Kodiak, Alaska Site 1 Wind Resource Report for Kodiak Electric Association

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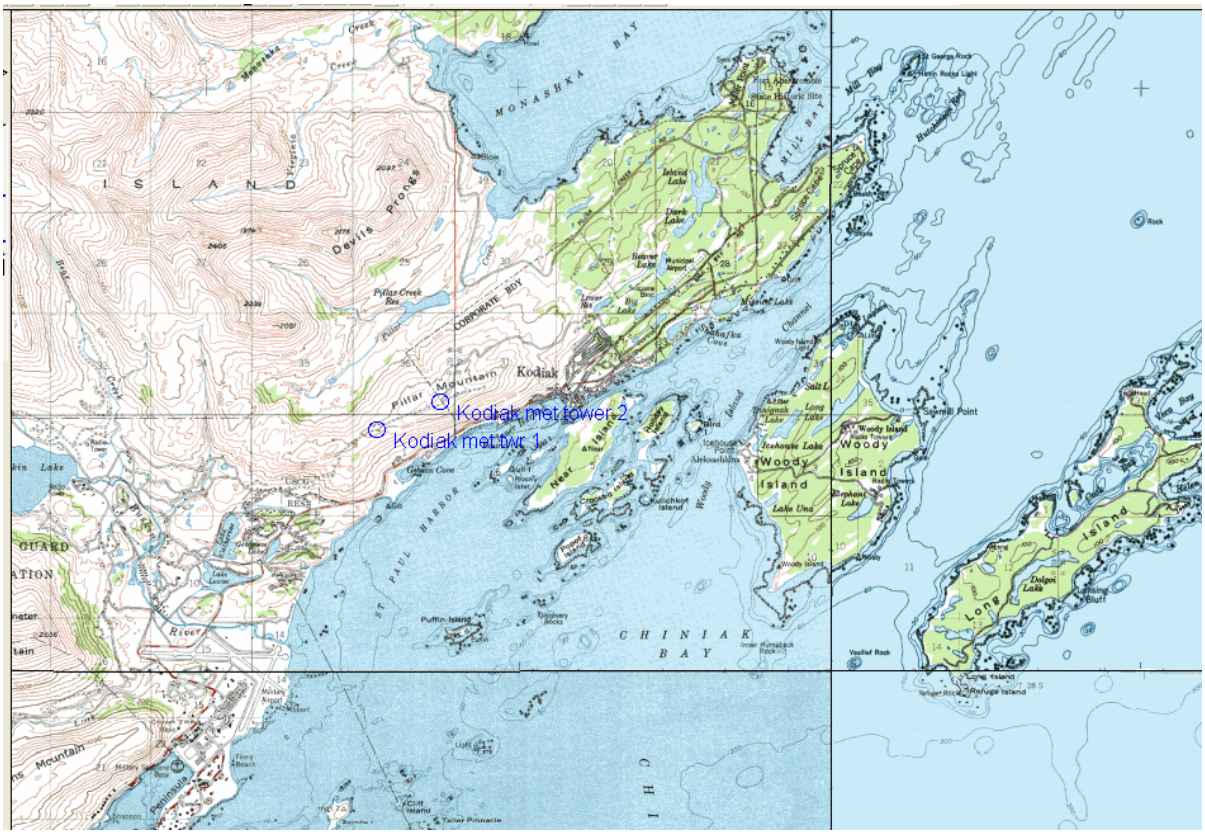
Date of report: August 23, 2006

Photo © Doug Vaught

General Site Information

Site number	7309
Site Description	Kodiak, Alaska, Pillar Mountain ridgeline
Latitude/longitude	N 057° 47.008'; W 152° 27.464'
Site elevation	300 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter Tall Tower, 152 mm (6 in) diameter

Kodiak is located near the north eastern tip of Kodiak Island in the Gulf of Alaska. Kodiak Island is known as "the emerald isle" and is the largest island in Alaska. Kodiak National Wildlife Refuge encompasses a large portion of Kodiak Island and nearby Afognak Island. Kodiak is 400 kilometers (250 miles) southwest of Anchorage, has a population of about 6000 people, and has jet and commuter turboprop aircraft service to Anchorage. The climate of the Kodiak has a strong marine influence. Severely cold temperatures are relatively infrequent for its northerly latitude and there is considerable rain and snowfall with frequent cloud cover and fog. Severe storms with high winds are common from December through February.



Data Synopsis

With the inclusion of summer data, Site 1 continues to exhibit exceptionally robust winds but with a continued decrease in reported mean wind speeds and wind power density from previous reports now that summer data is included.

Wind power class (measured to date)	Class 7 – Superb
Channel 1 average wind speed	7.87 m/s (at 30 meters)
Maximum wind speed	47.7 m/s, 3/9/06, 7:30 am (30 m level)
Mean wind power density (50 meters)	903 W/m^2 (predicted by calculation)
Roughness Class	0.79 (description: rough pasture)

Power law exponent	0.129 (moderate wind shear)
Time exceeding 25 m/s wind speed	75.7 hours (1.1% of the time)
Data start date	November 2, 2005
Most recent data date	August 21, 2006

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m	0.765	0.35	east
2	NRG #40 anemometer	30 m	0.765	0.35	south
3	NRG #40 anemometer	20 m	0.765	0.35	southeast
7	NRG #200P wind vane	30 m	0.351	165	NNW
9	NRG #110S Temp C	2 m	0.138	-86.383	N/A

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 data recovery during May through August was nearly 100%, but during the months of November through April some data was filtered, with March being the most ice prone as far as data loss is concerned.

		Ch 1 anemometer		Ch 2 anemometer		Ch 3 anemometer	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2005	Nov	3,991	97.6	3,989	97.5	3,995	97.7
2005	Dec	4,412	98.8	4,412	98.8	4,414	98.9
2006	Jan	4,394	98.4	4,390	98.3	4,365	97.8
2006	Feb	3,946	97.9	3,946	97.9	3,947	97.9
2006	Mar	4,282	95.9	4,270	95.7	4,349	97.4
2006	Apr	4,137	95.8	4,160	96.3	4,175	96.6
2006	May	4,459	99.9	4,445	99.6	4,461	99.9
2006	Jun	4,320	100.0	4,320	100.0	4,320	100.0
2006	Jul	4,464	100.0	4,464	100.0	4,464	100.0
2006	Aug	2,934	100.0	2,934	100.0	2,934	100.0
All data		41,339	98.4	41,330	98.4	41,424	98.6

