Napakiak, Alaska Wind Resource Report

Napakiak met tower (view to north), D. Vaught photo

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Summary

The wind resource measured at the Napakiak met tower site is very good with measured wind power Class 4 by measurement of wind power density (also Class 4 when considering only mean annual wind speed). Given the cold winter temperatures at Napakiak, air density is moderately higher than standard conditions, leading to the robust annual wind power density average. By other measures important for wind power analysis, the site has relatively low extreme wind probability and low turbulence.

Met tower data synopsis

Data dates	July 30, 2010 to August 30, 2011 (13 months); decommissioned
Wind power class	Class 4 (good), based on wind speed and wind power density
Wind power density mean, 30 m	385 W/m^2
Wind speed mean, 30 m	6.75 m/s (15.1mph)
Max. 10-min wind speed	23.5 m/s
Maximum 2-sec. wind gust	29.8 m/s (66.7 mph), February, 2011
Weibull distribution parameters	k = 2.00, c = 7.50 m/s
Wind shear power law exponent	0.197 (moderate)
Roughness class	1.48 (description: crops)
IEC 61400-1, 3rd ed. classification	Class III-C (at 30 meters)
Turbulence intensity, mean (at 30 m)	0.094 (at 15 m/s)
Calm wind frequency (at 30 m)	30% (< 4 m/s) (13 mo. measurement period)

Test Site Location

A 30 meter NRG Systems, Inc. tubular-type meteorological (met) tower was installed on the southwest slope of a broad plateau area that slopes toward a slough of the Kuskokwim River that separates the village of Napakiak from the mainland. The met tower site is approximately 1.5 km (1 mile) west of Napakiak. Winter access by foot, ski or snowmachine is very easy but summer access from Napakiak requires boat transport across the slough, which is very muddy at low tide, and then a hike up the hill. The met tower was installed immediately south and downhill of a power distribution line that connects the village of Napakiak with the larger community of Bethel located approximately 16 km (10 miles) to the northeast. At present a service road does not exist along the power distribution line. Access to Bethel is via aircraft or snowmachine in the winter and aircraft or boat (on the Kuskokwim River) in summer. The site was chosen for a met tower study due to Napakiak's interest in wind power development to serve its needs and possibly the needs of Bethel.

Site information

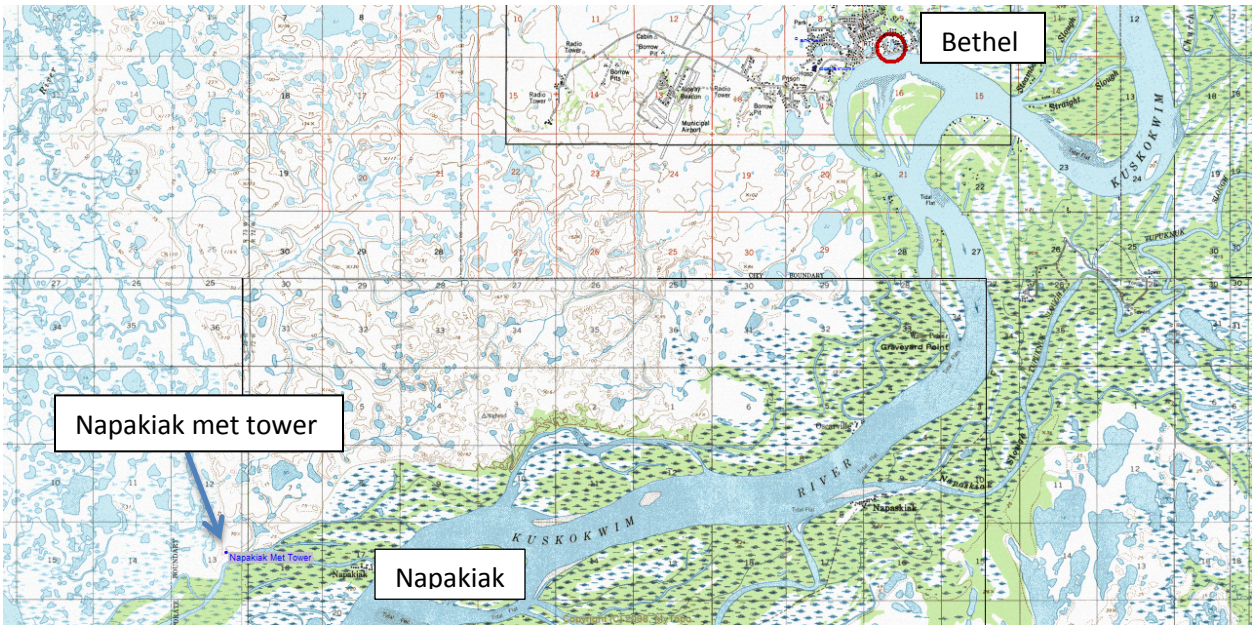
Site number	2543
Latitude/longitude	N 60° 41.895" W 162° 00.552"
Time offset	-9 hours from GMT (Yukon/Alaska time zone)
Site elevation	17 meters (55 ft.)
Datalogger type	NRG Symphonie Plus, 10 minute time step
Tower type	Tubular tall tower, 6-inch diam., 30 meter height

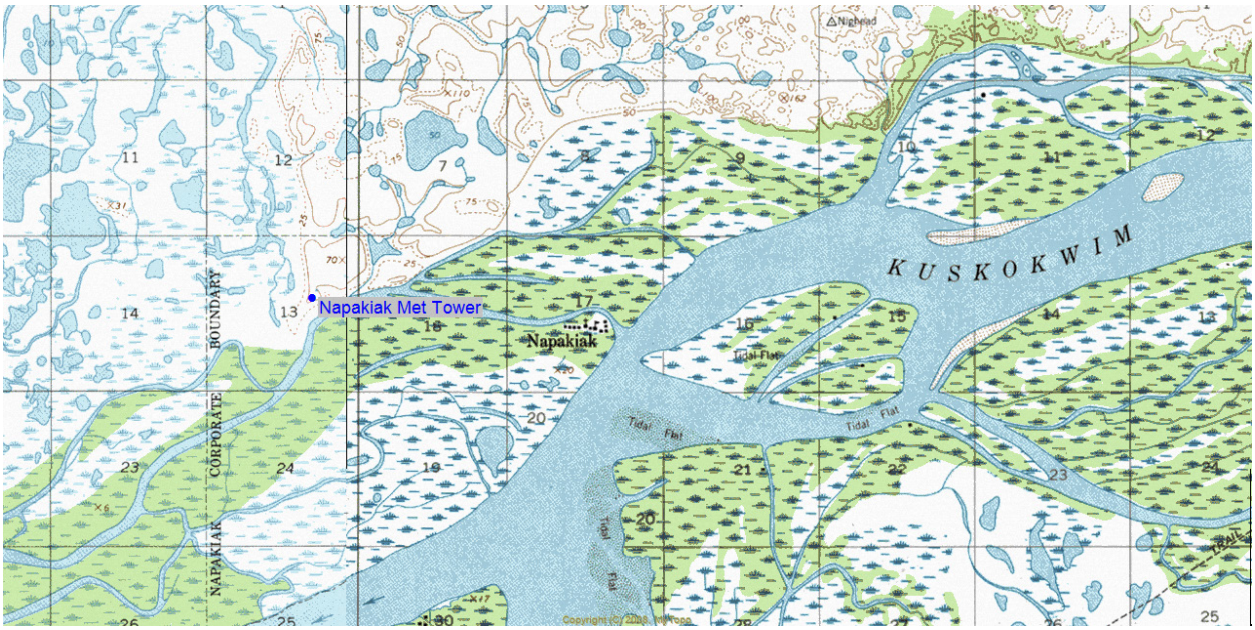
Tower sensor information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m A	0.765	0.35	Not recorded
2	NRG #40 anemometer	30 m B	0.765	0.35	Not recorded
3	NRG #40 anemometer	19 m	0.765	0.35	Not recorded
7	NRG #200P wind vane	23 m	0.351	359	359° T
9	NRG #110S Temp F	3 m	0.244	-123.5	N

