Kaktovik Wind Resource Report

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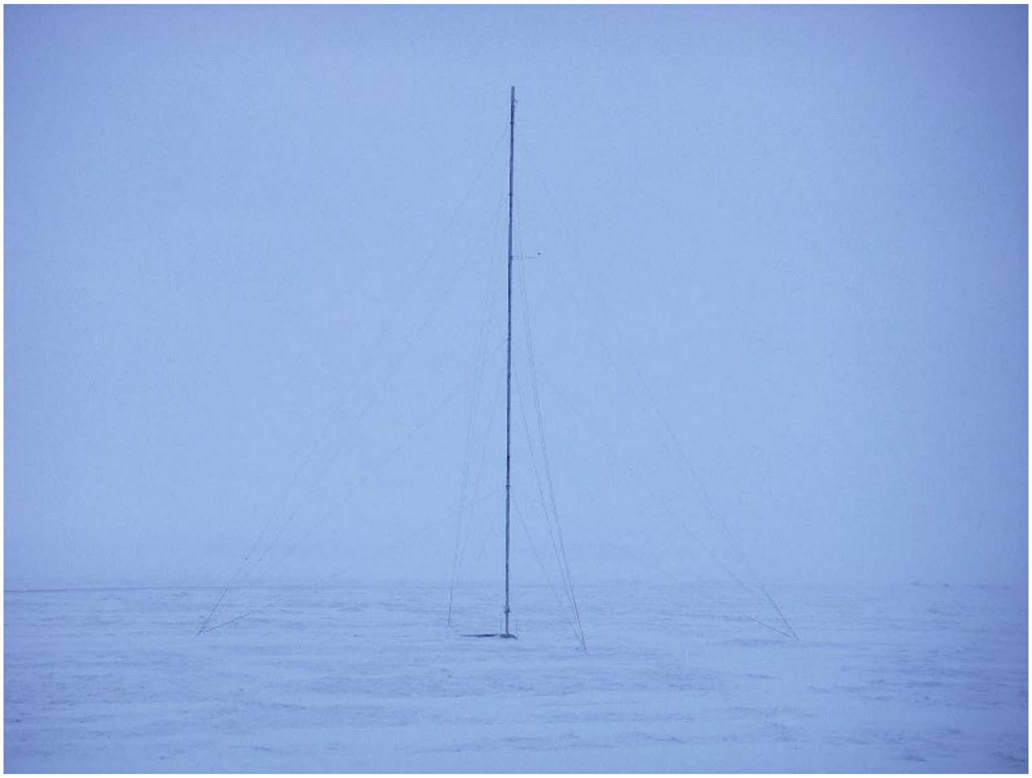

Kaktovik met tower; D. Vaught photo

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Summary Information

With reference to two nearby Automated Weather Observing System (AWOS) sources (Barter Island Airport and Barter Island DEW), the wind resource in Kaktovik is outstanding (Class 5 to 6), but verification with the met tower was fraught with difficulty, namely a lost data card, significant data loss due to icing, and loss of both 30 meter level anemometers in early January due to ice and wind damage that were not replaced until early March. Given the anemometer problems, met tower data as collected is not useful for calculating mean wind speed, but inserting synthesized data to the data set yields a wind resource prediction in-line with the AWOS data sources. Other parameters, including turbulence, wind shear, and directionality of winds, indicate a desirable wind resource for wind power development.

Met tower data synopsis

Data dates	June 26, 2009 to July 19, 2010 (13 months)
Wind power class	Presumed 5 (excellent) (from AWOS and synthesized data)
Power density mean, 30 m	479 W/m^2 (synthesized data)
Wind speed mean, 30 m	6.49 m/s (synthesized data)
Max 10-min wind speed average	29.3 m/s
Maximum wind gust	35.2 m/s (Feb 2010)
Weibull distribution	k = 1.82, c = 7.18 m/s (measured data)
Roughness class	0.68 (lawn grass)
IEC 61400-1, 3rd ed. classification	Class III-c (lowest defined and most common)
Turbulence intensity, mean	0.076 (at 15 m/s)
Calm wind frequency	24% (<3.5 m/s)

Community profile

Current Population:	286 (2009 DCCED Certified Population)
Incorporation Type:	2nd Class City
Borough Located In:	North Slope Borough
Taxes:	Sales: None, Property: 18.5 mills (Borough), Special: None
Coastal Management District:	North Slope Borough

Test Site Location

Met tower was located 650 meters (2100 ft) south of the village boundary near the village sewage treatment plant. This site is not considered ideal for wind power development as a more likely site is immediately west of the powerplant on the west-central edge of the village. But, the flat and featureless topography of Kaktovik ensures the met tower data is useable anywhere in the village environs.

Site information

Site number	0224
Latitude/longitude	N 70° 07.065' W 143° 36.342', WGS 84
Site elevation	2 meters
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	NRG 34-meter tall tower, 152 mm diameter, erected to 30 m
Anchor type	1.5 m screw-in

Google Earth image

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m (A)	0.760	0.43	181° T
2	NRG #40 anemometer	30 m (B)	0.754	0.43	271° T
3	NRG #40 anemometer	20 m	0.758	0.38	272° T
7	NRG #200P wind vane	29 m	0.351	357	357° T
9	NRG #110S Temp C	3 m	0.136	-86.383	N
10	RH-5 relative humidity	2 m	0.098	0	S
12	Voltmeter	2 m	0.021	0	n/a

Photographs

Missing 30 m anemometers, Feb 2010; D. Vaught photo

Alternate wind site behind powerplant; D. Vaught photo

Data recovery

Data recovery to date in Kaktovik was poor, with only 62 to 71 percent data return from the anemometers and wind vane with all of the missing data representing the winter months. This was due to several problems. First was loss of a data card and hence all data from Oct. 2 to Nov. 13. Then, beginning in early December, a number of apparent icing events rendered the anemometers and wind vane inoperable for much of the month. In early January, the two 30 meter level (channels 1 and 2) anemometers broke off the tower, apparently as a result of icing loads and high winds, and were not replaced until March 3. Throughout winter and spring, frequent and severe icing events resulted in significant data loss to the anemometers and wind vane. Note also much data loss from the relative humidity sensor occurred as well. The RH sensor lost function due to loss of battery power with loss of daylight (for recharge via the PV panels) and for unknown reasons, sensor function did not return with return of sunlight in spring.