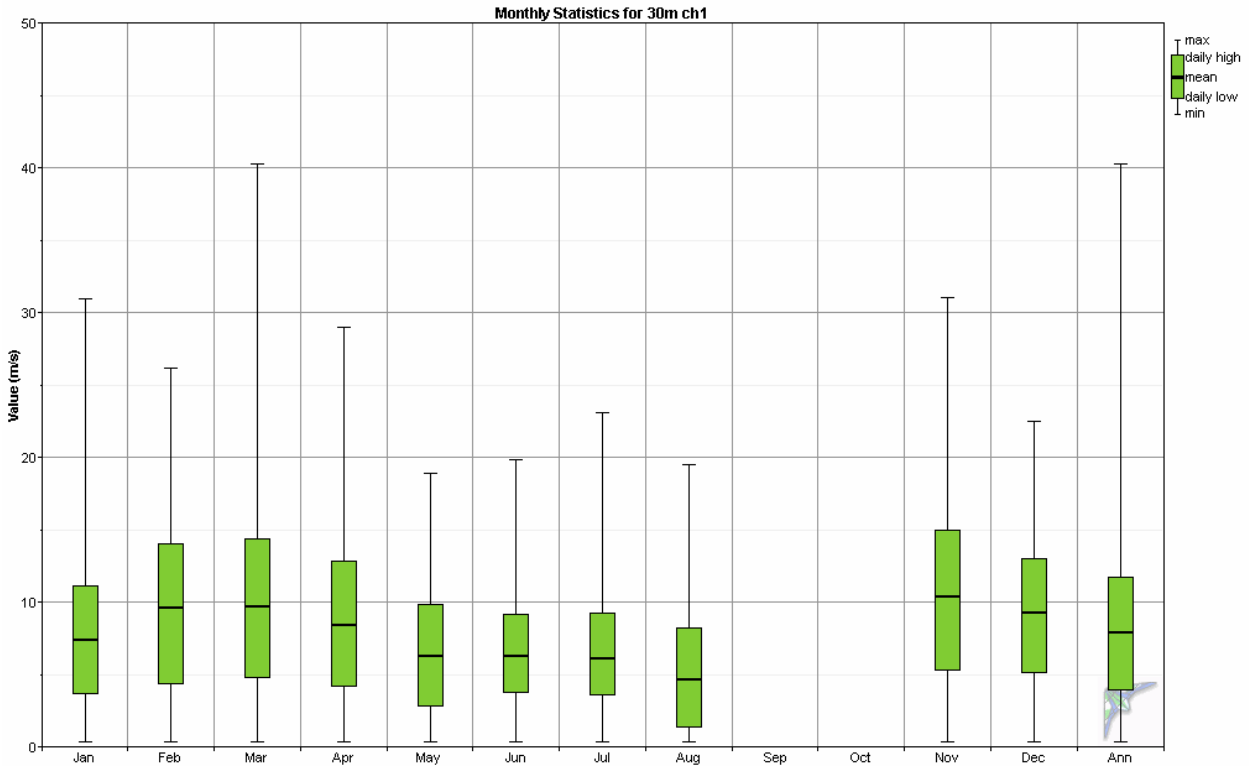
		Ch 7 vane		Ch 9 temperature	
Year	Month	Records	Recovery Rate (%)	Records	Recovery Rate (%)
2005	Nov	3,989	97.5	4,091	100.0
2005	Dec	4,412	98.8	4,464	100.0
2006	Jan	4,343	97.3	4,464	100.0
2006	Feb	3,946	97.9	4,032	100.0
2006	Mar	4,244	95.1	4,464	100.0
2006	Apr	4,133	95.7	4,320	100.0
2006	May	4,445	99.6	4,464	100.0
2006	Jun	4,320	100.0	4,320	100.0
2006	Jul	4,464	100.0	4,464	100.0
2006	Aug	2,934	100.0	2,934	100.0

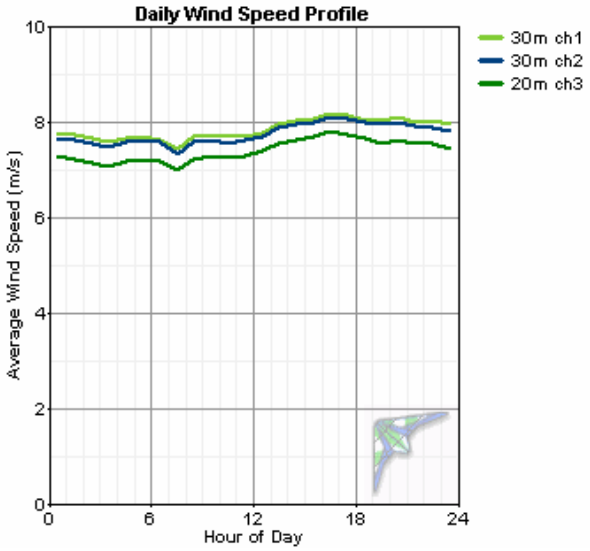
All data	41,230	98.1	42,017	100.0

Monthly Wind Speed Averages (Channel 1 – 30 meters)

The Channel 1 (30-meter) anemometer wind speed average for the reporting period is 7.87 m/s, the Channel 2 (30-meter) anemometer wind speed average is 7.78 m/s, and the Channel 3 (20-meter) anemometer wind speed average is 7.43 m/s. The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 3 to 8 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 4 to 5 p.m.

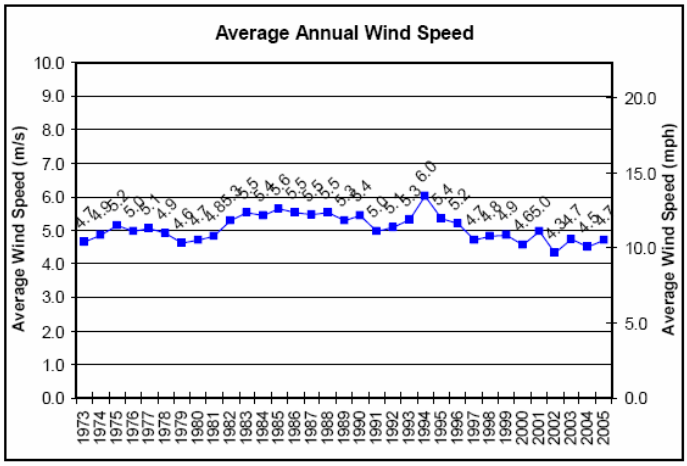
		Ch 1 (30 meters)					Ch 2 (30 m)		Ch 3 (20 m)	
Year	Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max (m/s)	Mean (m/s)	Max (m/s)
2005	Nov	10.37	31.1	6.17	1.69	11.58	10.23	31.1	9.67	31.3
2005	Dec	9.29	22.5	4.66	1.98	10.37	9.27	22.8	8.76	21.4
2006	Jan	7.40	31.0	4.58	1.64	8.25	7.31	31.2	6.79	29.9
2006	Feb	9.59	26.2	5.87	1.59	10.63	9.56	25.6	9.08	26.2
2006	Mar	9.74	40.3	7.90	1.29	10.56	9.57	40.7	9.16	40.4
2006	Apr	8.42	29.0	6.43	1.30	9.12	8.28	29.0	7.96	29.2
2006	May	6.29	18.9	3.95	1.62	7.02	6.18	19.2	5.99	18.4
2006	Jun	6.31	19.9	3.97	1.57	7.00	6.10	20.3	6.16	18.8
2006	Jul	6.08	23.1	4.90	1.16	6.41	6.12	22.9	5.74	22.6
2006	Aug	4.62	19.5	3.73	1.23	4.95	4.59	19.5	4.37	18.1
All data		**7.87**	40.3	5.67	1.39	8.61	**7.78**	40.7	**7.43**	40.4





