Wainwright Wind Resource Report

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Photo by D. Vaught

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Summary Information

The wind resource measured in Wainwright is very good, with measured high wind power class 4 (good) to low wind power class 5 (excellent). In addition to strong average wind speeds and wind power density, the site experiences highly directional prevailing winds, low turbulence and calculations indicate low extreme wind speed probability.

Met tower data synopsis

Data dates	June 19, 2009 to July 16, 2010 (13 months)
Wind power class	High 4 (good) to low 5 (excellent)
Power density mean, 30 m	413 W/m^2 (QC'd data); 392 W/m^2 (with synthetic data)
Wind speed mean, 30 m	7.05 m/s (QC'd data); 6.96 m/s (with synthetic data)
Max. 10-min wind speed average	22.2 m/s
Maximum wind gust	25.8 m/s (Feb. 2010)
Weibull distribution parameters	k = 2.2, c = 7.97 m/s
Wind shear power law exponent	0.137 (moderately low)
Roughness class	1.51 (crops)
IEC 61400-1, 3rd ed. classification	Class III-c (lowest defined and most common)
Turbulence intensity, mean	0.072 (at 15 m/s)
Calm wind frequency	16% (<3.5 m/s)

Community profile

Current Population:	551 (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 approximately 500 meters (1,600 ft) northeast of the village of Wainwright, near the Chukchi Sea shoreline. This site is relatively near the power plant and well exposed to winter winds with no upwind obstructions.

Site information

Site number	0222
Latitude/longitude	N 70° 38.824' W 160° 00.698', WGS 84

Site elevation ASL	14 meters (45 ft)
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

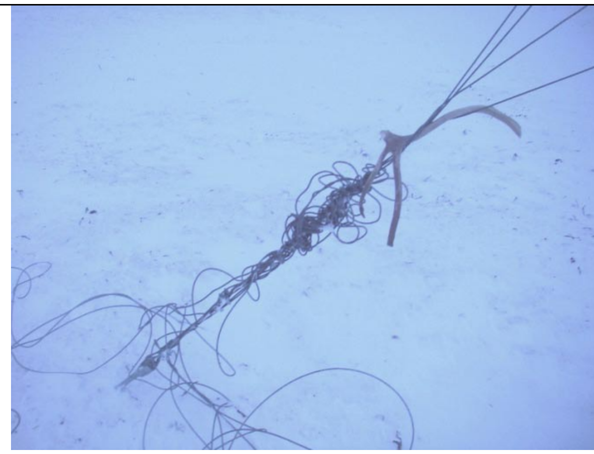
Google Earth image

Tower sensor information

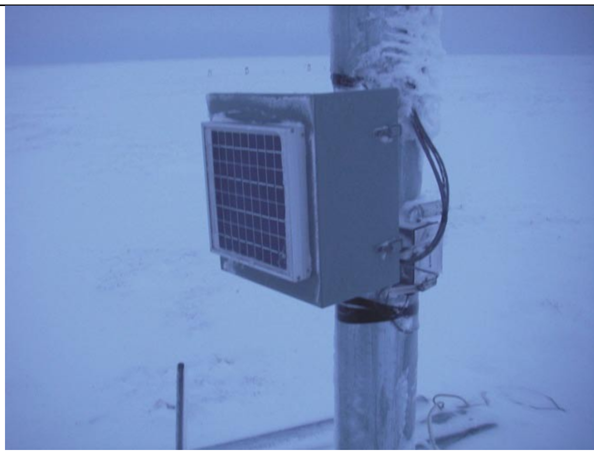
Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m (A)	0.757	0.39	187° T
2	NRG #40 anemometer	30 m (B)	0.757	0.39	273° T
3	NRG #40 anemometer	20 m	0.758	0.35	273° T
7	NRG #200P wind vane	29 m	0.351	359	358° T
9	NRG #110S Temp C	3 m	0.136	-86.383	N
10	RH-5 relative humidity	2 m	0.098	0	S
12	Voltmeter	2 m	0.021	0	n/a