Data recovery summary table

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 A	m/s	30 m	55,878	35,600	63.7
Speed 30 B	m/s	30 m	55,878	34,822	62.3
Speed 20	m/s	20 m	55,878	39,748	71.1
Direction 29	°	29 m	55,878	36,612	65.5
Temperature	°C		55,878	48,823	87.4
RH-5 Humidity %RH	%RH		55,878	14,196	25.4
iPack Voltmeter	volts		55,878	49,800	89.1

Anemometer data recovery

			30 m A		30 m B		20 m	
Year	Month	Possible Records	Valid Records	Recovery Rate (%)	Valid Records	Recovery Rate (%)	Valid Records	Recovery Rate (%)
2009	Jun	720	720	100.0	720	100.0	720	100.0
2009	Jul	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Aug	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2009	Sep	4,320	4,197	97.2	4,320	100.0	4,320	100.0
2009	Oct	4,464	228	5.1	228	5.1	228	5.1
2009	Nov	4,320	1,748	40.5	1,750	40.5	1,751	40.5
2009	Dec	4,464	1,033	23.1	750	16.8	750	16.8
2010	Jan	4,464	42	0.9	0	0.0	408	9.1
2010	Feb	4,032	0	0.0	0	0.0	3,971	98.5
2010	Mar	4,464	3,966	88.8	3,794	85.0	3,972	89.0
2010	Apr	4,320	3,602	83.4	3,213	74.4	3,483	80.6
2010	May	4,464	4,336	97.1	4,319	96.8	4,357	97.6
2010	Jun	4,320	4,202	97.3	4,202	97.3	4,262	98.7
2010	Jul	2,598	2,598	100.0	2,598	100.0	2,598	100.0
All data		55,878	35,600	63.7	34,822	62.3	39,748	71.1

Wind Speed

Wind data collected from the met tower, from the perspective of both mean wind speed and mean power density, indicates an excellent wind resource when sufficiently manipulated. The extremely cold arctic temperatures of Kaktovik contributed to the high wind power density. It is problematic, however, analyzing wind data with significant concentrated data loss, such as occurred in Kaktovik with the missing data card, broken 30 meter anemometers, and many icing events. To correct this problem, synthetic data was inserted in the data gaps to create a more realistic wind speed data profile. To be sure, long segments of synthetic data introduce uncertainty to the data set, but missing data does as well. To overcome this uncertainty, improved data collection with heated sensors would be necessary. But, considering the wind data collected and noting that two long-term airport AWOS data sources confirm a robust wind resource in Kaktovik, continuing a wind study with heated sensors is not absolutely necessary.

Anemometer data summary

	Original data set			Synthesized data set		
Variable	Speed 30 A	Speed 30 B	Speed 20	Speed 30 A	Speed 30 B	Speed 20
Measurement height (m)	30	30	20	30	30	20
MMM wind speed (m/s)	6.59	5.95	6.59	6.49	6.39	6.14
Max 10-min avg wind speed (m/s)	26.4	26.2	29.3	30.7	30.7	29.3
Max gust wind speed (m/s)	32.7	30.2	35.2			

Weibull k	1.82	1.82	1.68	1.63	1.63	1.62
Weibull c (m/s)	7.18	6.97	6.94	7.26	7.14	6.87
MMM power density (W/m²)	478	382	641	479	459	409
MMM energy content (kWh/m²/yr)	4,184	3,350	5,613	4,199	4,025	3,586
Energy pattern factor	2.16	2.15	2.49	2.55	2.57	2.58
Frequency of calms (%)	24.7	25.8	27.4	27.3	27.8	29.8
1-hr autocorrelation coefficient	0.952	0.950	0.958	0.957	0.956	0.957
Diurnal pattern strength	0.012	0.013	0.006	0.027	0.028	0.030
Hour of peak wind speed	23	21	1	4	5	4

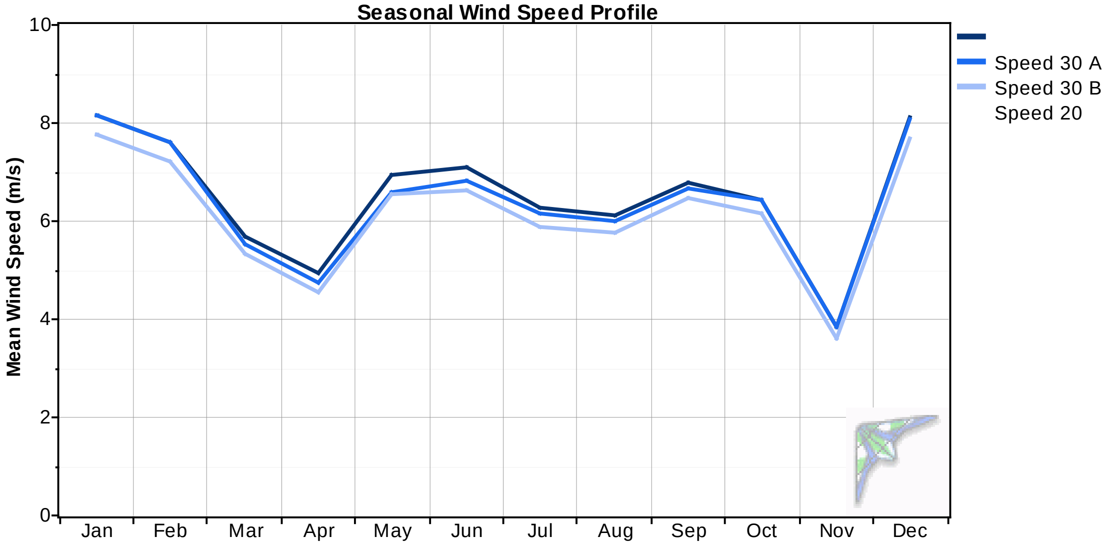
Time Series

Time series calculations indicate high wind speed averages throughout the year, even during the summer months. Because the 30 meter anemometers were inoperable (broken off the met tower) for an extended period of time, the data summary graph below is presented with 20 meter anemometer data which is more complete in original form.

20 m data summary

		Original data			Synthesized data			
Year	Month	Mean (m/s)	Max 10-min (m/s)	Max gust (m/s)	Mean (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2009	Jun	5.73	11.7	14.0	5.73	2.20	2.87	6.45
2009	Jul	6.26	12.7	14.8	6.26	2.77	2.42	7.05
2009	Aug	5.78	14.7	18.6	5.78	2.63	2.33	6.51
2009	Sep	6.47	18.0	22.4	6.47	3.90	1.74	7.28
2009	Oct	2.68	7.4	8.3	6.14	3.65	1.72	6.88
2009	Nov	4.66	14.9	17.1	3.63	2.69	1.44	4.02
2009	Dec	8.07	24.8	29.5	7.68	5.11	1.57	8.58
2010	Jan	14.58	24.7	28.8	7.77	4.99	1.62	8.69
2010	Feb	7.29	29.3	35.2	7.23	5.33	1.41	7.96
2010	Mar	5.42	16.7	18.9	5.32	2.87	1.91	5.99
2010	Apr	4.80	17.1	20.1	4.54	2.82	1.71	5.11
2010	May	6.68	19.1	22.7	6.56	3.93	1.70	7.36
2010	Jun	6.85	19.5	23.5	6.79	4.13	1.72	7.64
2010	Jul	5.24	13.6	17.4	5.24	2.63	2.10	5.91
MMM annual		6.59	29.3	35.2	6.13	3.95	1.62	6.86

