fuhrländer FL100	35	5.83	12.63	2.5	28.6	225,837	20.6
Fuhrländer FL250	42	6.00	12.33	0.3	63.3	499,245	19.0
Vestas V27	32	5.74	16.56	1.4	51.6	406,639	20.6
Vestas V27	42	6.00	15.71	1.8	56.8	447,440	22.7

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

Note: Annual energy output and average capacity factor assume a turbine availability of 90% (annual energy output x 0.90 and average capacity factor for 100% availability x 0.90)

Note: Calculated for the data period 9/11/04 to 7/12/06

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

Turbine	Annual Energy Output (kW-hr/yr)	Fuel Quantity Avoided (liters)	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)
Entegrity eW-15											
	99,860	28,001	7,397	$12,945	$14,794	$16,643	$18,493	$20,342	$22,191	$24,040	25
	107,107	30,033	7,934	$13,884	$15,868	$17,851	$19,835	$21,818	$23,802	$25,785	31
NPS NW100/19											
	138,543	38,848	10,262	$17,959	$20,525	$23,091	$25,656	$28,222	$30,787	$33,353	25
	150,284	42,140	11,132	$19,481	$22,264	$25,047	$27,830	$30,613	$33,396	$36,179	32
NPS NW100/20											
	146,930	41,199	10,884	$19,046	$21,767	$24,488	$27,209	$29,930	$32,651	$35,372	25
	159,331	44,676	11,802	$20,654	$23,605	$26,555	$29,506	$32,456	$35,407	$38,357	32
Fuhrländer FL100											
	225,837	63,325	16,729	$29,275	$33,457	$37,640	$41,822	$46,004	$50,186	$54,368	35
Fuhrländer FL250											
	499,245	139,988	36,981	$64,717	$73,962	$83,208	$92,453	$101,698	$110,943	$120,189	42
Vestas V27											
	406,639	114,022	30,121	$52,712	$60,243	$67,773	$75,304	$82,834	$90,364	$97,895	32
	447,440	125,462	33,144	$58,001	$66,287	$74,573	$82,859	$91,145	$99,431	$107,717	42

Notes:
1. Togiak electrical energy production efficiency assumed to be 13.5 kW-hr/gal or 3.57 kW-hr/L (AVEC data)
2. Assumes 90% 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)
4. Calculated for the data period 9/11/04 to 7/12/06

Select Turbine Performance Annual Output Data

	NPS NW100/20 turbine at 32 m hub height						Vestas V27 turbine at 32 m hub height					
Month	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Power Output (kW)	Average Energy Output (kWh)	Average Capacity Factor (%)	Hub Height Wind Speed (m/s)	Time At Zero Output (%)	Time At Rated Output (%)	Average Power Output (kW)	Average Energy Output (kWh)	Average Capacity Factor (%)
Jan	5.40	34.1	0.9	17.3	12,843	17.3	5.40	15.7	0.3	45.0	33,503	20.0
Feb	7.20	25.0	6.7	32.5	21,845	32.5	7.20	11.7	5.7	79.6	53,524	35.4
Mar	6.44	27.3	4.1	27.1	20,157	27.1	6.44	13.9	2.0	67.4	50,145	30.0
Apr	6.21	29.5	3.5	24.2	17,445	24.2	6.21	14.7	2.7	60.5	43,577	26.9
May	5.18	34.5	0.6	14.4	10,730	14.4	5.18	17.4	0.4	38.1	28,354	16.9
Jun	4.81	41.0	0.3	12.1	8,704	12.1	4.81	22.1	0.2	32.3	23,279	14.4
Jul	4.67	42.1	0.0	10.6	7,856	10.6	4.67	22.5	0.0	28.6	21,267	12.7
Aug	5.02	40.3	0.5	14.0	10,386	14.0	5.02	22.3	0.6	36.9	27,464	16.4
Sep	6.07	27.8	0.6	21.8	15,710	21.8	6.07	12.4	0.4	56.4	40,638	25.1
Oct	5.48	38.4	1.9	18.6	13,838	18.6	5.48	19.5	1.5	47.9	35,611	21.3
Nov	5.68	37.1	2.5	21.8	15,679	21.8	5.68	19.8	1.4	55.1	39,682	24.5
Dec	6.29	23.3	2.0	23.9	17,773	23.9	6.29	9.9	0.9	60.9	45,304	27.1
Overall	5.74	33.0	2.1	20.2	177,034	20.2	5.74	16.6	1.4	51.6	451,821	22.9

Notes:
1. Assumes 100% turbine availability
2. Calculated for data period 9/11/04 to 7/12/06

Temperature Conversion Chart °C to °F

°C	°F	°C	°F	°C	°F
-40	-40.0	-10	14.0	20	68.0
-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	-31.0	-5	23.0	25	77.0
-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	0	32.0	30	86.0
-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	-13.0	5	41.0	35	95.0
-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	-4.0	10	50.0	40	104.0
-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	5.0	15	59.0	45	113.0
-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	m/s	mph	m/s	mph
0.5	1.1	10.5	23.5	20.5	45.9	30.5	68.2	40.5	90.6
1.0	2.2	11.0	24.6	21.0	47.0	31.0	69.3	41.0	91.7
1.5	3.4	11.5	25.7	21.5	48.1	31.5	70.5	41.5	92.8
2.0	4.5	12.0	26.8	22.0	49.2	32.0	71.6	42.0	93.9
2.5	5.6	12.5	28.0	22.5	50.3	32.5	72.7	42.5	95.1
3.0	6.7	13.0	29.1	23.0	51.4	33.0	73.8	43.0	96.2
3.5	7.8	13.5	30.2	23.5	52.6	33.5	74.9	43.5	97.3
4.0	8.9	14.0	31.3	24.0	53.7	34.0	76.1	44.0	98.4
4.5	10.1	14.5	32.4	24.5	54.8	34.5	77.2	44.5	99.5
5.0	11.2	15.0	33.6	25.0	55.9	35.0	78.3	45.0	100.7
5.5	12.3	15.5	34.7	25.5	57.0	35.5	79.4	45.5	101.8
6.0	13.4	16.0	35.8	26.0	58.2	36.0	80.5	46.0	102.9
6.5	14.5	16.5	36.9	26.5	59.3	36.5	81.6	46.5	104.0
7.0	15.7	17.0	38.0	27.0	60.4	37.0	82.8	47.0	105.1
7.5	16.8	17.5	39.1	27.5	61.5	37.5	83.9	47.5	106.3
8.0	17.9	18.0	40.3	28.0	62.6	38.0	85.0	48.0	107.4
8.5	19.0	18.5	41.4	28.5	63.8	38.5	86.1	48.5	108.5
9.0	20.1	19.0	42.5	29.0	64.9	39.0	87.2	49.0	109.6
9.5	21.3	19.5	43.6	29.5	66.0	39.5	88.4	49.5	110.7
10.0	22.4	20.0	44.7	30.0	67.1	40.0	89.5	50.0	111.8

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.