Koliganek, Alaska Wind Resource Report

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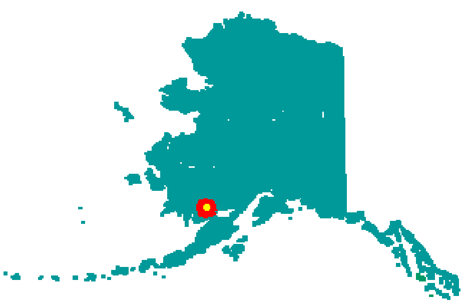
Photo by Hannah Willard



Summary Information

The wind resource study in Koliganek indicates very good potential for the development of wind power to augment the village's diesel power supply. One excellent advantage for the village is the old airstrip where the meteorological test tower was located. Because the village and surrounding area is comprised of permafrost soils, construction of wind turbines on the old airstrip would significantly reduce construction costs.

Meteorological Tower Data Synopsis

Wind power class	Class 4 – Good
Wind speed annual average (30 meters)	5.72 m/s
Maximum wind gust (2 sec. average)	36.5 m/s, 12/7/05
Mean wind power density (50 meters)	404 W/m^2 (calculated)
Mean wind power density (30 meters)	320 W/m^2 (measured)
Weibull distribution parameters	k = 1.60, c = 6.40 m/s
Roughness class	2.92 (many trees)
Power law exponent	0.227 (high wind shear)
Turbulence intensity	0.115 (low)
Data start date	July 8, 2005
Data end date	July 13, 2006

Community Profile

Current Population:	167 (2005 State Demographer est.)
Pronunciation/Other Names:	(koh-LIG-uh-neck)
Incorporation Type:	Unincorporated
Borough Located In:	Unorganized
School District:	Southwest Region Schools
Regional Native Corporation:	Bristol Bay Native Corporation

Location:

Koliganek is located on the left bank of the Nushagak River, and lies 65 miles northeast of Dillingham. The village hopes to get its own zip code. It currently shares one with Dillingham. It lies at approximately 59.728610° North Latitude and 157.284440° West Longitude. (Sec. 21, T005S, R047W, Seward Meridian.) Koliganek is located in the Bristol Bay Recording District. The area encompasses 12.5 sq. miles of land and 0.1 sq. miles of water.

History:

It is an Eskimo village first listed in the 1880 Census as "Kalignak." The name is local, recorded by the U.S. Geological Survey in 1930. Since that time, the village has moved four miles downstream from the original site.

Culture:

Koliganek is a Yup'ik Eskimo village with Russian Orthodox practices. Subsistence activities are an important part of the lifestyle.

Economy:

The school and village organization provide most year-round employment. Eighteen residents hold commercial fishing permits. Many residents trap, and subsistence activities are an important part of the economy. Residents are employed in sales and office work, management and professional, production and transportation, and service occupations. The town center contains the school, health clinic, two general stores, fuel storage, power generation building, and the village council building. A new health care clinic is scheduled to be constructed in 2006 and the existing facility will be remodeled for a family resource center. The IGAP program operates a recycling center.

Facilities:

Koliganek has operated a piped system for over 25 years. Water is derived from a well and is treated. Thirty-three homes and facilities are connected to the piped water and a community septic tank. Eight homes have individual wells and septic systems. Fifteen homes haul water and use honeybuckets. Koliganek purchases power from the School District, and also owns its own generator. The village has a "code red" fire suppression unit. The village has one village public safety officer. The community has completed a water and sewer feasibility study and is competing for funds to make improvements with the goal of connecting the entire community.

Transportation:

A new State-owned 3,000' long by 75' wide runway is available. Boats and ATVs are used in the summer; snow machines in the winter. Locals travel to New Stuyahok frequently. There are no docking facilities; goods are lightered from Dillingham.

Climate:

The area is in a climatic transition zone. The primary influence is maritime, although a continental climate affects the weather. Average summer temperatures range from 37 to 66; winter temperatures range from 4 to 30.

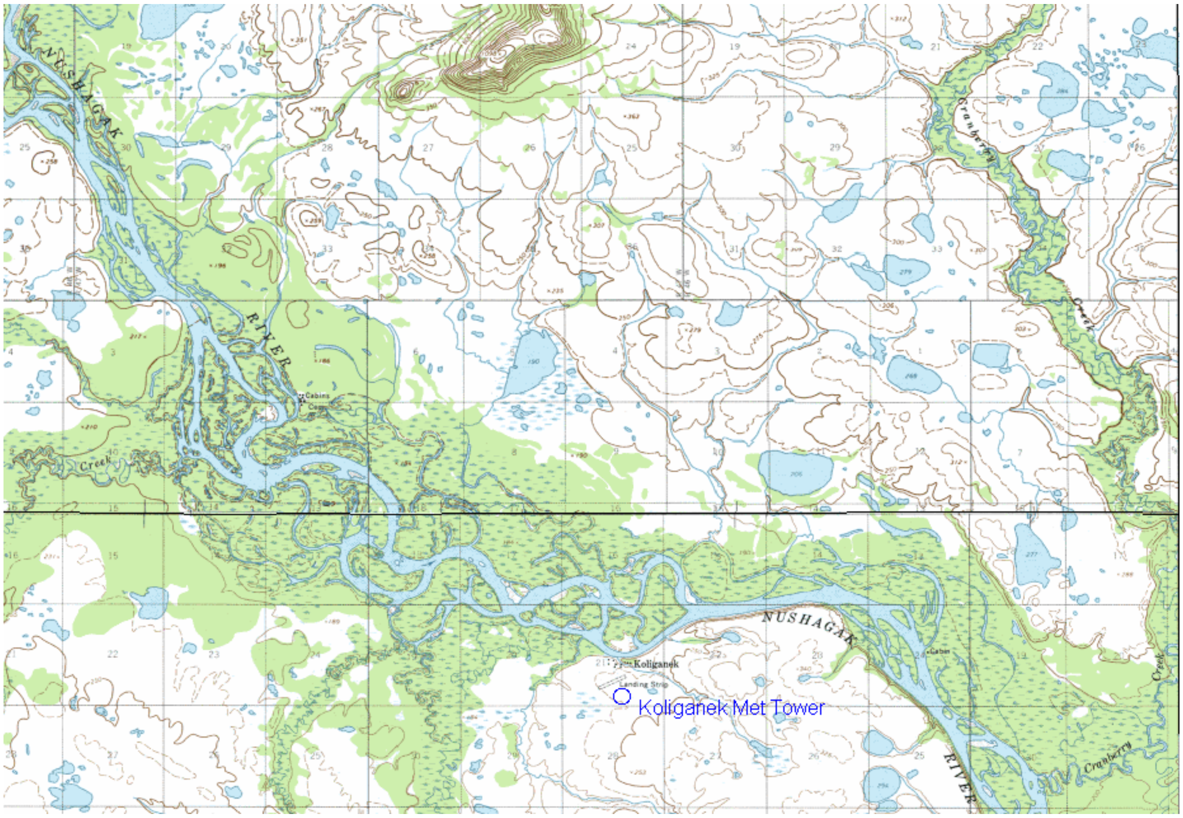
(Community profile information from State of Alaska Department of Commerce, Community, and Economic Development website, http://www.dced.state.ak.us/)

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m (A)	0.765	0.35	north
2	NRG #40 anemometer	30 m (B)	0.765	0.35	south
3	NRG #40 anemometer	20 m	0.765	0.35	north
7	NRG #200P wind vane	30 m	0.351	310	southeast
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

Site Information and Location

Site number	3296
Site Description	On south end of crosswind runway of previous airport
Latitude/longitude	N 59° 43.384’ W 157° 17.056’
Site elevation	95 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter


NUSHAGAK
RIVER
NUSHAGAK
RIVER
Cranberry
Creek
Creek
Cranberry
Koliganek
Landing Strip
Koliganek Met Tower

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. Note that data recovery during the months of March through September was 100%, but during the months of October through February some data was filtered, with November being quite ice prone with respect to data loss. Temperature data recovery was 100 percent, indicating full functioning of the temperature sensor. To make up for the lost icing data and to create a complete data set representative of all sensors fully functional, the removed icing data was synthesized with the data gap fill feature of the Windographer® wind analysis software.

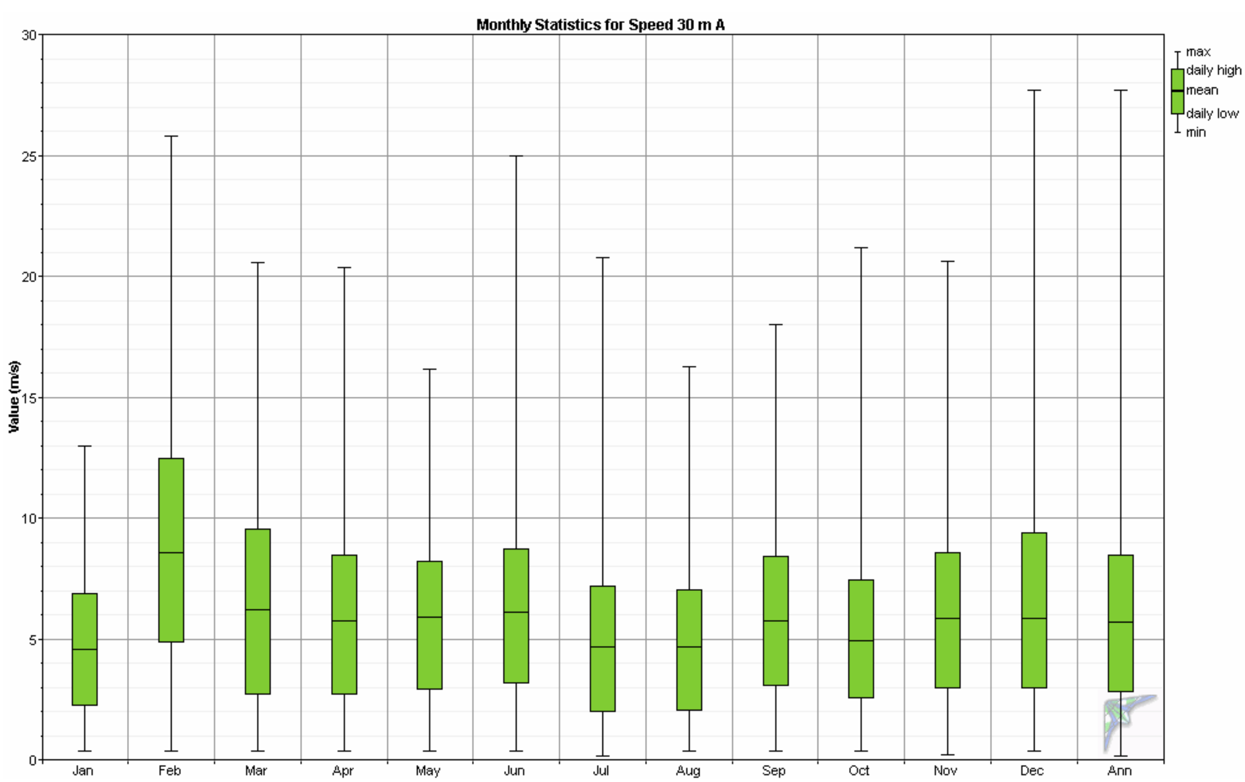
		30m (A) anemometer		30m (B) anemometer		20m anemometer	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2005	Jul	3,352	100	3,352	100	3,352	100
2005	Aug	4,464	100	4,464	100	4,464	100
2005	Sep	4,320	100	4,320	100	4,320	100
2005	Oct	4,388	98.3	4,464	100	4,372	97.9
2005	Nov	2,427	56.2	2,427	56.2	2,861	66.2
2005	Dec	4,464	100	4,036	90.4	4,040	90.5
2006	Jan	4,464	100	4,464	100	4,464	100
2006	Feb	4,032	100	3,844	95.3	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	1,812	100	1,812	100	1,812	100
All data		51,291	96.1	50,751	95.1	51,285	96.1

