Napaskiak, Alaska Wind Resource Assessment Report

Napaskiak met tower, photo by Connie Fredenberg

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Summary

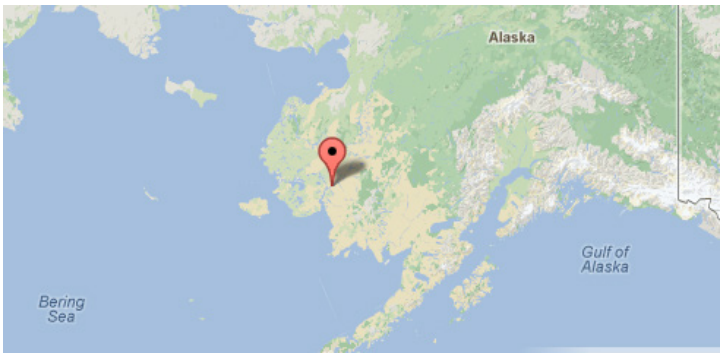
The wind resource measured at the Napaskiak met tower site is fair with mean annual wind speed of 5.66 m/s and wind power density of 208 W/m^2 at 34 meters above ground level. This confirms the AWS Truepower wind resource map which predicts Class 2 winds at Napaskiak. Although the wind resource in Napaskiak is modest compared to communities on the Bering Sea coast, development of renewable power in the village may be viable with turbines specifically suited to lower wind environments. Also of consideration is the high cost of fuel in Napaskiak and the environment risk of transporting and storing fossil fuel. Wind power provides a long-term renewable energy alternative for Napaskiak that has the potential to buffer residents from unpredictable variations of the petroleum market. These and other issues will be explored in a follow-up feasibility study.

Met tower data synopsis

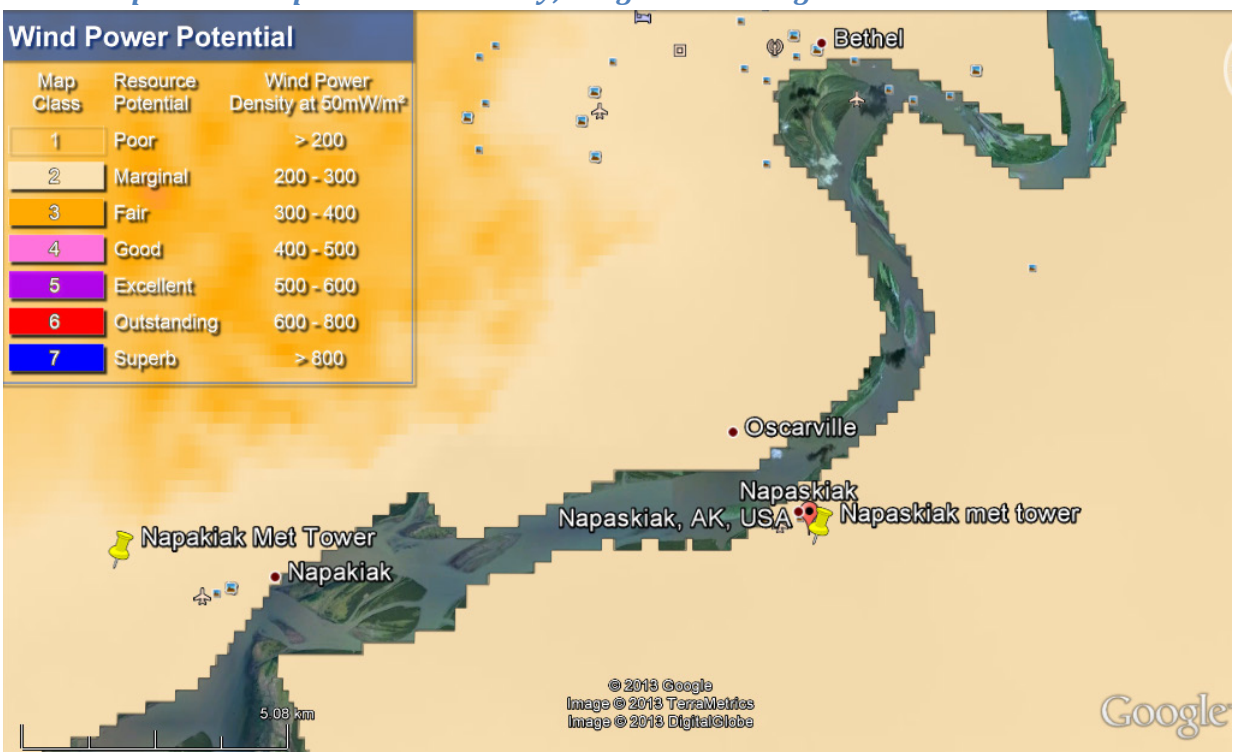
Data dates	12/04/2011 to 04/02/2013 (16 months)
Wind power density mean, 34 m	208 W/m^2
Wind speed mean, 34 m	5.66 m/s (12.6 mph)
Max. 10-min wind speed	28.6 m/s
Maximum 2-sec. wind gust	37.1 m/s (83.0 mph), December 2011
Weibull distribution parameters	k = 2.16, c = 6.43 m/s
Wind shear power law exponent	0.303 (high)
Roughness class	3.79 (description: forest)
IEC 61400-1, 3rd ed. classification	Class III-A (at 34 meters)
Turbulence intensity, mean (at 34 m)	0.133 (at 15 m/s)
Calm wind frequency (at 34 m)	28% (< 4 m/s) (16 mo. measurement period)

Test Site Location

A 34 meter NRG Systems, Inc. tubular-type meteorological (met) tower was installed in Napaskiak in an open area of corporation land located south of the village and east of the airport runway. Napaskiak is located on the east bank of the Kuskokwim River along the Napaskiak Slough, about seven miles southeast of Bethel. It is a traditional Yup'ik Eskimo village, population of 434 people (2012 Alaska Dept. of Labor estimate), largely dependent on fishing and subsistence activities (Alaska DCED website). Napaskiak is strongly influenced by storms and patterns in the Bering Sea and also by inland continental weather. Average annual precipitation is 16 inches, with 50 inches of snowfall.



AWS Truepower wind power class overlay; Google Earth image



Site information

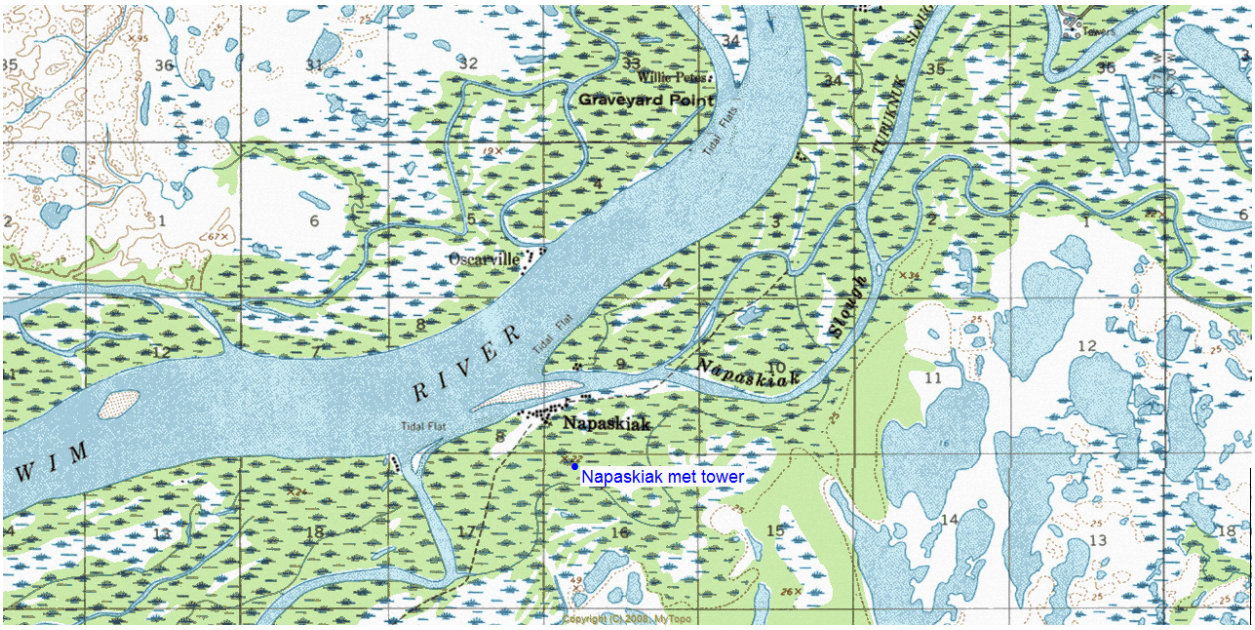
Site number	1101
Latitude/longitude	N 60° 42.157’ W 161° 45.649’
Time offset	-9 hours from GMT (Yukon/Alaska time zone)
Site elevation	1 meter (3 ft.)
Datalogger type	NRG Symphonie, 10 minute averaging time step
Tower type	Tubular tall tower, 6-inch diameter, 34 meter height

Tower sensor information

Channel	Sensor type	SN	Height	Multiplier	Offset	Orientation
1	NRG #40C anemometer	87878	34.1 m	0.757	0.38	338 T
2	NRG #40C anemometer	87863	34.1 m	0.757	0.37	158 T
3	NRG #40C anemometer	88311	18.2 m	0.758	0.34	338 T
7	NRG #200P wind vane		34 m	0.351	047	047 T
9	NRG #110S Temp C		4 m	0.136	-86.383	Not avail.