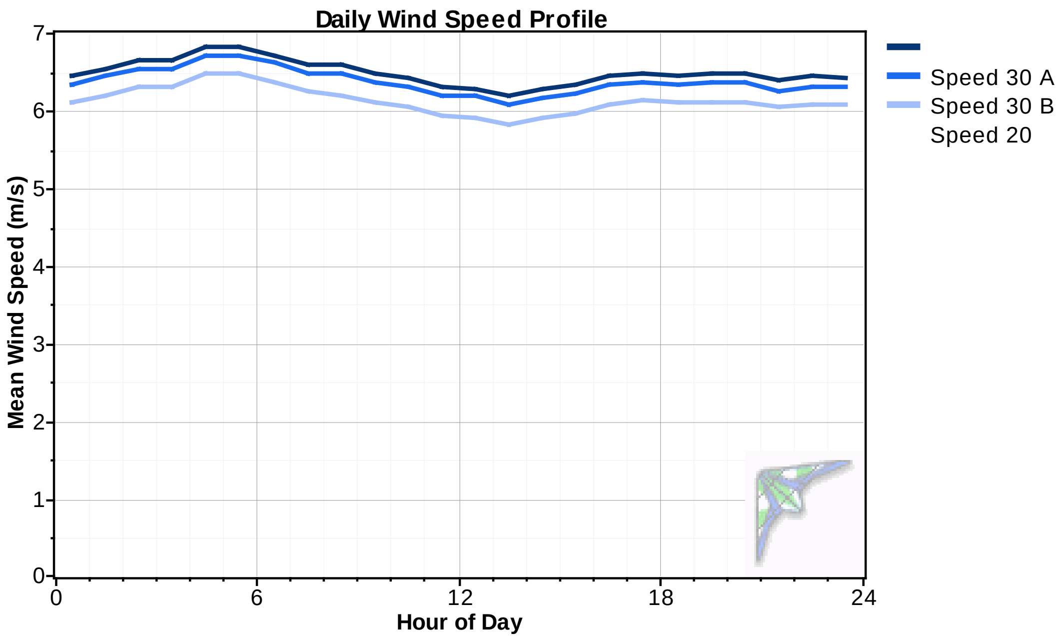
Time series graph, synthesized data



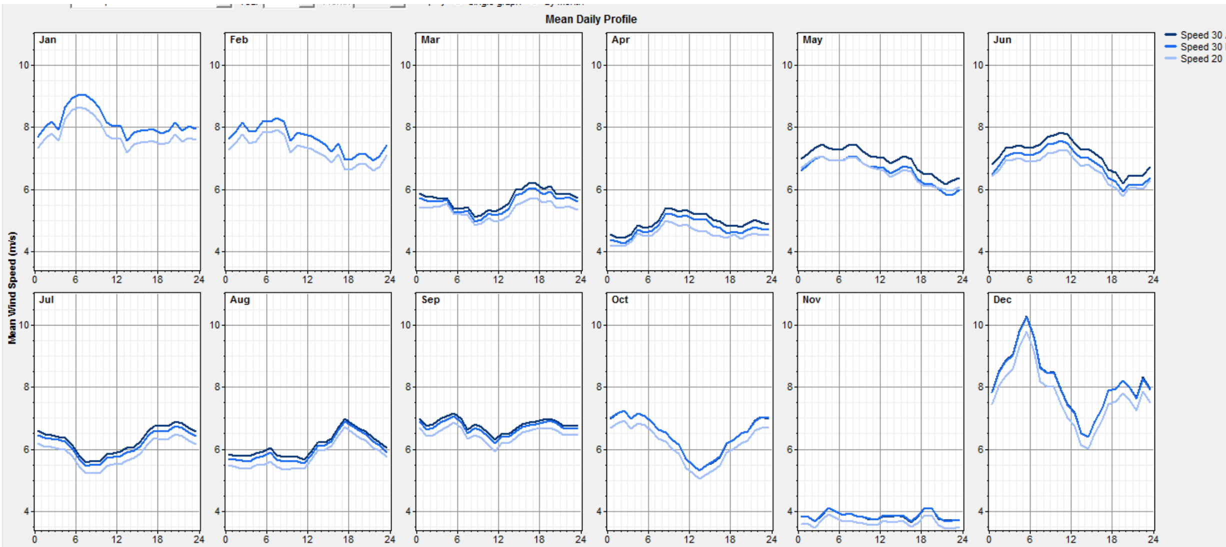
Daily Wind Profile

The daily wind profile indicates a minor variation of wind speeds throughout the day, with lowest wind speeds during the morning hours and highest wind speeds during late afternoon and early evening hours. This perspective changes somewhat when considering monthly views of daily profiles as more variation is observed.

Annual daily wind profile (synth. data)

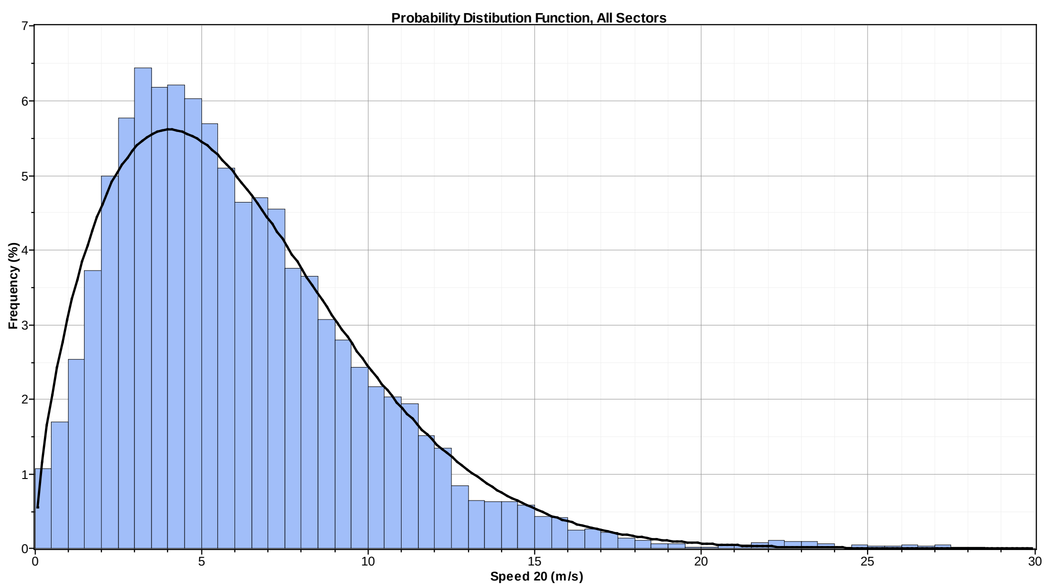


Monthly daily wind profiles (synth. data)