		Wind direction		Temperature	
		Records	Recovery Rate (%)	Records	Recovery Rate (%)
2005	Jul	3,352	100	3,353	100
2005	Aug	4,464	100	4,464	100
2005	Sep	4,320	100	4,320	100
2005	Oct	4,390	98.3	4,464	100
2005	Nov	2,392	55.4	4,320	100
2005	Dec	3,270	73.3	4,464	100
2006	Jan	4,269	95.6	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	1,812	100	1,812	100
All data		49,869	93.5	53,261	100

Measured Wind Speeds

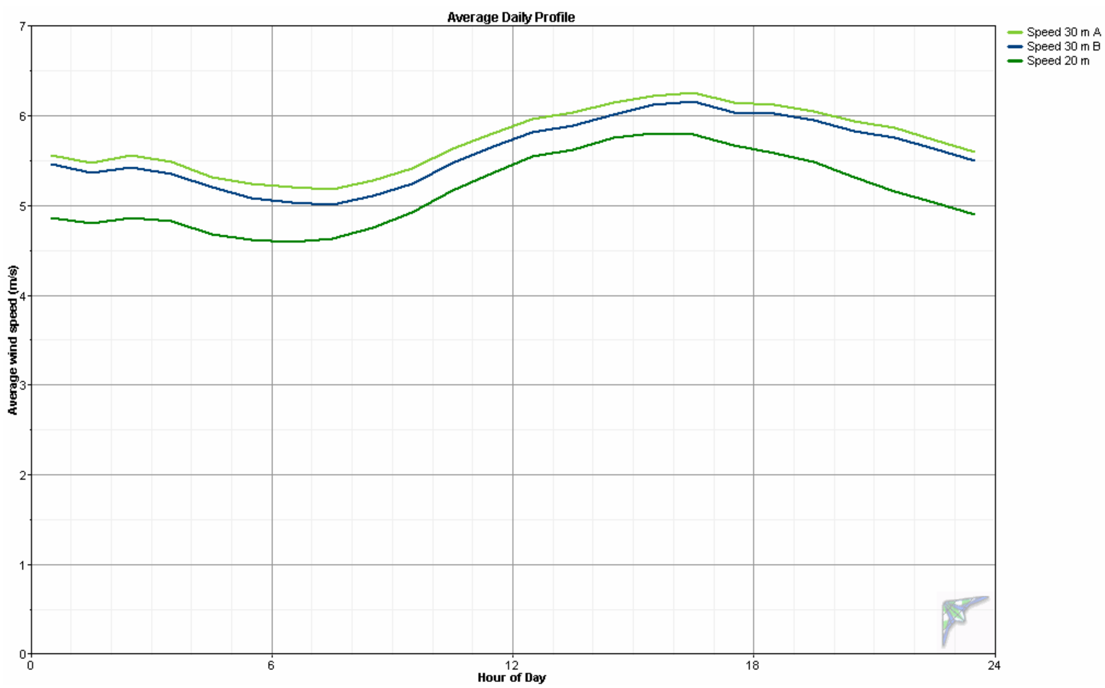
The 30 meter (A) anemometer annual wind speed average for the reporting period is 5.72 m/s, the 30 meter (B) anemometer wind speed average is 5.59 m/s and the 20 meter anemometer wind speed average is 5.16 m/s.

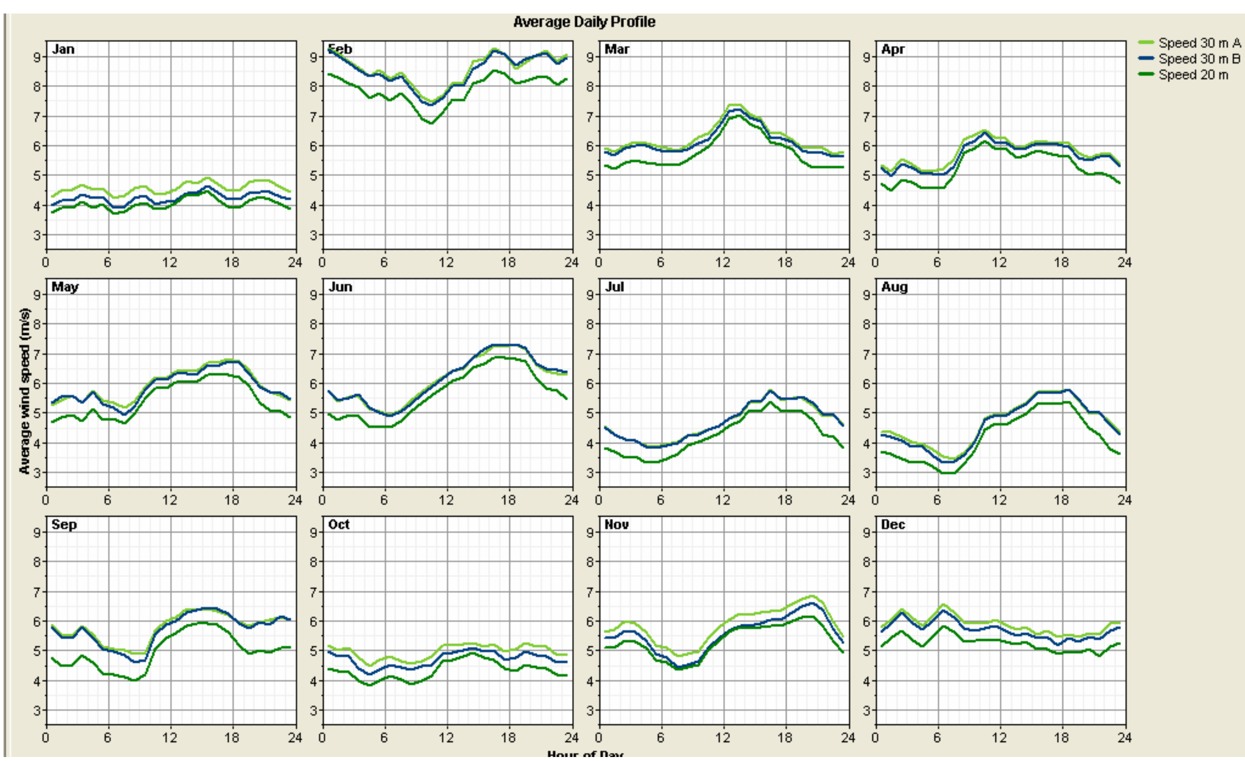
	30m (A) speed					30m (B) speed		20m speed	
Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)
Jul	4.79	14.80	2.69	1.849	5.393	4.75	14.60	4.26	14.10
Aug	4.68	16.30	2.91	1.631	5.218	4.60	16.50	4.16	14.50
Sep	5.79	18.00	3.06	1.951	6.515	5.72	18.00	5.00	16.70
Oct	5.13	21.20	3.43	1.583	5.728	4.86	21.10	4.51	18.10
Nov	5.94	15.00	2.87	2.099	6.648	5.42	14.90	4.96	13.80
Dec	6.08	27.70	4.64	1.471	6.788	6.16	27.50	5.78	26.40
Jan	4.60	13.00	2.29	2.117	5.200	4.28	12.60	4.06	11.50
Feb	8.67	25.80	5.36	1.651	9.691	8.49	25.60	7.96	24.80
Mar	6.35	20.60	4.20	1.585	7.105	6.23	20.40	5.86	19.70
Apr	5.81	20.40	3.26	1.861	6.548	5.70	20.20	5.30	19.80
May	5.95	16.20	2.81	2.242	6.722	5.90	16.10	5.45	15.30
Jun	6.13	25.00	4.00	1.605	6.855	6.14	24.80	5.65	23.60
Jul	4.68	20.80	3.59	1.439	5.191	4.74	20.70	4.36	19.60
Annual	**5.72**	27.70	3.74	1.635	6.476	**5.59**	27.50	**5.16**	26.40