Google Earth image, Napaskiak

Topographic map



Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data and non-variant wind direction data. Data that met criteria listed below were automatically filtered. In addition, data was manually filtered for obvious icing that the automatic filter didn't catch, and invalid or low quality data for situations such as logger initialization and other situations.

- Anemometer icing – data filtered if temperature < 1°C, speed SD = 0, and speed changes < 0.25 m/s for minimum 2 hours
- Vane icing – data filtered if temperature < 1°C and vane SD = 0 for minimum of 2 hours
- Tower shading of 34 meter A and B paired anemometers – refer to graphic below

Note that all data was lost for the period February 3 to March 5, 2012 due to a misplaced data card. Missing data, due to the lost data card and from icing loss, was synthesized with a Windographer software gap filling utility. This smooths the data somewhat and results in a more realistic and likely representation of actual wind speed during the time periods of missing data.

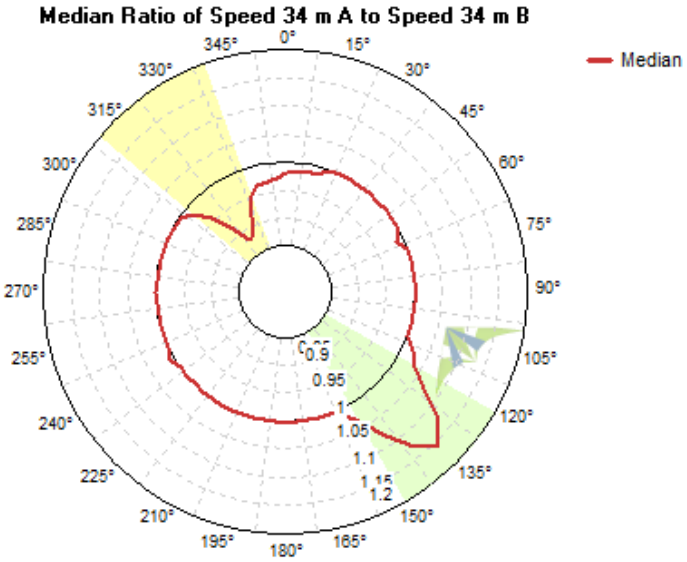
Sensor data recovery table

Data Column	Possible Records	Valid Records	Recovery Rate (%)	Unflagged data	Icing	Invalid	Tower shading
Speed 34 m A	69,894	56,415	80.7%	56,415	3,534	13	6,375
Speed 34 m B	69,894	59,627	85.3%	59,627	2,726	8	3,112
Speed 20 m	69,894	63,173	90.4%	63,173	2,273	14	0
Direction 34 m	69,894	60,064	85.9%	60,064	5,329	67	0
Temperature	69,894	65,449	93.6%	65,449	0	11	0

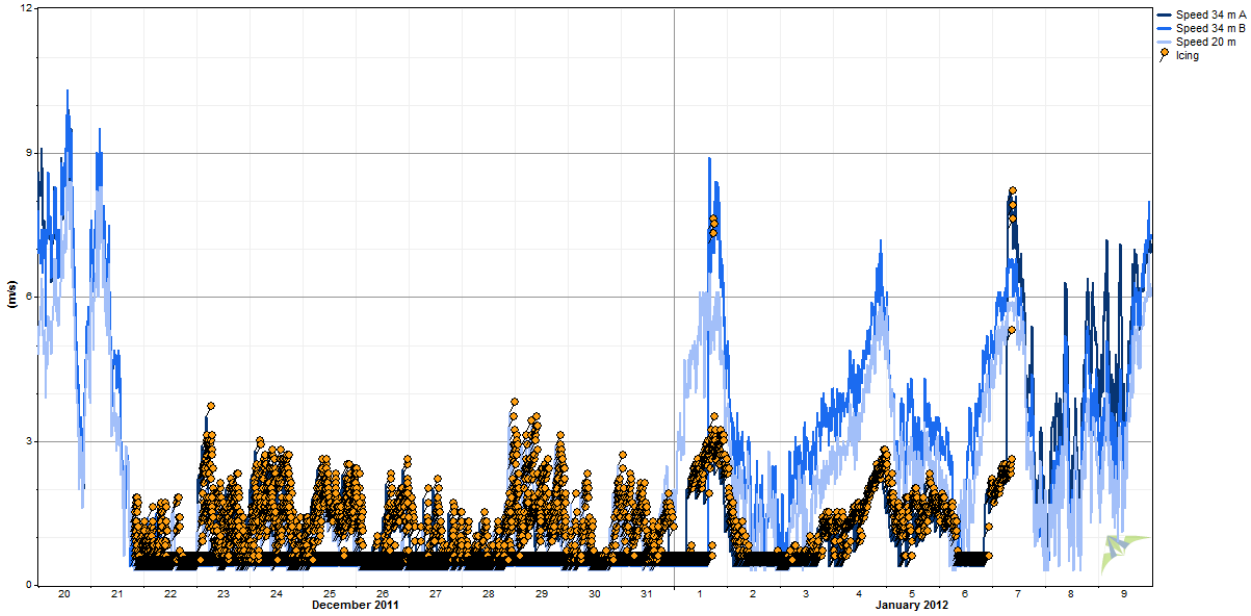
Sensor data recovery rate by month

		Sensors				
Year	Month	34 m A	34 m B	20 m	Vane	Temp
2011	Dec	63.1	56.4	64.7	88.0	100.0
2012	Jan	73.6	97.3	99.3	97.1	100.0
2012	Feb	8.0	8.9	8.9	8.9	8.9
2012	Mar	73.9	81.2	84.7	44.9	85.9
2012	Apr	89.9	95.1	100.0	100.0	100.0
2012	May	85.6	97.7	100.0	99.5	100.0
2012	Jun	89.3	96.7	100.0	100.0	100.0
2012	Jul	93.7	92.5	100.0	100.0	100.0
2012	Aug	98.2	91.7	100.0	100.0	99.8
2012	Sep	88.1	90.7	100.0	100.0	100.0
2012	Oct	82.4	92.4	100.0	97.1	100.0
2012	Nov	82.0	89.5	89.3	89.2	100.0
2012	Dec	90.4	95.7	100.0	92.1	100.0
2013	Jan	93.0	89.7	96.6	69.7	100.0
2013	Feb	86.8	94.9	99.7	93.7	100.0
2013	Mar	87.9	88.4	96.7	91.6	100.0
2013	Apr	97.5	95.5	100.0	100.0	100.0
All data		81.4	85.5	90.6	86.6	93.8

Tower shading filter plot



Icing Data Loss, December 2011



Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a relatively fair wind resource. Note that cold temperatures contributed to a higher wind power density than standard conditions would yield for the measured mean wind speeds.