Probability Distribution Function

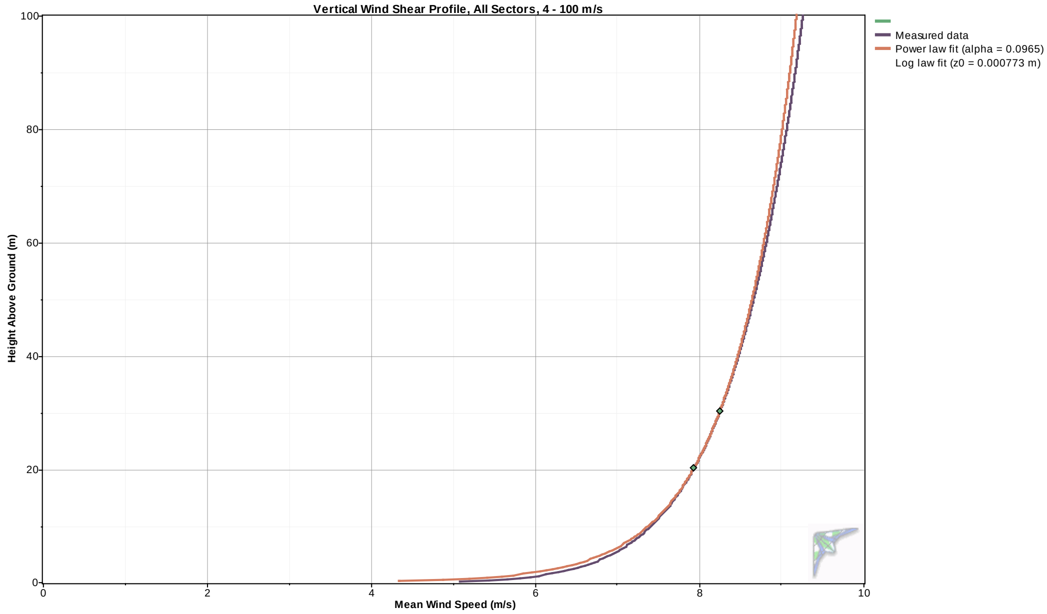
The probability distribution function (or histogram) of wind speed is a useful statistical tool to describe a site with "normal" a wind range of wind speeds (normal is defined as the Raleigh distribution with a Weibull k of 2.0). Given the data recovery problems in Kaktovik the probability distribution function should be considered suspect in accuracy, both with original data and with synthesized data.



Wind Shear and Roughness

A wind shear power law exponent of 0.097 indicates very low wind shear at the site; hence turbine construction at a low hub height is possibly a desirable option, although note again that data recovery problems impact the accuracy of this calculation. Related to wind shear, a calculated surface roughness of 0.0059 meters (indicating the height above ground level where wind velocity would be zero) indicates very smooth terrain (roughness description: lawn grass) surrounding the met tower, especially toward the primary wind direction of northeast, location of a large lagoon (with a frozen surface most of the year).

Vertical wind shear profile (synth. data), wind speed > 4 m/s



Wind shear by direction sector table (synth. data), wind speed > 4 m/s

Direction Sector	Time Steps	Mean Wind Speed (m/s) Speed 30 B	Speed 20	Best-Fit Power Law Exp	Surface Roughness (m)
348.75° - 11.25°	557	7.53	7.11	0.142	0.0212
11.25° - 33.75°	1,324	6.38	6.03	0.141	0.0199
33.75° - 56.25°	8,212	7.91	7.71	0.063	0.0000
56.25° - 78.75°	7,959	9.02	8.91	0.030	0.0000
78.75° - 101.25°	1,619	8.33	7.94	0.116	0.0045
101.25° - 123.75°	1,065	9.11	8.70	0.114	0.0038
123.75° - 146.25°	849	8.43	8.03	0.122	0.0065
146.25° - 168.75°	492	9.02	8.60	0.118	0.0051
168.75° - 191.25°	543	7.77	7.32	0.149	0.0298
191.25° - 213.75°	857	7.05	6.61	0.159	0.0456
213.75° - 236.25°	3,310	8.64	8.13	0.149	0.0296
236.25° - 258.75°	4,683	9.06	8.58	0.133	0.0134
258.75° - 281.25°	2,287	8.27	7.88	0.119	0.0055
281.25° - 303.75°	1,584	8.37	7.97	0.120	0.0057
303.75° - 326.25°	634	8.22	7.86	0.112	0.0031
326.25° - 348.75°	517	7.38	7.08	0.103	0.0015

Extreme Winds

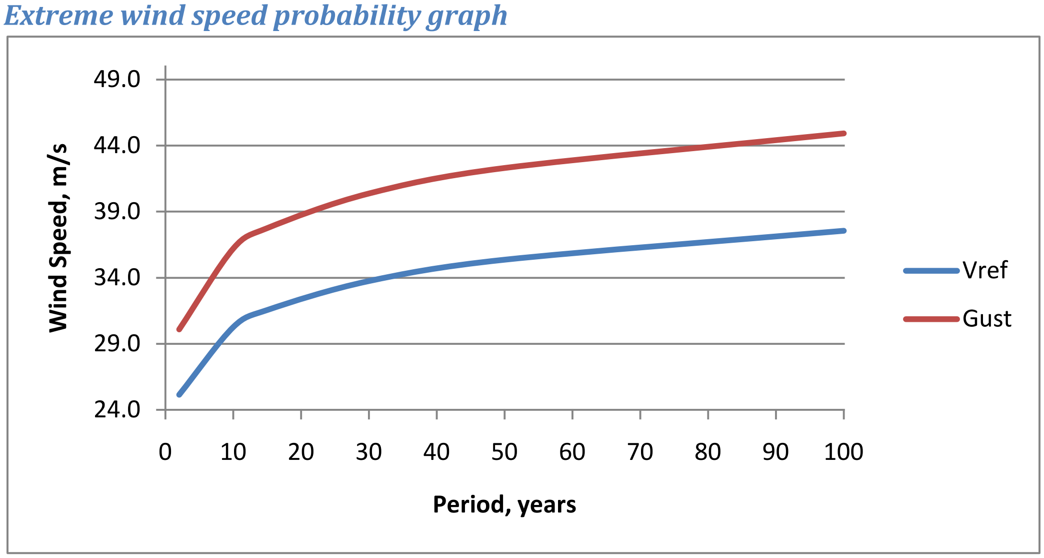
Although thirteen months of data is minimal for calculation of extreme wind probability, use of a modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, yields reasonably good results. Caution should be exercised though in that one month of data – October 2009 – had to be removed due to the lost data card and data recovery in general was problematic in Kaktovik. That said, extreme wind analysis indicates a desirable situation in Kaktovik: moderately high mean wind speed combined with relatively low (probable) extreme wind speeds. This may be explained by particular climactic aspects of Kaktovik which because of its extreme northerly latitude, is not exposed to Gulf of Alaska storm winds which tend to significantly increase the long-term probability of damaging winds.