Daily wind profile

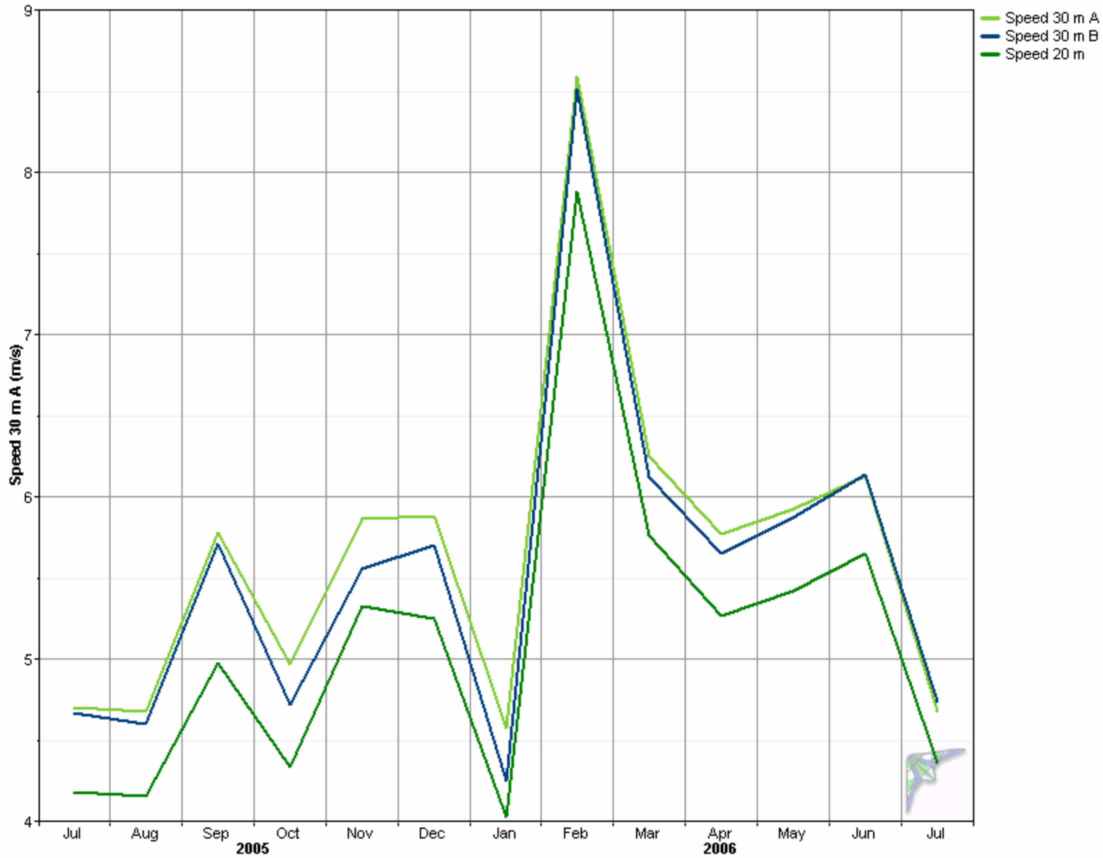
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 8 a.m. to 11 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 5 p.m. to 9 p.m. The daily variation of wind speed is minimal on an annual basis but more pronounced on a monthly basis.

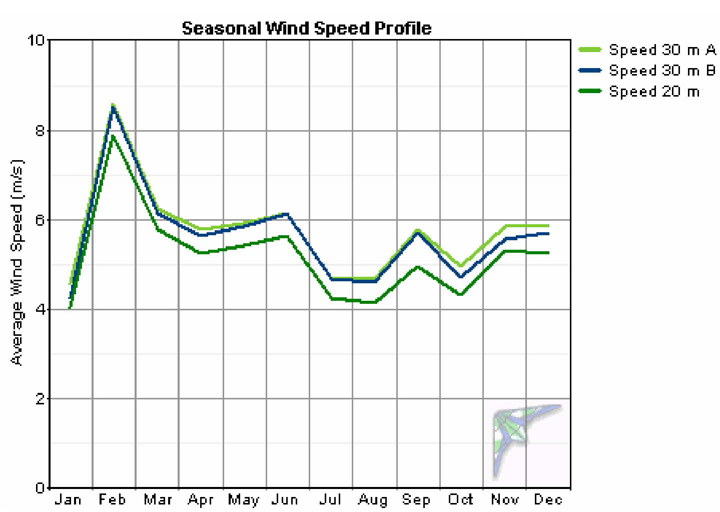




Time Series of Wind Speed Monthly Averages

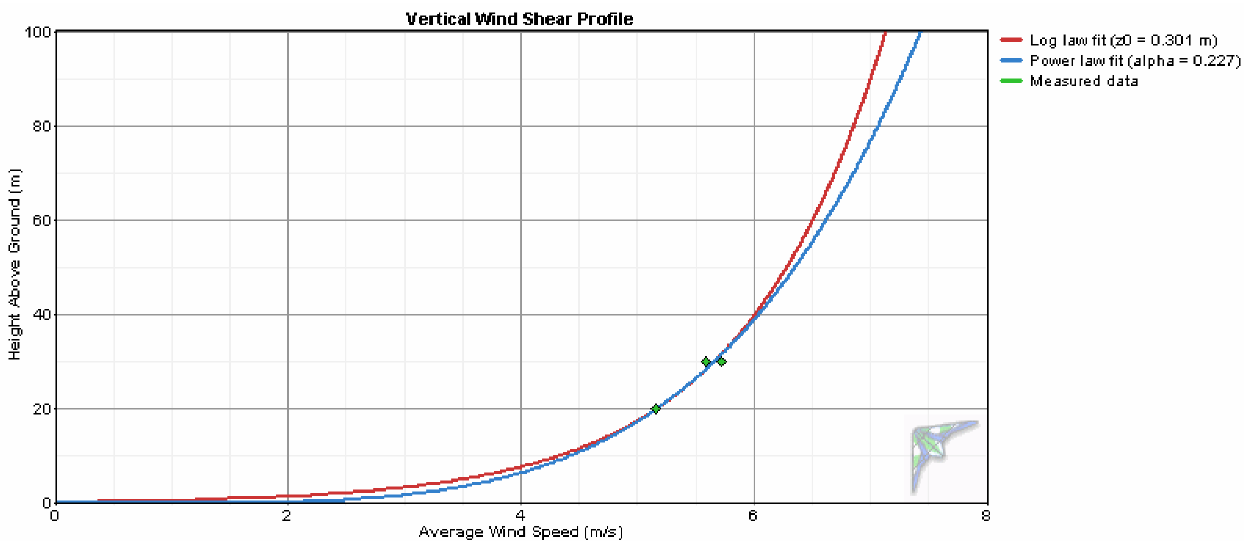
Koliganek's highest winds occur during the fall, winter and spring months with the lowest winds during the summer. The unusually low winds measured in January 2006 were due to a persistent high pressure system over Alaska that month that yielded calm winds and extremely cold weather Statewide. Had the January winds been higher and more representative of a typical year, it is expected that the wind power average for this site would be higher, possibly in the mid-Class 4 range.