Photographs

Top of met tower; D. Vaught photo



Caribou antler in guy wires; D. Vaught photo



Datalogger weather box and PV panel; D. Vaught photo

Datalogger with snow in weather box; D. Vaught photo

Data Recovery

Data recovery in Wainwright was mostly acceptable, with 75 to 80 percent data recovery of the anemometers and wind vane. The exception is the 30 m A anemometer which lost a cup in December or January. This rendered the sensor useless and all subsequent data was removed from analysis. Note that data recovery in December and January was particularly poor, apparently due to hoarfrost conditions during this deep cold period of mid-winter. It is curious that similar data loss was not observed at the Point Hope met tower during the same time period. Note also that data loss from the relative humidity (RH) sensor was due to voltage drawdown of the iPack battery during the dark months of winter (the battered is recharged with photovoltaic panels). Functionality of the RH sensor eventually recovered after return of daylight in springtime.

Data recovery summary table

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 A	m/s	30 m	56,489	22,058	39.0
Speed 30 B	m/s	30 m	56,489	44,218	78.3
Speed 20	m/s	20 m	56,489	44,806	79.3
Direction 30	°	30 m	56,489	43,295	76.6
Temperature	°C		56,489	56,436	99.9
RH-5 Humidity %RH	%RH		56,489	36,673	64.9
Voltmeter	volts		56,489	56,489	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	1,637	1,621	99.0	1,621	99.0	1,621	99.0
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	4,310	99.8	4,320	100.0	4,320	100.0
2009	Oct	4,464	3,805	85.2	3,839	86.0	3,864	86.6
2009	Nov	4,320	2,575	59.6	2,578	59.7	2,567	59.4
2009	Dec	4,464	819	18.4	819	18.4	819	18.4
2010	Jan	4,464	0	0.0	1,086	24.3	1,086	24.3
2010	Feb	4,032	0	0.0	3,623	89.9	4,032	100.0
2010	Mar	4,464	0	0.0	2,523	56.5	2,758	61.8
2010	Apr	4,320	0	0.0	4,158	96.3	4,024	93.2
2010	May	4,464	0	0.0	4,240	95.0	4,275	95.8
2010	Jun	4,320	0	0.0	4,223	97.8	4,252	98.4
2010	Jul	2,292	0	0.0	2,260	98.6	2,260	98.6
All data		56,489	22,058	39.1	44,218	78.3	44,806	79.3

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. The cold arctic temperatures of Wainwright contributed to the high wind power density. It is problematic, however, analyzing wind data with significant concentrated data loss, such as occurred in Wainwright during November through January, then again in March. 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 robust wind resource measured and noting the long-term airport AWOS data confirming the wind resource measured by the met tower, continuing a wind study with heated sensors is not truly necessary in Wainwright.

Anemometer data 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
MMM wind speed (m/s)	6.82	7.05	6.62	6.96	6.96	6.56
Max 10-min avg wind speed (m/s)	18.4	22.2	21.7	22.2	22.2	21.7
Max gust wind speed (m/s)	22.7	25.8	25.3			
Weibull k	2.28	2.20	2.07	2.18	2.18	2.09
Weibull c (m/s)	7.597	7.975	7.512	7.87	7.87	7.41
MMM power density (W/m²)	347	413	358	393	392	339
MMM energy content (kWh/m²/yr)	3,041	3,620	3,135	3,444	3,437	2,973
Energy pattern factor	1.69	1.71	1.79	1.72	1.72	1.78
Frequency of calms (%)	15.6	15.9	19.4	16.4	16.3	19.3
1-hr autocorrelation coefficient	0.941	0.952	0.952	0.947	0.947	0.947
Diurnal pattern strength	0.031	0.031	0.035	0.029	0.029	0.033
Hour of peak wind speed	18	18	17	18	18	17