Anemometer data summary (filtered data)

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Measurement height (m)	34.1	34.1	18.2
Mean wind speed (m/s)	5.71	5.65	4.65
MoMM wind speed (m/s)	5.66	5.62	4.64
Median wind speed (m/s)	5.50	5.40	4.40
Max 10-min avg wind speed (m/s)	28.4	28.6	22.8
Max gust wind speed (m/s)	36.7	37.1	34.1
Weibull k	2.16	2.11	2.06
Weibull c (m/s)	6.43	6.35	5.24
Mean power density (W/m²)	207	213	120
MoMM power density (W/m²)	201	208	118
Mean energy content (kWh/m²/yr)	1,811	1,862	1,055
MoMM energy content (kWh/m²/yr)	1,764	1,820	1,037
Energy pattern factor	1.773	1.791	1.832
Frequency of calms (%) (< 4 m/s)	29.2	30.5	44.6

MoMM = mean of monthly means

Anemometer data summary (with filtered and gap-filled data)

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Mean wind speed (m/s)	5.65	5.60	4.61
MoMM wind speed (m/s)	5.63	5.60	4.61
Weibull k	2.13	2.09	2.05
Weibull c (m/s)	6.37	6.30	5.19
Mean power density (W/m²)	204	209	119
MoMM power density (W/m²)	200	206	117
Mean energy content (kWh/m²/yr)	1,784	1,832	1,038
MoMM energy content (kWh/m²/yr)	1,752	1,803	1,023

MoMM = mean of monthly means

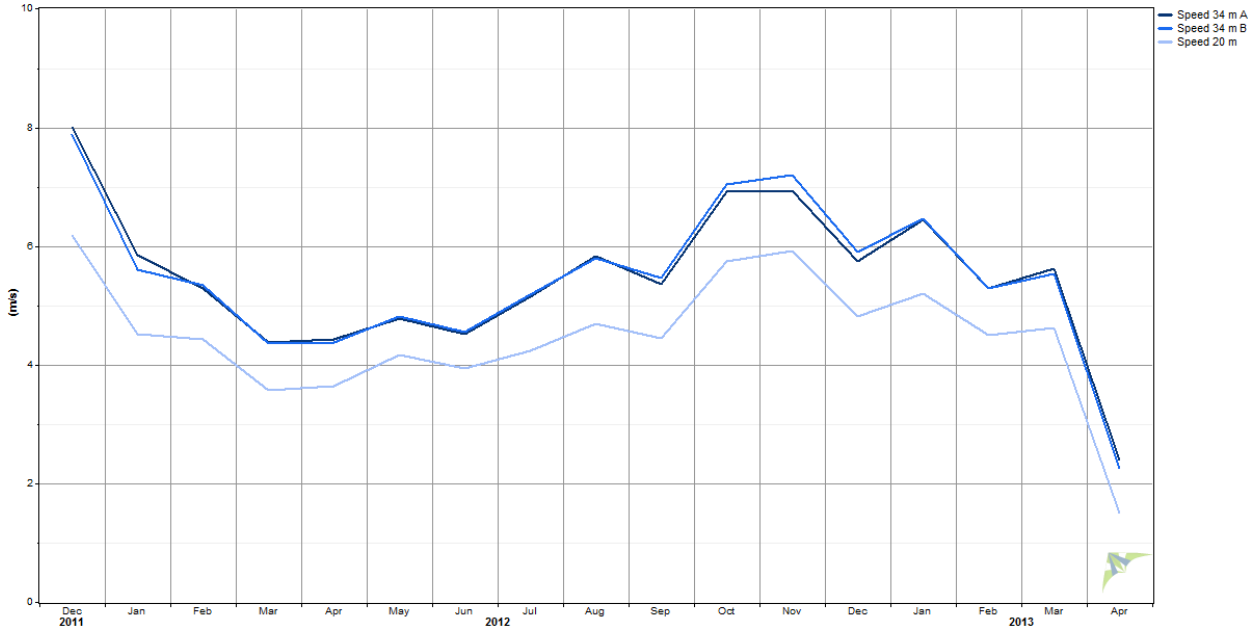
Time Series

Time series calculations indicate higher wind speeds during the winter months compared to the summer months. This correlates well with Napaskiak's load profile where there is high demand for electricity and heat during winter months and lower energy demand during summer. The daily wind profile (annual basis) indicates relatively even wind speeds throughout the day with slightly higher wind speeds during night hours.

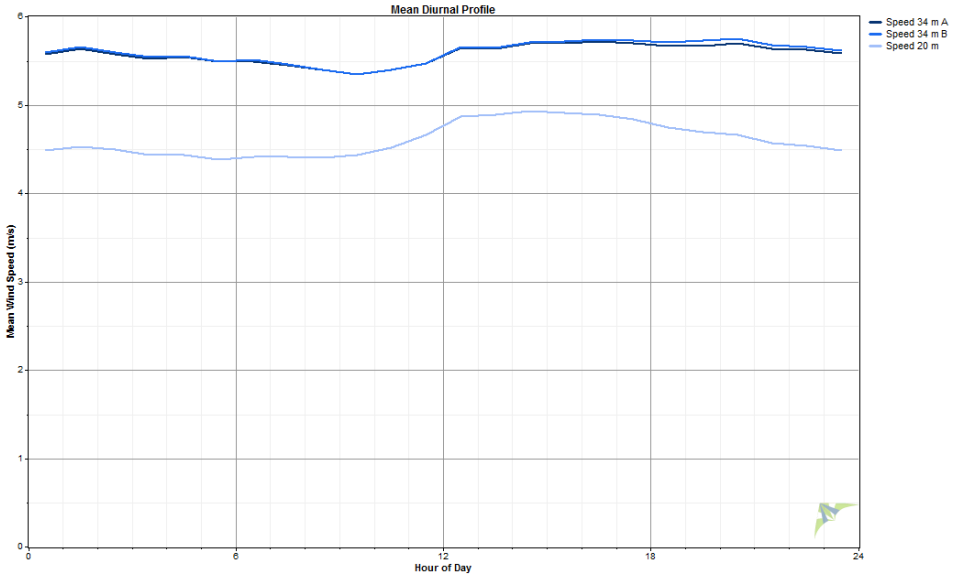
34 m A anemometer data summary

Year	Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
2011	Dec	8.03	28.4	36.7	3.30	1.52	8.37
2012	Jan	6.05	13.4	19.3	2.90	2.19	6.81
2012	Feb	5.30	15.5	21.9	2.84	1.94	5.97
2012	Mar	4.38	13.5	17.8	2.46	1.82	4.92
2012	Apr	4.50	17.2	21.6	2.34	1.99	5.06
2012	May	4.88	10.6	14.4	1.82	2.90	5.47
2012	Jun	4.57	11.8	15.5	1.72	2.84	5.13
2012	Jul	5.25	15.9	21.9	2.44	2.26	5.92
2012	Aug	5.91	16.1	22.4	3.18	1.94	6.66
2012	Sep	5.30	14.3	19.7	2.49	2.24	5.97
2012	Oct	6.85	16.5	24.6	2.99	2.40	7.70
2012	Nov	7.04	14.2	20.4	2.47	3.12	7.88
2012	Dec	5.92	14.7	20.0	2.65	2.33	6.65
2013	Jan	6.49	15.5	19.7	2.52	2.79	7.29
2013	Feb	5.35	14.3	18.6	2.49	2.24	6.02
2013	Mar	5.72	16.3	20.4	2.70	2.20	6.43
2013	Apr	2.41	6.0	6.4	1.46	1.61	2.67
All Data		5.63	28.4	36.7	2.76	2.13	6.37

Monthly time series, mean wind speeds (gap-filled)



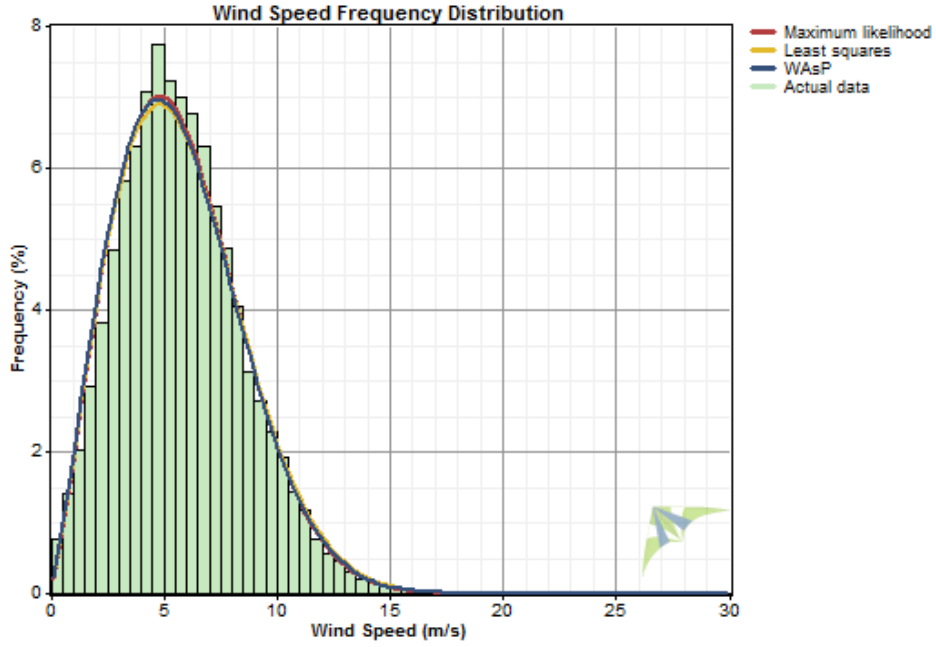
Daily wind profile (annual)