Industry standard reference of extreme wind is the 50 year, 10-minute average probable wind speed, referred to as V_{ref}. For Wainwright, this calculates to 35.4 m/s, below the threshold of International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria (of 37.5 m/s) for a Class III site. Note that Class III extreme wind classification is the lowest defined and all wind turbines are designed for this wind regime.

Extreme wind sped probability table

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
2	25.1	30.1	I	50.0
10	30.3	36.2	II	42.5
15	31.6	37.8	III	37.5
30	33.7	40.4	S	designer-specified
50	35.4	42.3		
100	37.5	44.9		
average gust factor:	1.20			

Extreme wind speed probability graph



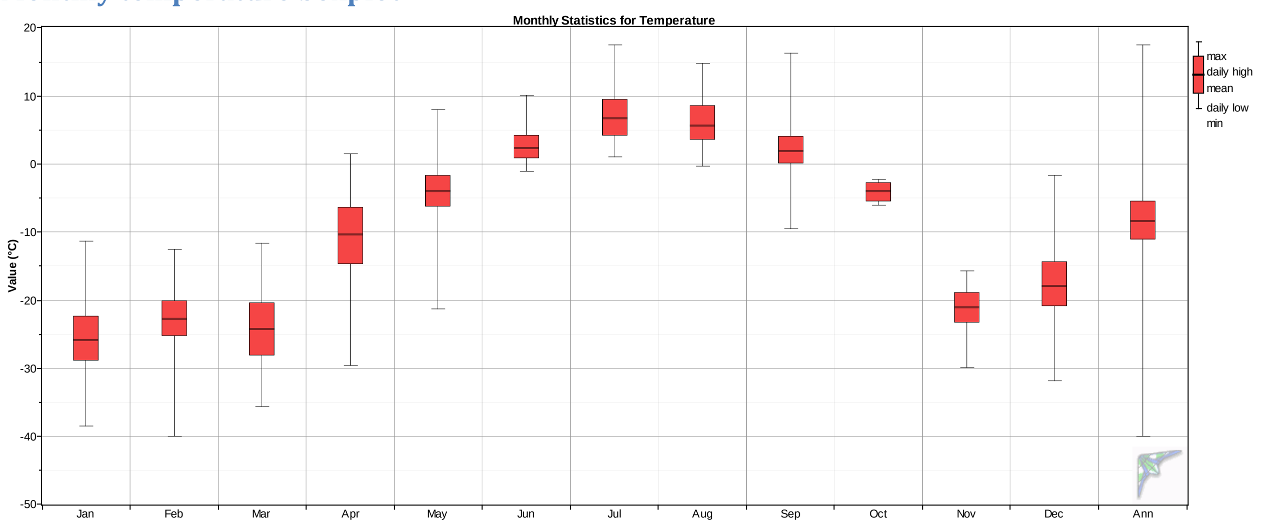
Temperature and Density

Kaktovik experiences cool summers and very cold winters. The result is high air density. Calculated air density exceeds standard air density for a sea level elevation (1.225 Kg/m^3) by over eight percent. This is advantageous in wind power operations as wind turbines produce more power at low temperatures (high air density) than at standard temperature and density.

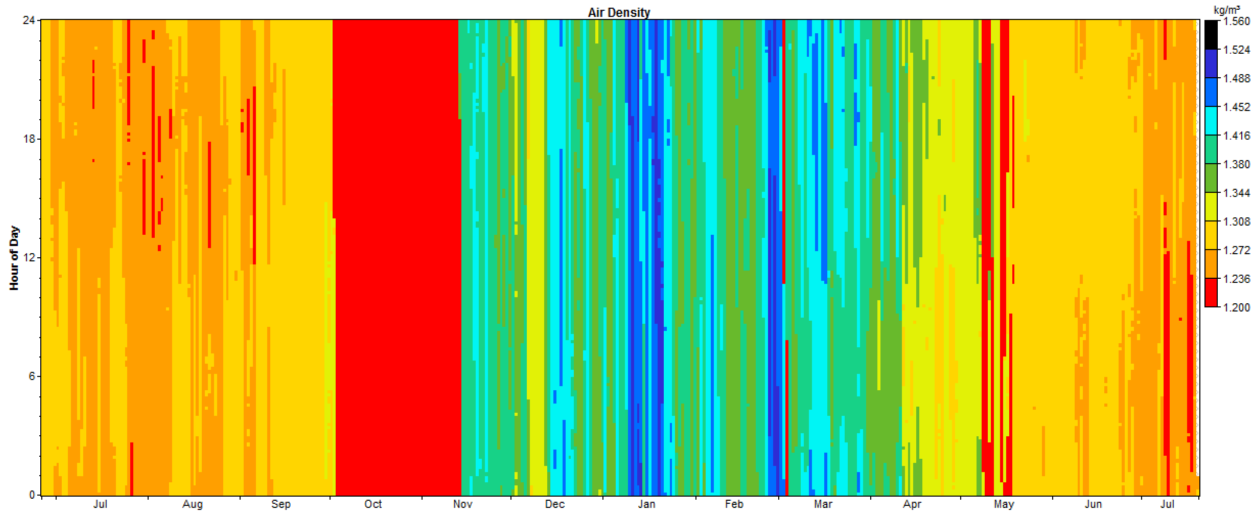
Temperature and density table

	Temperature			Air Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-25.8	-38.6	-11.4	1.427	1.348	1.504
Feb	-22.7	-40.1	-12.6	1.410	1.354	1.513
Mar	-24.2	-35.7	-11.7	1.412	1.224	1.485
Apr	-10.3	-29.7	1.5	1.343	1.284	1.449
May	-4.0	-21.4	8.0	1.294	1.224	1.401
Jun	2.4	-1.1	10.0	1.280	1.246	1.296
Jul	6.7	1.0	17.4	1.261	1.214	1.287
Aug	5.7	-0.4	14.7	1.265	1.225	1.293
Sep	1.9	-9.5	16.3	1.283	1.219	1.338
Oct	-4.0	-6.1	-2.4	1.229	1.224	1.321
Nov	-21.1	-30.0	-15.8	1.325	1.224	1.451
Dec	-17.9	-31.9	-1.7	1.383	1.299	1.462
Annual	-9.4	-40.1	17.4	1.325	1.214	1.513