Time Series

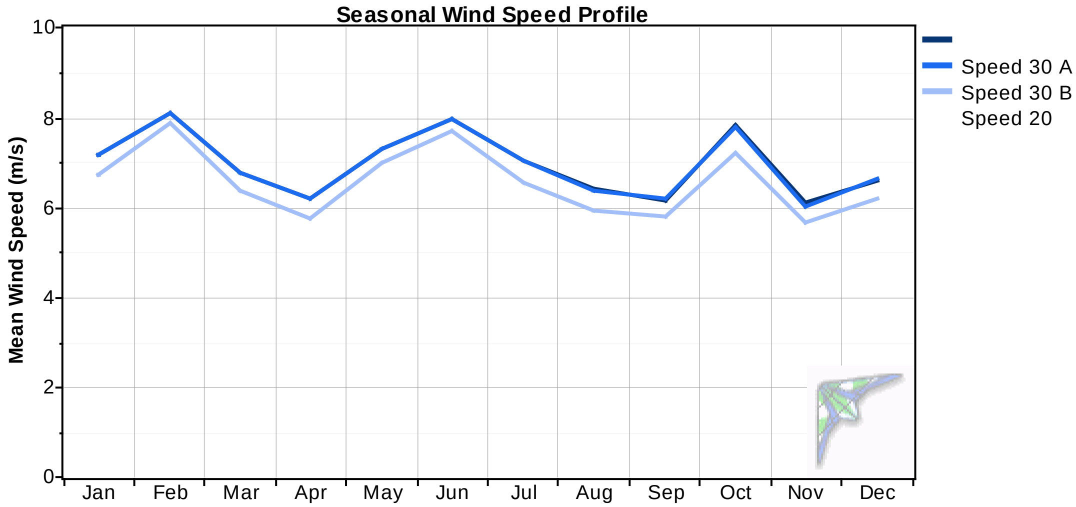
Time series calculations indicate high wind speed averages throughout the year, even during summer. Note that the October 2009 wind speed average was high compared to September and November. This likely is a statistical variation that would even out with multi-year data collection. Curiously, the October 2009 wind speed anomaly in Wainwright is opposite to that observed in Point Hope where wind speeds that month were unusually low compared to September and November 2009.

30m B data summary

Year	Month	Original Data Mean (m/s)	Max 10-min (m/s)	Max gust (m/s)	Synthesized Data Mean (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2009	Jun	8.59	12.8	15.1	8.61	2.30	4.60	9.42
2009	Jul	6.66	14.3	17.4	6.66	3.09	2.27	7.49
2009	Aug	6.39	16.7	21.2	6.39	3.04	2.21	7.20
2009	Sep	6.21	18.1	22.7	6.21	3.25	2.01	7.01
2009	Oct	7.68	18.3	22.4	7.80	3.01	2.75	8.78
2009	Nov	5.88	13.9	16.7	6.00	2.54	2.53	6.76
2009	Dec	6.46	17.9	21.2	6.62	3.19	2.17	7.46
2010	Jan	7.78	16.2	18.9	7.19	3.45	2.19	8.11
2010	Feb	7.98	22.2	25.8	8.11	4.52	1.77	9.05

2010	Mar	7.55	18.0	20.4	6.76	3.79	1.78	7.56
2010	Apr	6.27	14.9	17.4	6.19	3.04	2.10	6.96
2010	May	7.48	16.6	18.9	7.32	3.31	2.37	8.26
2010	Jun	7.73	16.5	19.3	7.74	3.29	2.54	8.71
2010	Jul	7.77	12.9	15.9	7.73	2.48	3.57	8.56
MMM annual		7.05	22.2	25.8	6.96	3.34	2.18	7.87