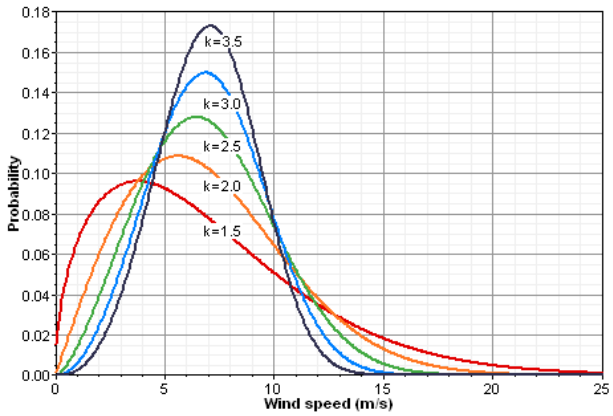
Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Napaskiak met tower site wind speed indicates a shape curve dominated by moderate wind speeds and is reflective of 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. As seen below in the wind speed distribution of the 34 meter A anemometer, the most frequently occurring wind speeds are between 3 and 7 m/s with very few wind events exceeding 18 m/s (note that the cutout speed of most wind turbines is 25 m/s; see following wind speed statistical table).

PDF of 34 m A anemometer (all data)



Weibull k shape curve table



Weibull values table, 34m A anemometer

Algorithm	Weibull k (-)	Weibull c (m/s)	Mean (m/s)	Proportion Above 5.706 m/s	Power Density (W/m2)	R Squared (-)
Maximum likelihood	2.157	6.431	5.695	0.462	201	0.9938
Least squares	2.122	6.473	5.733	0.465	208	0.9922
WAsP	2.124	6.408	5.675	0.458	202	0.9923
Actual data			5.706	0.458	202	

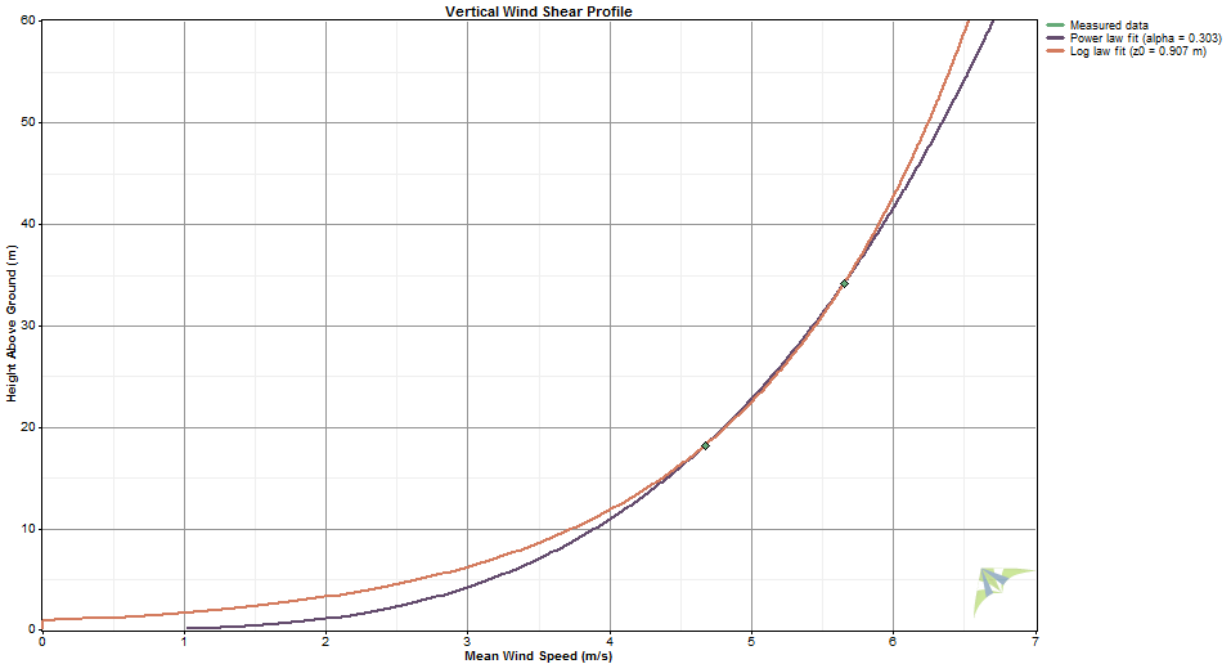
Occurrence by wind speed bin (34 m A anemometer)

Bin Endpoints (m/s)		Occurrences		Cumulat.	Bin Endpoints (m/s)		Occurrences		Cumulat.
Lower	Upper	No.	Percent	Percent	Lower	Upper	No.	Percent	Percent
0	1	1,480	2.43%	2.43%	15	16	85	0.14%	99.89%
1	2	3,145	5.17%	7.60%	16	17	19	0.03%	99.92%
2	3	5,447	8.95%	16.55%	17	18	9	0.01%	99.93%
3	4	7,381	12.13%	28.68%	18	19	6	0.01%	99.94%
4	5	9,059	14.89%	43.57%	19	20	5	0.01%	99.95%
5	6	8,549	14.05%	57.62%	20	21	8	0.01%	99.97%
6	7	7,910	13.00%	70.62%	21	22	6	0.01%	99.98%
7	8	6,273	10.31%	80.93%	22	23	3	0.00%	99.98%
8	9	4,261	7.00%	87.93%	23	24	1	0.00%	99.98%
9	10	2,968	4.88%	92.81%	24	25	3	0.00%	99.99%
10	11	2,010	3.30%	96.11%	25	26	0	0.00%	99.99%
11	12	1,141	1.88%	97.99%	26	27	2	0.00%	99.99%
12	13	592	0.97%	98.96%	27	28	5	0.01%	100.00%
13	14	297	0.49%	99.45%	28	29	1	0.00%	100.00%
14	15	183	0.30%	99.75%	29	30	0	0.00%	100.00%

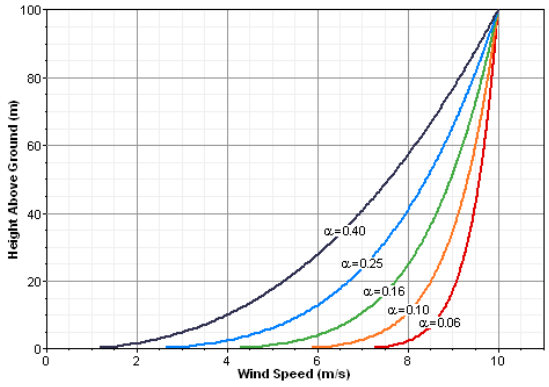
Wind Shear and Roughness

Wind shear at the Napaskiak met tower site was calculated with the 34 m A and 20 m anemometers, both of which are oriented toward 338° T. The calculated power law exponent of 0.303 indicates a very high wind shear at the site. Calculated surface roughness at the site is 0.86 m (the height above ground where wind speed would be zero) for a roughness class of 3.79 (description: forest). Although the area surrounding the met tower is not covered by very tall trees, they are high and dense enough to result in significant roughness and wind shear. Given the high power law exponent, extrapolation of wind speed above 34 meters should be done with caution and the shear likely decreases with elevation above ground level.