Long-term Comparison

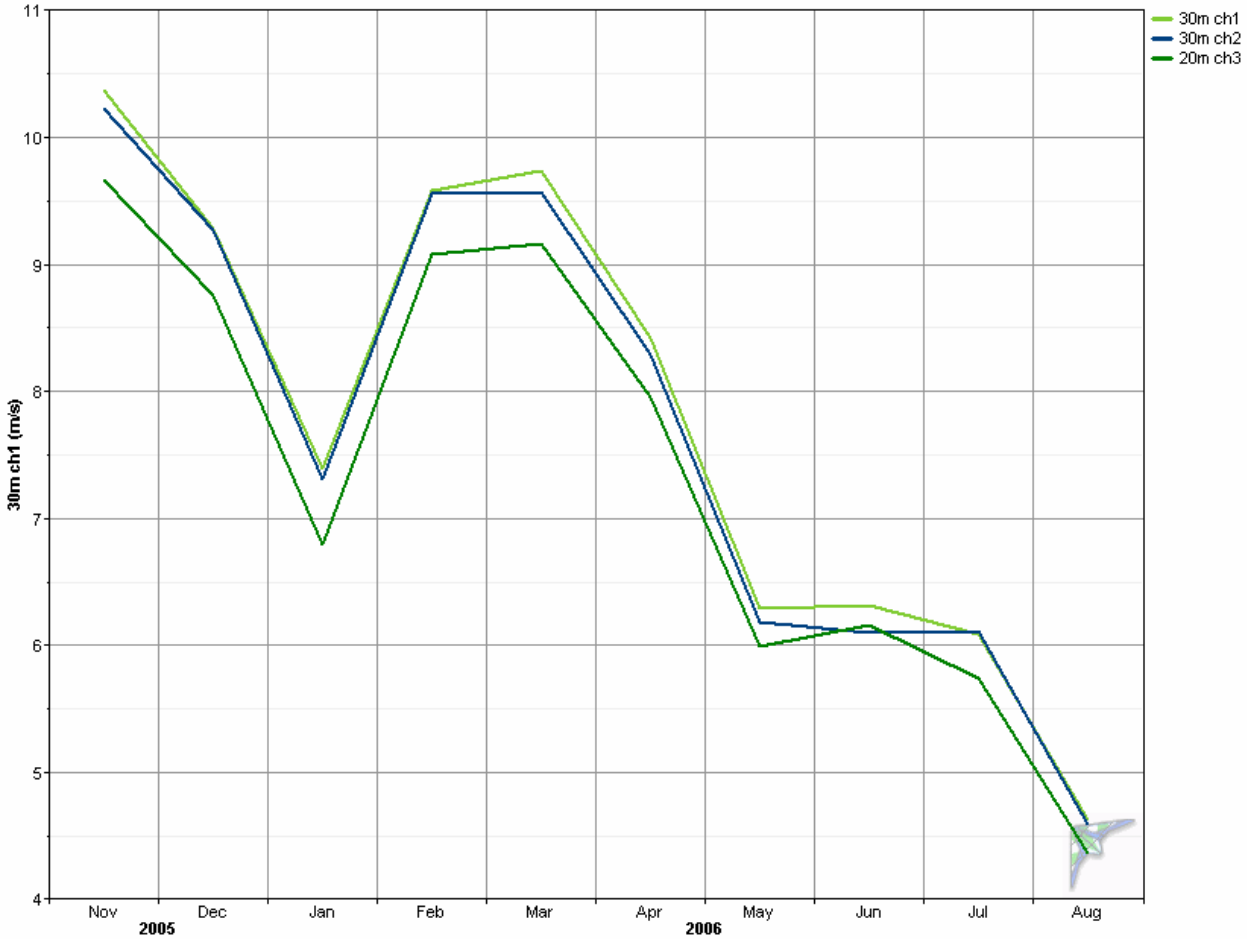
The graph below of average annual wind speed for the nearby Kodiak airport indicates that 2005 experienced possibly low average annual wind speeds when compared to data over the past thirty-two years, although in comparison to the last eight years, the 2005 data is about average. The discrepancy between earlier data and the past eight years can be attributed to an ASOS equipment upgrade. Adjusted wind data collected during the measurement period against long-term data measurement may be included in a later revision of this report, although for Site 1 this effort may be of marginal interest considering the exceptionally strong wind resource at the site.



Time Series of Wind Speed Measurement

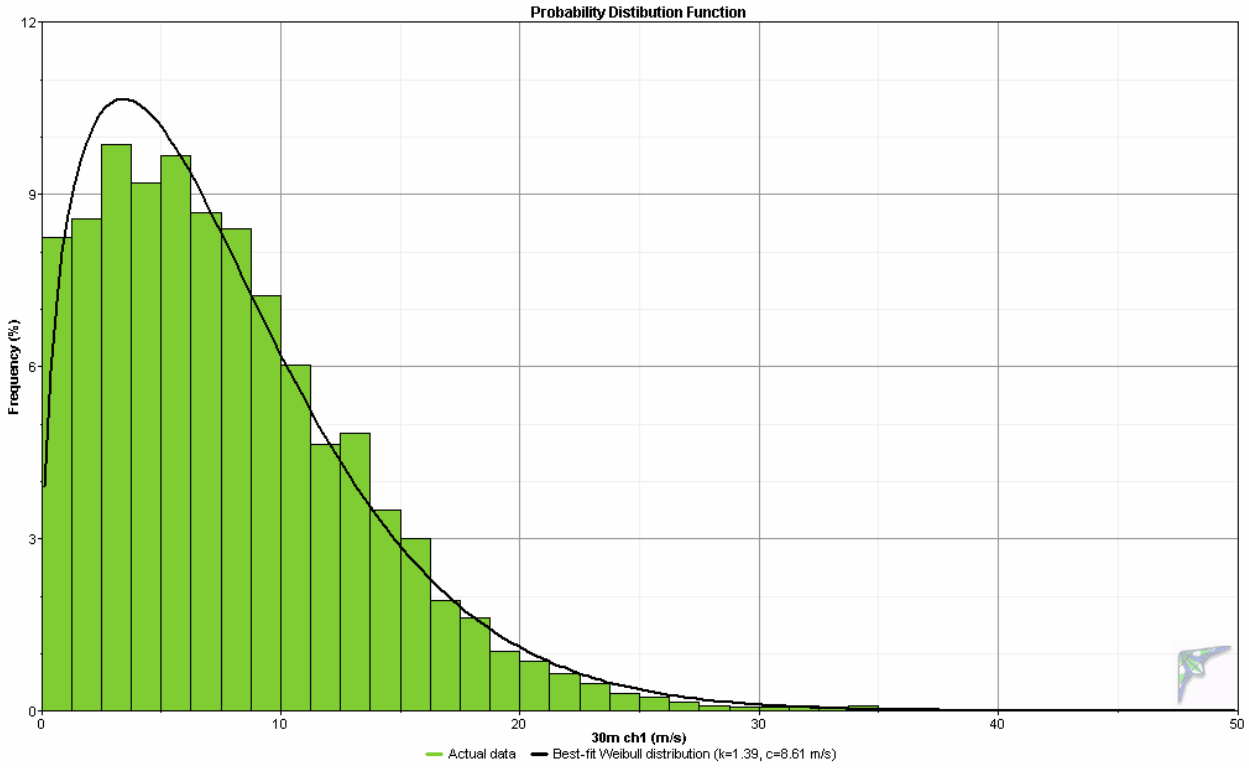
The average wind speed at 30 meters for the measurement period is 7.87 m/s. As expected, the highest winds occurred during the fall through spring months (September and October data still not collected) with relatively light winds during the late summer months of July and August.

The unusually low winds measured in January 2006 were due to a persistent high pressure system over Alaska that month that resulted in relatively calm winds and extremely cold temperatures Statewide.



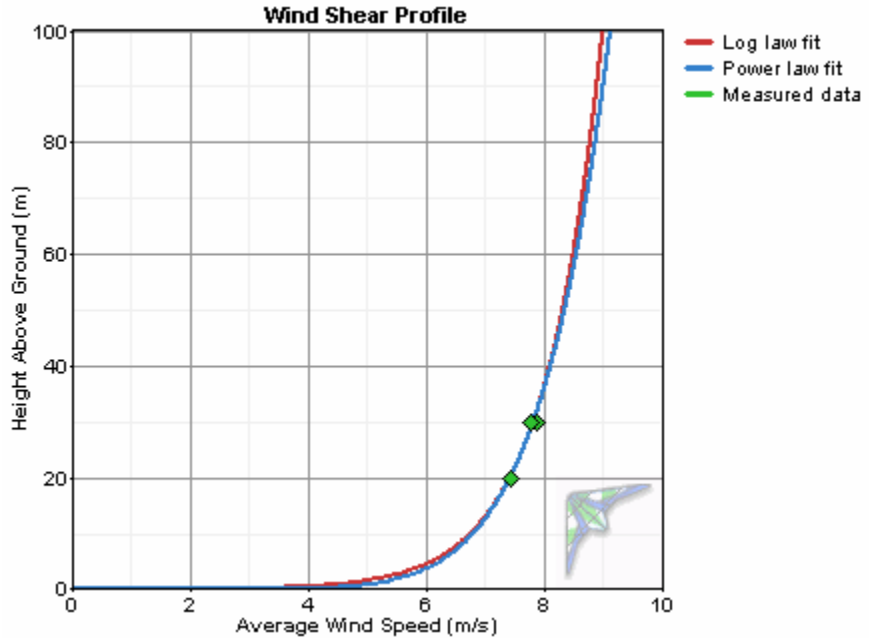
Probability Distribution Function

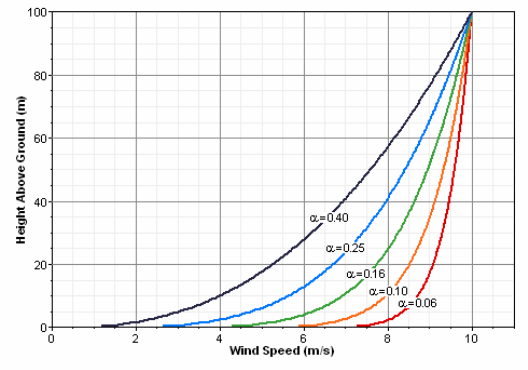
The probability distribution function provides a visual indication of measured wind speeds in one meter per second "bins". Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s – the "cut-in" wind speed. The black line in the graph is a best fit Weibull distribution.