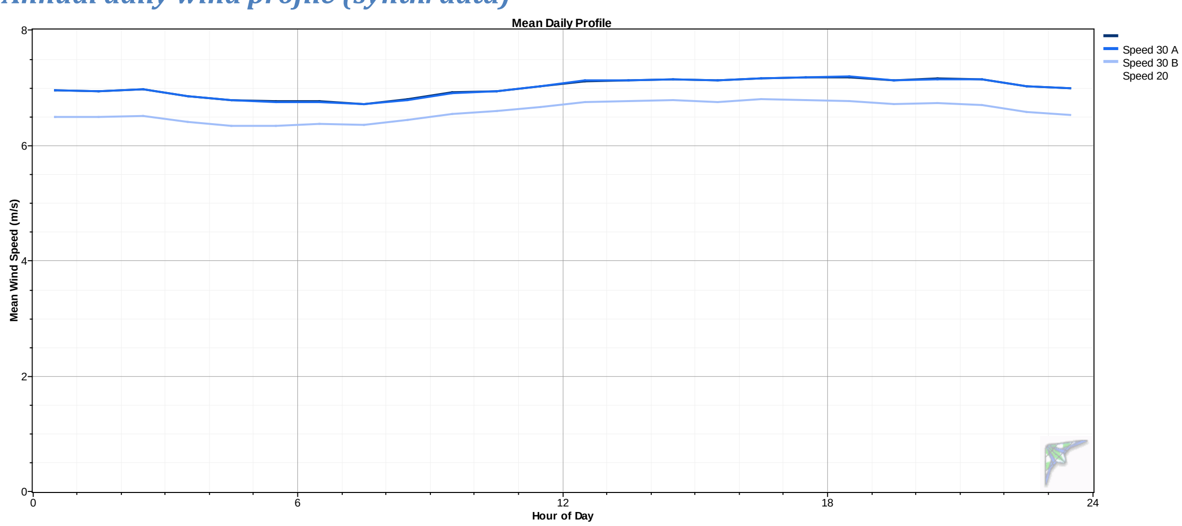
Time series graph



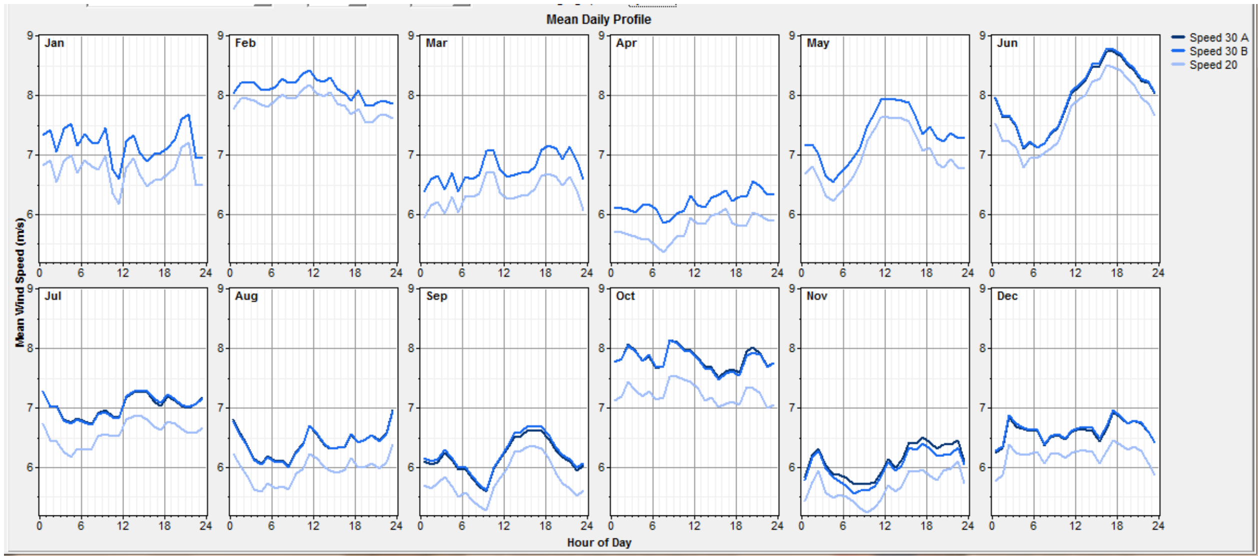
Daily Wind Profile

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)

