Anaktuvuk Pass Wind Resource Report

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Anaktuvuk Pass met tower; D. Vaught photo

Contents

Summary

The wind resource measured in Anaktuvuk Pass is somewhat low by most standards of wind power development with projected wind power class 2 (marginal). But, the viability of wind power in a remote community is primarily dependent on the cost of fuel for electricity generation. Given the very high cost of diesel fuel in Anaktuvuk Pass, the economics of wind development may well be favorable.

Met tower data synopsis

Data dates	June 28, 2009 to July 21, 2010 (13 months)
Wind power class	Class 2 (marginal)
Power density mean, 30 m	170 W/m^2
Wind speed mean, 30 m	5.15 m/s
Max. 10-min wind speed average	18.8 m/s
Maximum wind gust	20.8 m/s (Aug. 2009)
Weibull distribution parameters	k = 1.88, c = 5.78 m/s
Temperature average	-7.1° C, *to date*
Wind shear power law exponent	0.163 (moderate)
Roughness class	0.47 (snow surface)
Turbulence intensity, mean	0.050 (at 15 m/s)
IEC3 turbulence category	C (lowest)
Calm wind frequency	36% (<3.5 m/s)

Community profile

Current Population:	287 (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

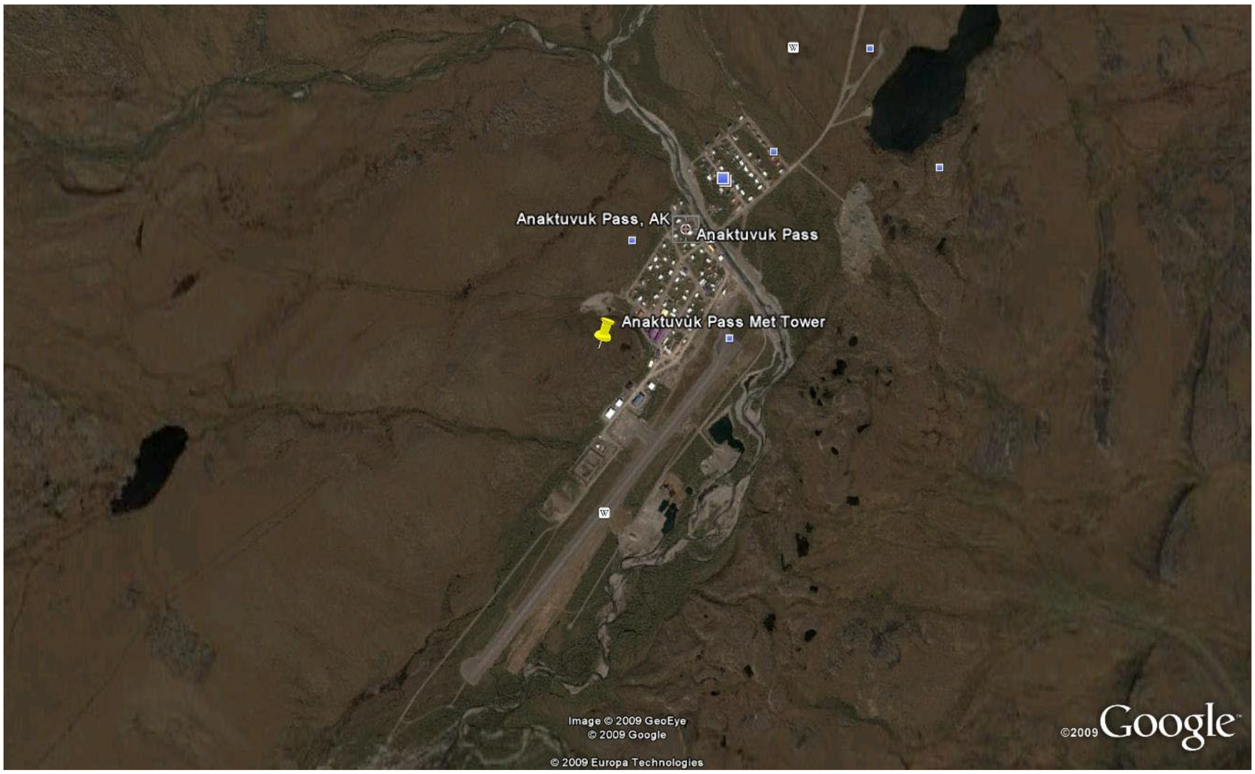
Test Site Location

Met tower was installed on a prominent hill above the power plant and behind (southwest) of the school. Given the geographic constraints of the valley and location and orientation of the airport, this site is the only viable location for wind power development. It has the considerable advantage of very close proximity to the power plant and very good exposure to winds from all directions.

Site Information

Site number	0225
Site description	Southwest edge of village; west of airport runway
Latitude/longitude	N 68° 08.353' W 151° 44.631', WGS 84
Site elevation	668 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)	0.756	0.42	179° T
2	NRG #40 anemometer	30 m (B)	0.756	0.38	272° T
3	NRG #40 anemometer	20 m	0.759	0.34	272° T
7	NRG #200P wind vane	29 m	0.351	358	358° 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

Top of tower and obstruction balls; D. Vaught photo

Datalogger weather box and PV panel; D. Vaught photo

View from site southeast to powerplant; D. Vaught photo

View from site northeast to village; D. Vaught photo

Data recovery

Data recovery of the Anaktuvuk Pass met tower was generally good, except for three long periods of data loss: 10/27 thru 11/5, 12/10 thru 12/18, and 2/21 thru 3/7. In all three circumstances, the cause appears to be icing conditions. During the first data loss event, however, the anemometers were non-functional yet the wine vane returned data and the RH sensor indicated lower than expected humidity for an icing event. For the other two data loss events, loss of wind vane data appears to confirm icing, but a non-functional RH sensor (due to voltage drawdown of the iPack battery from lack of sunlight) does not allow confirmation of the high humidity typical of rime icing conditions. Given the very cold temperatures during the three data loss periods and the location of Anaktuvuk Pass well away from the coast, the icing losses are undoubtedly due to hoarfrost conditions and not rime icing.