Wind Shear Profile

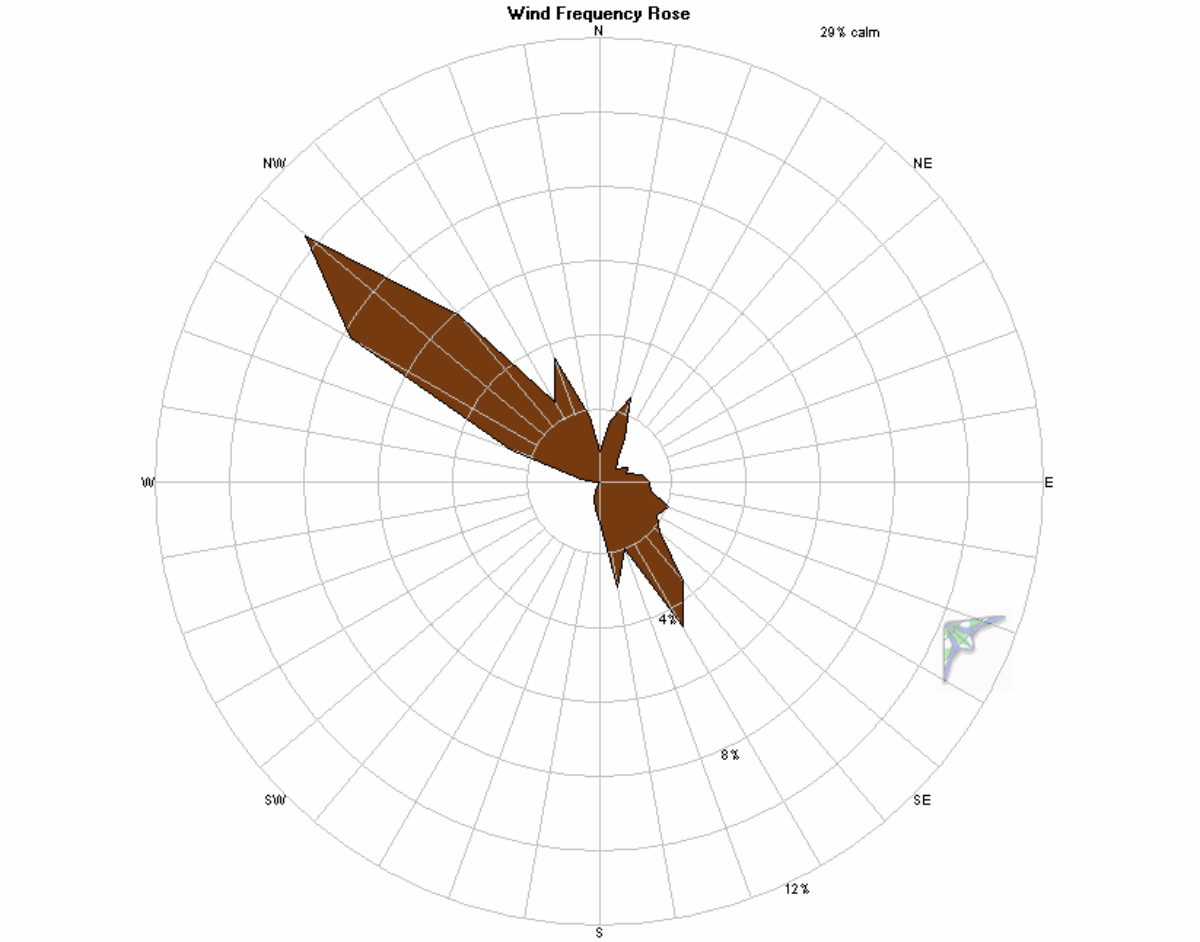
The power law exponent was calculated at 0.129, indicating low wind shear at Site 1. The practical application of this information is that a lower turbine tower height is possible as there is relatively low marginal gain in average wind speed with height. A tower height/power recovery/construction cost tradeoff study is advisable.