Monthly temperature boxplot



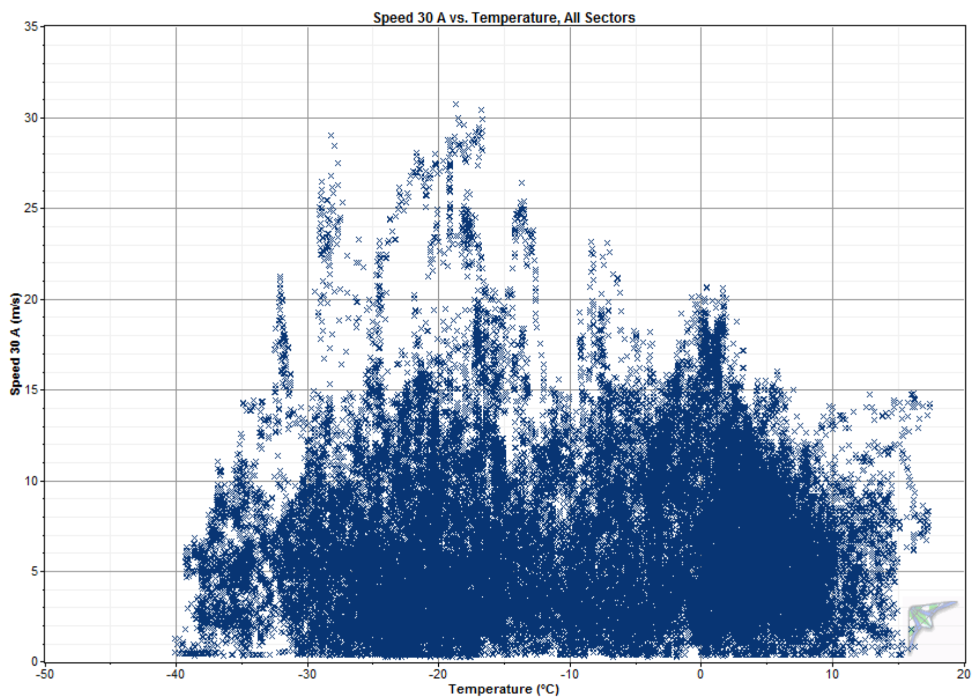
Air density DMap



Wind Speed Scatterplot

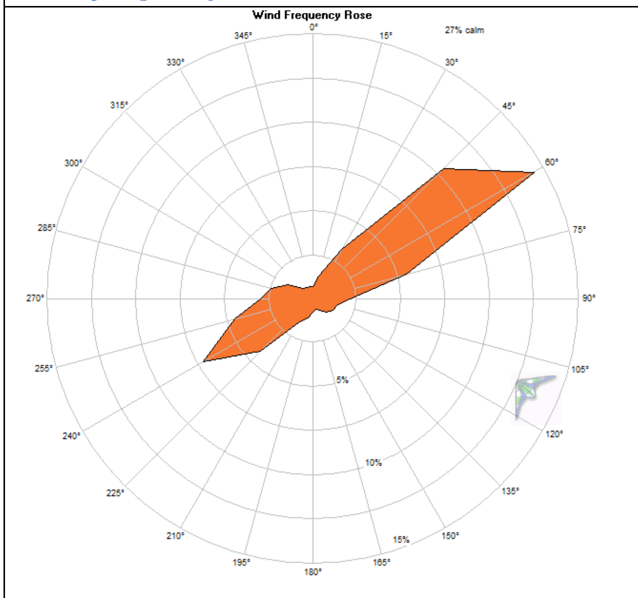
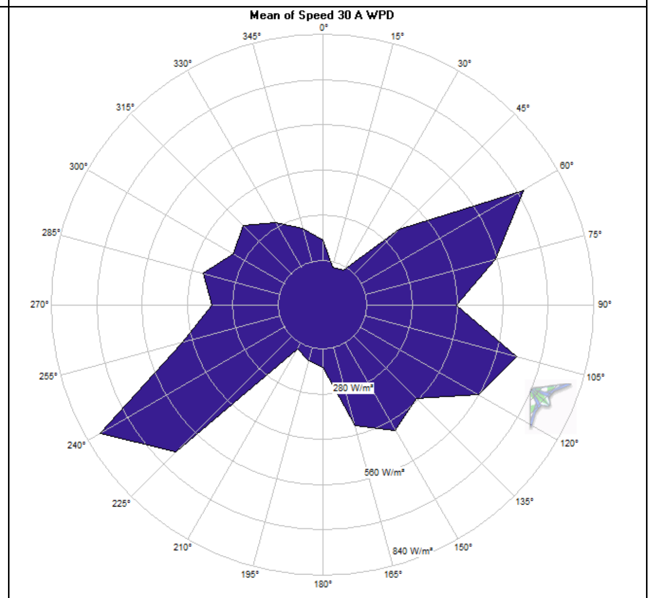
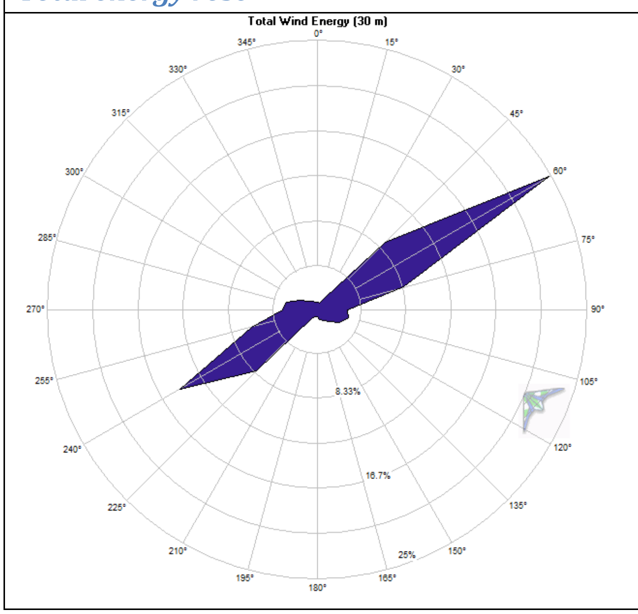
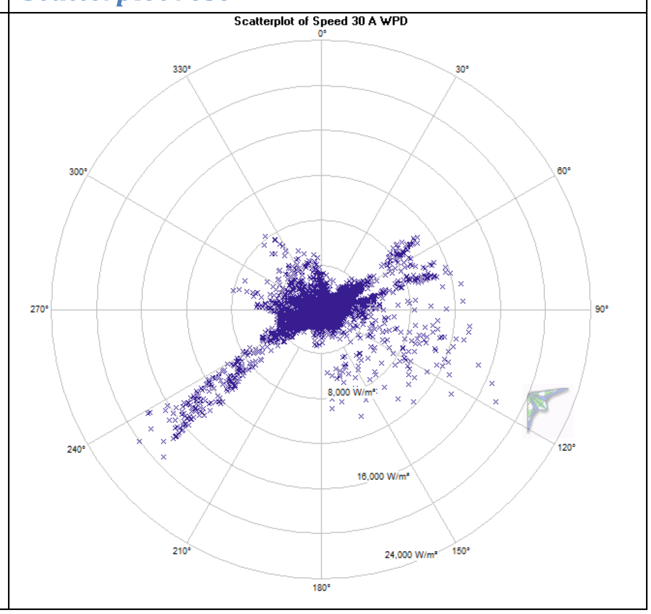
The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Kaktovik coincides with very cold temperatures, as one would expect give the location on the Arctic Ocean coast. Temperatures have fallen below -40°C, the minimum operating temperature of arctic-capable wind turbines presently operating in Alaska, but only a few times during the measurement period.