Data recovery summary table

Label	Units	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 A	m/s	55844	50,554	90.5
Speed 30 B	m/s	55844	50,641	90.7
Speed 20	m/s	55844	50,897	91.1
Direction 29	°	55844	51,924	93.0
Temperature	°C	55844	55,716	99.8
RH-5 Humidity %RH	%	55844	39,642	71.0
iPack Voltmeter	volts	55844	55,844	100.0

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	362	358	98.9	358	98.9	358	98.9
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	4,269	98.8	4,320	100.0	4,320	100.0
2009	Oct	4,464	3,404	76.3	3,404	76.3	3,404	76.3
2009	Nov	4,320	3,716	86.0	3,716	86.0	3,716	86.0
2009	Dec	4,464	3,050	68.3	3,050	68.3	3,305	74.0
2010	Jan	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2010	Feb	4,032	2,951	73.2	2,987	74.1	2,988	74.1
2010	Mar	4,464	3,508	78.6	3,508	78.6	3,508	78.6
2010	Apr	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2010	May	4,464	4,464	100.0	4,464	100.0	4,464	100.0
2010	Jun	4,320	4,320	100.0	4,320	100.0	4,320	100.0
2010	Jul	2,922	2,802	95.9	2,802	95.9	2,802	95.9
All data		55,844	50,554	90.5	50,641	90.7	50,897	91.1

Wind Speed

Wind data collected from the met tower, from the perspective of both mean wind speed and mean power density, indicates a rather low wind resource. The discrepancy in mean wind speed between the 30 m A and the 30 m B anemometer is due to the placement of the of the 30 m A anemometer at 179° True. With frequent NNE winds, the 30 m A anemometer experienced some tower shadowing effects.

Note that it can be problematic analyzing wind data with concentrated data loss, such as occurred in Anaktuvuk Pass during a few of the winter months. 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.

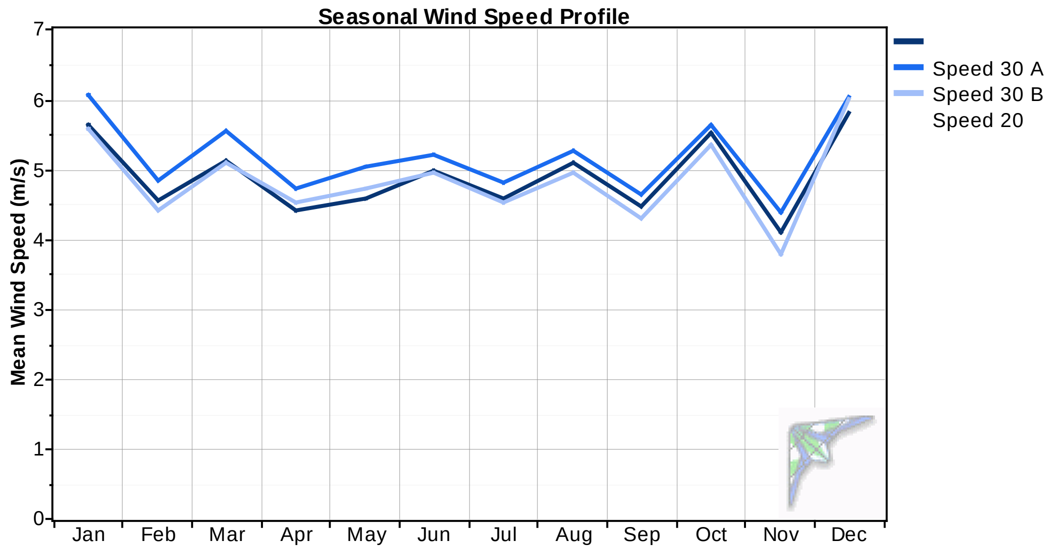
Anemometer summary

Variable	Original data set Speed 30 A	Speed 30 B	Speed 20	Synthesized data set Speed 30 A	Speed 30 B	Speed 20
Measurement height (m)	30	30	20	30	30	20
Mean wind speed (m/s)	4.91	5.19	4.86	4.94	5.20	4.85
Max 10-min avg wind speed (m/s)	18.5	18.8	18.9			
Max gust wind speed (m/s)	20.4	20.8	21.2			
Weibull k	1.78	1.88	1.80	1.76	1.85	1.80
Weibull c (m/s)	5.47	5.78	5.40	5.53	5.82	5.42
Mean power density (W/m²)	156	172	149	163	178	149
Mean energy content (kWh/m²/yr)	1,368	1,507	1,309	1,432	1,558	1,303
Energy pattern factor	2.13	1.99	2.09	2.19	2.05	2.11
Frequency of calms (%)	36.1	30.5	34.6	35.5	30.5	34.5
1-hr autocorrelation coefficient	0.863	0.861	0.857	0.860	0.858	0.854
Diurnal pattern strength	0.168	0.155	0.166	0.151	0.140	0.155
Hour of peak wind speed	16	16	16	16	16	16

30m B 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	4.70	10.0	12.8	4.71	2.53	1.86	5.27
2009	Jul	4.51	13.3	18.9	4.51	2.61	1.74	5.05
2009	Aug	5.25	15.5	20.8	5.25	2.51	2.17	5.91
2009	Sep	4.63	12.0	15.5	4.63	2.40	1.95	5.19
2009	Oct	5.63	15.2	17.4	5.41	2.84	1.97	6.09
2009	Nov	4.39	14.2	18.1	4.26	2.81	1.57	4.76
2009	Dec	6.04	18.8	20.0	6.68	3.95	1.74	7.49
2010	Jan	6.07	15.1	18.9	6.07	2.85	2.25	6.86
2010	Feb	4.85	14.1	17.4	4.95	2.56	1.99	5.57
2010	Mar	5.55	16.3	17.4	5.24	2.62	2.08	5.90
2010	Apr	4.73	15.0	20.4	4.73	2.91	1.65	5.28
2010	May	5.03	14.0	17.4	5.03	2.67	1.94	5.65
2010	Jun	5.25	14.1	17.4	5.25	2.69	1.99	5.90
2010	Jul	5.31	12.6	15.9	5.29	2.59	2.11	5.95
Annual		5.19	18.8	20.8	5.20	2.87	1.85	5.82