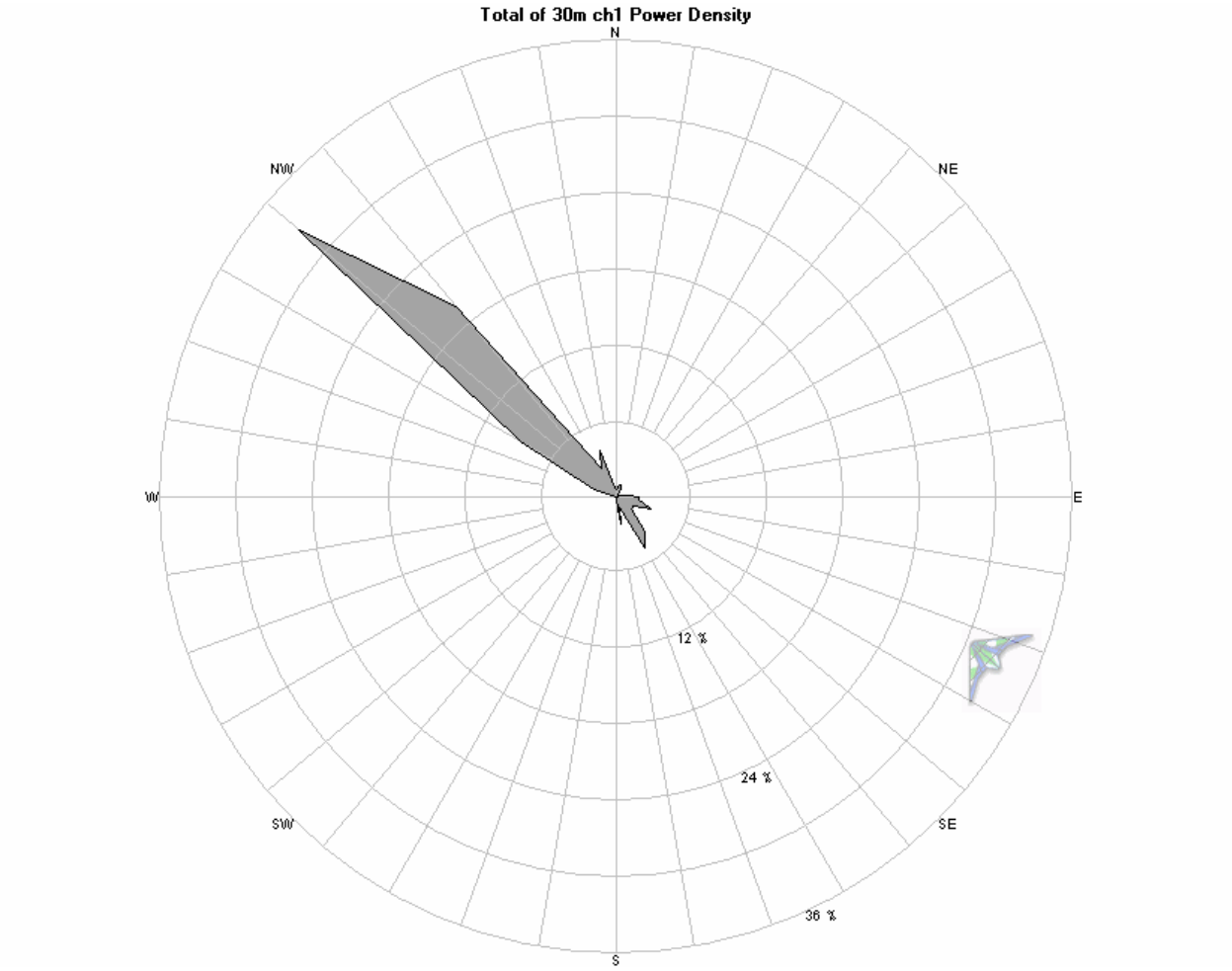


Wind Roses

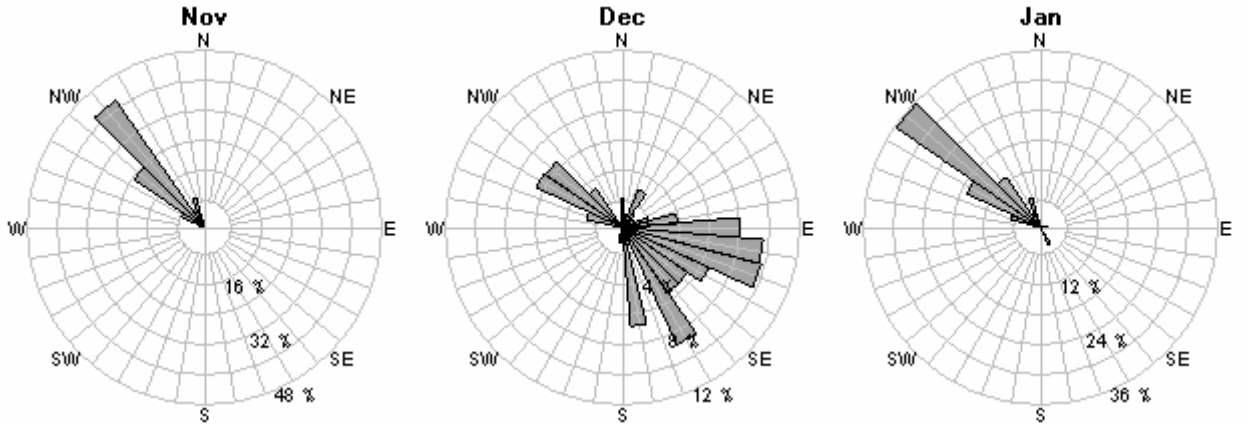
Winds continue to be strongly directional from the northwest. This data observation is even stronger when one considers the power density rose (second wind rose). The majority of the power producing winds are concentrated in one ten-degree sector centered on northwest with a less often power winds from south-southeast. The practical application of this information is that several turbines can potentially be spaced closely together perpendicular to the prevailing NW and SSE winds.

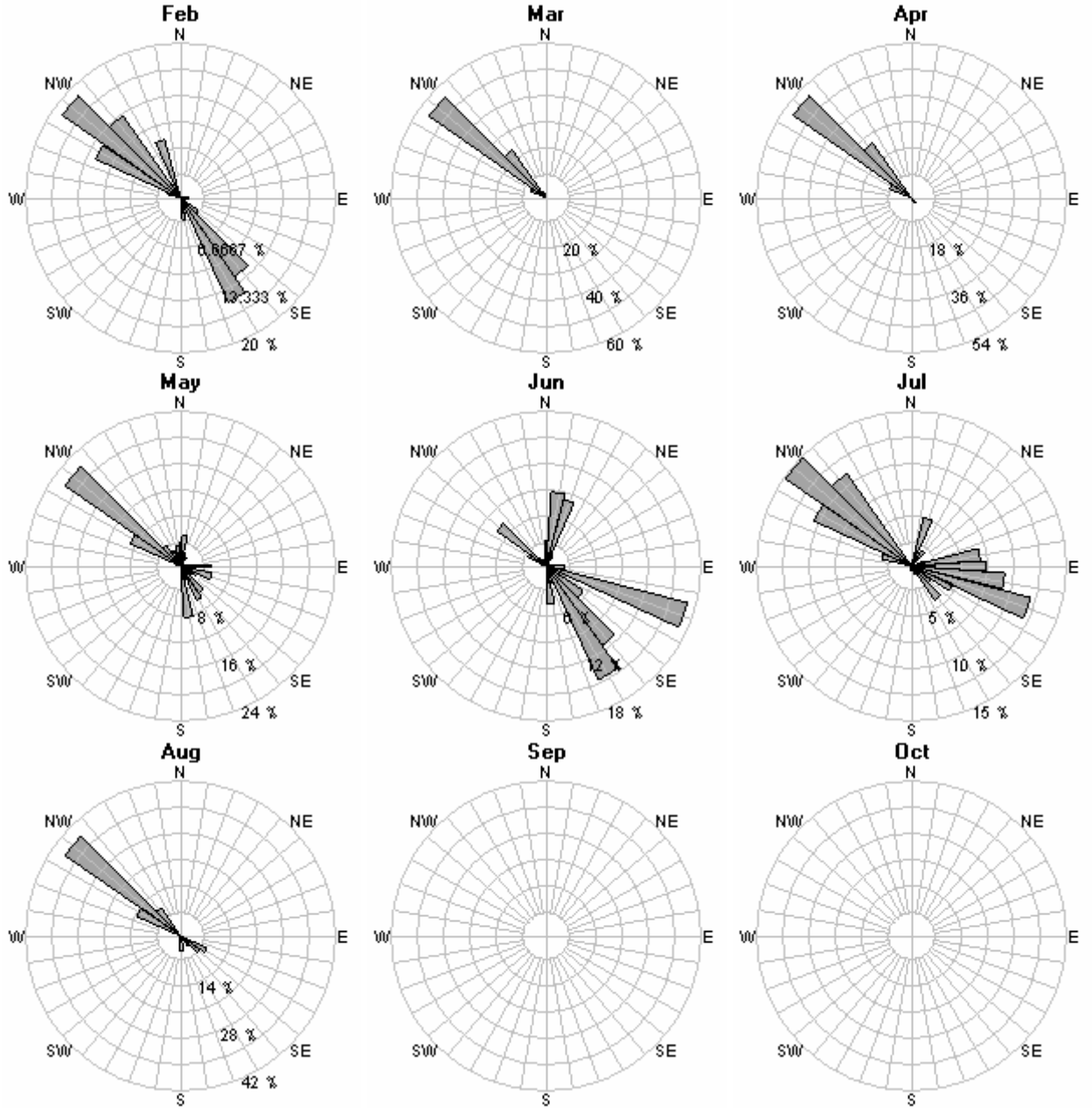


Wind Power Density Rose Annual (30 meters)



Wind Power Density Rose by Month (30 meters)