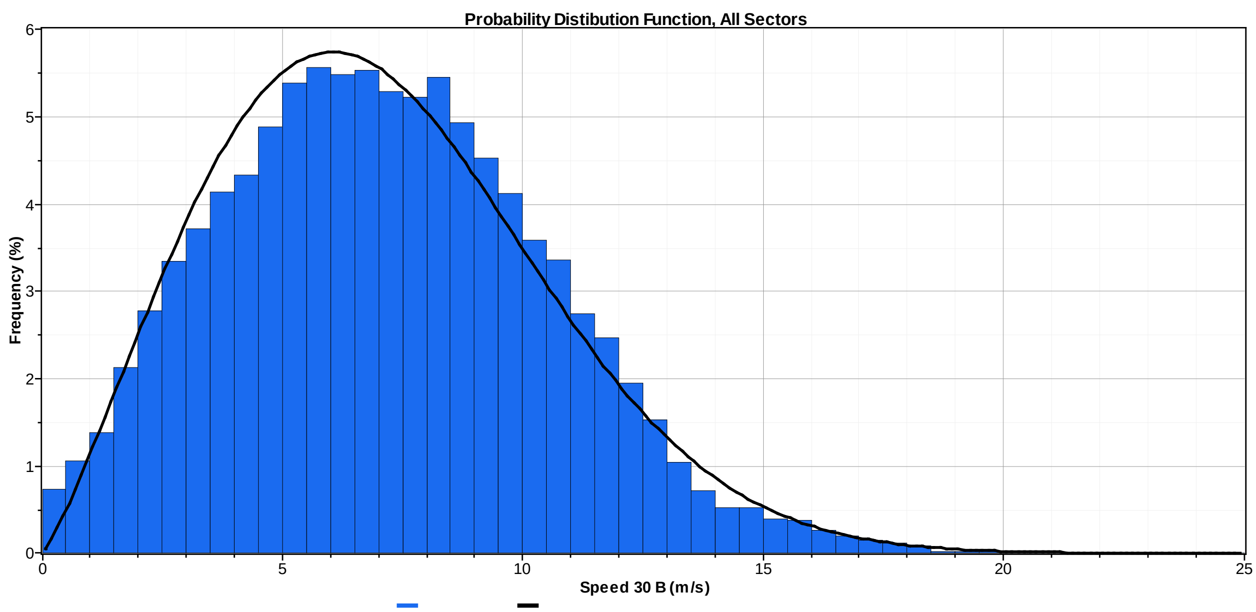


Monthly daily wind profiles (synth. data)