Vertical wind shear profile



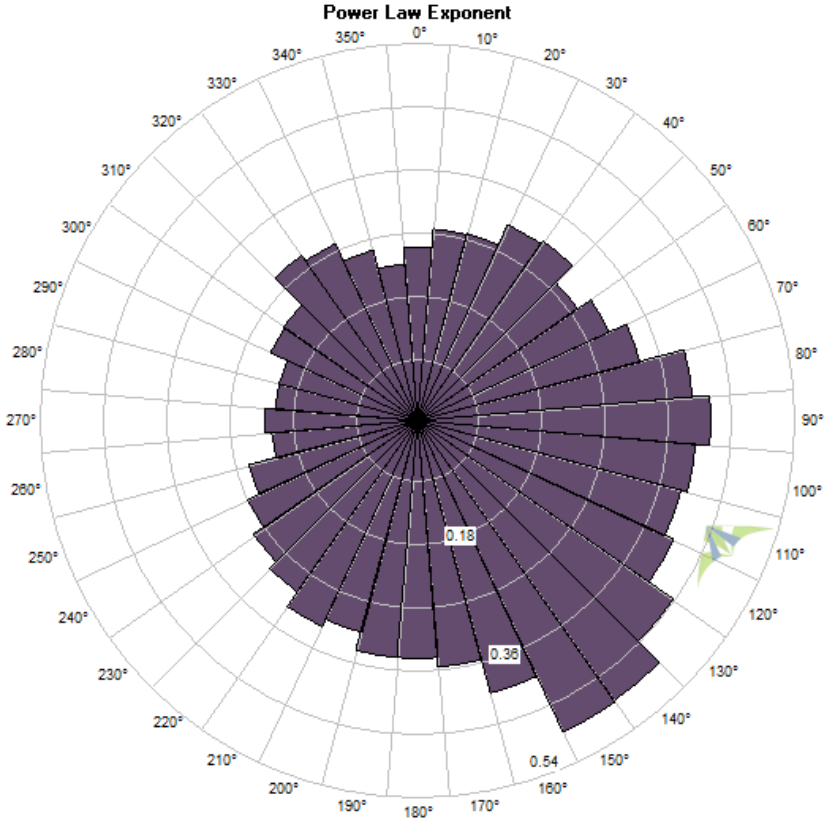
Comparative wind shear profiles



Wind shear by direction sector table

Direction Sector	Time Steps	Mean Wind Speed (m/s) Speed 34 m A	Speed 20 m	Best-fit Power Law Exponent	Surface Roughness (m)
345° - 015°	11,466	6.02	5.14	0.252	0.465
015° - 045°	7,766	6.05	5.03	0.295	0.833
045° - 075°	5,788	5.99	4.96	0.300	0.877
075° - 105°	2,575	5.18	4.01	0.406	2.097
105° - 135°	2,072	4.94	3.80	0.419	2.261
135° - 165°	4,727	7.03	5.28	0.456	2.743
165° - 195°	5,399	6.15	4.95	0.347	1.378
195° - 225°	3,116	5.05	4.14	0.316	1.045
225° - 255°	2,286	4.46	3.77	0.268	0.590
255° - 285°	4,044	4.60	4.03	0.212	0.220
285° - 315°	5,813	5.21	4.53	0.224	0.287
315° - 345°	1,628	5.07	4.30	0.263	0.550

Wind shear by direction sector graph



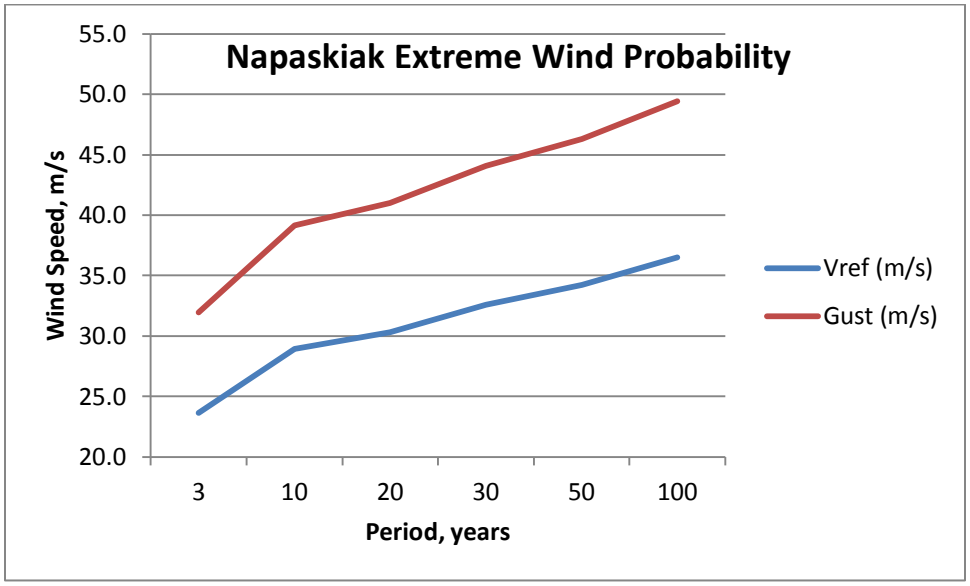
Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Napaskiak met tower site. Sixteen months of data though are minimal at best and hence results should be viewed with considerable 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 34.2 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 indicates moderate winds and that turbines installed at this location can be IEC3 Class III rated. It would be highly beneficial, however, to obtain more met tower data before making a final determination of IEC extreme wind classification.

Site extreme wind probability table, 34 m data

	V_{ref}	Gust	IEC 61400-1, 3rd ed.	
Period (years)	(m/s)	(m/s)	Class	V_{ref}, m/s
3	23.6	32.0	I	50.0
10	29.0	39.2	II	42.5
20	30.3	41.0	III	37.5
30	32.6	44.1	S	designer-specified
50	34.2	46.3		
100	36.5	49.4		
average gust factor:	1.35			

Extreme wind graph, by annual method



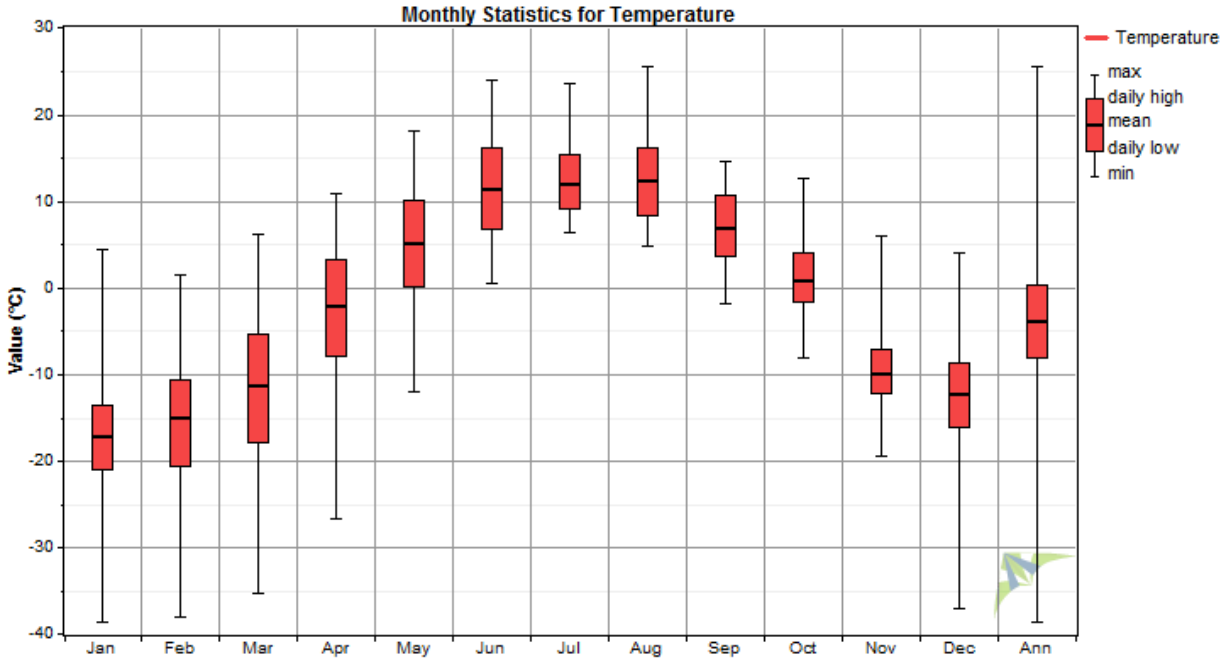
Temperature, Density, and Relative Humidity