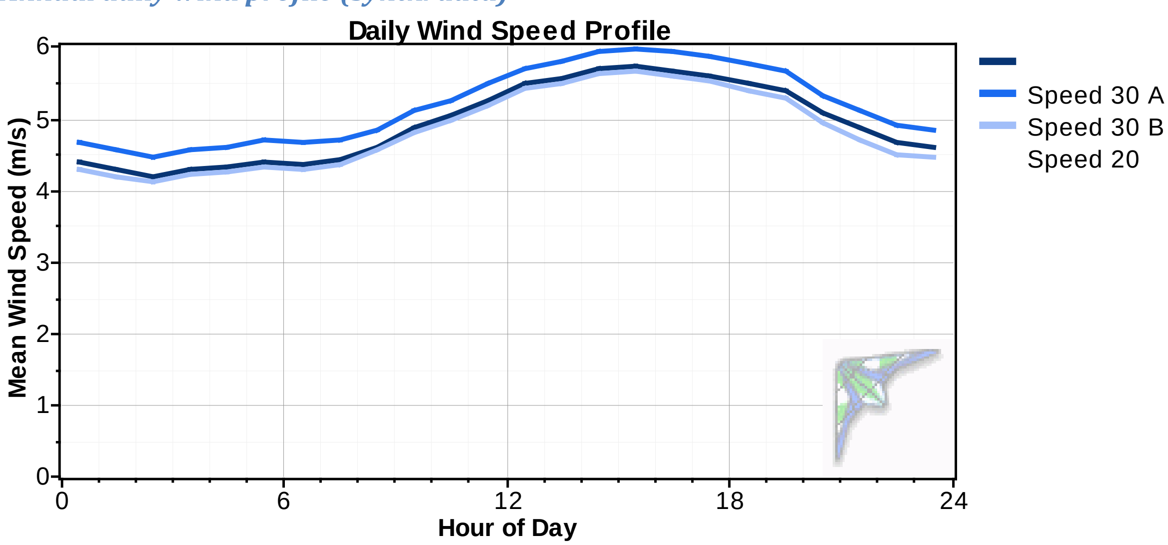
Time series graph



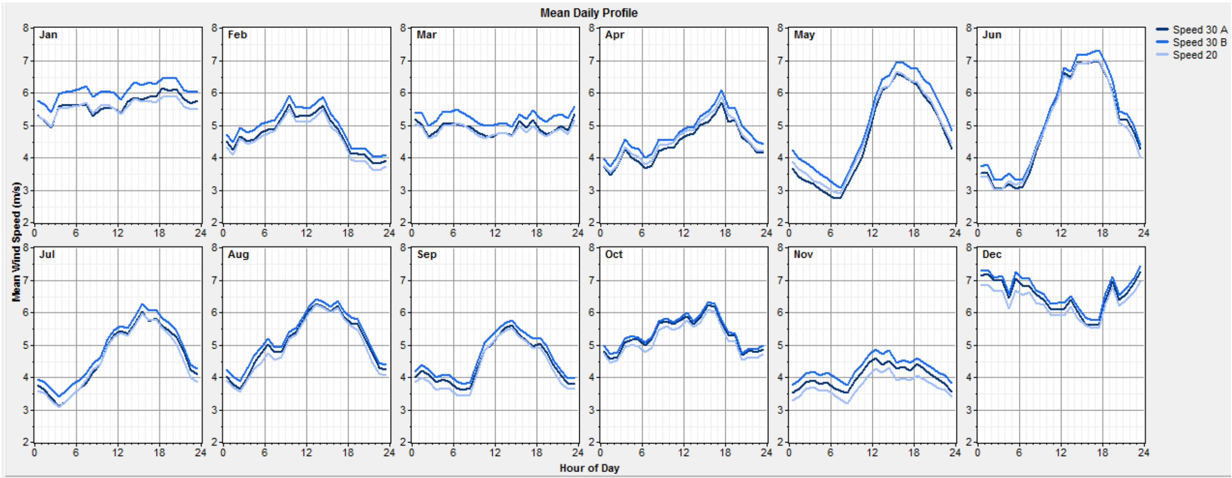
Daily Wind Profile

The daily wind profile indicates significant variation of wind speeds throughout the day, with lowest wind speeds during the early morning hours and highest wind speeds during late afternoon hours when electric load is highest. This perspective is amplified when considering monthly views of daily profiles as even more variation is observed.

Annual daily wind profile (synth. data)

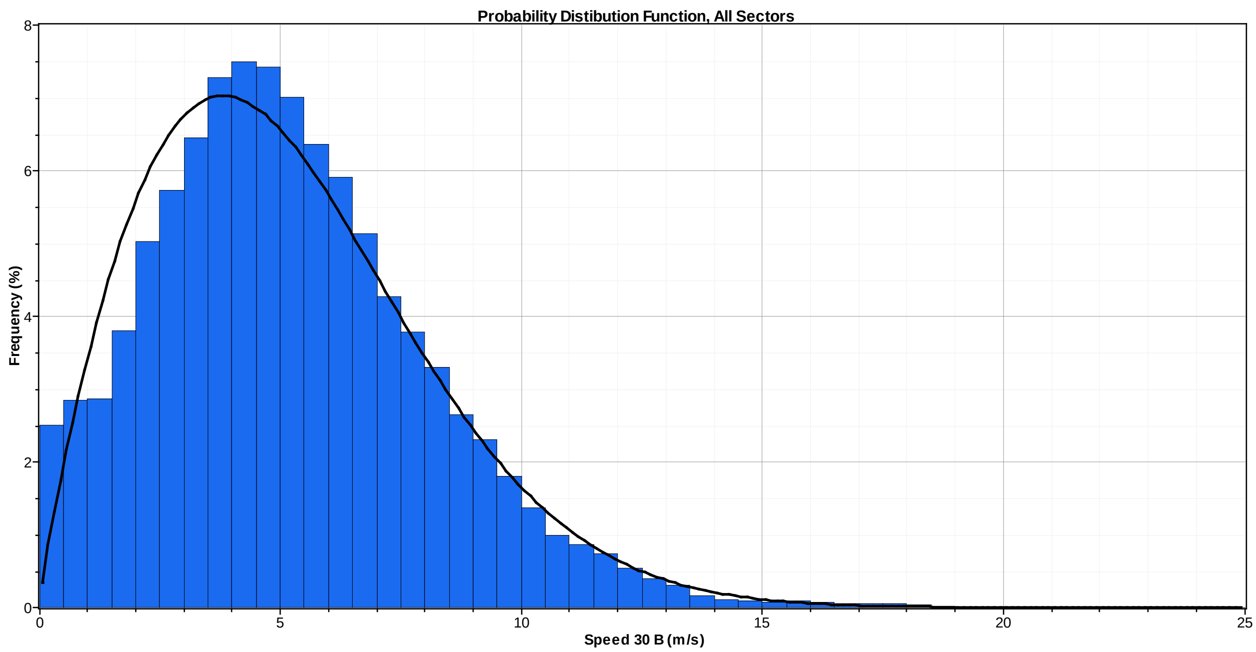


Monthly daily wind profile (synth. data)