Probability Distribution Function

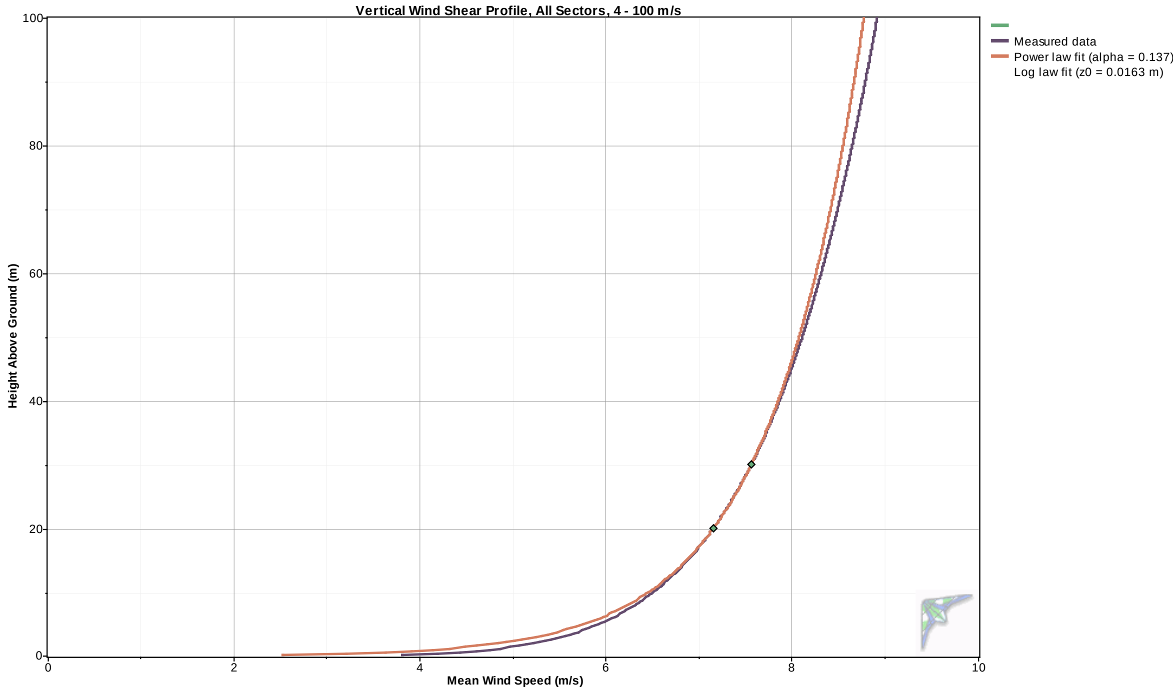
The probability distribution function (or histogram) of wind speed indicates a near-normal shape curve, defined as the Raleigh distribution (k=2.0), considered standard for wind power sites.



Wind Shear and Roughness

A wind shear power law exponent of 0.137 indicates moderately low wind shear at the site; hence turbine construction at a low hub height is possibly a desirable option. Related to wind shear, a calculated surface roughness of 0.0557 meters (indicating the height above ground level where wind velocity would be zero) indicates relatively smooth terrain (roughness description: crops) surrounding the met tower, especially in the direction of the prevailing northeast to east-northeast winds.

Vertical wind shear profile, wind > 4 m/s



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

Direction Sector	Time Steps	Sector Wind (%)	Mean Wind Speed (m/s) Speed 30 B	Mean Wind Speed (m/s) Speed 20	Best-Fit Power Law Exp	Best-Fit Surface Roughness (m)
348.75° - 11.25°	2,010	5.6%	6.44	6.05	0.153	0.0351
11.25° - 33.75°	3,232	9.0%	7.11	6.75	0.128	0.0097
33.75° - 56.25°	8,989	25.1%	8.53	8.17	0.106	0.0019
56.25° - 78.75°	7,687	21.5%	8.57	8.18	0.113	0.0035
78.75° - 101.25°	2,356	6.6%	6.33	5.47	0.357	1.4771
101.25° - 123.75°	1,038	2.9%	5.78	5.25	0.239	0.3688
123.75° - 146.25°	796	2.2%	5.47	5.12	0.163	0.0536
146.25° - 168.75°	715	2.0%	5.39	4.86	0.252	0.4622
168.75° - 191.25°	1,042	2.9%	5.30	4.77	0.261	0.5276
191.25° - 213.75°	1,470	4.1%	7.19	6.38	0.296	0.8288
213.75° - 236.25°	1,488	4.2%	7.42	7.02	0.137	0.0162
236.25° - 258.75°	1,547	4.3%	7.71	7.44	0.091	0.0004
258.75° - 281.25°	972	2.7%	6.52	6.28	0.09	0.0003
281.25° - 303.75°	730	2.0%	6.56	6.32	0.092	0.0005
303.75° - 326.25°	644	1.8%	5.62	5.32	0.137	0.0166
326.25° - 348.75°	1,074	3.0%	5.67	5.29	0.172	0.0728