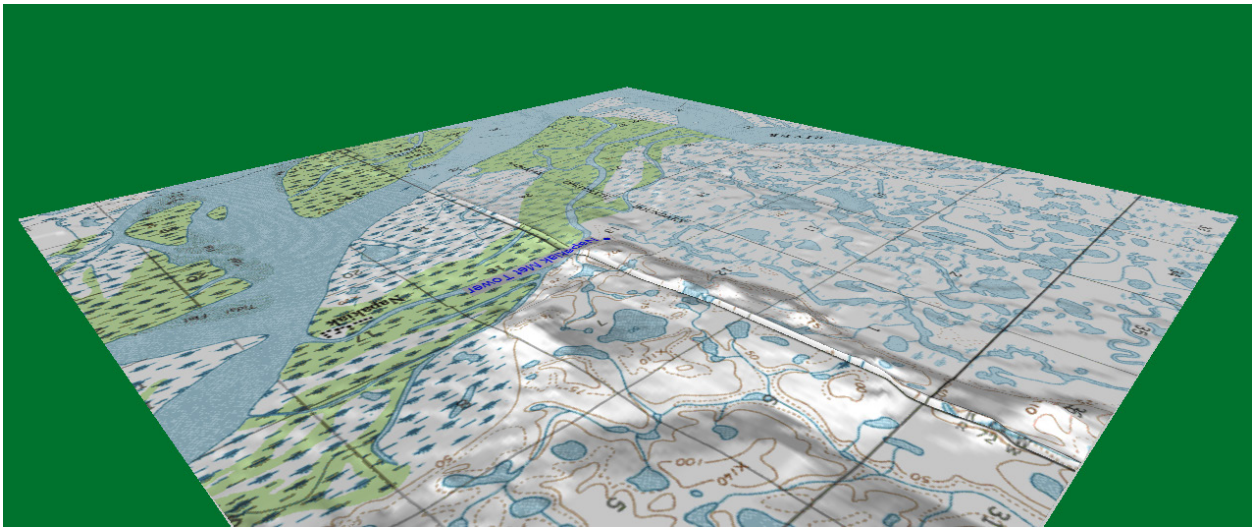
Google Earth image, Napakiak

Topographic maps, Napakiak





Topography from Direction of Prevailing Wind (view toward the southwest)



Data Quality Control

Data quality is generally good with data recovery of all three anemometers greater than 83 percent and data recovery of the wind vane over 97 percent. Data recovery of the temperatures sensor would have been 100 percent but for a few missing partial days of files. It was noted, however, that anemometer 30 m B (channel 2) returned suspect data on occasion, with speed returns substantially lower than those of anemometer 30 m A (channel 1) and anemometer 19 m (channel 3). The reason for this data discrepancy is undetermined.

Data was automatically flagged and filtered from the data set according to four criteria listed below. In addition, some data was manually filtered for obvious icing events but missed by the automatic filter. An example would be icing events where the temperature warms to greater than 1° C.

1. Icing: Anemometer data when, over a two hour period, mean speed changes less than 0.25 m/s, standard deviation equals zero (indicating no movement of the sensor), and temperature is less than 1° C.
2. Icing: Wind vane (direction) data when, over a two hour period, standard deviation equals zero (indicating no movement of the sensor), and temperature is less than 1° C.
3. Low quality data: 30 m B data is flagged when the difference between 30 m A mean and 30 m B mean is greater than 1.0 m/s.
4. Tower shading: Because 30 m A and 30 m B are paired anemometers and hence comparative analysis possible, 30 m A when wind direction is 15° either side of 125° T; and 30 m B when wind direction is 15° either side of 270° T.

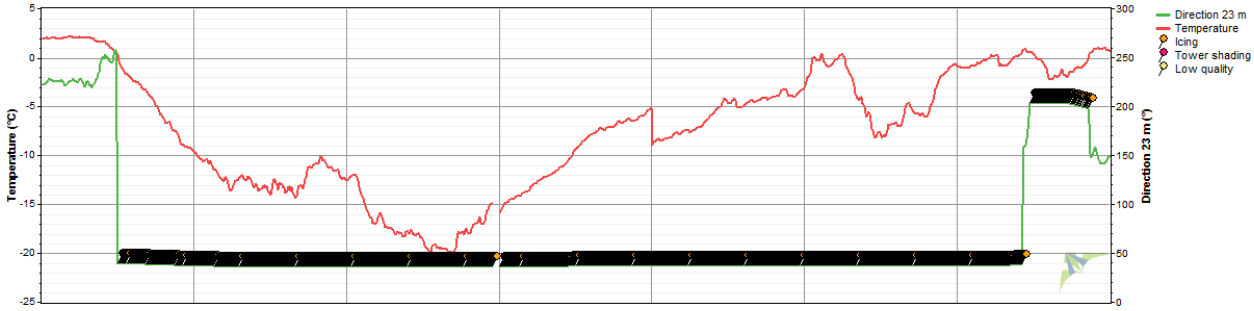
Sensor data recovery table

Year	Month	Possible Records	Valid Records	30 m A Recovery Rate (%)	30 m B Recovery Rate (%)	19 m Recovery Rate (%)	Vane Recovery Rate (%)	Temp Recovery Rate (%)
2010	Jul	180	145	80.6	95.0	100.0	100.0	100.0
2010	Aug	4,464	4,237	94.9	91.4	99.2	99.2	99.2
2010	Sep	4,320	3,909	90.5	92.4	97.9	97.9	97.9
2010	Oct	4,464	4,183	93.7	72.5	99.2	84.4	100.0
2010	Nov	4,320	3,331	77.1	57.7	88.9	41.9	99.9
2010	Dec	4,464	3,464	77.6	70.0	95.5	10.5	98.0
2011	Jan	4,464	3,827	85.7	99.6	100.0	87.8	100.0
2011	Feb	4,032	3,042	75.5	87.4	91.4	51.4	96.4
2011	Mar	4,464	4,180	93.6	98.4	98.7	99.5	100.0
2011	Apr	4,320	3,969	91.9	69.1	98.3	93.5	100.0
2011	May	4,464	3,805	85.2	79.6	98.0	97.7	98.0
2011	Jun	4,320	3,868	89.5	90.1	100.0	100.0	100.0
2011	Jul	4,464	4,192	93.9	90.5	100.0	100.0	100.0
2011	Aug	4,176	4,032	96.6	90.4	100.0	100.0	100.0
All data		56,916	50,184	88.2	83.8	97.5	82.0	99.2

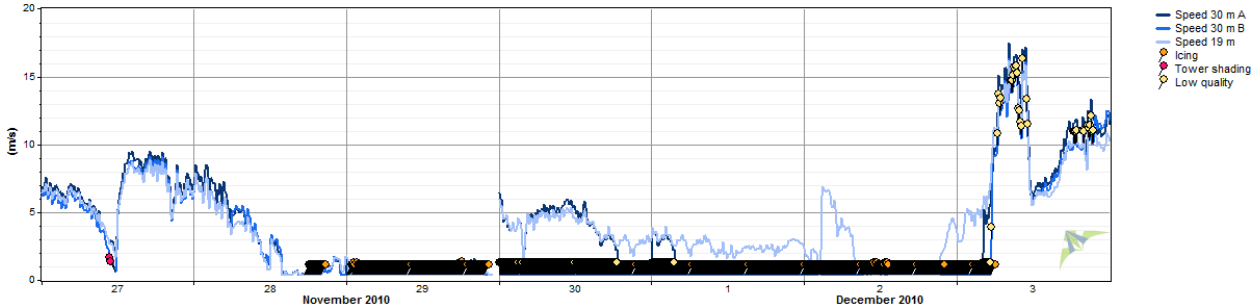
Icing Event

The Napakiak met tower site is at an elevation of 17 meters, too low for destructive (hard) rime ice to form, although soft rime icing (hoarfrost) occurs occasionally. Freezing rain, sleet, and other similar cold climate events occur more often, which can compromise anemometer and wind vane data. These are not likely however to seriously impede wind turbine operations.

Apparent icing event, November 2010, wind vane and temperature data



Apparent icing event, November 2010, anemometer data



Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate an excellent wind resource. Mean wind speeds are greater at higher elevations on the met tower, as one would expect, although perhaps more than expected. Note that cold temperatures contributed to a higher wind power density than standard conditions would indicate for the measured mean wind speeds.