Probability Distribution Function

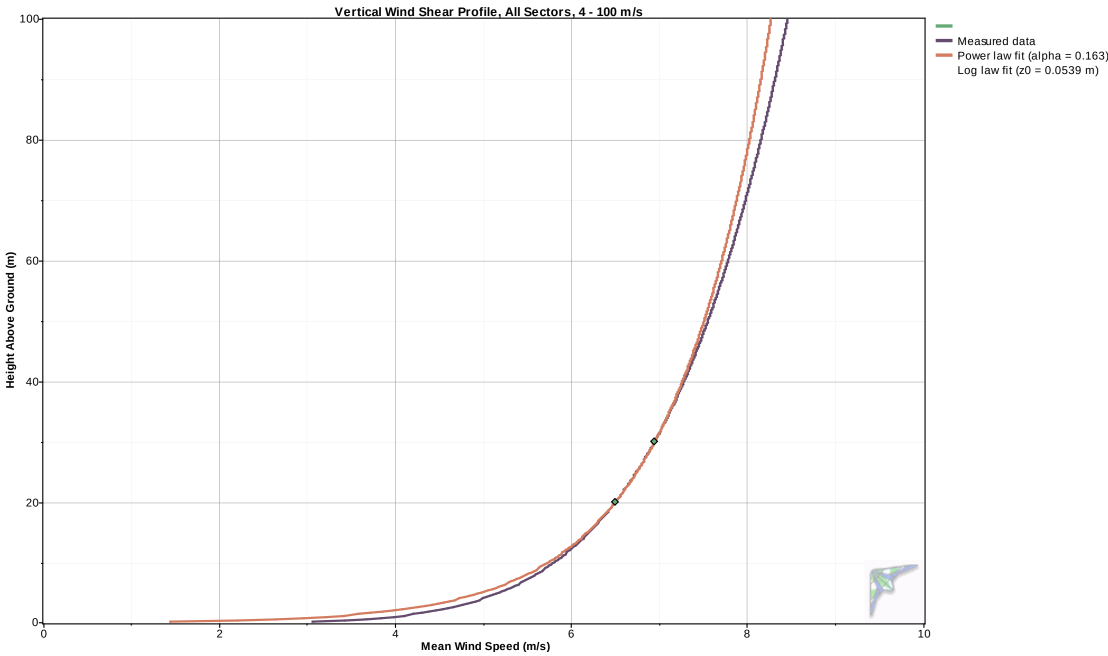
The probability distribution function (or histogram) of wind speed indicates a near-normal shape curve of wind speeds (defined as the Raleigh distribution, k=2.0).



Wind Shear and Roughness

A wind shear power law exponent of 0.163 indicates moderate wind shear at the site; hence it is likely cost effective and advantageous to build wind turbines at the highest hub height practicable, construction cost considerations notwithstanding. Related to wind shear, a calculated surface roughness of 0.0021 meters (indicating the height above ground level where wind velocity would be zero) indicates relatively smooth terrain (snow surface and lower terrain) surrounding the met tower, especially toward the prevailing wind direction of north to north-northeast.

Vertical wind shear profile, wind speeds > 4 m/s



Wind shear by direction sector, wind speeds > 4 m/s

Direction Sector	Time Steps	Sector Wind (%)	Mean Wind Speed (m/s) Speed 30 B	Speed 20	Best-Fit Power Law Exp	Best-Fit Surface Roughness (m)
348.75° - 11.25°	8,610	27.3%	5.86	5.49	0.163	0.0530
11.25° - 33.75°	8,306	26.4%	7.15	6.59	0.203	0.1790
33.75° - 56.25°	646	2.1%	6.76	5.99	0.299	0.8626
56.25° - 78.75°	28	0.1%	6.86	6.50	0.136	0.0155
78.75° - 101.25°	4	0.0%	6.45	6.43	0.010	0.0000
101.25° - 123.75°	24	0.1%	6.16	6.02	0.059	0.0000
123.75° - 146.25°	275	0.9%	7.10	6.91	0.067	0.0000
146.25° - 168.75°	3,918	12.4%	6.34	5.97	0.147	0.0265
168.75° - 191.25°	5,265	16.7%	6.49	6.05	0.173	0.0749
191.25° - 213.75°	3,205	10.2%	9.35	8.93	0.115	0.0040
213.75° - 236.25°	130	0.4%	6.92	6.66	0.094	0.0006
236.25° - 258.75°	13	0.0%	6.56	6.45	0.041	0.0000
258.75° - 281.25°	48	0.2%	8.03	7.78	0.077	0.0001
281.25° - 303.75°	58	0.2%	8.14	7.88	0.082	0.0001
303.75° - 326.25°	168	0.5%	6.55	6.33	0.084	0.0002
326.25° - 348.75°	799	2.5%	5.10	4.92	0.089	0.0003

Extreme Winds

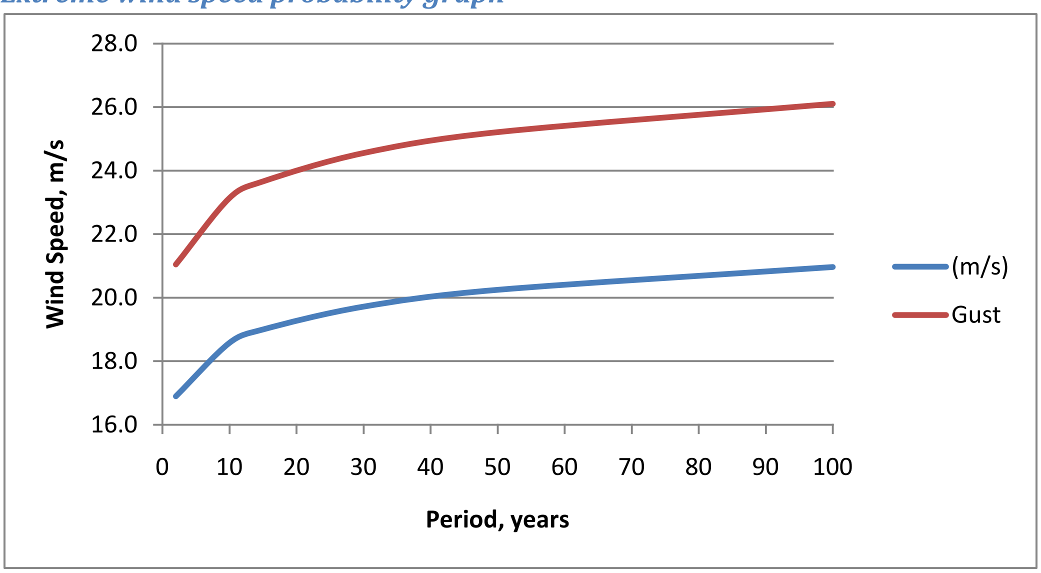
Although thirteen months of data is minimal for calculation of extreme wind probability, use of a modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, yields reasonably good results. Extreme wind analysis indicates a very low probability of extreme wind events. This may be particular climactic aspects of Anaktuvuk Pass which include considerable distance from the windy sea coast and lack of exposure to Gulf of Alaska storm winds.