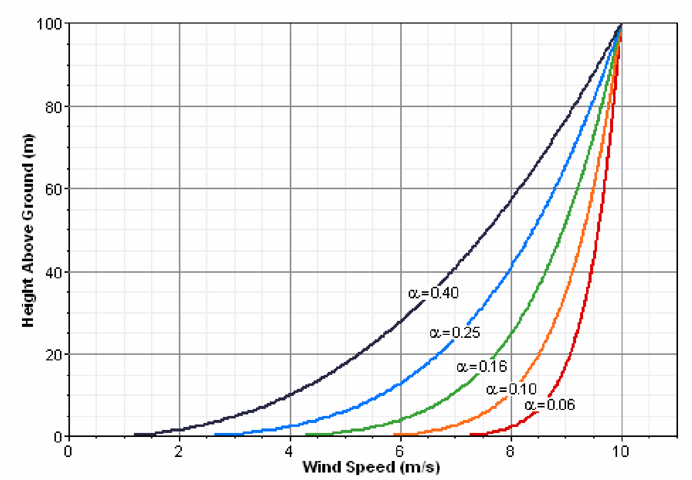


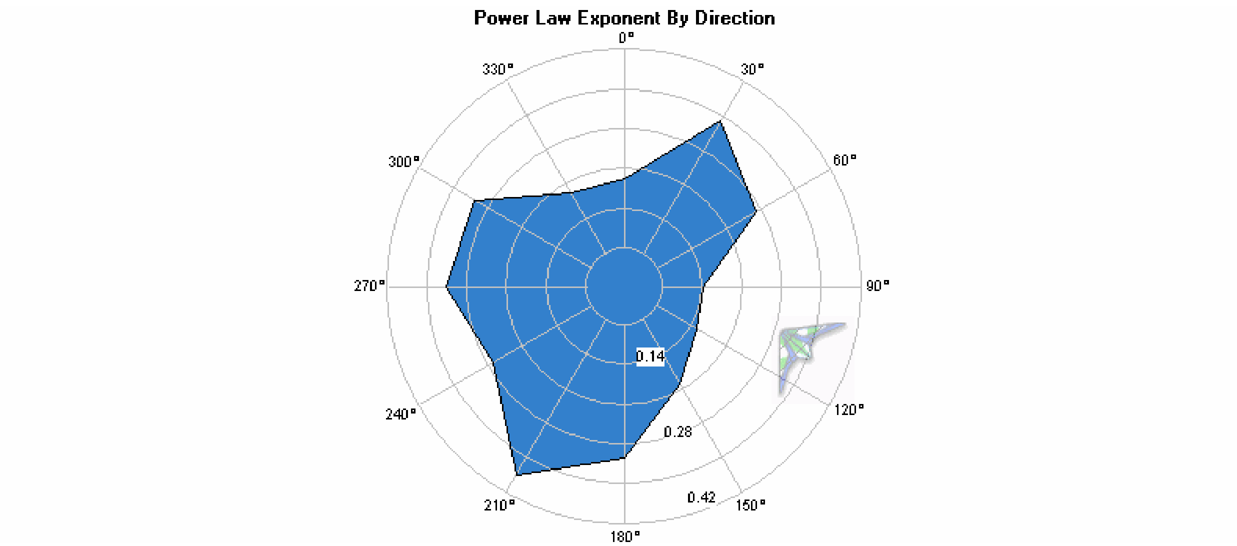


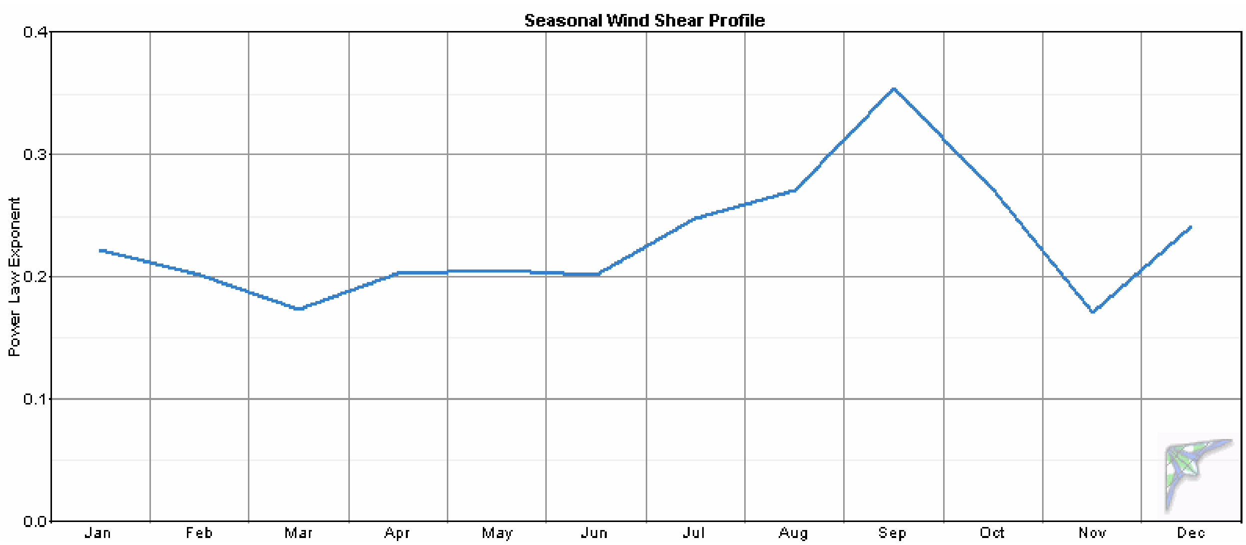
Wind Shear Profile

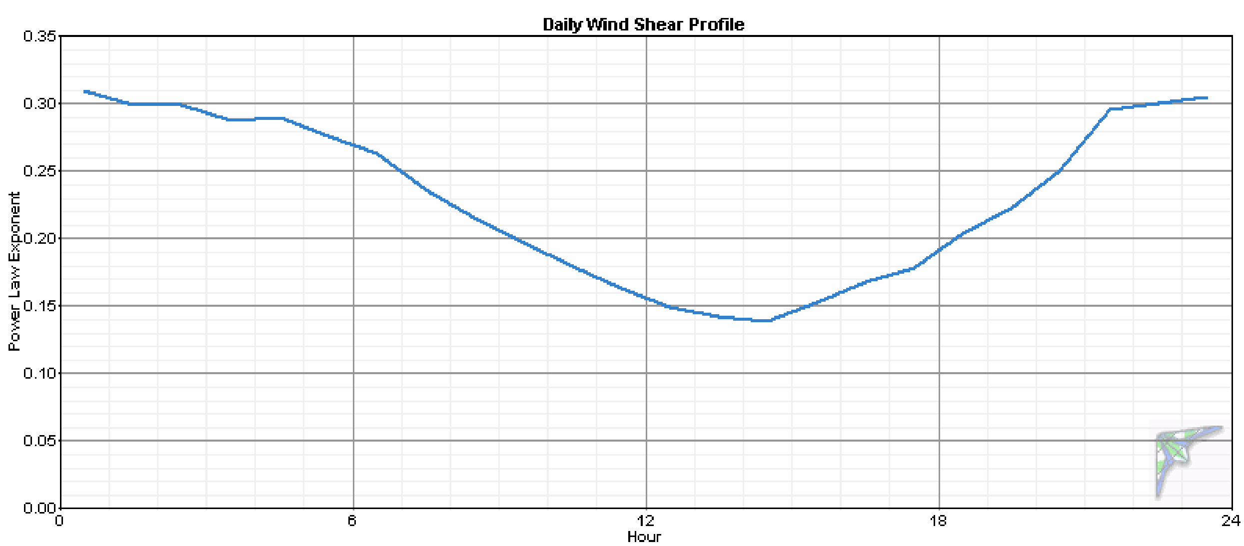
The power law exponent was calculated at 0.227 indicating relatively high wind shear at the Koliganek test site. The practical application of this data is that a higher turbine tower height is advantageous as there is an appreciable marginal gain in average wind speed and power recovery with additional height. However, a tower height/power recovery/construction cost tradeoff study would be advisable should a wind power project be initiated.





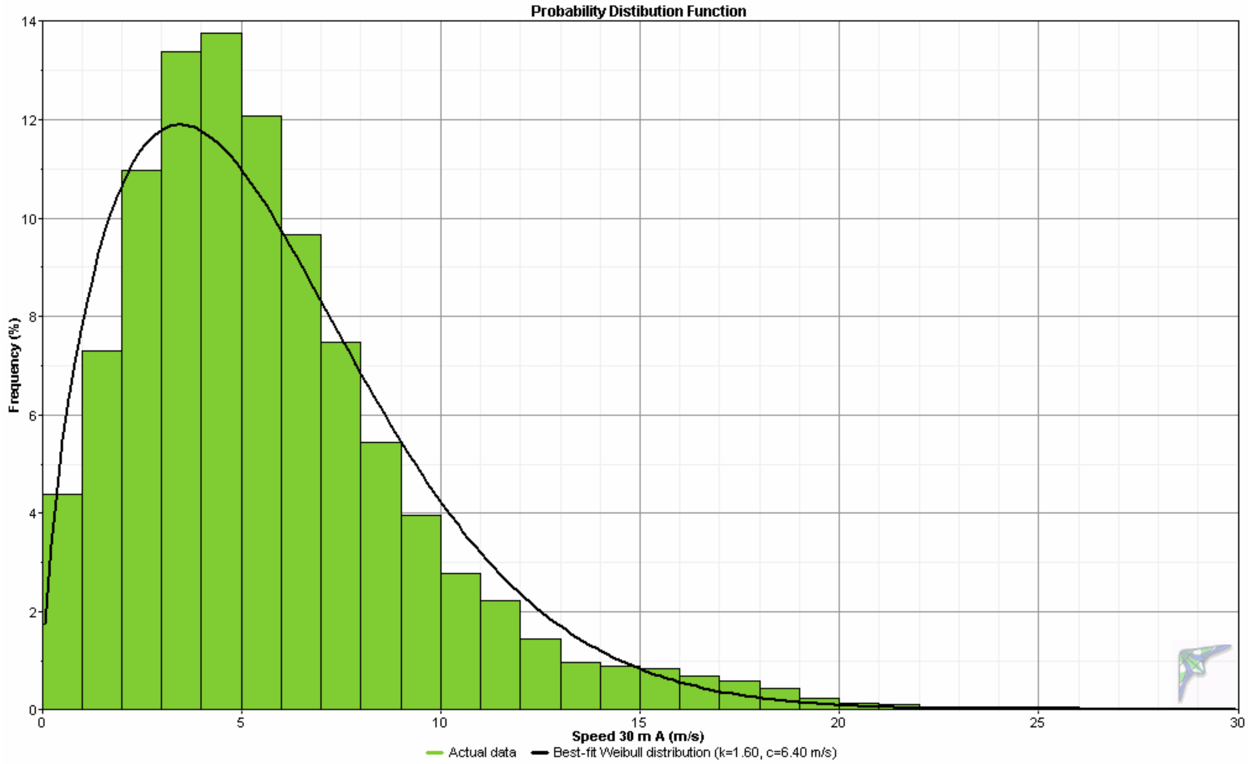

Power Law Exponent By Direction
0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0.14
0.28
0.42

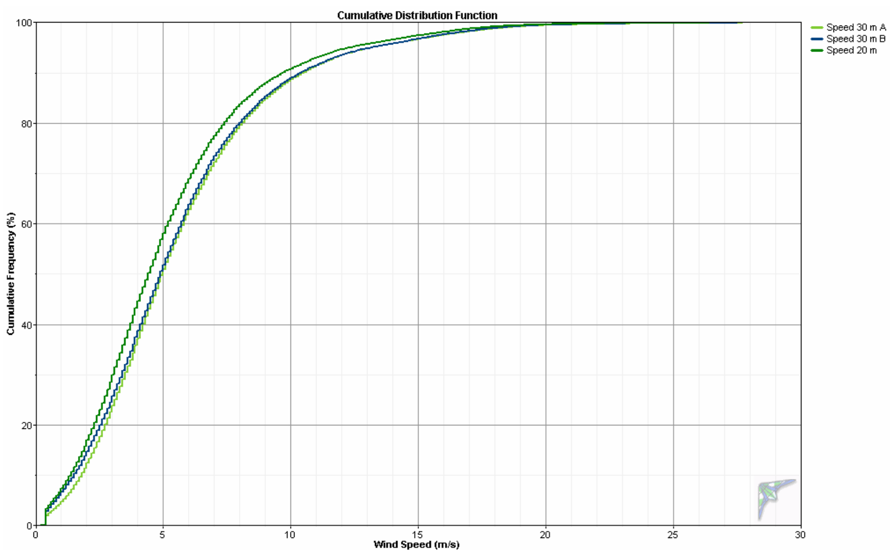

Seasonal Wind Shear Profile
Power Law Exponent
0.0
0.1
0.2
0.3
0.4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Daily Wind Shear Profile
Power Law Exponent
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0
6
12
18
24
Hour

Probability Distribution Function

The probability distribution function (PDF) 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 = 1.60 (indicates a moderate distribution of wind speeds) and c = 6.40 m/s (a scale factor for the Weibull distribution). The PDF information is shown visually in another manner in the second graph, the cumulative distribution function.