The Napaskiak met tower site experiences cool summers and cold 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 1.225 kg/m^3 standard air density for a sea level elevation by 5.8 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 (°C)			Temperature (°F)			Air Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-17.2	-38.6	4.3	1.0	-37.5	39.7	1.382	1.272	1.504
Feb	-15.0	-38.0	1.4	5.0	-36.4	34.5	1.302	1.225	1.501
Mar	-11.3	-35.4	6.2	11.6	-31.7	43.2	1.341	1.225	1.484
Apr	-2.0	-26.7	10.9	28.3	-16.1	51.6	1.302	1.242	1.432
May	5.1	-12.0	18.0	41.2	10.4	64.4	1.269	1.212	1.351
Jun	11.4	0.5	23.9	52.5	32.9	75.0	1.240	1.188	1.290
Jul	12.0	6.3	23.6	53.6	43.3	74.5	1.238	1.189	1.263
Aug	12.3	4.8	25.6	54.2	40.6	78.1	1.236	1.181	1.270
Sep	7.0	-1.8	14.6	44.5	28.8	58.3	1.260	1.226	1.300
Oct	0.9	-8.2	12.6	33.7	17.2	54.7	1.288	1.235	1.332
Nov	-9.9	-19.5	5.9	14.3	-3.1	42.6	1.341	1.265	1.391
Dec	-12.3	-37.1	4.0	9.8	-34.8	39.2	1.355	1.273	1.495
Annual	-1.5	-38.6	25.6	29.3	-37.5	78.1	1.296	1.181	1.504

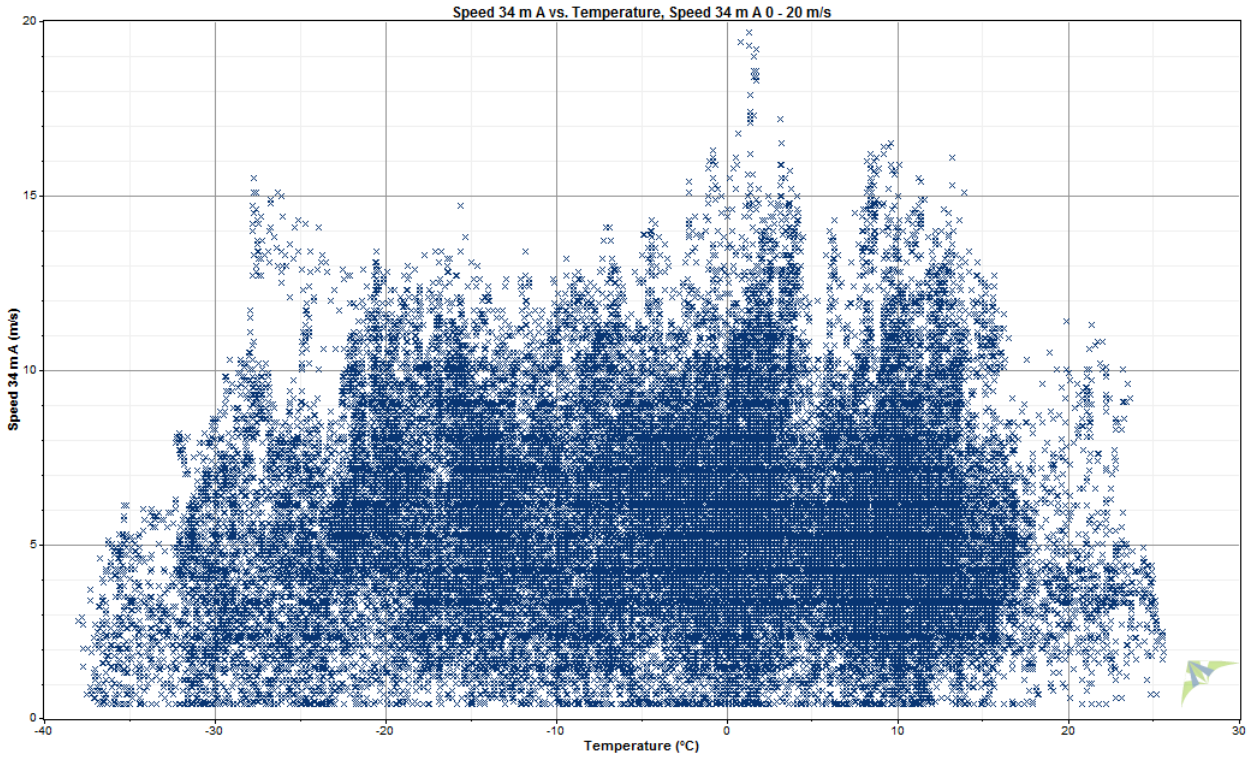
Napaskiak temperature boxplot graph



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates cold temperatures at the Napaskiak met tower site with a preponderance of below freezing temperatures. During the met tower test period, temperatures were often below -20° C (-4° F), the minimum operating temperature for most standard-environment wind turbines. Note that arctic-capable (operational rating to -40°C) wind turbines would be required at Napaskiak, but that extreme cold temperatures, although not infrequent, are associated with generally calm wind conditions.

Wind speed/temperature

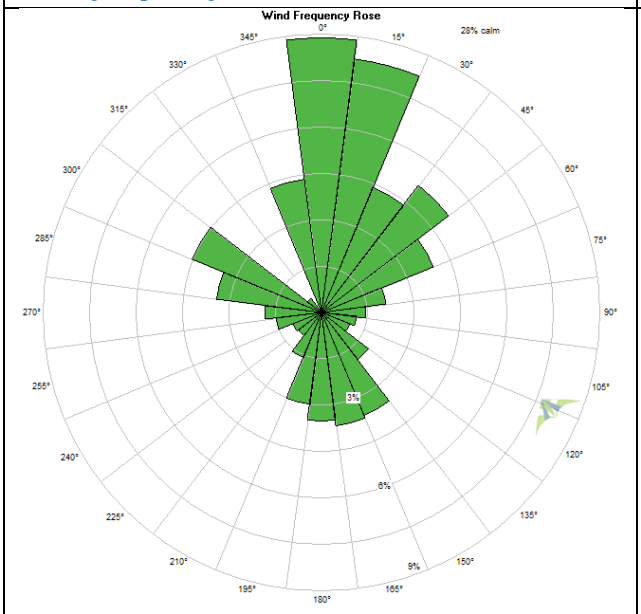


Wind Direction

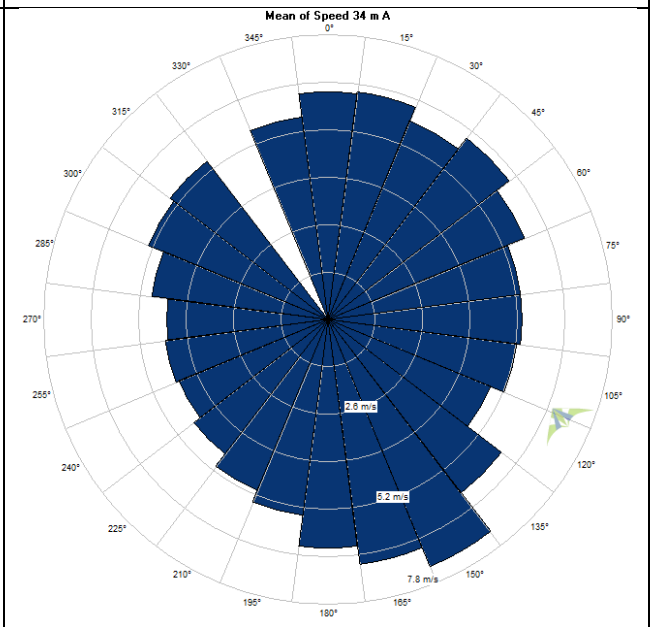
Wind frequency rose data indicates that winds at the Napaskiak met tower site are primarily bi-directional, with northerly and southerly winds predominating. The mean value rose indicates that east-southerly winds are of higher intensity than northerly winds, but with more frequent northerly winds, the energy winds are mostly balanced between northerly and southerly.

Calm frequency (the percent of time that winds at the 34 meter level are less than 4 m/s, a typical cut-in speed of larger wind turbines) was 28 percent during the 16 month test period.