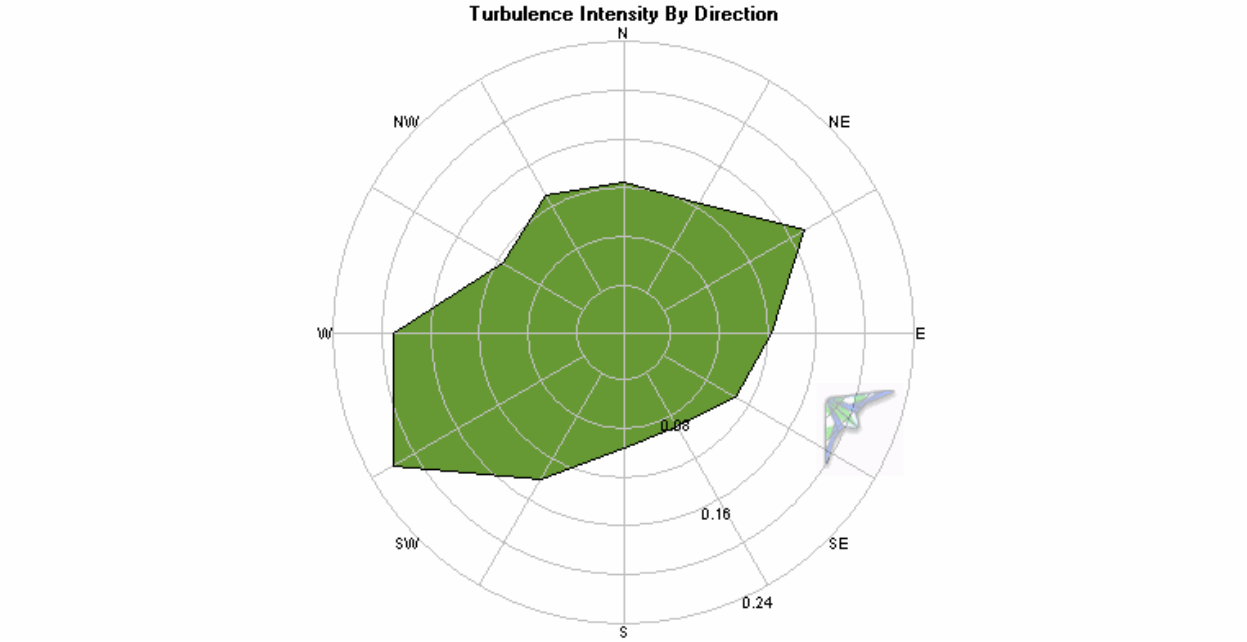




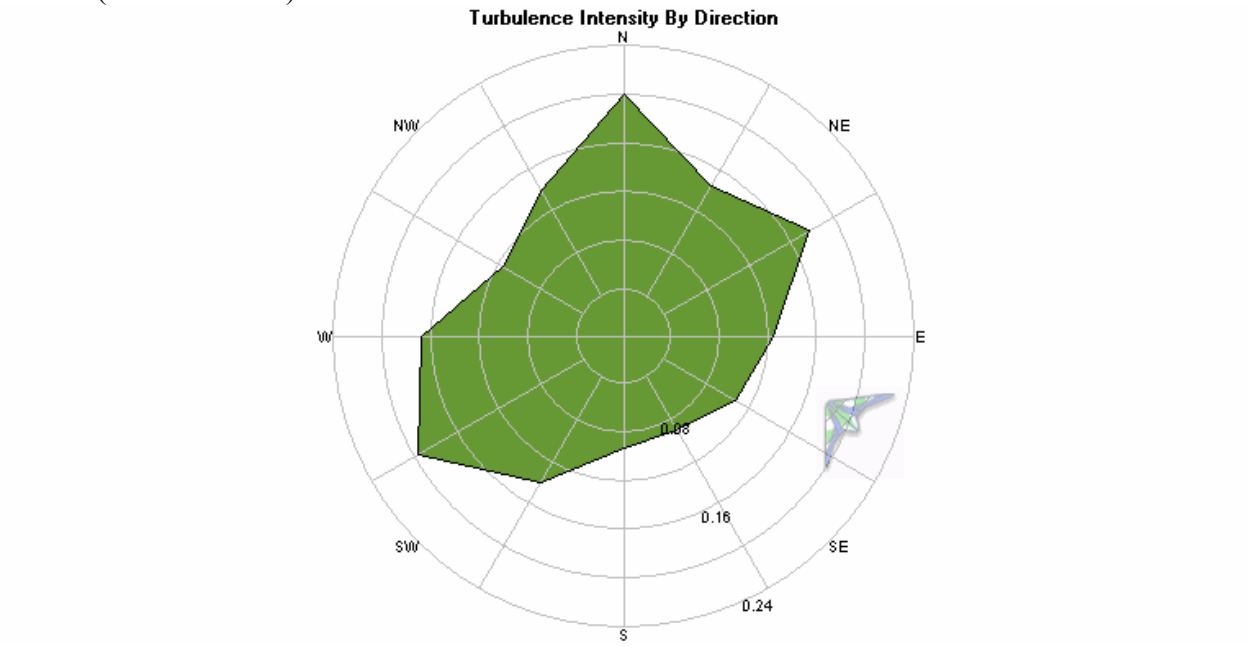
Turbulence Intensity

The turbulence intensity remains quite acceptable for the northwest prevailing wind direction – approximately 0.118. As indicated below, turbulence is well below International Energy Agency (IEA) Category A and B standards for all wind directions and at al measured wind speeds.

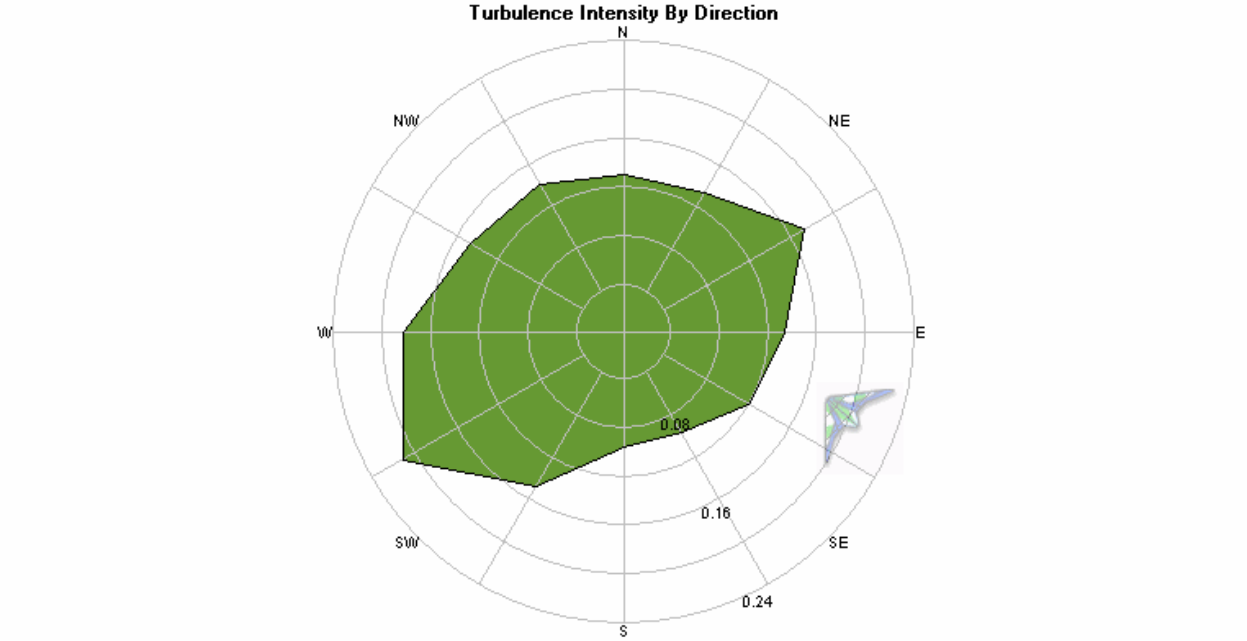
30-meter Ch 1 Turbulence Intensity
(Mean = 0.118)