Industry standard reference of extreme wind is the 50 year, 10-minute average probable wind speed, referred to as V_{ref}. For Anaktuvuk Pass, this calculates to 20.2 m/s, well below the 37.5 m/s threshold of International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria 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 speed probability table

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
2	16.9	21.0	I	50.0
10	18.6	23.1	II	42.5
15	19.0	23.7	III	37.5
30	19.7	24.6	S	designer-specified
50	20.2	25.2		
100	21.0	26.1		
average gust factor:	1.25			

Extreme wind speed probability graph



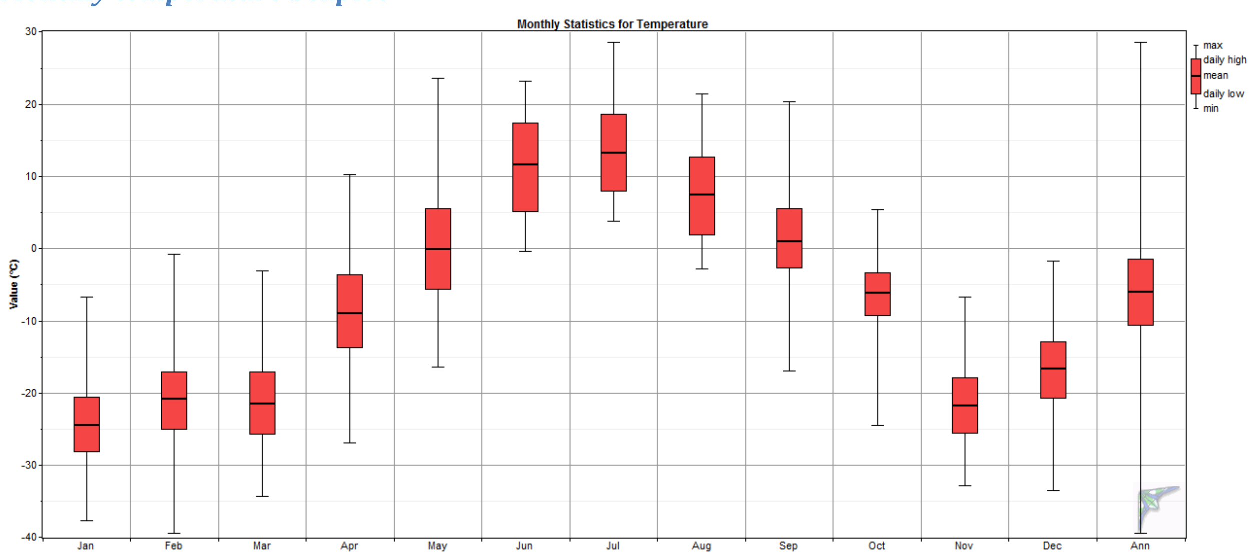
Temperature and density

Although Anaktuvuk Pass experiences warm summers, winter temperatures are very cold. The result is high air density; calculated air density exceeds standard air density for a 668 meter elevation (1.148 Kg/m^3) by seven 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.

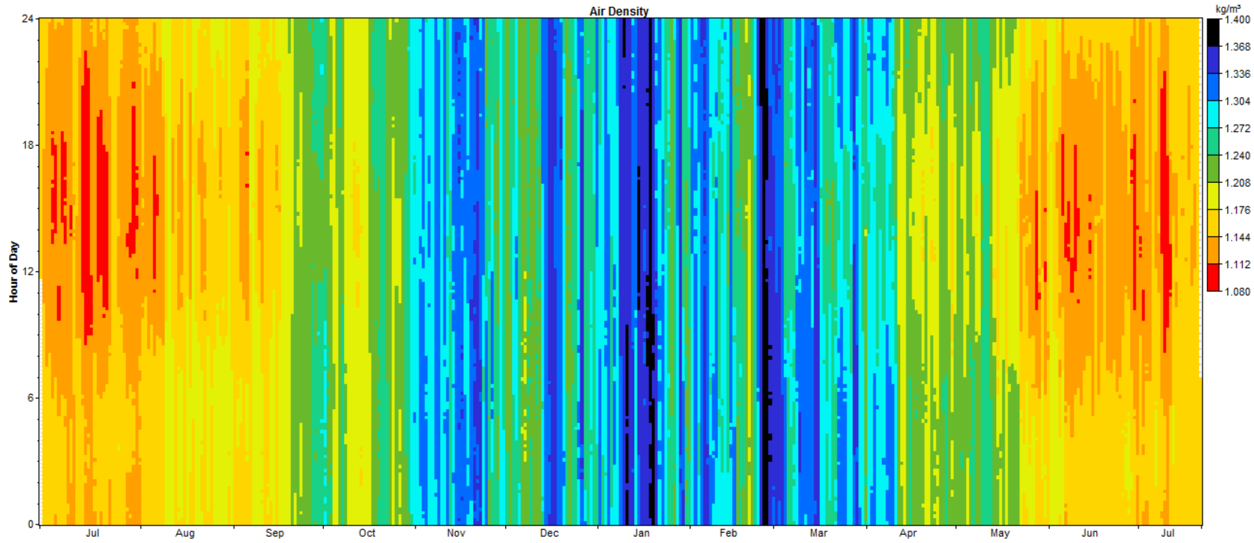
Temperature and density table

	Temperature			Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-24.3	-37.7	-6.7	1.312	1.224	1.385
Feb	-20.7	-39.5	-0.8	1.294	1.197	1.396
Mar	-21.5	-34.3	-3.1	1.296	1.207	1.365
Apr	-8.9	-27.0	10.2	1.235	1.151	1.325
May	0.0	-16.4	23.6	1.195	1.099	1.270
Jun	11.7	-0.4	23.1	1.145	1.101	1.196
Jul	13.3	3.7	28.5	1.139	1.081	1.178
Aug	7.5	-2.8	21.4	1.162	1.107	1.206
Sep	1.0	-17.0	20.3	1.190	1.111	1.273
Oct	-6.1	-24.5	5.3	1.222	1.171	1.311
Nov	-21.7	-32.8	-6.7	1.298	1.224	1.357
Dec	-16.6	-33.6	-1.8	1.272	1.202	1.361
Annual	-7.2	-39.5	28.5	1.230	1.081	1.396