Anemometer data summary

Variable	Speed 30 A m	Speed 30 m B	Speed 19 m
Measurement height (m)	29.2	29.2	18.6
Mean wind speed (m/s)	6.65	6.43	5.95
MMM wind speed (m/s)	**6.75**	**6.52**	**6.03**
Max wind speed (m/s)	23.5	23.1	22.2
Weibull k, annual	2.00	1.89	2.00
Weibull c (m/s), annual	7.50	7.23	6.71
Mean power density (W/m²)	369	350	266
MMM power density (W/m²)	**385**	**364**	**277**
Mean energy content (kWh/m²/yr)	3,234	3,069	2,332
MMM energy content (kWh/m²/yr)	3,372	3,190	2,422
Energy pattern factor	1.91	2.01	1.93
Frequency of calms (%)	25.1	27.1	29.9
Hour of peak wind speed	19	19	19

MMM = mean of monthly mean, or *annualized*

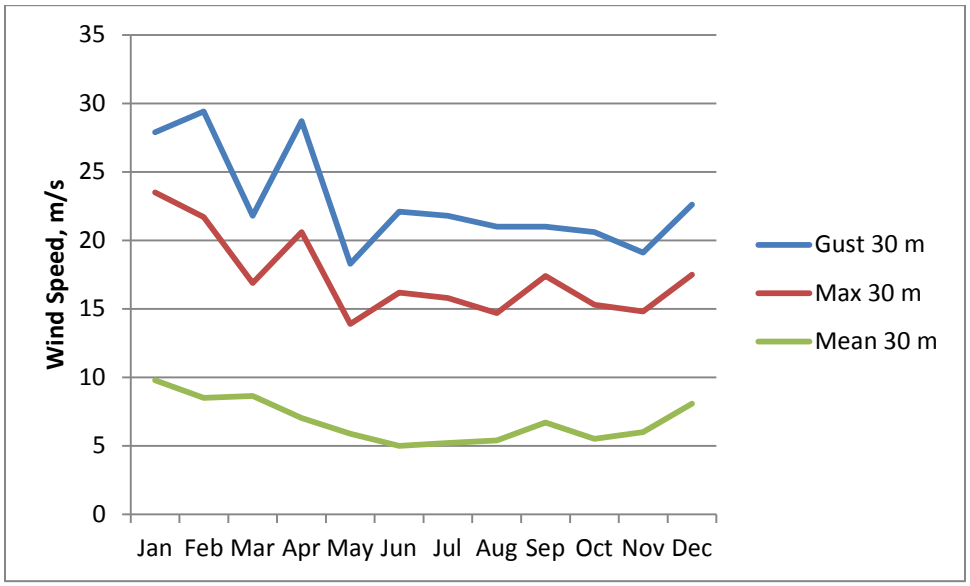
Time Series

Time series calculations indicate high mean wind speeds during the winter months with more moderate mean wind speeds during summer months. This correlates well with the a typical Alaska village load profile where winter months have a high electric load and heat demand and summer months see a much lower demand for electricity and heat.

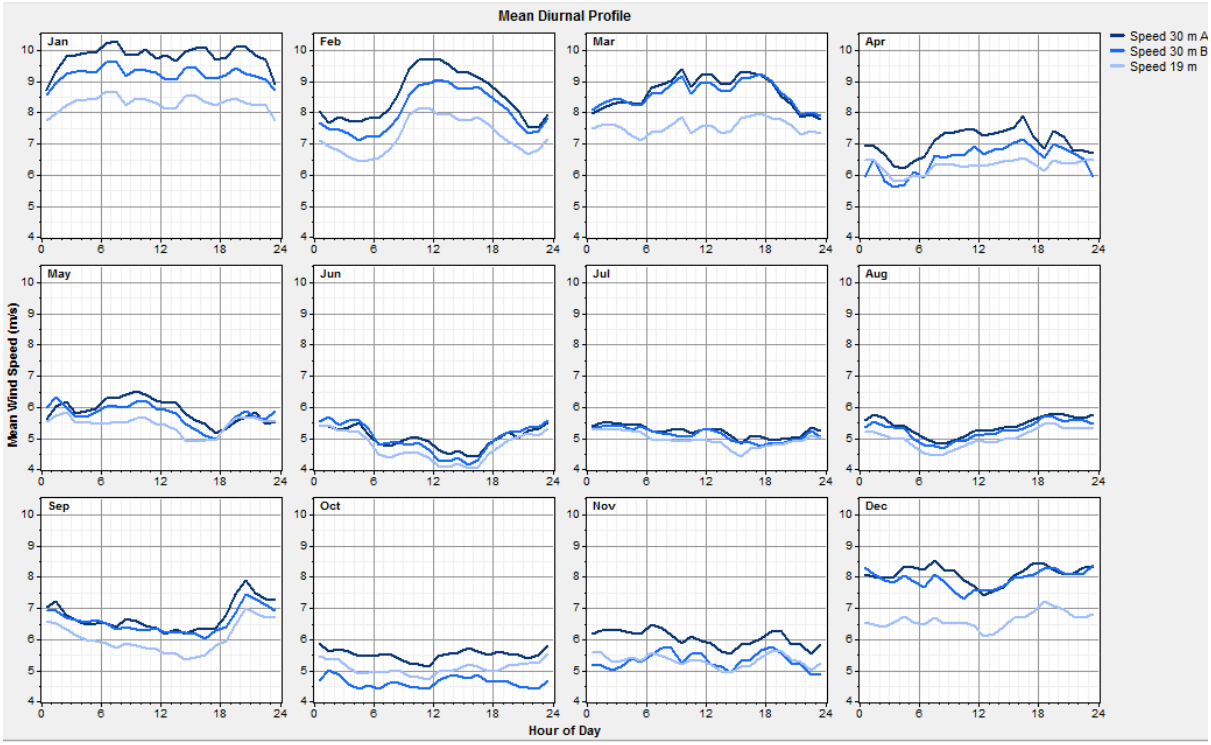
30 m A anemometer data summary

Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
Jan	9.78	23.5	27.9	4.18	2.51	11.02
Feb	8.50	21.7	29.4	3.65	2.46	9.57
Mar	8.64	16.9	21.8	3.29	2.90	9.67
Apr	7.04	20.6	28.7	3.85	1.90	7.93
May	5.89	13.9	18.3	2.43	2.59	6.63
Jun	5.00	16.2	22.1	2.64	1.99	5.65
Jul	5.22	15.8	21.8	2.72	2.00	5.88
Aug	5.39	14.7	21.0	2.74	2.05	6.08
Sep	6.71	17.4	21.0	3.70	1.90	7.57
Oct	5.51	15.3	20.6	2.50	2.33	6.22
Nov	6.01	14.8	19.1	2.93	2.08	6.73
Dec	8.09	17.5	22.6	2.82	3.13	8.97
Annual	6.75	23.5	29.4	3.47	2.00	7.50

Annual time series, mean and max wind speed



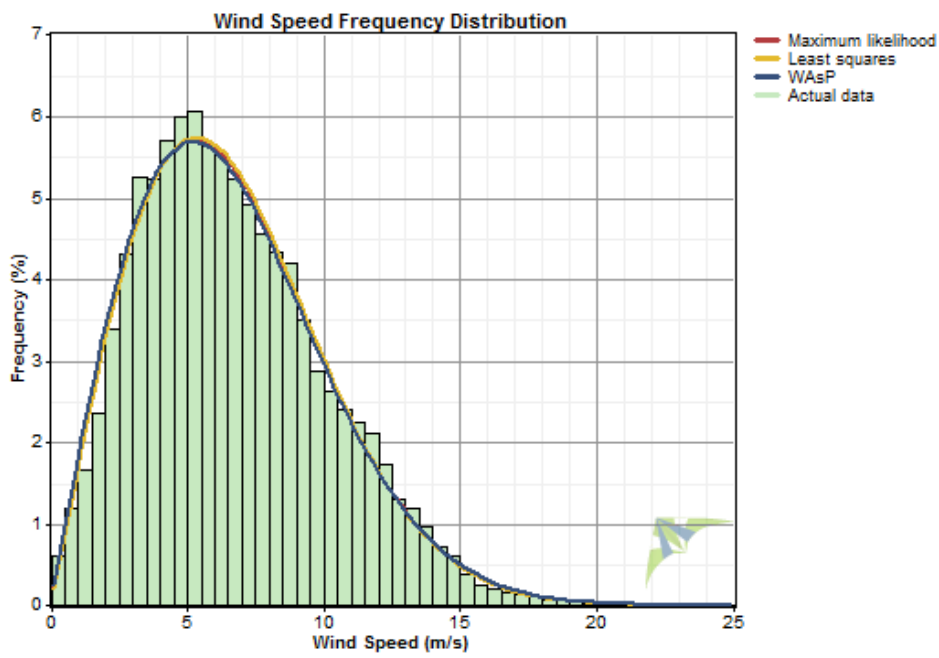
Daily wind profiles (per month)



Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Napakiak met tower wind speed indicates a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis.