Wind speed versus temperature scatterplot (synth. data)

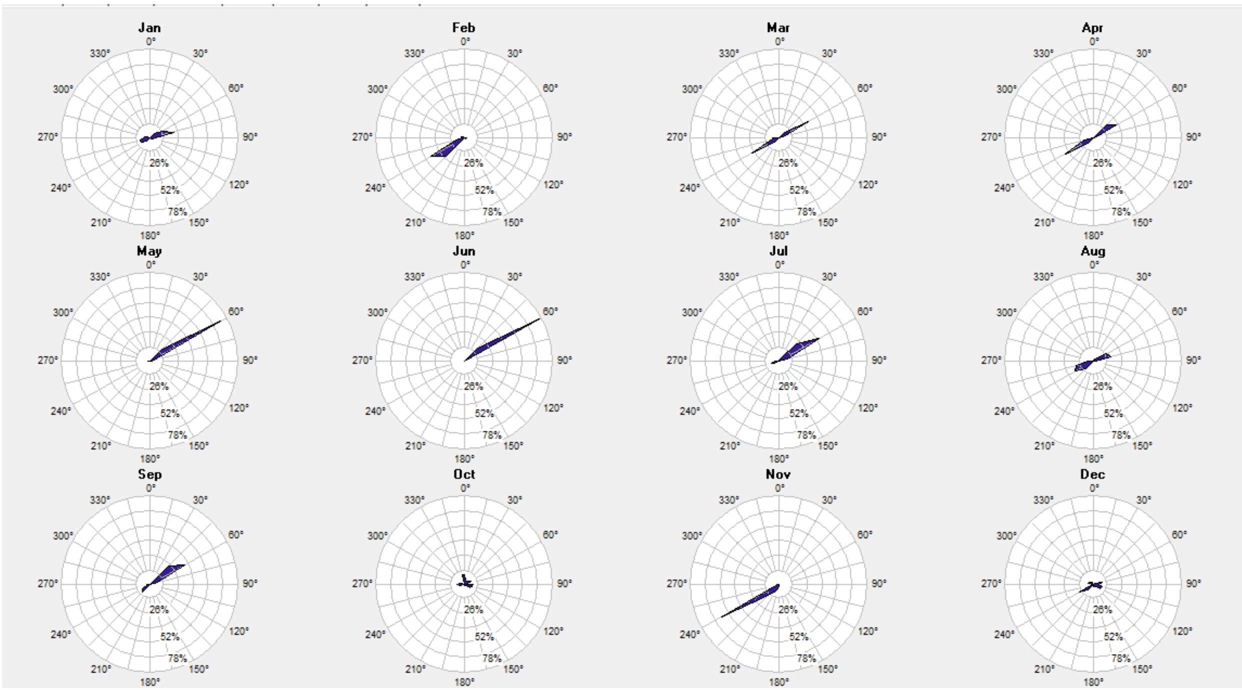


Wind direction

Wind frequency rose data indicates highly directional winds from the northeast and southwest. Power density rose data (representing the power in the wind) indicates power winds are very strongly directional, from 060°T and directly opposite, from 240°T. Calm frequency (percent of time that winds at 30 meter level are less than 3.5 m/s) was 27 percent during the met tower test period, but this statistic may be suspect due to the large amount of data loss.