Monthly temperature boxplot



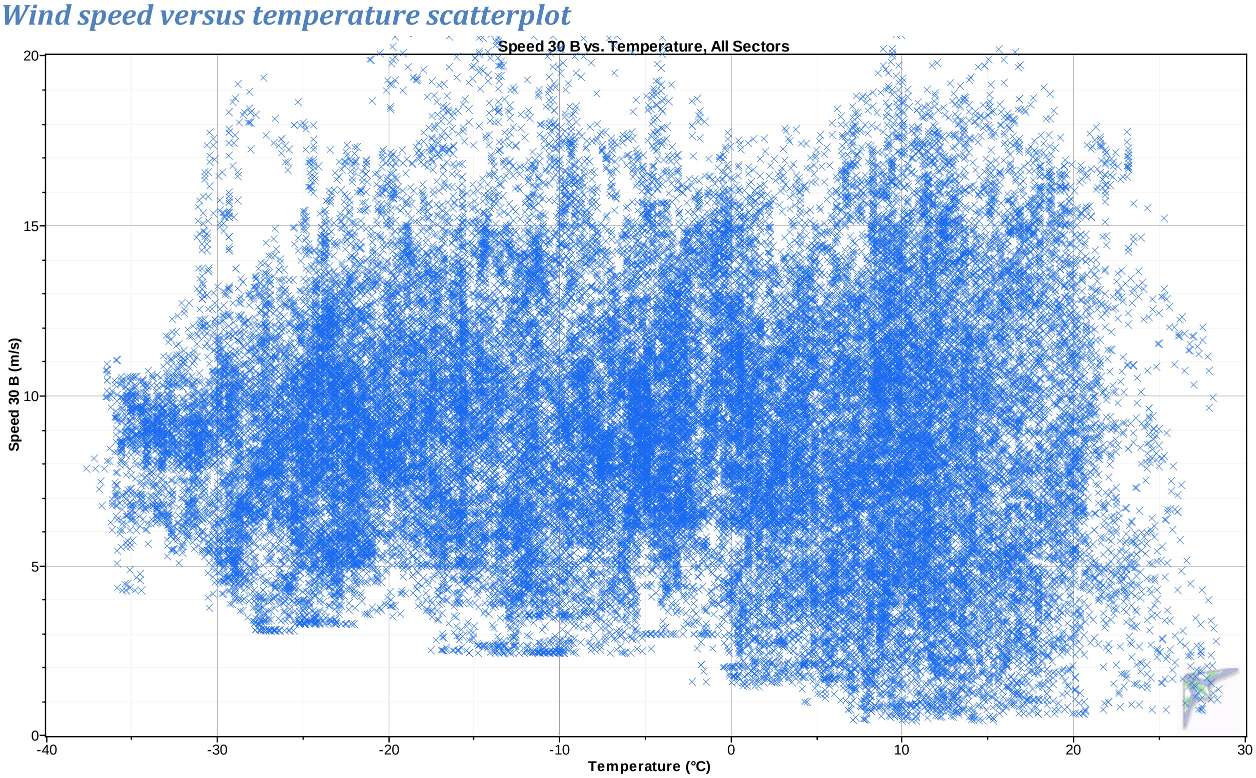
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Anaktuvuk Pass coincides with very cold temperatures, as one would expect give the location in the Brooks Range. During the met tower test period, temperatures did not fall below -40°C, the minimum operating temperature of arctic-capable wind turbines presently operating in Alaska.

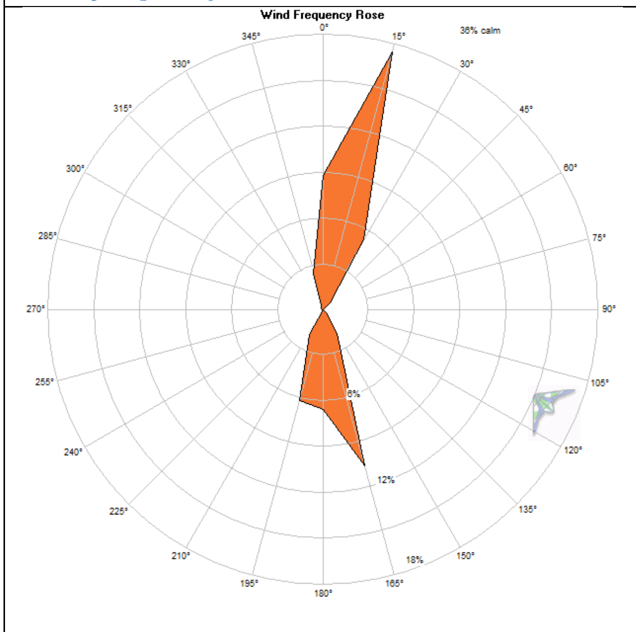
Wind speed versus temperature scatterplot



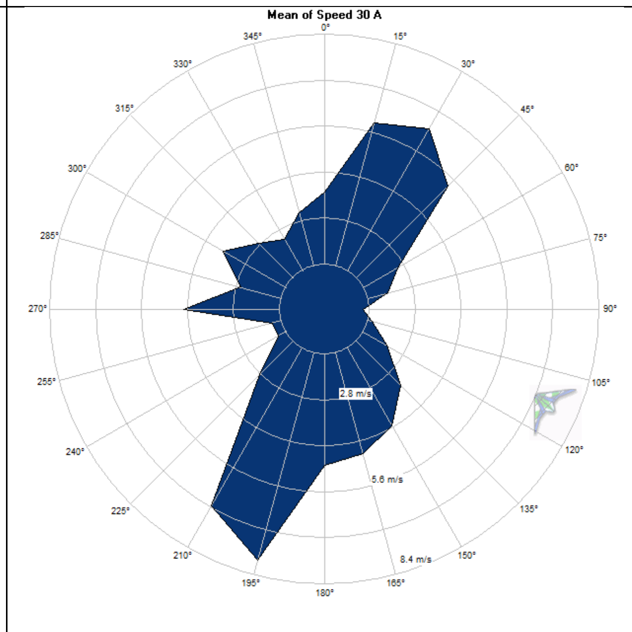
Wind Direction

Wind frequency rose data indicates very highly directional winds entirely concentrated at 015° T and about 160° T to 200° T. Power density rose data (representing the power in the wind) indicates the winds are nearly exclusively directional at 020° T and 200° T, directly opposite each other. Calm frequency (percent of time that winds at the 30 meter level are less than 3.5 m/s) was 36 percent during the met tower test period.