PDF of 30 m A anemometer (13 months' data)



Weibull table

Algorithm	Weibull k	Weibull c (m/s)	Mean (m/s)	Proportion Above 6.649 m/s	Power Density (W/m2)	R Squared
Maximum likelihood	2.000	7.500	6.646	45.6%	343.5	0.9916
Least squares	2.013	7.506	6.651	45.7%	342.0	0.9914
WAsP	1.967	7.461	6.614	45.1%	344.2	0.9917
Actual data	(50,184 time steps)		6.649	45.1%	344.2	

Occurrence by wind speed bin (30 m A anemometer)

Bin Endpoints (m/s)		Occurrences			Bin Endpoints (m/s)		Occurrences		
Lower	Upper	No.	Percent	Cumul.	Lower	Upper	No.	Percent	Cumul.
0	1	902	1.80	1.8	13	14	1,083	2.16	97.1
1	2	2,017	4.02	5.8	14	15	658	1.31	98.4
2	3	3,862	7.70	13.5	15	16	306	0.61	99.0
3	4	5,260	10.48	24.0	16	17	177	0.35	99.4
4	5	5,864	11.68	35.7	17	18	124	0.25	99.6
5	6	5,880	11.72	47.4	18	19	71	0.14	99.8
6	7	5,402	10.76	58.2	19	20	37	0.07	99.8
7	8	4,748	9.46	67.6	20	21	25	0.05	99.9
8	9	4,282	8.53	76.2	21	22	29	0.06	99.9
9	10	3,205	6.39	82.5	22	23	23	0.05	100.0
10	11	2,524	5.03	87.6	23	24	6	0.01	100.0
11	12	2,186	4.36	91.9	24	25	0	0.00	100.0
12	13	1,513	3.01	94.9					

Wind Shear and Roughness

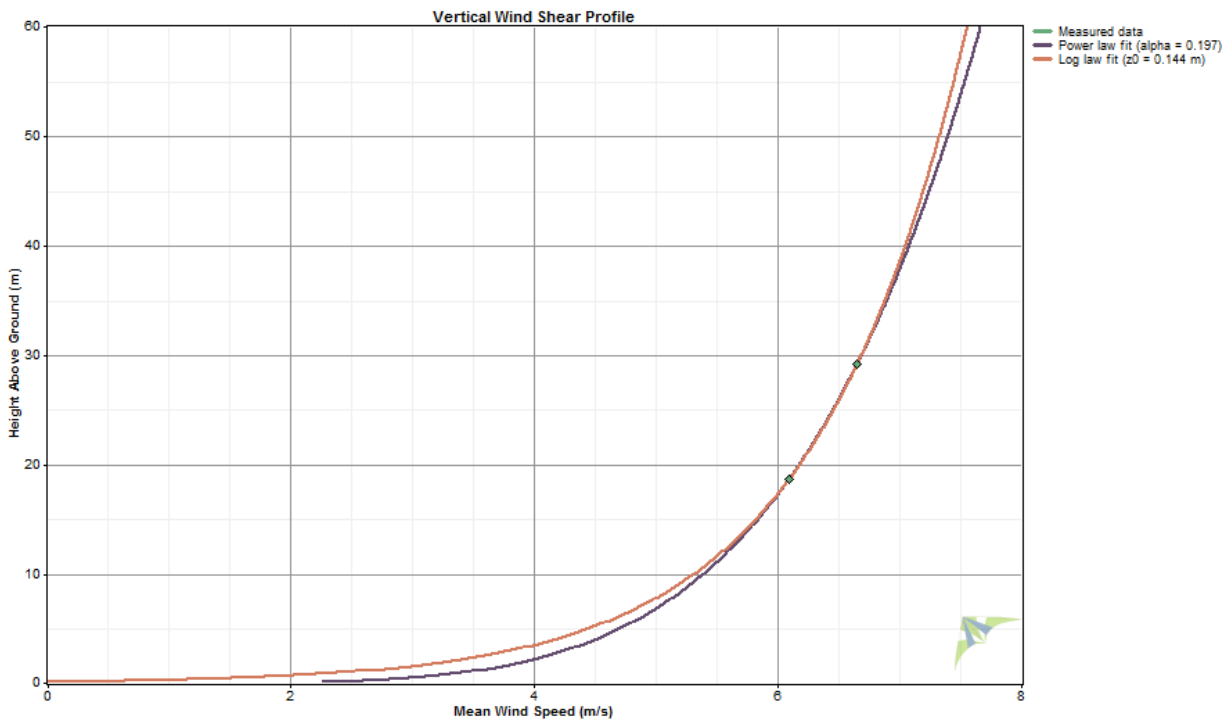
A wind shear power law exponent (α) of 0.197 indicates moderate wind shear at the site. Related to wind shear, a calculated surface roughness of 0.054 meters (indicating the height above ground level where wind velocity would be zero) indicates reasonably smooth terrain (roughness description: crops) surrounding the met tower. Wind shear is relatively high in the direction of the NE prevailing wind and relatively low in the direction of the southerly storm wind, indicating the effects of exposure of the site to a long fetch of tundra to the NE and exposed, open terrain to the south.

Wind shear by direction sector

Sector	Time Steps	Mean Speed (m/s) Speed 30 m A	Speed 19 m	Best-Fit Power Law Exponent	Surface Roughness (m)
345° - 15°	3,537	6.13	5.36	0.298	0.810
15° - 45°	6,156	8.13	7.28	0.246	0.400

45° - 75°	7,179	8.58	7.77	0.221	0.254
75° - 105°	4,747	6.12	5.66	0.174	0.074
105° - 135°	1,054	5.78	5.44	0.133	0.013
135° - 165°	3,881	6.92	6.12	0.274	0.600
165° - 195°	4,289	7.59	7.02	0.173	0.073
195° - 225°	4,439	5.68	5.38	0.120	0.006
225° - 255°	3,301	5.22	5.00	0.097	0.001
255° - 285°	2,658	4.64	4.42	0.112	0.003
285° - 315°	3,017	5.43	5.12	0.131	0.011
315° - 345°	5,843	5.88	5.41	0.185	0.105

Vertical wind shear profile



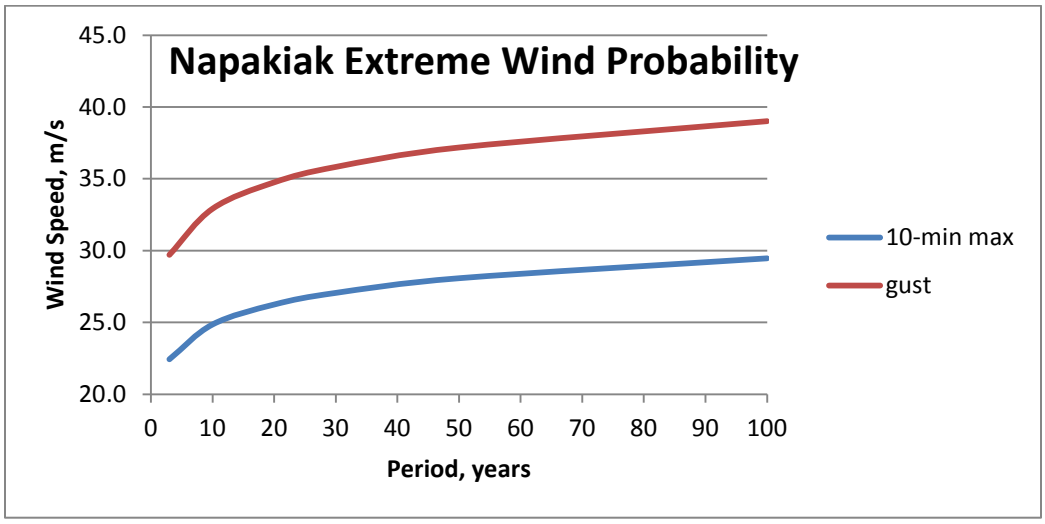
Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Napakiak met tower site. Thirteen months of data though are very minimal at best and hence results should be viewed with caution. Nevertheless, with data available the predicted Vref (maximum ten-minute average wind speed) in a 50 year return period (in other words, predicted to occur once every 50 years) is 28.1 m/s. This result classifies the site as Class III by International Electrotechnical Commission 61400-1, 3rd edition (IEC3) criteria. IEC extreme wind probability classification is one criteria – with turbulence the other – that describes a site with respect to suitability for particular wind turbine models. Note that the IEC3 Class III extreme wind classification, which appears to apply to the Napakiak met tower site, is the lowest and most common classification. All wind turbines are designed to operate in IEC3 Class III sites.