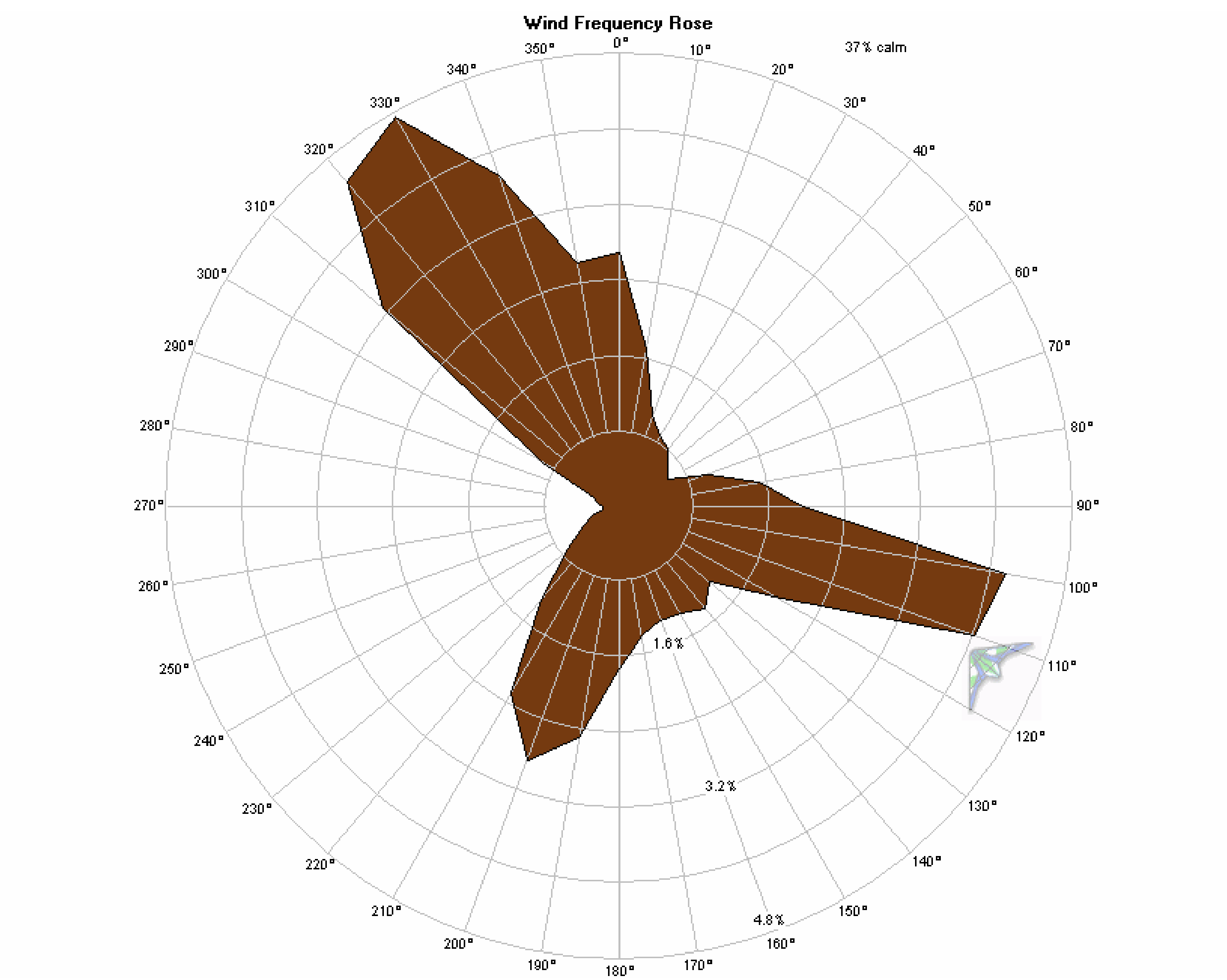


Wind Roses

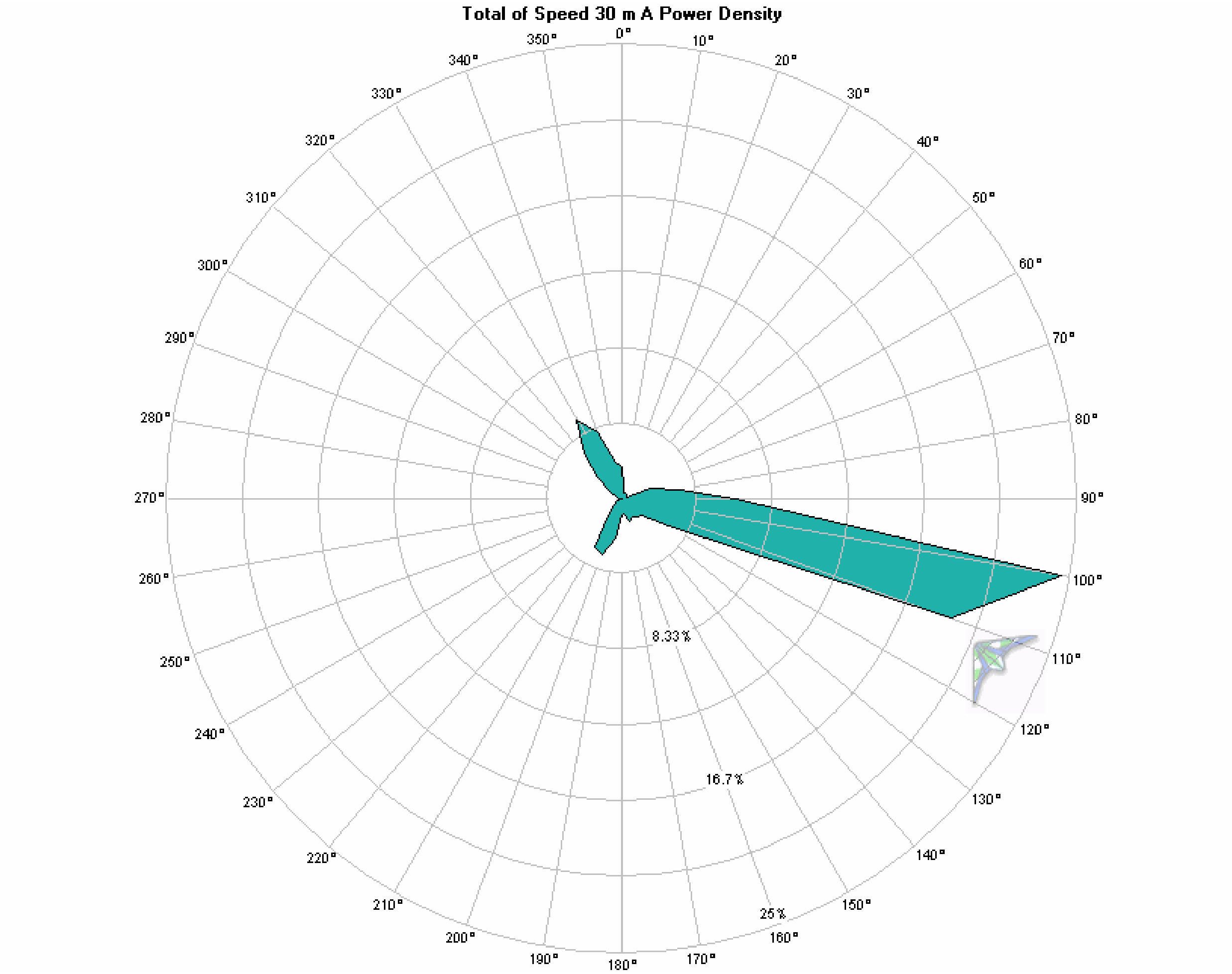
Koliganek winds are rather directional; the wind frequency rose indicates northwest, east-southeast and south-southwest winds. Interestingly though, the power producing winds are strongly dominated by the east-southeast direction, with northwest and south-southwest to a much lesser extent. The practical application of this information is that a site should be selected with adequate freedom from ground interference toward these sectors and if more than one wind turbine is installed, the turbines should be adequately spaced apart to prevent downwind (from the power producing winds) interference 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, Koliganek experienced 37 percent calm conditions during the measurement period (see wind frequency rose below).

Wind Frequency Rose (30 meters)