Extreme Winds

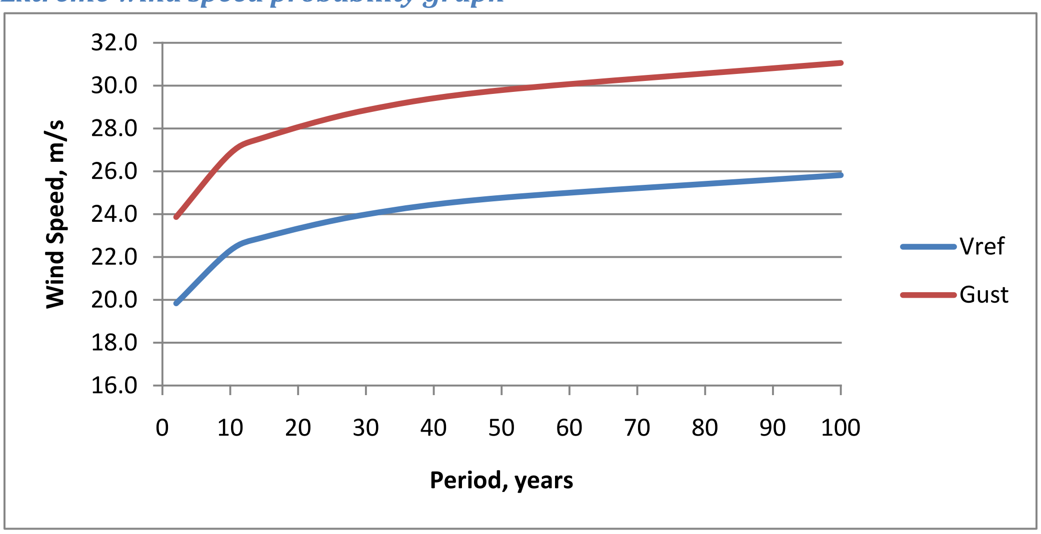
Although thirteen months of data is minimal for calculation of extreme wind probability, use of a modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, yields reasonably good results. Extreme wind analysis indicates a highly desirable situation in Wainwright: moderately high mean wind speeds combined with low extreme wind speed probabilities. This may be explained by particular climactic aspects of Wainwright which include prominent coastal exposure, offshore wind conditions, and due to the extreme northerly latitude, 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 Wainwright, this calculates to 24.8 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 speed probability table

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
2	19.8	23.9	I	50.0
10	22.3	26.8	II	42.5
15	22.9	27.6	III	37.5
30	24.0	28.8	S	designer-specified
50	24.8	29.8		
100	25.8	31.1		
average gust factor:	1.20			