Site extreme wind probability table, 30 m A data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	22.4	29.7	I	50.0
10	24.9	32.9	II	42.5
20	26.2	34.8	III	37.5
30	27.1	35.8	S	designer-specified
50	28.1	37.2		
100	29.5	39.0		
average gust factor:	1.32			

Extreme wind graph, by return period



Temperature, Density, and Relative Humidity

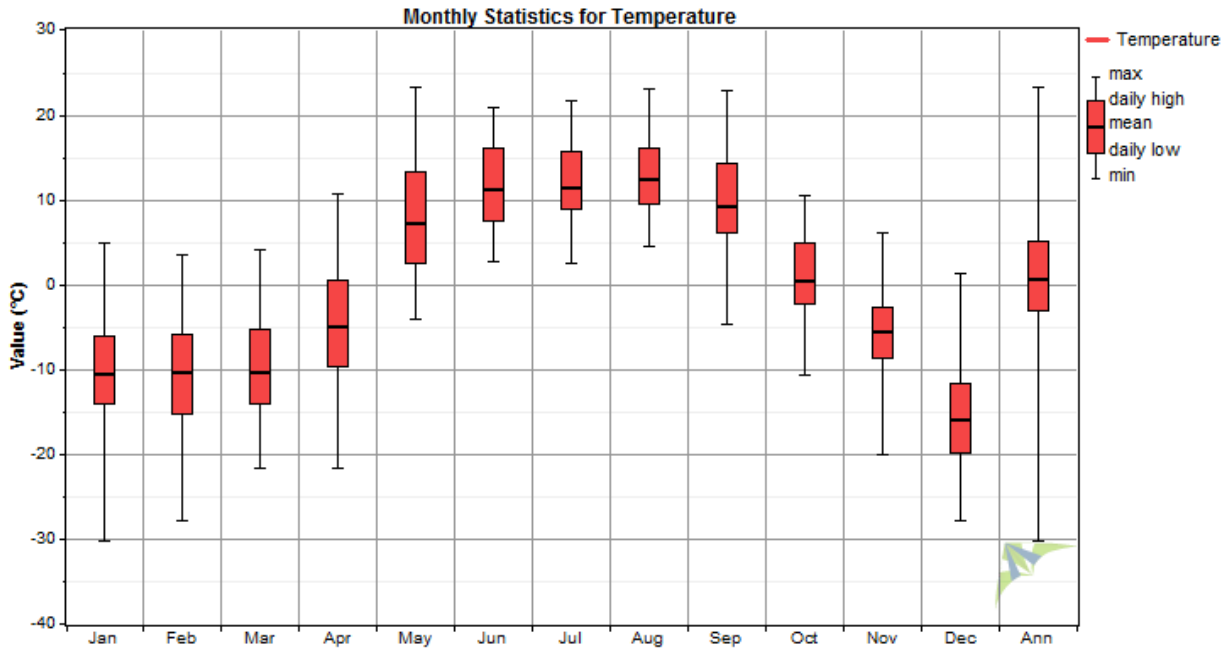
The Napakiak met tower site experiences warm summers and cool winters with resulting higher than standard air density. Calculated mean-of-monthly-mean (or annual) air density during the met tower test period exceeds the 1.223 kg/m^3 standard air density for a 17 meter elevation by 5.9 percent. This is 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

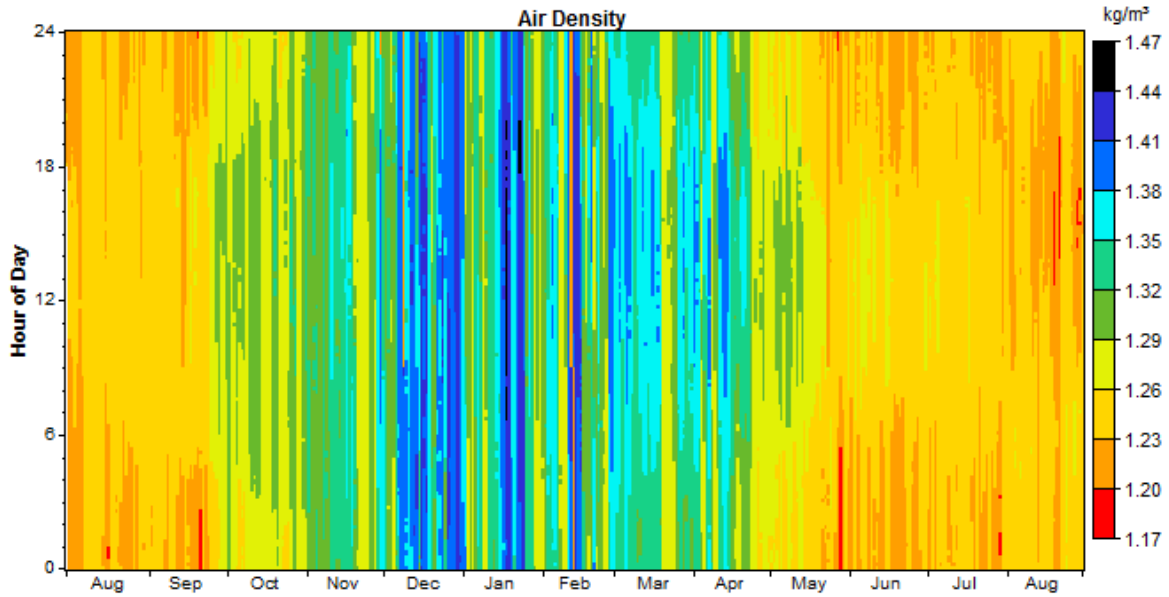
Month	Temperature Mean (°C)	Temperature Min (°C)	Temperature Max (°C)	Air Density Mean (kg/m³)	Air Density Min (kg/m³)	Air Density Max (kg/m³)
Jan	-10.4	-30.3	4.8	1.345	1.270	1.453
Feb	-10.3	-27.8	3.4	1.340	1.225	1.438
Mar	-10.2	-21.7	4.0	1.343	1.273	1.403
Apr	-5.0	-21.7	10.6	1.317	1.244	1.403
May	7.3	-4.2	23.2	1.258	1.191	1.312

Jun	11.2	2.7	20.9	1.241	1.200	1.279
Jul	11.5	2.5	21.7	1.240	1.197	1.280
Aug	12.4	4.5	23.0	1.236	1.192	1.271
Sep	9.3	-4.7	22.8	1.249	1.192	1.314
Oct	0.6	-10.7	10.5	1.289	1.244	1.345
Nov	-5.5	-20.0	6.0	1.319	1.225	1.394
Dec	-15.9	-27.8	1.3	1.370	1.225	1.438
Annual	-0.4	-30.3	23.2	1.295	1.191	1.453

Temperature graph



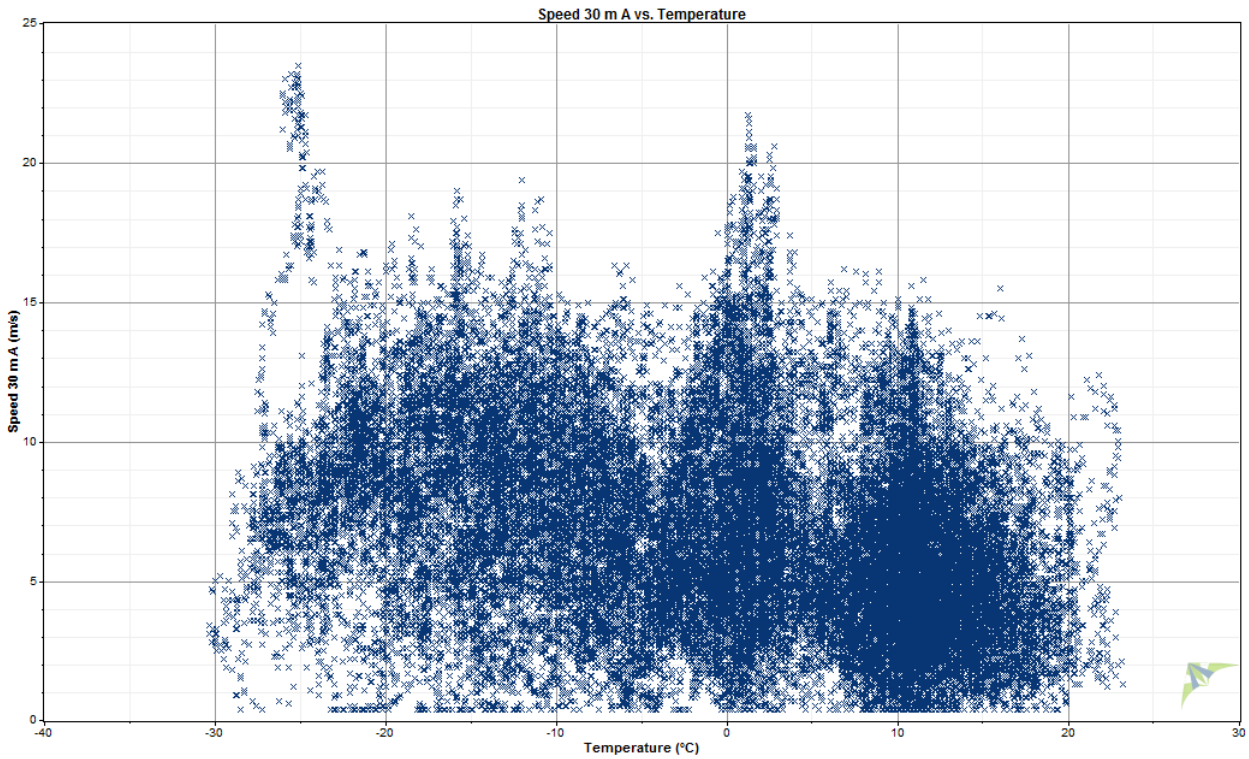
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates cold temperatures at the Napakiak met tower site with below freezing temperatures most of the time. During the met tower test period, temperatures were colder than -30° C (-22° F) on a few occasions, which is well above the minimum operating temperature of -40° C (-40° F) of arctic-rated wind turbines. But, data was not collected during the extremely cold months of November 2011 through January 2012 when temperatures likely approached or were colder than -40° C, by reference to weather reports from Bethel.