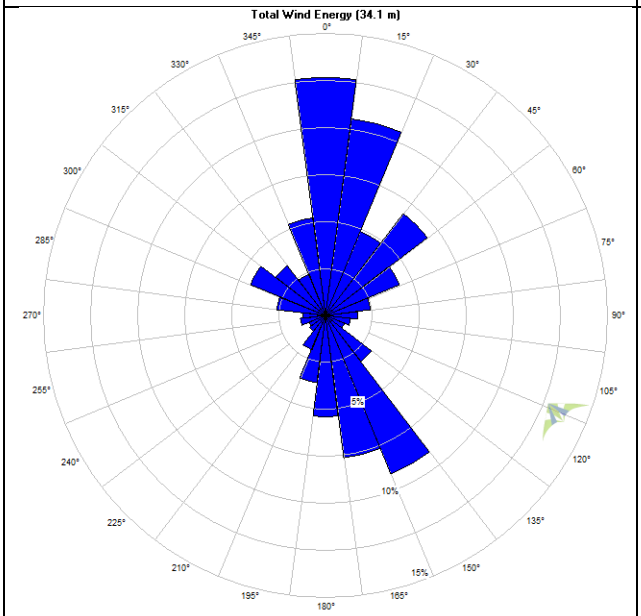
Wind frequency rose



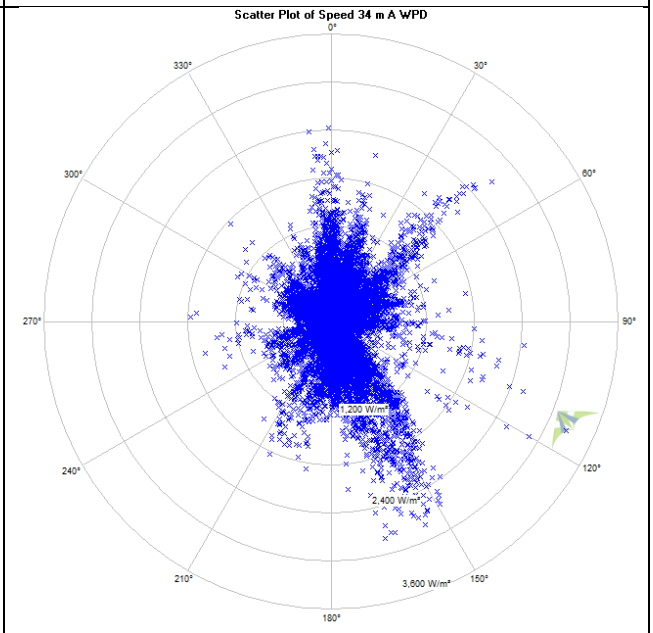
Mean value rose



Wind energy rose



Scatterplot rose of wind power density



Turbulence

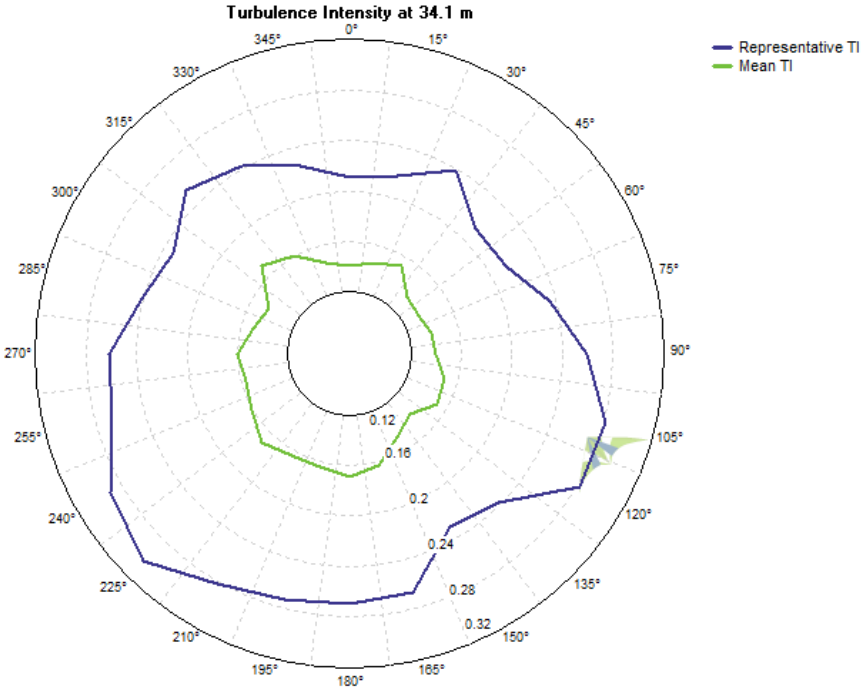
The turbulence intensity (TI) calculated from the 34 m A anemometer at the Napaskiak met tower site is relatively high with a mean turbulence intensity of 0.133 and a representative turbulence intensity of 0.161 at 15 m/s wind speed, indicating fairly rough air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category B, which is the middle defined category.

Note however that data from the 34 m B anemometer indicates IEC 61400-1 Category A turbulence, which is the highest defined category. Data from the 20 m anemometer is more turbulent yet, at IEC 61400-1 Category S, or special conditions. The fairly high turbulence at the Napaskiak met tower is due to the surrounding trees and brush with resultant high roughness. Smoother air would be found at higher elevation above ground level as the effect of surface roughness diminishes with height.

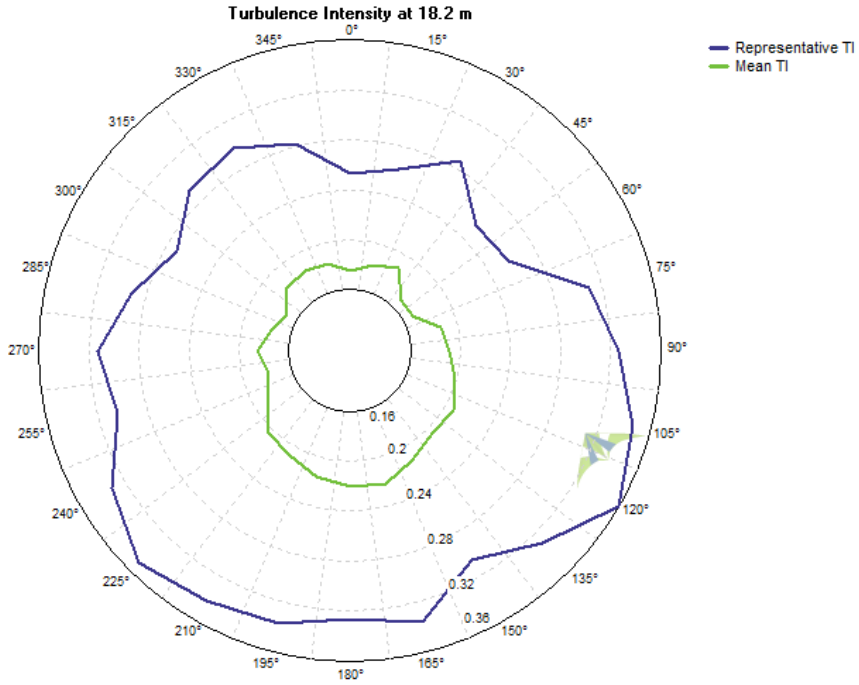
Turbulence synopsis

	34 m A anem.			34 m B 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	0.133	0.161	B	0.140	0.164	A	S	>0.16
315° to 045°	0.147	0.165	A	0.147	0.166	A	A	0.14-0.16
045° to 135°	0.138	0.181	B	0.138	0.165	B	B	0.12-0.14
135° to 225°	0.130	0.155	B	0.137	0.162	B	C	0-0.12
225° to 315°	-	-	-	-	-	-		