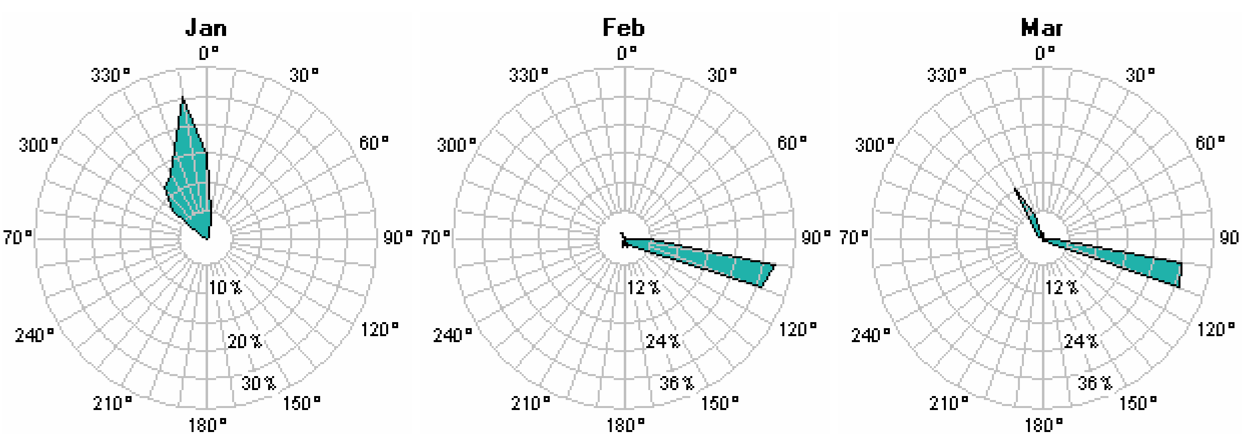


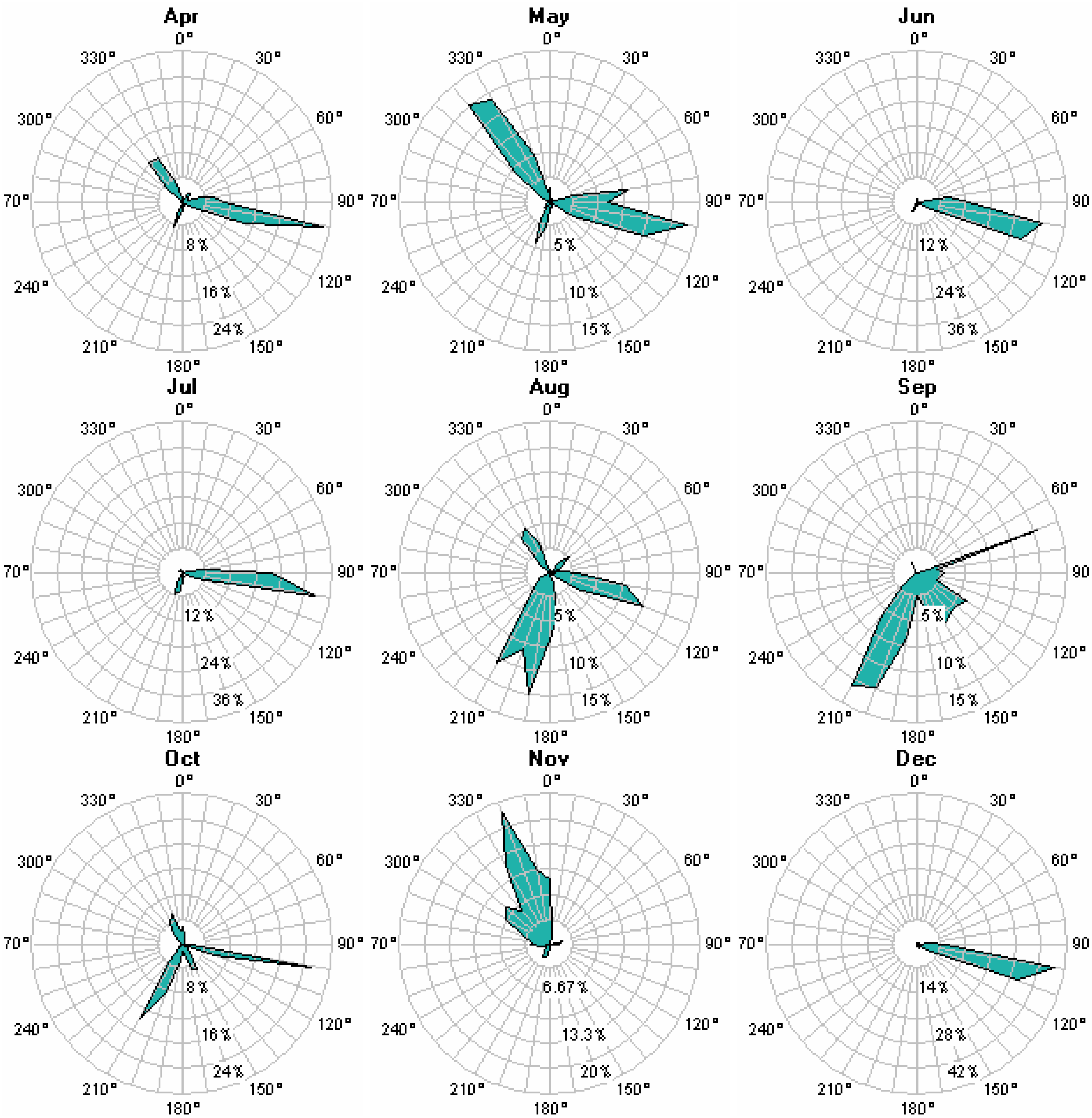
Wind Power Density Rose (30 meters)



Wind Power Density Rose by Month (30 meters)

Note: for easier visualization of monthly wind power variation, the scale is <u>not</u> common

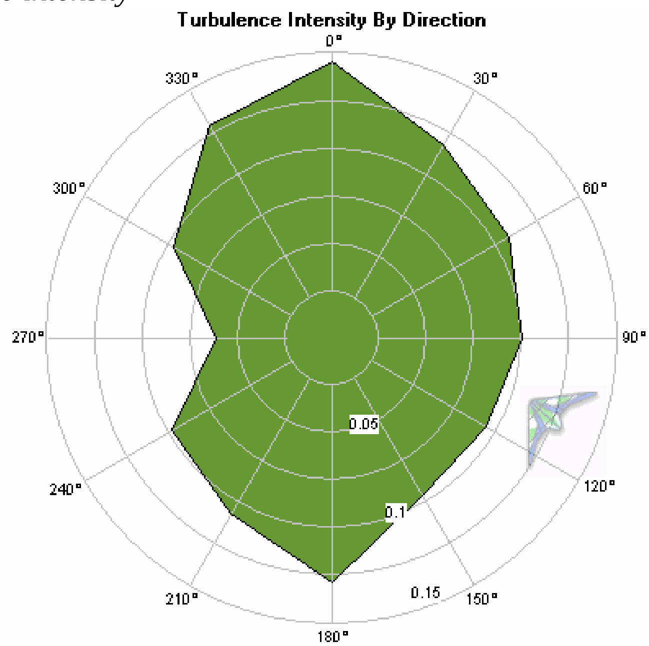



Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
0°
30°
60°
90°
120°
150°
180°
210°
240°
70°
300°
330°
8%
16%
24%
5%
10%
15%
12%
24%
36%
14%
28%
42%
6.67%
13.3%
20%

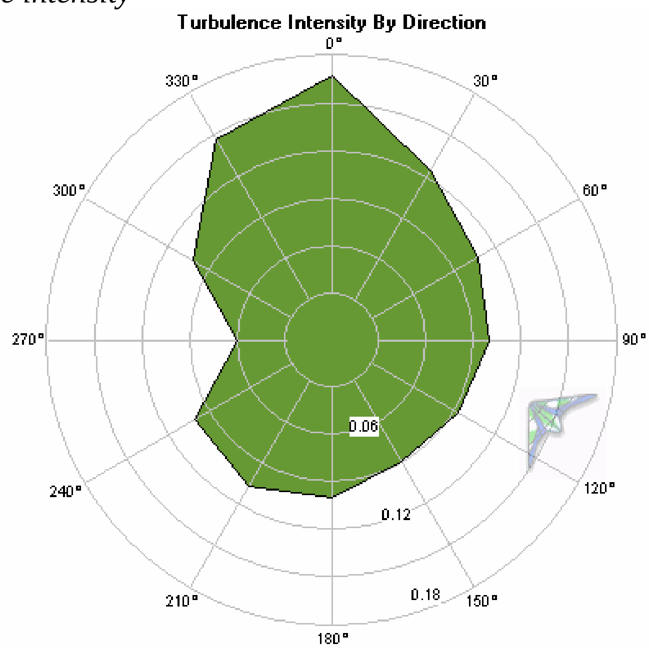
Turbulence Intensity

The turbulence intensity (TI) is quite acceptable for all wind direction, with a mean turbulence intensity of 0.115 (channel 1 – 30 meter A) and 0.117 (channel 2 – 30 meter B), indicating moderately smooth air. These TIs are calculated with a threshold wind speed of 4 m/s. The spike of relatively high turbulence to the north to northeast in both graphs is likely due to the presence of two old water tanks located several hundred meters north of the met tower test site and heavy brush and higher terrain both north and northeast of the met tower location.

30 meter (A) turbulence intensity

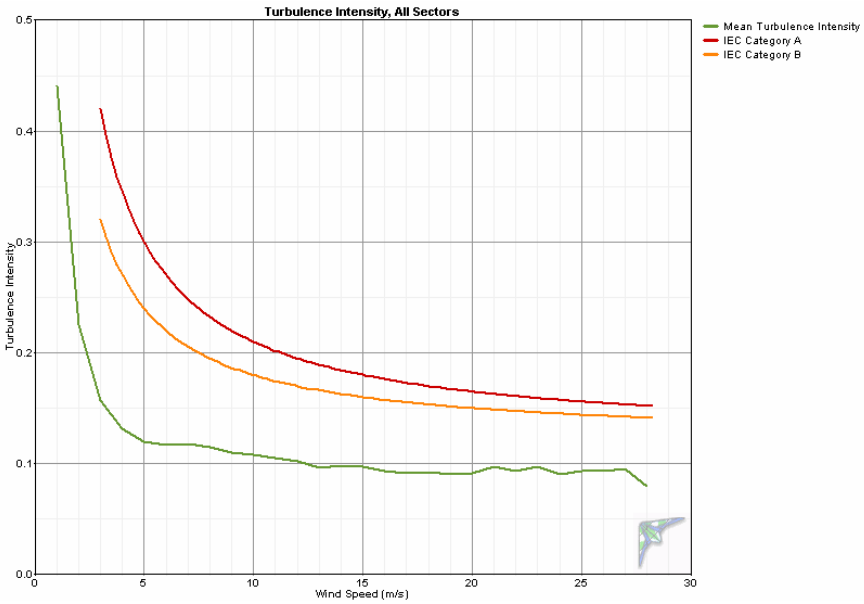


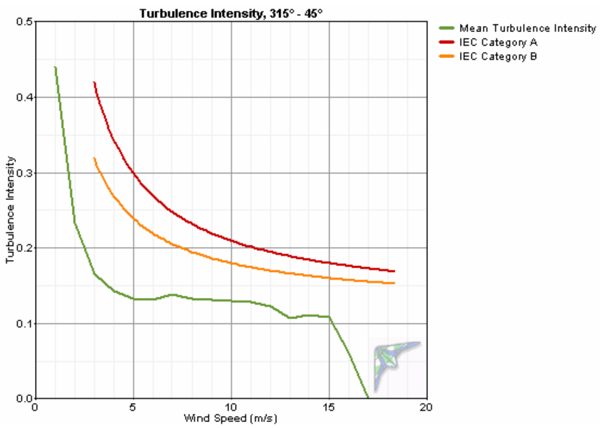
30 meter (B) turbulence intensity

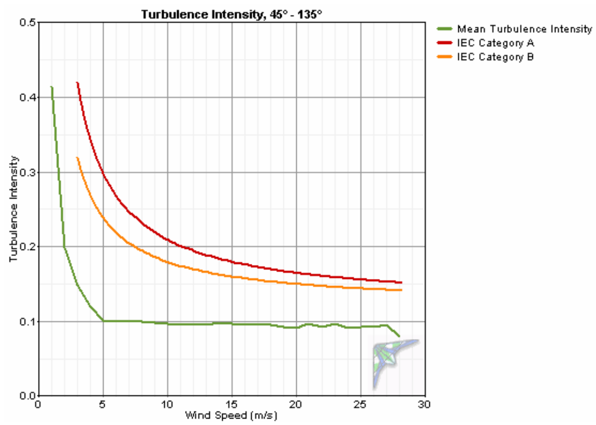


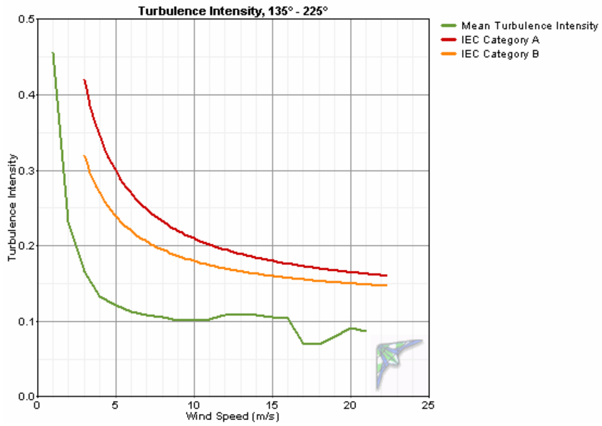
IEC Turbulence Intensity Standards

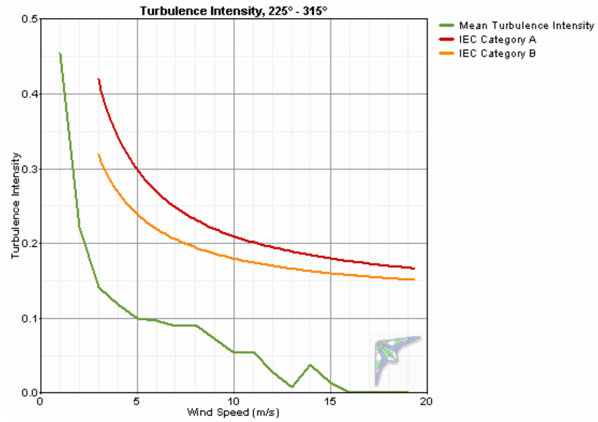
As indicated in the graphs below, turbulence at the Koliganek project test site is well below International Electrotechnical (IEC) standards at all measured wind speeds and from all four quadrants of the wind rose.