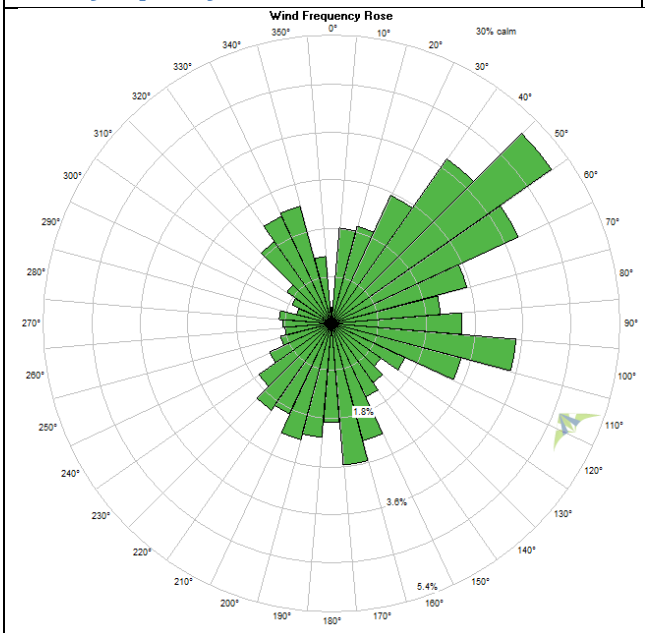
Wind speed/temperature



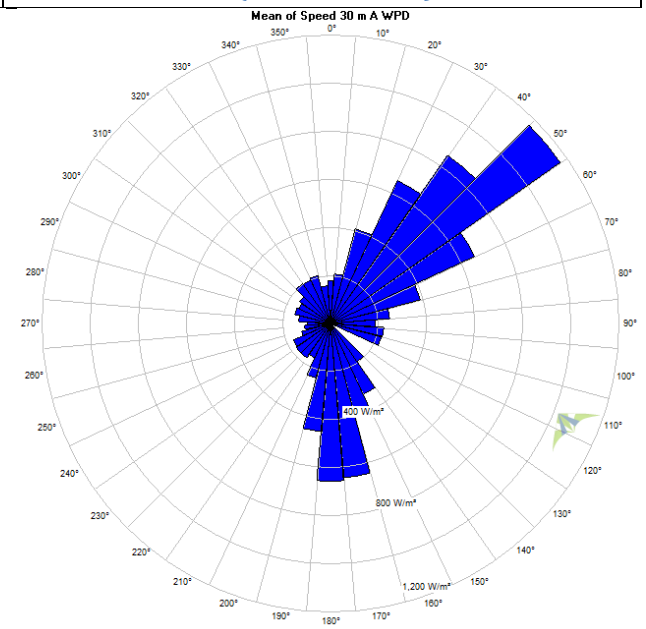
Wind Direction

Wind frequency rose data indicates that winds at the Napakiak met tower site are relatively directional from the northeast but also frequent winds from the east, south, and northwest occur. The mean value rose, however, indicates that northeasterly and southerly winds, when they do occur, are of much higher energy than winds from other directions. Hence, the resulting wind energy rose indicates that for wind turbine operations, power-producing winds are strongly dominated by northeasterly winds with a lesser component of southerly winds. Calm frequency (the percent of time that winds at the 30 meter level are less than 4 m/s, a typical cut-in speed of larger wind turbines) was a moderate 30 percent during the met tower test period (13 months of data).

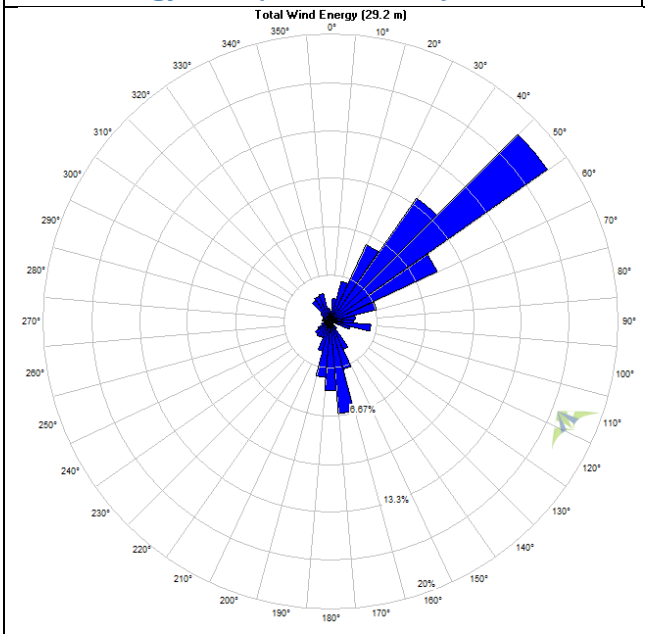
Wind frequency rose



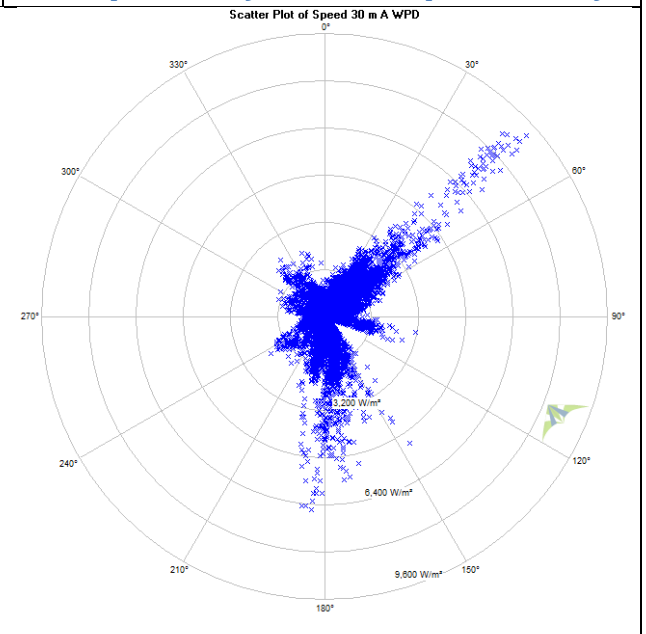
Mean value rose (30 m A anem.)



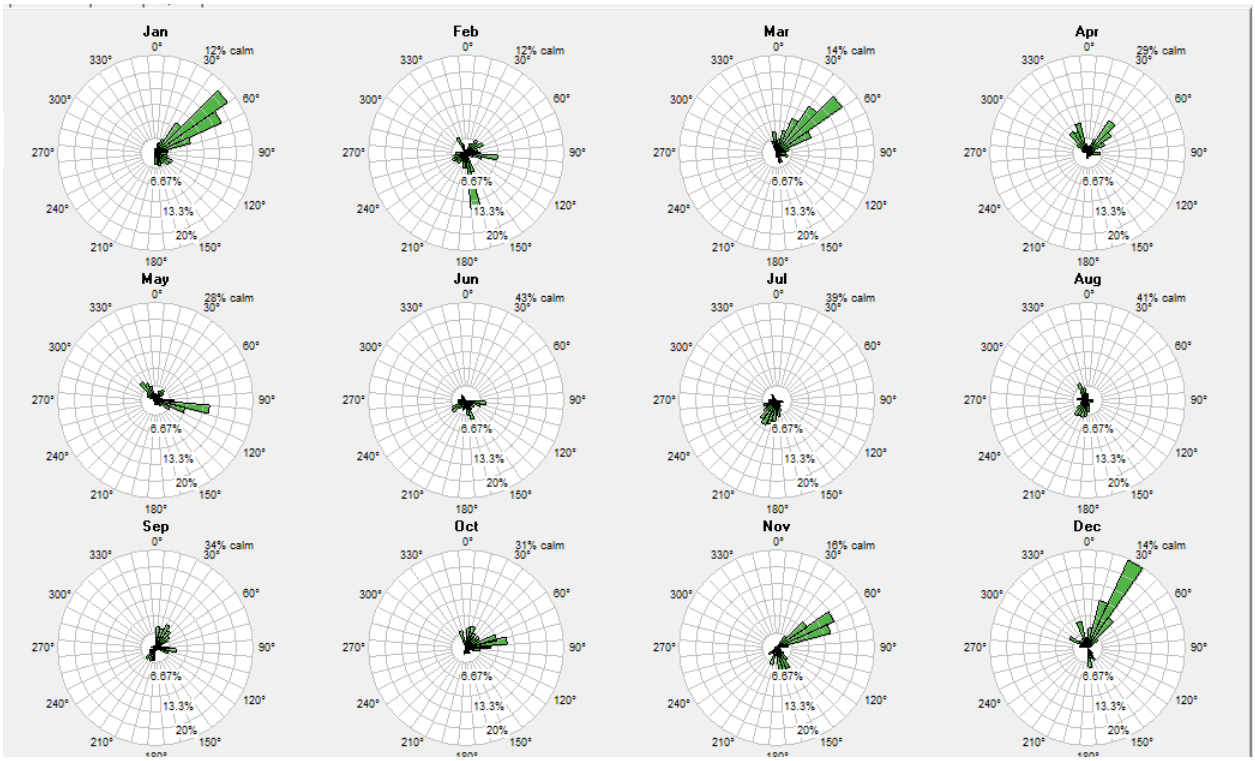
Wind energy rose (30 m A anem.)