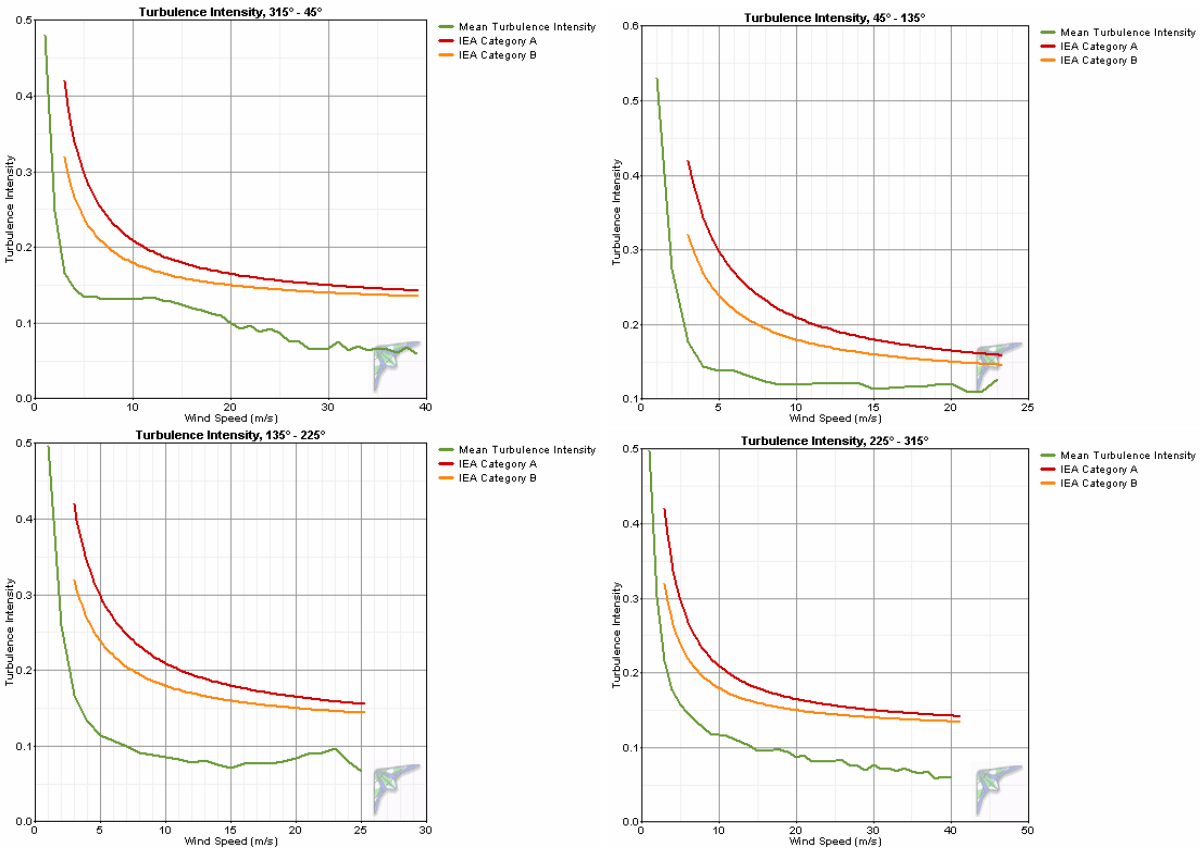


30-meter Ch 2 Turbulence Intensity
(Mean = 0.125)



20-meter Ch 3 Turbulence Intensity
(Mean = 0.132)

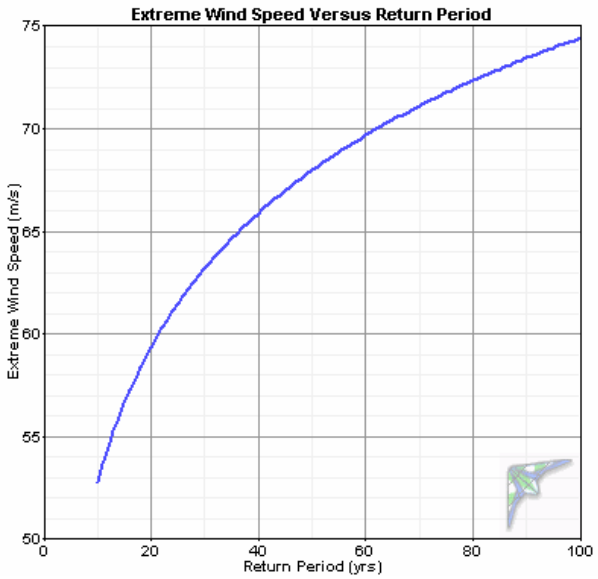


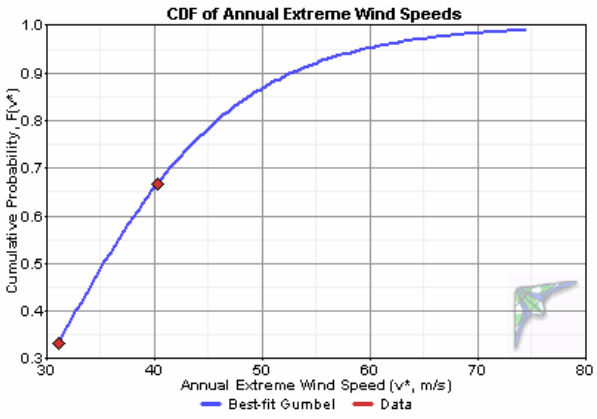


Extreme Wind Analysis

For design purposes, it is important to consider maximum predicted wind speeds at this site, but with less than ten months of data, one must use this information with caution. By probability,

Kodiak Site 1 winds are expected to exceed 61.5 m/s every 25 years and 68.0 m/s every 50 years. Note that this calculation was with average wind speeds. Predicted extreme wind would be higher with use of maximum winds (but the accuracy of the prediction decreases).

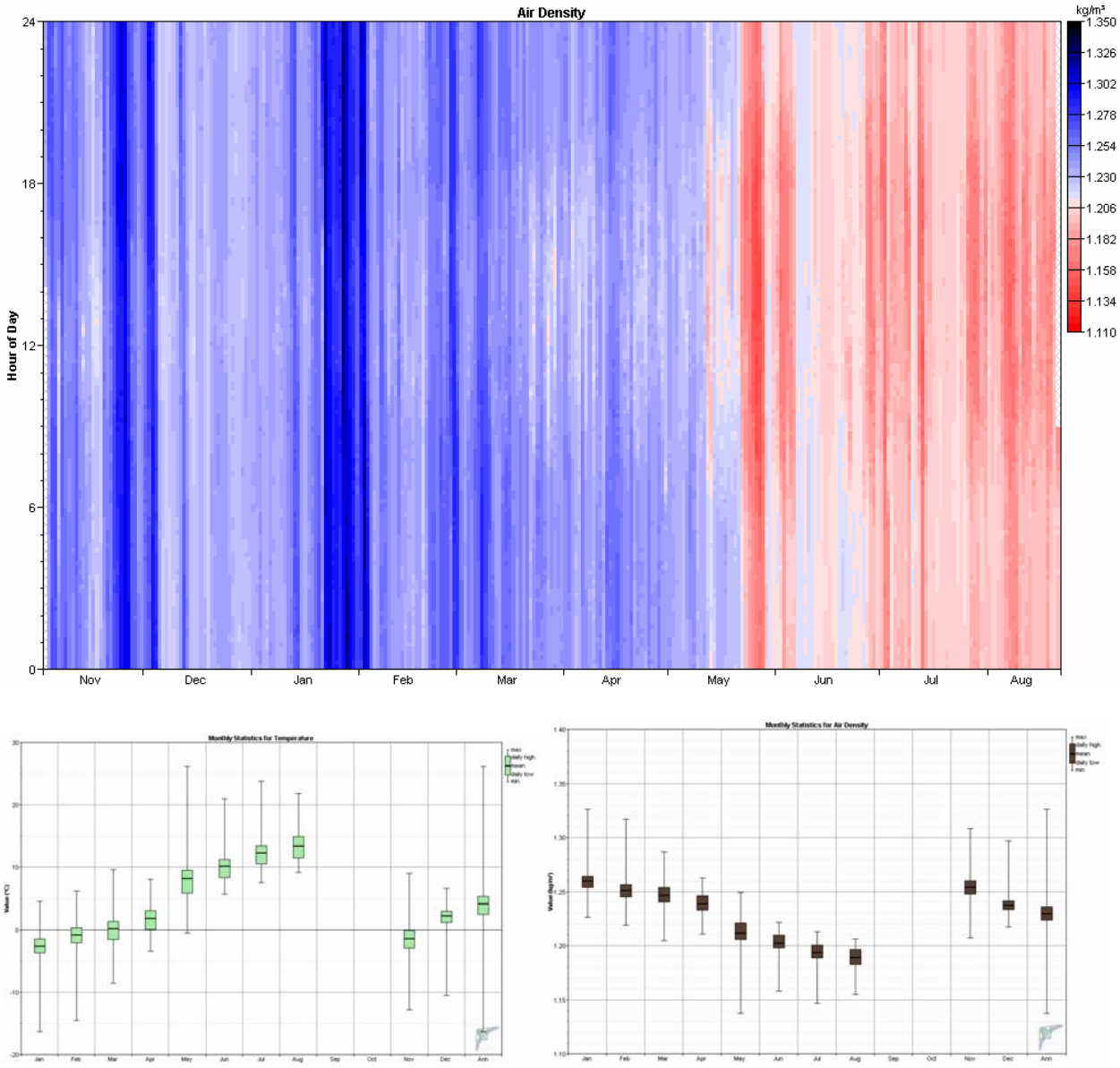




Air Temperature and Density

Over the reporting period, Kodiak Site 1 had an average temperature of 4.1° C. The minimum recorded temperature during the measurement period was -16.3° C and the maximum temperature was 26.2° C, indicating a cool temperate operating environment for wind turbine operations. Consequent to Kodiak's cool temperatures, but counterbalanced by Site 1's elevation of 300 meters, the average air density of 1.229 kg/m^3 is just slightly higher than the standard air density of 1.225 kg/m^3 (at 20° C). The density variance from standard is accounted for in the turbine performance predictions.