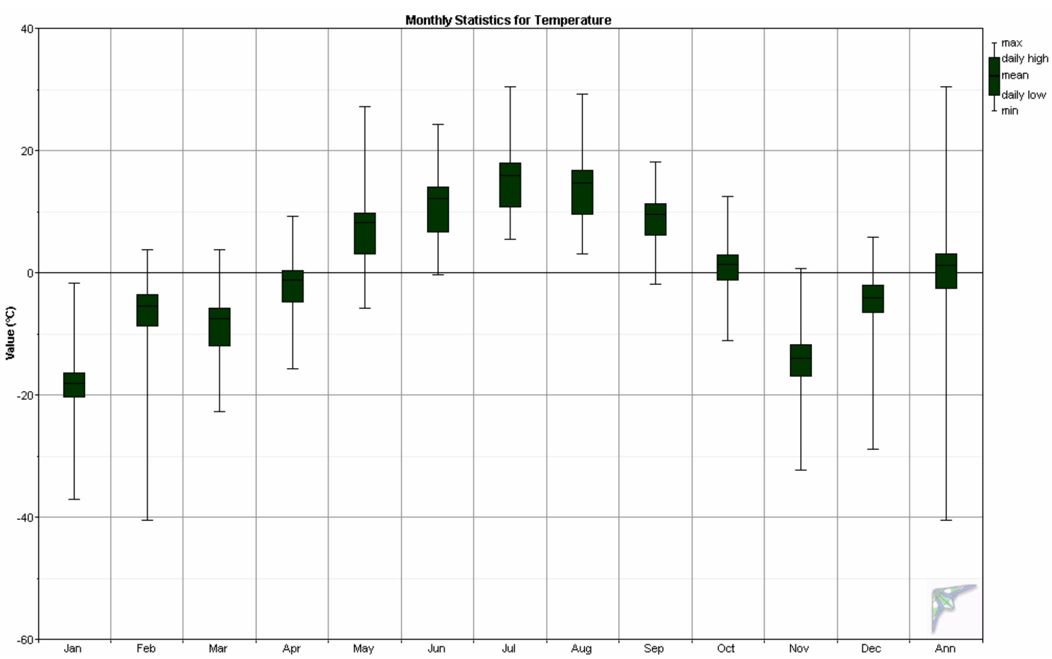
Turbulence Table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Standard Deviation of WindSpeed (m/s)	Mean Turbulence Intensity	Standard Deviation of Turbulence Intensity	Characteristic Turbulence Intensity
1	0.5	1.5	2765	0.416	0.441	0.220	0.662
2	1.5	2.5	5021	0.437	0.225	0.132	0.357
3	2.5	3.5	6670	0.463	0.157	0.088	0.245
4	3.5	4.5	7378	0.521	0.132	0.063	0.195
5	4.5	5.5	7007	0.592	0.120	0.053	0.173
6	5.5	6.5	5742	0.696	0.117	0.051	0.169
7	6.5	7.5	4641	0.815	0.117	0.047	0.164
8	7.5	8.5	3373	0.909	0.115	0.043	0.157
9	8.5	9.5	2455	0.982	0.110	0.040	0.151
10	9.5	10.5	1789	1.071	0.108	0.038	0.146
11	10.5	11.5	1343	1.155	0.106	0.034	0.140
12	11.5	12.5	945	1.217	0.102	0.032	0.134
13	12.5	13.5	613	1.248	0.097	0.034	0.130
14	13.5	14.5	456	1.376	0.099	0.033	0.132
15	14.5	15.5	489	1.454	0.097	0.027	0.124
16	15.5	16.5	398	1.483	0.093	0.029	0.122
17	16.5	17.5	354	1.547	0.091	0.030	0.122
18	17.5	18.5	267	1.660	0.093	0.029	0.122
19	18.5	19.5	185	1.702	0.090	0.024	0.114
20	19.5	20.5	100	1.820	0.092	0.018	0.110
21	20.5	21.5	66	2.029	0.097	0.021	0.118
22	21.5	22.5	52	2.038	0.093	0.015	0.108
23	22.5	23.5	27	2.237	0.097	0.011	0.109
24	23.5	24.5	25	2.184	0.091	0.013	0.104
25	24.5	25.5	34	2.326	0.093	0.010	0.103
26	25.5	26.5	20	2.415	0.093	0.012	0.105
27	26.5	27.5	8	2.550	0.095	0.007	0.102
28	27.5	28.5	1	2.200	0.079	0.000	0.079

Air Temperature and Density

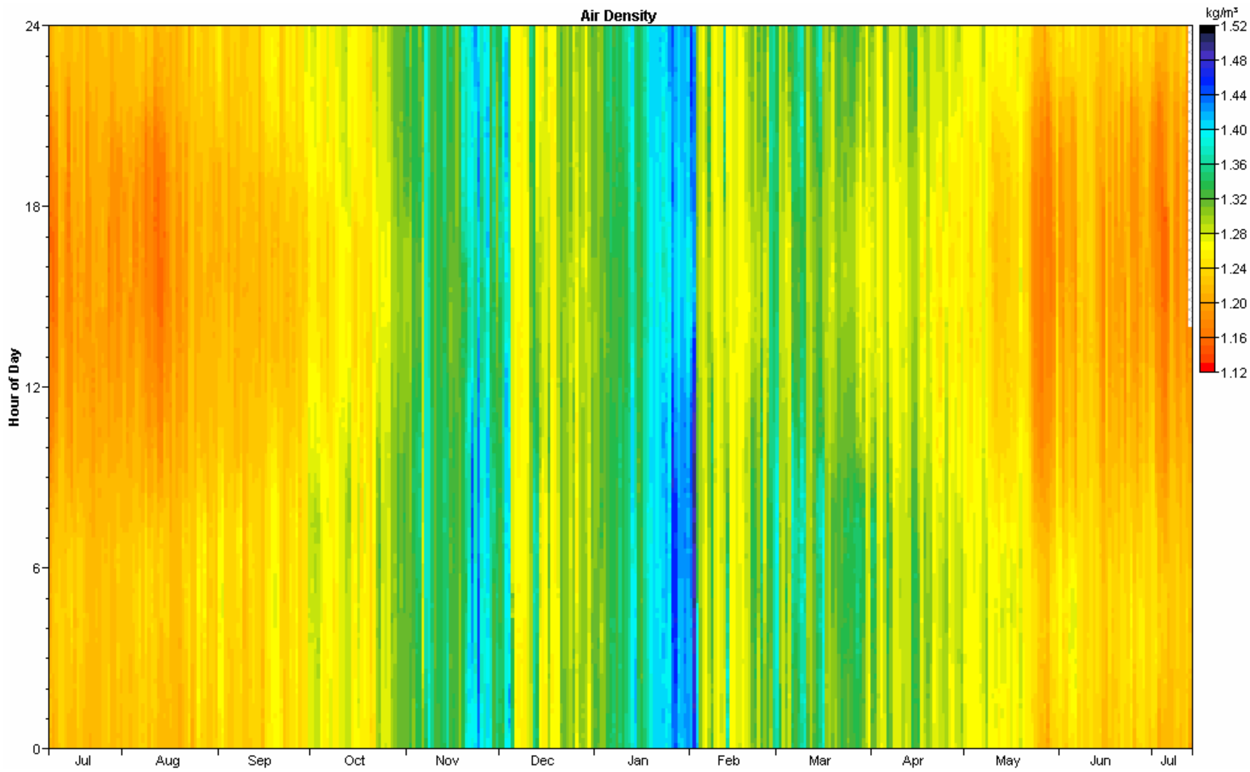
Over the reporting period, Koliganek had an average temperature of 1.3° C. The minimum recorded temperature during the measurement period was -40.4° C and the maximum temperature was 30.5° C, indicating a wide variability of the ambient temperature operating environment important to wind turbine operations. Consequent to Koliganek's cool temperatures, the average air density of 1.274 kg/m^3 is five percent higher than the standard air density of 1.214 kg/m^3 (at 14.39° C temperature and 101.17 kPa pressure at 95 m elevation), indicating that Koliganek, due to its cool annual temperature average, has denser air than the standard air density used to calculate turbine power curves.

		Temperature				Density		
Year	Month	Mean (°C)	Min (°C)	Max (°C)	Std. Dev. (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
2005	Jul	15.8	7.6	29.0	3.9	1.208	1.155	1.243
2005	Aug	14.8	3.1	29.3	4.7	1.212	1.154	1.263
2005	Sep	9.7	-1.8	18.2	3.6	1.234	1.198	1.286
2005	Oct	1.4	-11.0	12.5	4.8	1.271	1.222	1.331
2005	Nov	-13.9	-32.2	0.8	6.3	1.347	1.274	1.448
2005	Dec	-4.1	-28.8	5.9	7.6	1.298	1.251	1.428
2006	Jan	-18.0	-37.0	-1.7	7.5	1.369	1.286	1.478
2006	Feb	-5.4	-40.4	3.8	9.2	1.305	1.260	1.499
2006	Mar	-7.5	-22.6	3.8	5.8	1.314	1.260	1.393
2006	Apr	-1.1	-15.7	9.3	4.3	1.283	1.235	1.355
2006	May	8.2	-5.8	27.3	6.8	1.241	1.161	1.305
2006	Jun	12.2	-0.2	24.4	4.5	1.223	1.173	1.278
2006	Jul	16.3	5.6	30.5	5.5	1.206	1.149	1.252
Annual		**1.3**	-40.4	30.5	12.4	**1.274**	1.149	1.499



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 predicted by the turbine power curve, while densities lower than standard will yield lower turbine power than predicted. Density variance from standard is accounted for in the turbine performance predictions.