Scatterplot rose of 30m A wind power density



Wind density roses by month (common scale)



Turbulence

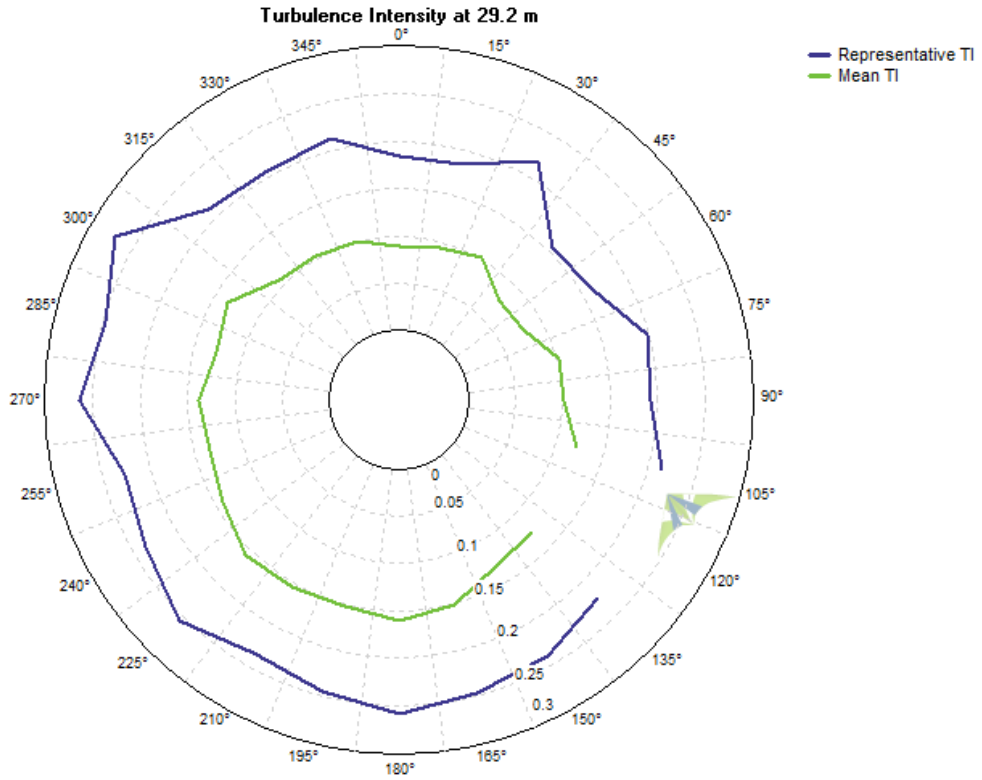
Turbulence intensity (TI) at the Napakiak met tower site is acceptable with an overall IEC 61400-1, 3rd edition (IEC3) classification of turbulence category C, the lowest defined, at 30 meters and 19 meters. Note that turbulence intensity of winds from the northeast, which predominate, is lower than for southerly winds. This likely is due to the nature of the upwind landscape: to the northeast is featureless tundra while to the south, at the bottom of the slope and surrounding the slough (of the Kuskokwim River) are trees and alder thickets which likely affect the met tower site, at least at lower elevations. Depending on hub height, turbulence might be a consideration for turbine placement.

Turbulence synopsis

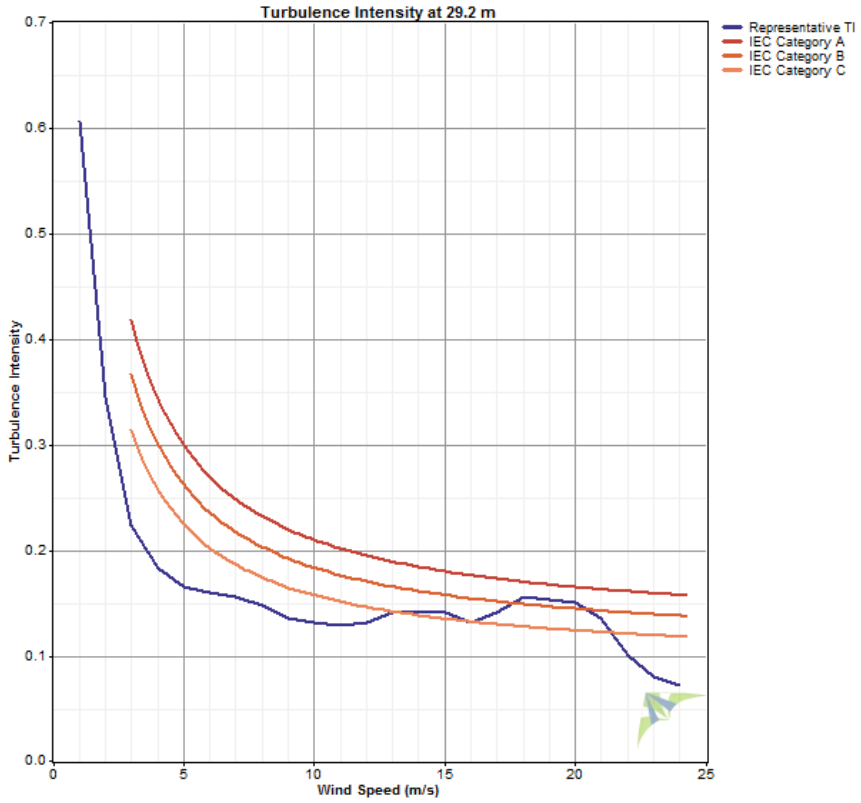
	30 m A anem.			19 m anem.			Legend	
Sector	Mean TI at 15 m/s	Repres. TI at 15 m/s	IEC3 Category	Mean TI at 15 m/s	Repres. TI at 15 m/s	IEC3 Category	IEC3 Categ.	Mean TI at 15 m/s
all	0.094	0.141	C	0.100	0.141	C	S	>0.16
045° to 075°	0.061	0.083	C	0.078	0.092	C	A	0.14-0.16
165° to 195°	0.134	0.153	B	0.143	0.159	A	B	0.12-0.14
							C	0.00-0.12