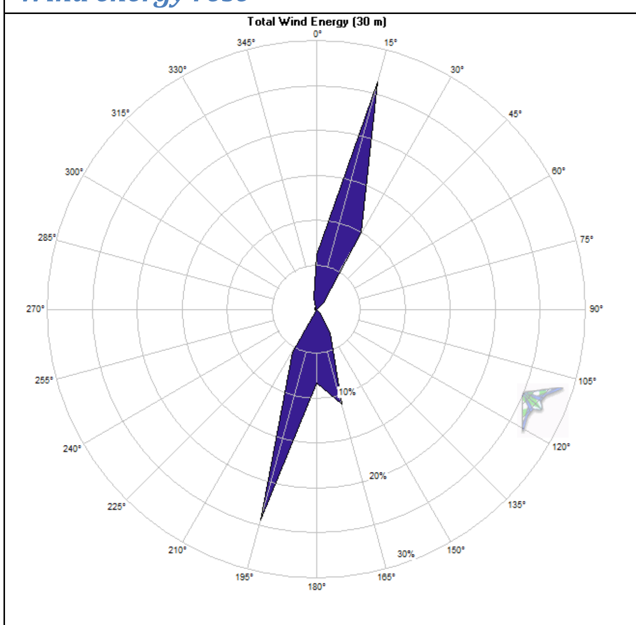
Wind frequency rose



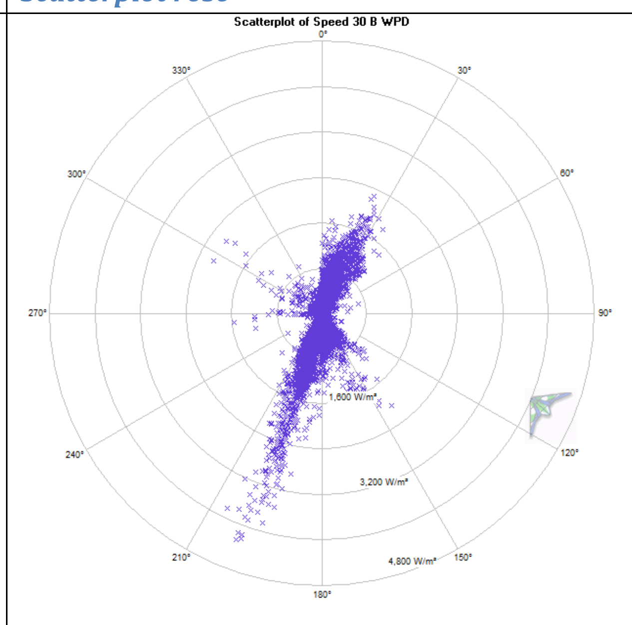
Mean value rose



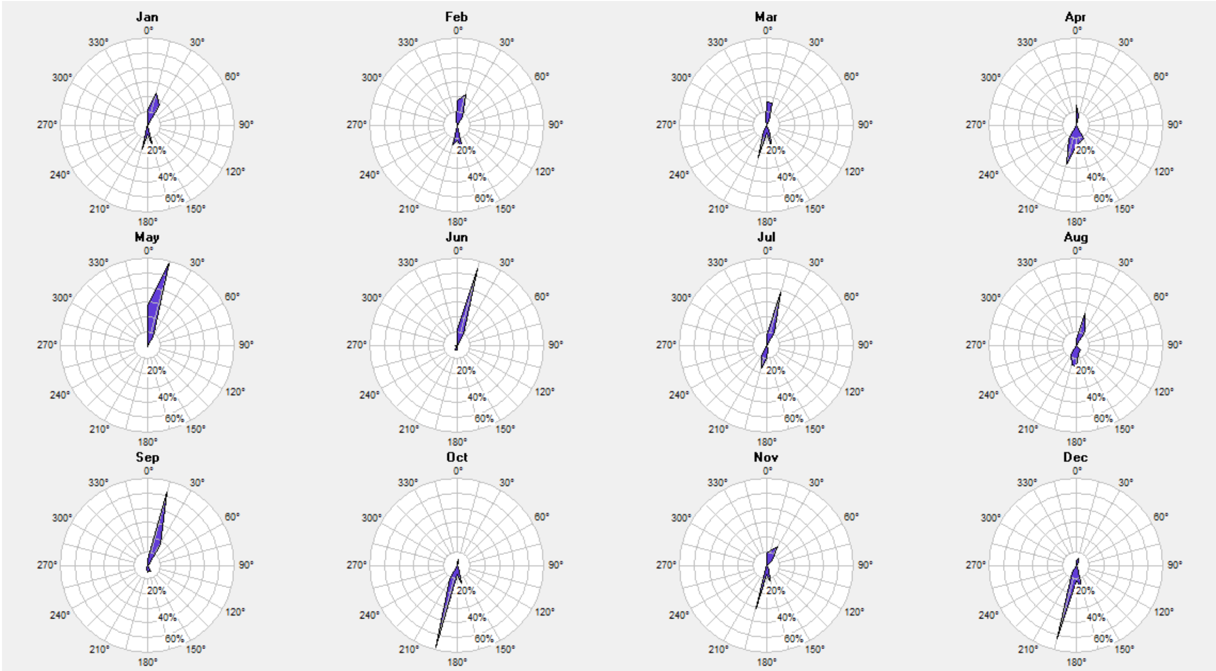
Wind energy rose



Scatterplot rose



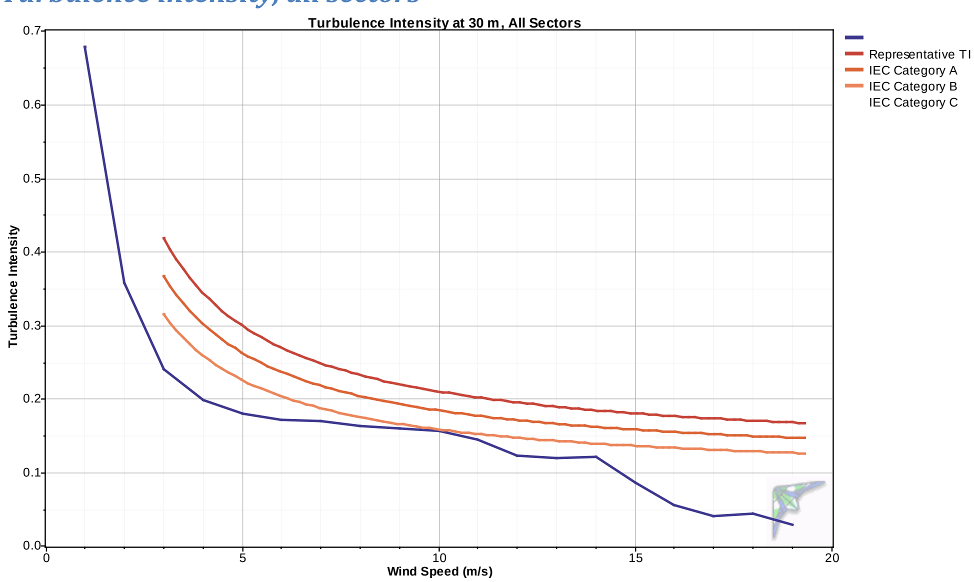
Wind density roses by month



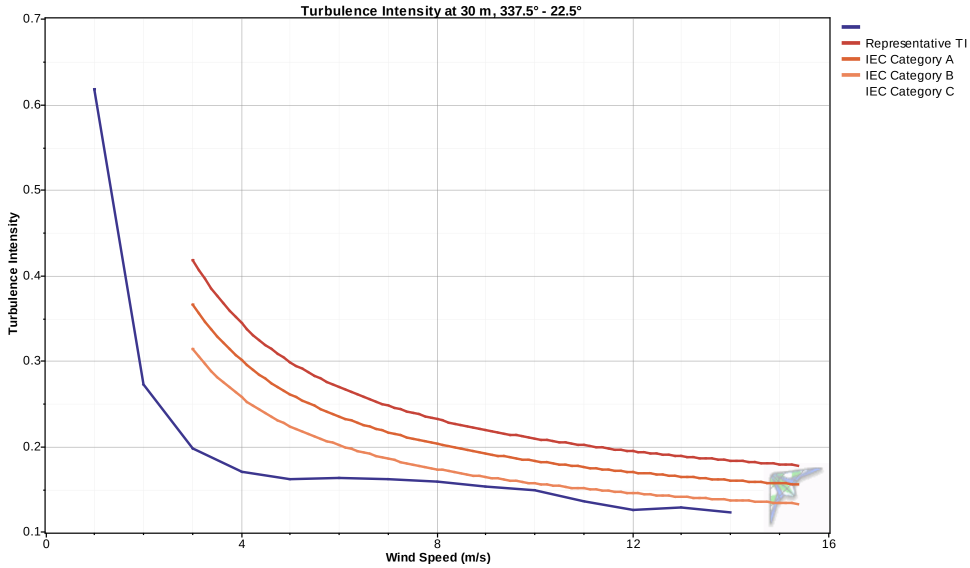
Turbulence

To date, turbulence intensity is within acceptable standards with a classification of IEC (International Electrotechnical Commission) 61400-1, 3rd edition (2005) turbulence category C (lowest).