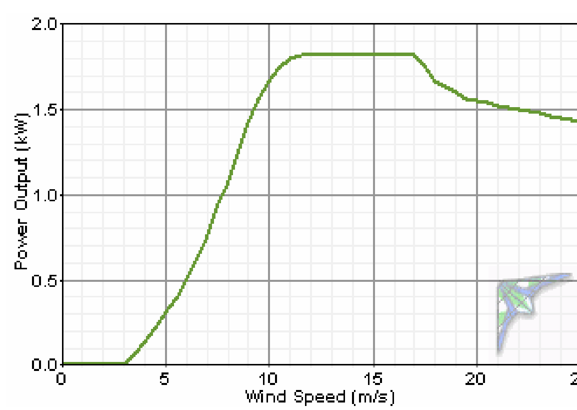
Wind Turbine Performance

The turbine performance predictions noted below are based on 100 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.

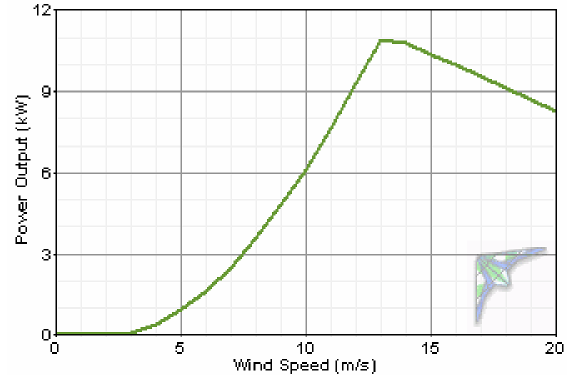
Note that these performance estimates were predicted with use of Windographer® wind analysis software; power curves provided by manufacturers are not independently verified and are assumed to be accurate. The power curves are presented for a standard air density of 1.225 kg/m^3 at sea level and 15° C.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

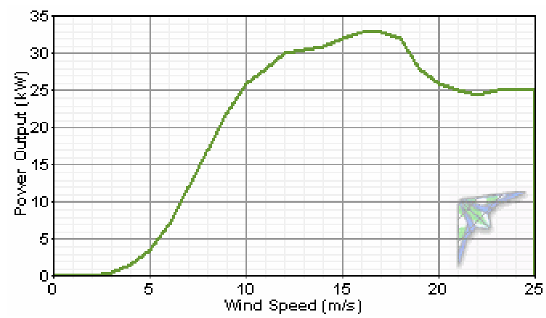
Southwest Skystream 3.7: 1.8 kW rated power output, 3.7 meter rotor diameter, stall-controlled. Available tower heights: 10.7 and 33.5 meters. Additional information is available at www.skystreamenergy.com.



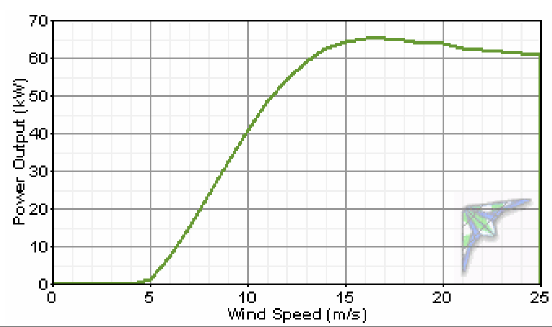
Bergey Excel-S: 10 kW rated power output, 6.7 meter rotor diameter, stall-controlled. Available tower heights: 18, 24, 30, 37 and 43 meters. Additional information is available at www.bergey.com.



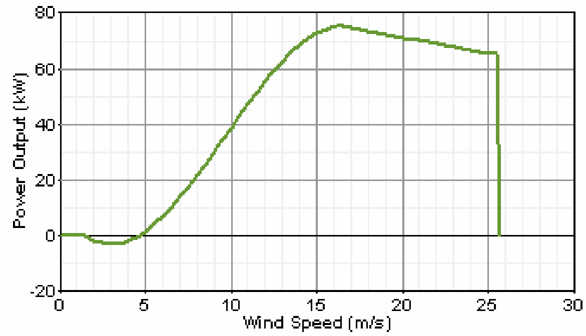
Fuhrländer FL30: 30 kW rated power output, 13 meter rotor, stall-controlled (power curve provided by Lorax Energy, LLC). Available tower heights: 26 and 30 meters. Additional information is available at http://www.fuhrlaender.de/ and http://www.lorax-energy.com/.



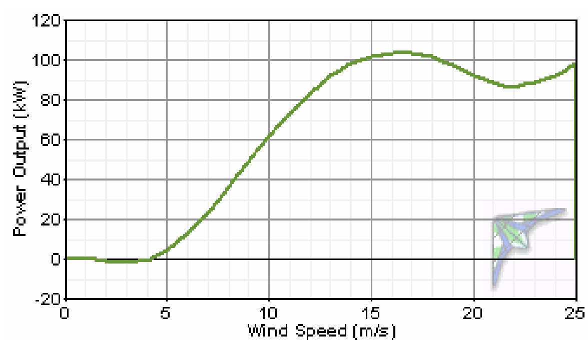
Entegrity eW-15: 65 kW rated power output, 15 meter rotor, stall-controlled (power curve provided by Entegrity Energy Systems). Available tower heights: 25 and 31 meters. Additional information is available at http://www.entegritywind.com/.



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 100/20: 100 kW rated power output, 20 meter rotor (19 meter rotor blades with 0.6 meter blade root extensions added), 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% 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 (%)
Southwest Skystream 3.7	10.7	4.59	37.1	5.3	0.4	3,387	21.5
Southwest Skystream 3.7	33.5	5.74	24.0	8.6	0.6	5,029	31.9
Bergey Excel-S	24	5.37	15.4	3.2	2.0	17,115	19.5
Bergey Excel-S	37	5.87	13.5	3.8	2.3	20,079	22.9
Fuhrländer FL30	26	5.46	15.0	2.0	8.1	71,117	24.6
Fuhrländer FL30	30	5.72	12.5	2.1	8.8	76,617	26.5
Entegrity eW-15 60 Hz	25	5.42	40.5	3.1	11.7	102,612	18.0
Entegrity eW-15 60 Hz	31	5.65	37.4	3.4	12.8	111,880	19.6
Vestas V15	25	5.42	48.4	2.1	10.7	93,939	14.3
Vestas V15	34	5.76	43.8	2.4	12.4	108,608	16.5
Northern Power NW 100/20	25	5.42	40.5	2.9	17.4	152,548	17.4
Northern Power NW 100/20	32	5.69	37.0	3.2	19.2	168,281	19.2

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 Power Output (kW)	Annual Energy Output (kWh/yr)	Average Capacity Factor (%)
Southwest Skystream 3.7	10.7	4.59	37.1	5.3	0.3	3,028	19.2
Southwest Skystream 3.7	33.5	5.74	24.0	8.6	0.5	4,496	28.5
Bergey Excel-S	24	5.37	15.4	3.2	1.8	15,302	17.5
Bergey Excel-S	37	5.87	13.5	3.8	2.1	17,952	20.5
Fuhrländer FL30	26	5.46	15.0	2.0	7.3	63,582	22.0
Fuhrländer FL30	30	5.72	12.5	2.1	7.8	68,498	23.7
Entegrity eW-15 60 Hz	25	5.42	40.5	3.1	10.5	91,739	16.1
Entegrity eW-15 60 Hz	31	5.65	37.4	3.4	11.4	100,025	17.6
Vestas V15	25	5.42	48.4	2.1	9.6	83,985	12.8
Vestas V15	34	5.76	43.8	2.4	11.1	97,100	14.8
Northern Power NW 100/20	25	5.42	40.5	2.9	15.6	136,384	15.6
Northern Power NW 100/20	32	5.69	37.0	3.2	17.2	150,449	17.2

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 (%)	5	
Array (%)	1	
Icing/soiling (%)	3	
Other (%)	2	
Total (%)	10.6	(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 (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)
Southwest Skystream 3.7	3,028	917	242	$424	$484	$545	$606	$666	$727	$787	10.7
Southwest Skystream 3.7	4,496	1,362	360	$629	$719	$809	$899	$989	$1,079	$1,169	33.5
Bergey Excel-S	15,302	4,634	1,224	$2,142	$2,448	$2,754	$3,060	$3,366	$3,672	$3,979	24
Bergey Excel-S	17,952	5,436	1,436	$2,513	$2,872	$3,231	$3,590	$3,949	$4,308	$4,668	37
Fuhrländer FL30	63,582	19,255	5,087	$8,901	$10,173	$11,445	$12,716	$13,988	$15,260	$16,531	26
Fuhrländer FL30	68,498	20,743	5,480	$9,590	$10,960	$12,330	$13,700	$15,070	$16,440	$17,809	30
Entegrity eW-15 60 Hz	91,739	27,782	7,339	$12,843	$14,678	$16,513	$18,348	$20,183	$22,017	$23,852	25
Entegrity eW-15 60 Hz	100,025	30,291	8,002	$14,004	$16,004	$18,005	$20,005	$22,006	$24,006	$26,007	31
Vestas V15	83,985	25,433	6,719	$11,758	$13,438	$15,117	$16,797	$18,477	$20,156	$21,836	25
Vestas V15	97,100	29,405	7,768	$13,594	$15,536	$17,478	$19,420	$21,362	$23,304	$25,246	34
Northern Power NW 100/20	136,384	41,301	10,911	$19,094	$21,821	$24,549	$27,277	$30,004	$32,732	$35,460	25
Northern Power NW 100/20	150,449	45,561	12,036	$21,063	$24,072	$27,081	$30,090	$33,099	$36,108	$39,117	32

Notes:

1. Koliganek electrical energy production efficiency assumed to be 12.5 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.