		Temperature				Air Density		
Year	Month	Mean (°C)	Min (°C)	Max (°C)	Std. Dev. (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
2005	Nov	-1.4	-12.8	9.0	4.43	1.254	1.207	1.308
2005	Dec	2.3	-10.5	6.6	3.61	1.237	1.218	1.297
2006	Jan	-2.6	-16.3	4.6	5.63	1.260	1.226	1.326
2006	Feb	-0.8	-14.5	6.2	4.18	1.251	1.219	1.317
2006	Mar	0.2	-8.5	9.6	2.74	1.246	1.205	1.287
2006	Apr	1.8	-3.4	8.1	2.09	1.239	1.211	1.263
2006	May	8.2	-0.5	26.2	6.04	1.211	1.138	1.249
2006	Jun	10.2	5.7	21.0	2.91	1.203	1.158	1.222
2006	Jul	12.3	7.6	23.8	3.03	1.194	1.147	1.213
2006	Aug	13.4	9.2	21.8	2.65	1.189	1.155	1.206
All data		**4.1**	-16.3	26.2	6.85	**1.229**	1.138	1.326

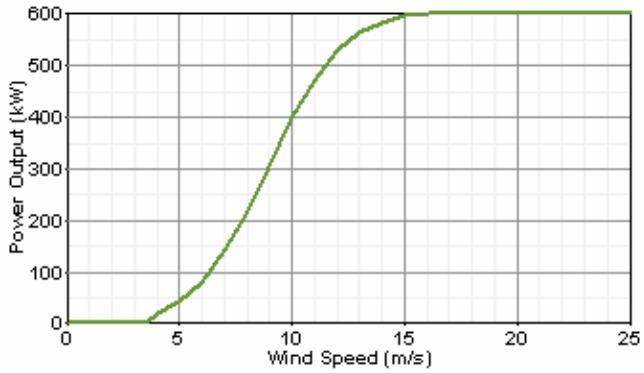


Turbine Performance Predictions for Site 1 (100% availability of turbines)

Predicted turbine performances at Site 1 are extremely promising, so much so that one must consider turbines designed for high wind environments. Although the performance predictions are adjusted to air density, they do not account for maintenance and other expected down time of turbines.

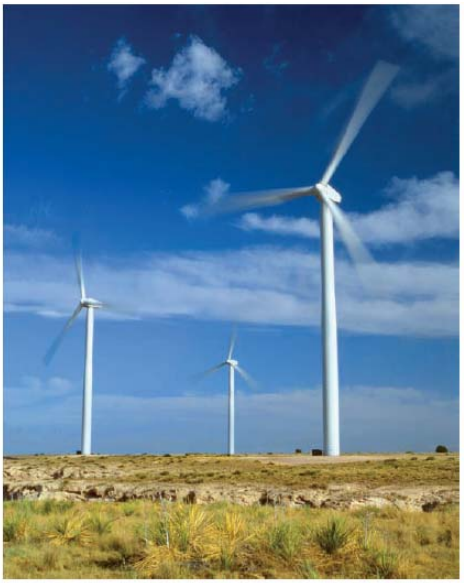
Because the wind speeds are exceptionally high at this site, the data was analyzed for ten-minute blocks of time where the winds exceeded 25 m/s, a common cut-off speed for wind turbines. For the data collection period 11/2/05 through 8/21/06, 75.6 hours met this criterion, or approximately 1.1% of the time (of the testing period). These periods of no wind power production *are* accounted for in the following turbine output data.

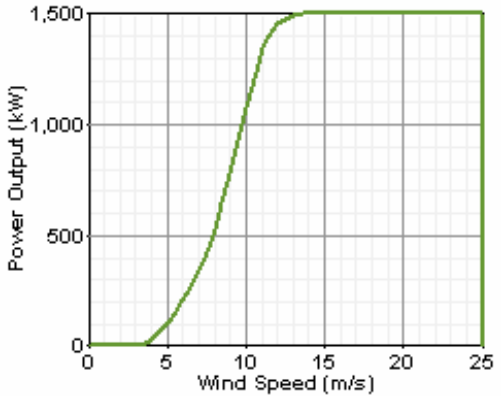
Vestas RRB 47/600: 600 kW output, 47 meter rotor, pitch-controlled (power curve provided by Vestas RRB, India)



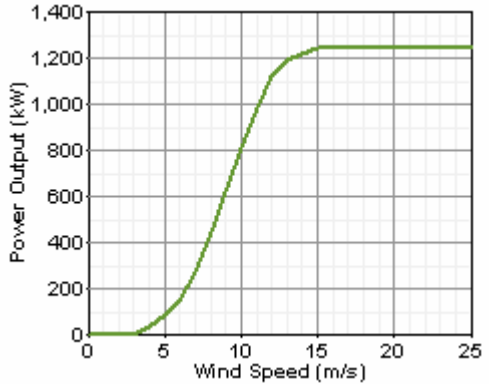
Fuhrländer FL1000^{plus}: 1000 kW output (nominal), 50 to 62 m rotor options (58 m nominal), pitch controlled (power curve from Fuhrländer)

General Electric GE1.5S: 1500 kW output, 70.5 m rotor diameter, pitch-controlled (power curve from Windographer® software)





Suzlon S.64/1250: 1250 kW output, 64 m rotor diameter, pitch-controlled (power curve from Windographer® software)



Turbine Power Output Comparison

	Manufacturer	Vestas RRB		Fuhrländer		Suzlon	
	Model	47/600		FL1000plus		S.64/1250	
	Rated Power	600 kW		1000 kW		1250 KW	
Hub Height (m)	Mean Wind Speed (m/s)	Capacity Factor (%)	Annual Energy Output (kW-hr/yr)	Capacity Factor (%)	Annual Energy Output (kW-hr/yr)	Capacity Factor (%)	Energy Output (kW-hr/yr)
50	8.25	38.9	2,045,000	TBD	TBD	38.7	4,239,000
60	8.43	39.6	2,084,000				
65	8.51					39.8	4,353,000

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

Fuel Cost Avoided for Electrical Energy Generation by Diesel Genset

Turbine	Annual Energy Output (kW-hr/yr)	Fuel Quantity Avoided (gallons)	Fuel Price (dollars delivered) $2.00	$2.25	$2.50	$2.75	$3.00	$3.25	$3.50	Hub Height (m)
Vestas RRB 47/600										
	2,045,000	131,935	$263,871	$296,855	$329,839	$362,823	$395,806	$428,790	$461,774	50
	2,084,000	134,452	$268,903	$302,516	$336,129	$369,742	$403,355	$436,968	$470,581	60
Fuhrländer FL1000plus										
		0	$0	$0	$0	$0	$0	$0	$0	50
		0	$0	$0	$0	$0	$0	$0	$0	60
Suzlon S.64/1250										
	4,239,000	273,484	$546,968	$615,339	$683,710	$752,081	$820,452	$888,823	$957,194	50
	4,353,000	280,839	$561,677	$631,887	$702,097	$772,306	$842,516	$912,726	$982,935	65

Notes: Energy production efficiency assumed to equal 15.5 kW-hr/gal;
Assumes 100% turbine availability

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.