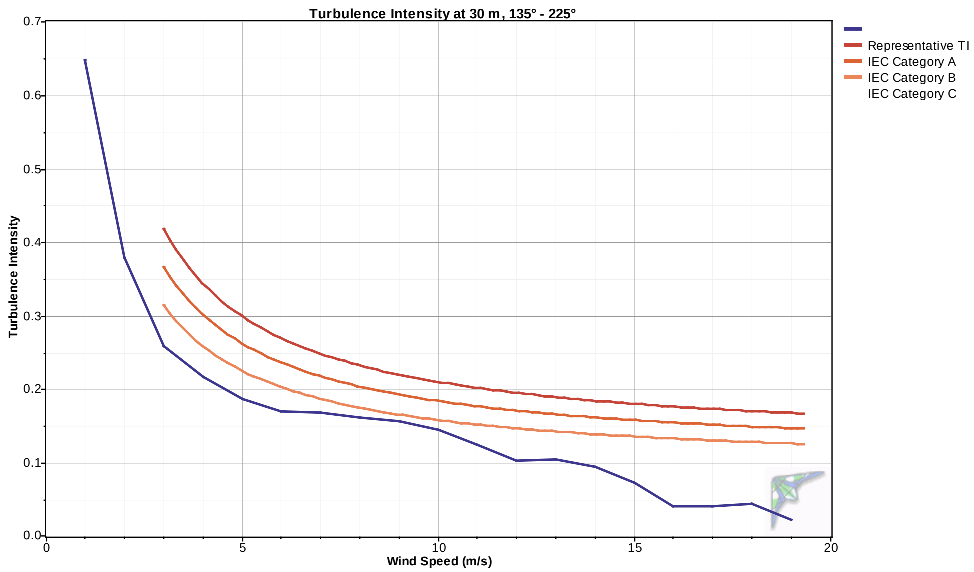
Turbulence intensity, all sectors



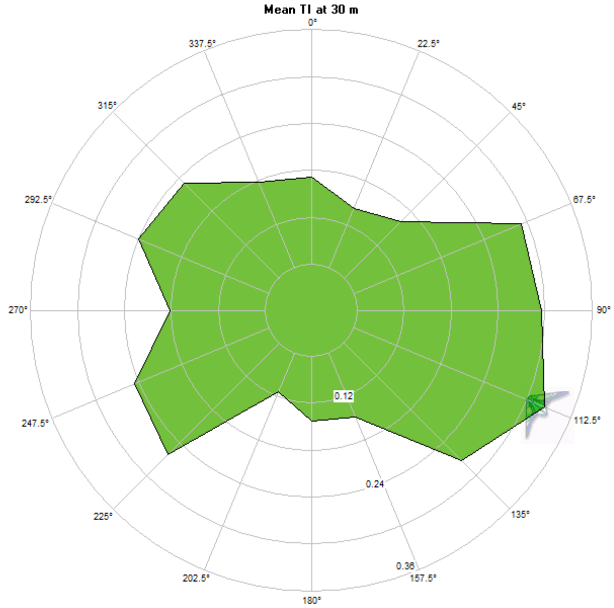
Turbulence intensity, NNW to NNE sector



Turbulence intensity, SW sector



Turbulence intensity by direction



Turbulence table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records in Bin	Mean TI	Std Dev. of TI	Representative TI	Peak TI
1	0.5	1.5	2,881	0.460	0.170	0.678	1.091
2	1.5	2.5	4,437	0.206	0.118	0.358	1.067
3	2.5	3.5	6,093	0.141	0.078	0.241	0.778
4	3.5	4.5	7,492	0.119	0.061	0.198	0.800
5	4.5	5.5	7,359	0.112	0.054	0.180	0.612
6	5.5	6.5	6,312	0.109	0.048	0.171	0.639
7	6.5	7.5	4,790	0.112	0.045	0.170	0.554
8	7.5	8.5	3,606	0.110	0.042	0.164	0.453
9	8.5	9.5	2,560	0.105	0.043	0.160	0.379
10	9.5	10.5	1,604	0.099	0.044	0.156	0.414
11	10.5	11.5	919	0.090	0.043	0.145	0.342
12	11.5	12.5	630	0.075	0.037	0.123	0.275
13	12.5	13.5	331	0.069	0.039	0.119	0.230
14	13.5	14.5	132	0.070	0.040	0.121	0.243
15	14.5	15.5	74	0.050	0.028	0.086	0.140
16	15.5	16.5	58	0.032	0.018	0.055	0.123
17	16.5	17.5	30	0.031	0.008	0.041	0.047
18	17.5	18.5	14	0.031	0.010	0.044	0.050
19	18.5	19.5	4	0.023	0.005	0.029	0.027

Airport ASOS 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. Anaktuvuk Pass Airport (ICAO station identifier: PAKP) AWOS was installed in 1981.

The AEA report documents data from AWOS sensor, which is 9 meters above ground level. To compare this data to the met tower upper sensor height of 30 meters, the data was adjusted using an exponent extrapolation function with a power law exponent value of 0.14, which is more conservative than the 0.175 power law exponent calculated from met tower data and more typical of large open areas in Alaska.

Comparing to the met tower 30 meter B anemometer (both the collected data set and the synthesized data set), one can see that average wind speeds recorded by the met tower are higher than that predicted by the AWOS data. This would account for the higher wind class prediction of the met tower (Class 2) over the airport data (Class 1). The primary reason for this discrepancy is likely the superior elevation and exposure of the met tower compared to the AWOS sensors.

Airport/met tower data comparison

	Anaktuvuk Pass Airport		Met Tower, 30m B anem.	
	AWOS, 9 m sensor (m/s)	Data adj. to 30 m (m/s)	Collected data (m/s)	Synthesized data (m/s)
Jan	4.1	4.85	6.07	6.07
Feb	4.2	4.97	4.85	4.95
Mar	3.9	4.62	5.55	5.24
Apr	3.8	4.50	4.73	4.73
May	3.7	4.38	5.03	5.03
Jun	3.7	4.38	5.21	5.21
Jul	3.5	4.14	4.82	4.82
Aug	3.7	4.38	5.25	5.25
Sep	3.5	4.14	4.63	4.63
Oct	3.6	4.26	5.63	5.41
Nov	3.8	4.50	4.39	4.26
Dec	4.0	4.73	6.04	6.68
Annual	3.8	4.49	5.18	5.19