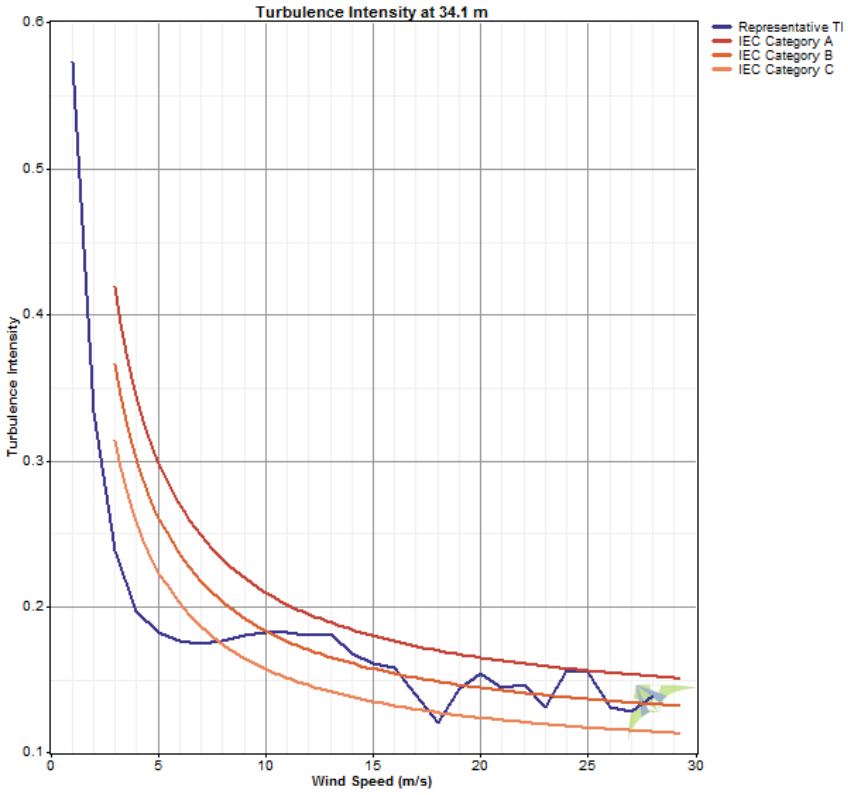
Turbulence rose, 34m A anemometer



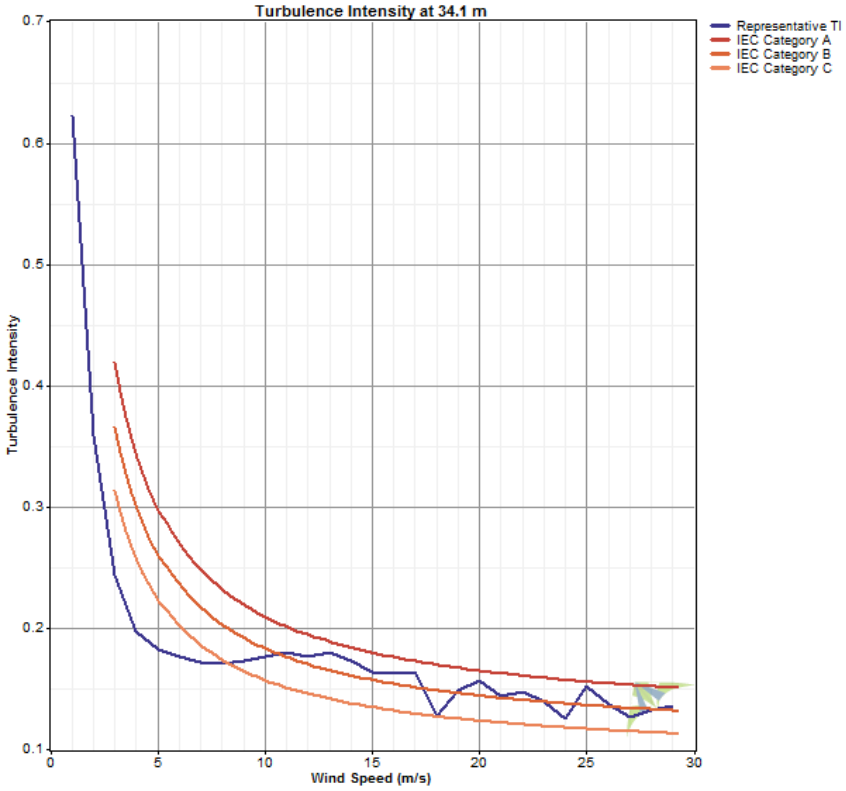
Turbulence rose, 20m anemometer



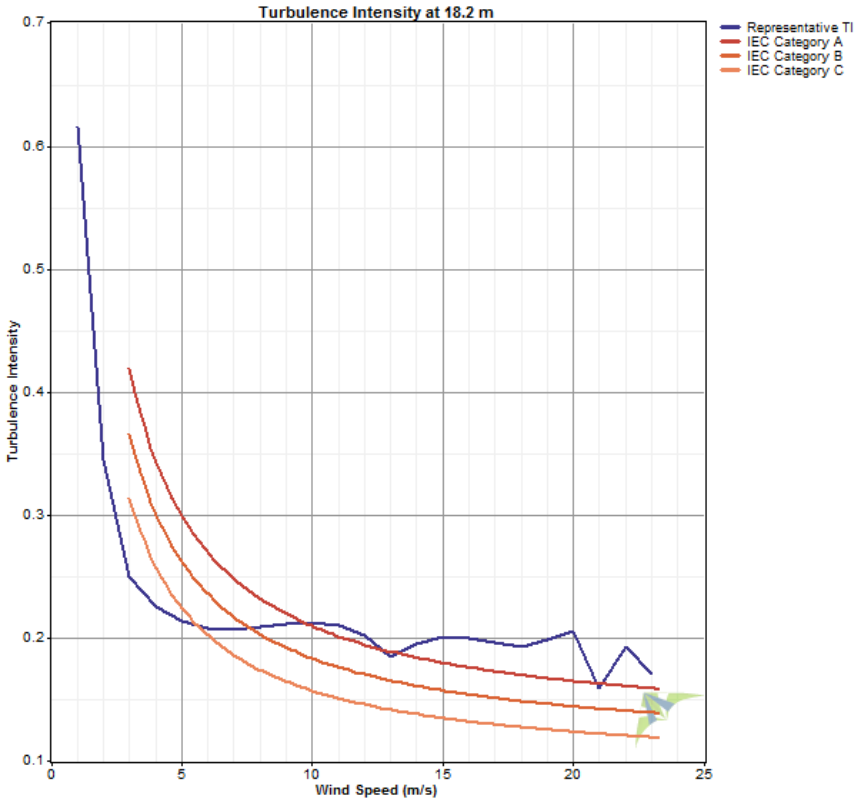
Turbulence intensity, 34 m A, all direction sectors



Turbulence intensity, 34 m B, all direction sectors



Turbulence intensity, 20 m, all direction sectors



Turbulence table, 34 m A data, all sectors

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	0.5	1.5	1,937	0.382	0.149	0.573	1.111
2	1.5	2.5	3,801	0.208	0.097	0.333	0.867
3	2.5	3.5	6,014	0.153	0.066	0.238	0.759
4	3.5	4.5	7,551	0.132	0.051	0.197	0.718
5	4.5	5.5	8,438	0.126	0.044	0.182	0.609
6	5.5	6.5	7,775	0.130	0.036	0.176	0.435
7	6.5	7.5	6,641	0.134	0.032	0.175	0.319
8	7.5	8.5	5,042	0.138	0.030	0.177	0.363
9	8.5	9.5	3,298	0.144	0.028	0.180	0.261
10	9.5	10.5	2,375	0.147	0.027	0.182	0.238
11	10.5	11.5	1,486	0.147	0.028	0.183	0.243
12	11.5	12.5	762	0.145	0.027	0.180	0.237
13	12.5	13.5	431	0.143	0.030	0.181	0.232
14	13.5	14.5	224	0.137	0.024	0.168	0.201
15	14.5	15.5	114	0.133	0.022	0.161	0.190
16	15.5	16.5	45	0.131	0.021	0.158	0.182
17	16.5	17.5	11	0.115	0.020	0.140	0.167
18	17.5	18.5	5	0.108	0.010	0.121	0.120
19	18.5	19.5	6	0.119	0.019	0.143	0.150
20	19.5	20.5	8	0.134	0.016	0.154	0.160
21	20.5	21.5	6	0.126	0.014	0.144	0.146
22	21.5	22.5	3	0.132	0.011	0.146	0.144
23	22.5	23.5	1	0.131	0.000	0.131	0.131
24	23.5	24.5	2	0.137	0.015	0.156	0.148
25	24.5	25.5	2	0.133	0.017	0.155	0.145
26	25.5	26.5	1	0.131	0.000	0.131	0.131
27	26.5	27.5	1	0.128	0.000	0.128	0.128
28	27.5	28.5	6	0.126	0.010	0.139	0.137
29	28.5	29.5	0				