Wind frequency rose	*Mean value rose*
	
Total energy rose	*Scatterplot rose*
	

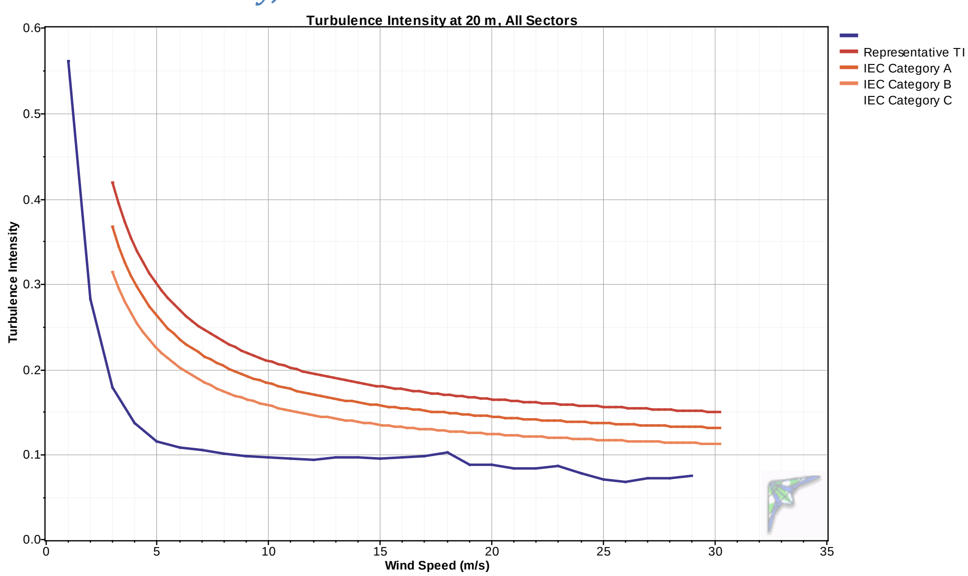
Wind density roses by month



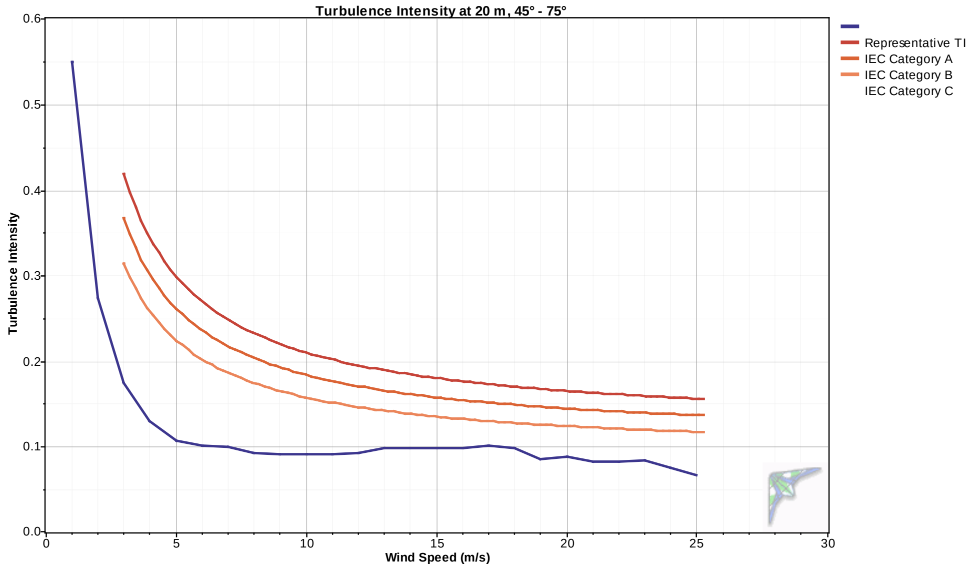
Turbulence

Turbulence intensity at the Kaktovik test site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. Mean turbulence intensity at 15 m/s is 0.076 (at 20 meters).

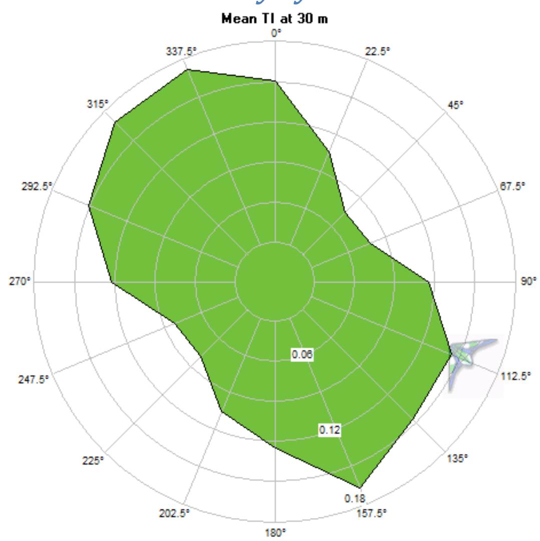
Turbulence intensity, all wind sectors



Turbulence intensity, NE to ENE wind sector



Turbulence intensity by direction



Turbulence table (20 m anemometer)

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	Std. Deviation of TI	Representative TI	Peak TI
1	0.5	1.5	1,676	0.363	0.155	0.561	1.111
2	1.5	2.5	3,458	0.174	0.084	0.282	1.250
3	2.5	3.5	4,851	0.115	0.049	0.178	0.515
4	3.5	4.5	4,924	0.090	0.037	0.137	0.400
5	4.5	5.5	4,654	0.076	0.031	0.116	0.378
6	5.5	6.5	3,863	0.073	0.027	0.108	0.309

7	6.5	7.5	3,671	0.074	0.024	0.105	0.269
8	7.5	8.5	2,936	0.073	0.021	0.101	0.320
9	8.5	9.5	2,328	0.073	0.019	0.098	0.326
10	9.5	10.5	1,826	0.074	0.017	0.096	0.231
11	10.5	11.5	1,579	0.074	0.016	0.094	0.159
12	11.5	12.5	1,134	0.074	0.015	0.094	0.183
13	12.5	13.5	587	0.076	0.016	0.097	0.154
14	13.5	14.5	499	0.077	0.015	0.096	0.152
15	14.5	15.5	404	0.076	0.014	0.095	0.166
16	15.5	16.5	261	0.080	0.013	0.097	0.123
17	16.5	17.5	189	0.080	0.014	0.098	0.145
18	17.5	18.5	95	0.080	0.017	0.102	0.183
19	18.5	19.5	46	0.075	0.011	0.088	0.104
20	19.5	20.5	15	0.076	0.009	0.088	0.097
21	20.5	21.5	40	0.074	0.008	0.084	0.086
22	21.5	22.5	74	0.072	0.010	0.084	0.096
23	22.5	23.5	73	0.074	0.010	0.087	0.100
24	23.5	24.5	34	0.068	0.007	0.078	0.085
25	24.5	25.5	28	0.062	0.007	0.071	0.080
26	25.5	26.5	33	0.060	0.007	0.068	0.073
27	26.5	27.5	29	0.063	0.008	0.072	0.089
28	27.5	28.5	13	0.064	0.006	0.072	0.076
29	28.5	29.5	4	0.067	0.006	0.074	0.072
30	29.5	30.5	0				

Airport AWOS Data

In 2005, Alaska Energy Authority (AEA) personnel analyzed the wind resource at all Automated Weather Observing Station (AWOS) and Automated Surface Observing System (ASOS) sites in Alaska. At most stations, AWOS/ASOS data has been collected for twenty-five or more years. Barter Island DEW Station (ICAO station identifier: PABA) data has been collected by an AWOS since 1973. AWOS data summarized below is through 2004.

The AEA report documents data from AWOS sensor, which is 8 meters above ground level. To compare this data to the met tower lower sensor height of 20, the AWOS data was adjusted using an exponent extrapolation function with a power law exponent value of 0.097, the measured shear value at the met tower site. Comparing to the met tower 20 meter anemometer (both the collected data set and the synthesized data set), one can see that average wind speeds recorded by the met tower are approximately that predicted by the Barter Island DEW Station AWOS data. By itself, the AWOS data indicates a Class 6 wind resource, hence confirming the wind resource measured at the met tower site, data recovery problems aside.

DEW Station/met tower data comparison

	Barter Island DEW		Met Tower, 20m anem.	
	AWOS, 8 m sensor (m/s)	Data adj. to 20 m (m/s)	Collected data (m/s)	Synthesized data (m/s)
Jan	6.8	7.43	14.58	7.77
Feb	5.9	6.45	7.29	7.23
Mar	5.7	6.23	5.42	5.32
Apr	5.2	5.68	4.80	4.54
May	6.0	6.56	6.68	6.56
Jun	5.2	5.68	6.69	6.64
Jul	5.3	5.79	5.88	5.88
Aug	5.2	5.68	5.78	5.78
Sep	5.8	6.34	6.47	6.47
Oct	7.0	7.65	2.68	6.14
Nov	6.9	7.54	4.66	3.63
Dec	6.2	6.78	8.07	7.68
Annual	5.9	6.48	6.59	6.14