TI = turbulence intensity

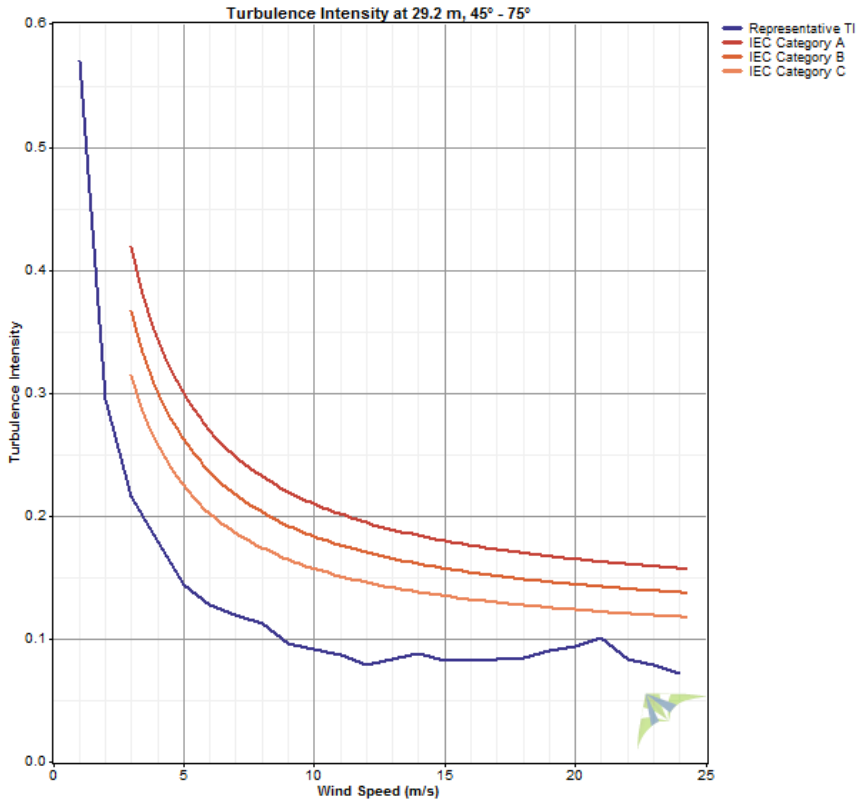
Turbulence rose, 30 m A anemometer



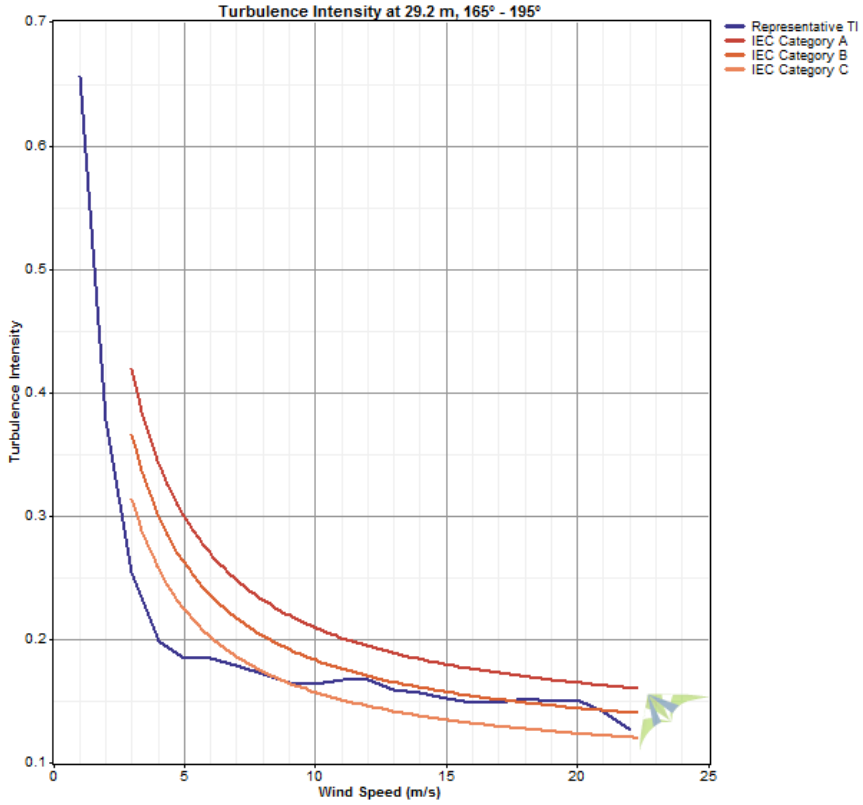
Turbulence intensity, 30 m A, all direction sectors



Turbulence intensity, 30 m A, 045° to 075° True (northeasterly winds)



Turbulence intensity, 30m A, 165° to 195° True (southerly winds)



Turbulence table, 30 m A data, all sectors

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records in Bin	Mean TI	SD of TI	Repres. TI	Peak TI
1	0.5	1.5	1,423	0.398	0.162	0.606	1.222
2	1.5	2.5	2,886	0.203	0.111	0.345	1.273
3	2.5	3.5	4,801	0.136	0.069	0.224	0.853
4	3.5	4.5	5,480	0.118	0.051	0.183	0.575
5	4.5	5.5	6,048	0.107	0.045	0.165	0.542
6	5.5	6.5	5,615	0.103	0.044	0.159	0.456
7	6.5	7.5	5,087	0.100	0.044	0.156	0.343
8	7.5	8.5	4,464	0.093	0.043	0.148	0.325
9	8.5	9.5	3,863	0.085	0.039	0.135	0.281
10	9.5	10.5	2,763	0.081	0.039	0.131	0.245
11	10.5	11.5	2,330	0.078	0.040	0.129	0.217
12	11.5	12.5	1,928	0.078	0.041	0.131	0.224
13	12.5	13.5	1,246	0.089	0.041	0.141	0.209
14	13.5	14.5	840	0.091	0.039	0.141	0.197
15	14.5	15.5	490	0.094	0.037	0.141	0.172
16	15.5	16.5	216	0.087	0.035	0.132	0.174
17	16.5	17.5	145	0.095	0.035	0.141	0.160
18	17.5	18.5	93	0.111	0.034	0.155	0.162
19	18.5	19.5	62	0.110	0.033	0.153	0.155
20	19.5	20.5	24	0.112	0.030	0.151	0.164
21	20.5	21.5	27	0.100	0.027	0.135	0.147
22	21.5	22.5	29	0.078	0.018	0.100	0.125
23	22.5	23.5	14	0.070	0.007	0.079	0.079
24	23.5	24.5	1	0.072	0.000	0.072	0.072

Wind Turbine Performance

The selection of suitable wind turbines for a wind power project in Napakiak is beyond the scope of this report, but for initial planning purposes, predicted annual energy output and capacity factor for the 100 kW Northwind 100 B model (21 meter rotor, 37 meter hub height) and 225 kW Aeronautica AW29-225 (29 meter rotor, 40 meter hub height) are presented below.

Note that the Alaska Energy Authority considers 82 percent turbine availability (percent of time that the turbine is operational and available to produce power, irrespective of wind speed) as the default value for planning village power projects. Many wind turbines in rural Alaska operate with better than 82 percent availability, but for a number of reasons some operate with lower than 82 percent availability.

NW100 wind turbine performance

	100% availability Northwind 100/B/21 (37 meters)				82% availability Northwind 100/B/21			
Month	Hub Height Wind Speed (m/s)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)	Hub Height Wind Speed (m/s)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	9.9	64.0	47,642	64.0	9.9	52.5	39,066	52.5
Feb	8.5	51.5	34,600	51.5	8.5	42.2	28,372	42.2
Mar	9.2	60.7	45,131	60.7	9.2	49.7	37,007	49.7
Apr	7.1	37.9	27,276	37.9	7.1	31.1	22,366	31.1
May	6.0	24.2	18,036	24.2	6.0	19.9	14,790	19.9
Jun	5.1	17.2	12,366	17.2	5.1	14.1	10,140	14.1
Jul	5.2	18.2	13,566	18.2	5.2	15.0	11,124	15.0
Aug	5.5	21.2	15,766	21.2	5.5	17.4	12,928	17.4
Sep	6.7	33.2	23,914	33.2	6.7	27.2	19,609	27.2
Oct	5.3	19.0	14,143	19.0	5.3	15.6	11,597	15.6
Nov	5.6	23.8	17,164	23.8	5.6	19.5	14,074	19.5
Dec	8.3	54.2	40,301	54.2	8.3	44.4	33,047	44.4
Annual	6.9	35.4	309,905	35.4	6.9	29.1	254,120	29.1

Aeronautica 29-225 wind turbine performance

	100% availability Aeronautica 29-225 (40 meters)				82% availability Aeronautica 29-225			
Month	Hub Height Wind Speed (m/s)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)	Hub Height Wind Speed (m/s)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	10.1	142.7	106,156	63.4	10.1	117.0	87,048	52.0
Feb	8.7	113.0	75,965	50.2	8.7	92.7	62,292	41.2
Mar	9.5	135.2	100,624	60.1	9.5	110.9	82,512	49.3
Apr	7.2	81.0	58,338	36.0	7.2	66.4	47,837	29.5
May	6.0	47.8	35,533	21.2	6.0	39.2	29,137	17.4
Jun	5.2	32.4	23,301	14.4	5.2	26.5	19,107	11.8
Jul	5.3	34.5	25,634	15.3	5.3	28.3	21,020	12.6
Aug	5.6	41.9	31,173	18.6	5.6	34.4	25,562	15.3
Sep	6.8	69.9	50,355	31.1	6.8	57.3	41,291	25.5
Oct	5.3	35.7	26,543	15.9	5.3	29.3	21,765	13.0
Nov	5.6	47.3	34,024	21.0	5.6	38.8	27,900	17.2
Dec	8.6	121.7	90,521	54.1	8.6	99.8	74,227	44.3
Annual	7.0	75.3	658,167	33.4	7.0	61.7	539,698	27.4