Extreme wind speed probability graph



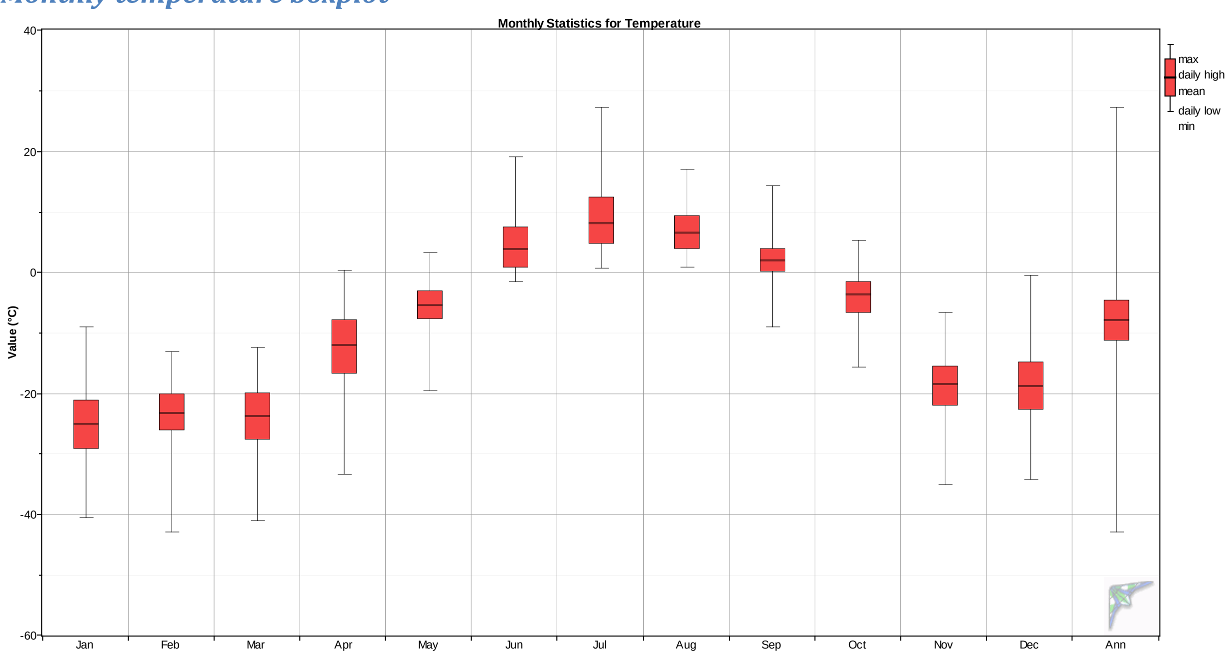
Temperature and Density

Wainwright experiences cool summers and extremely 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 nine 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.

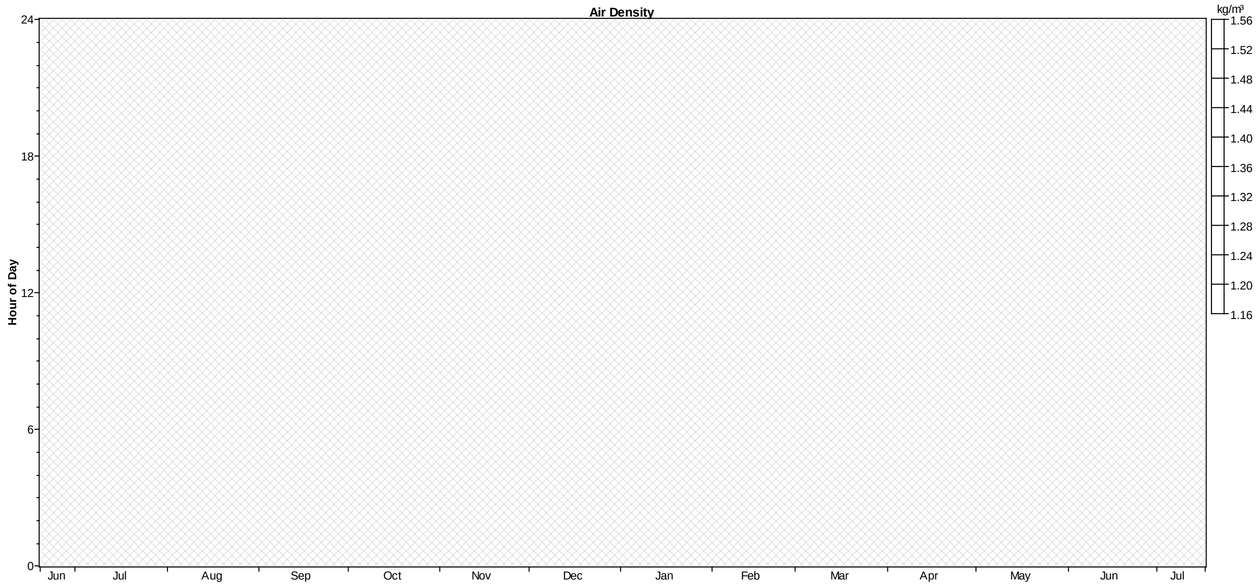
Temperature and density table

Month	Temperature			Air Density		
	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-25.1	-40.6	-9.1	1.421	1.334	1.515
Feb	-23.1	-43.0	-13.2	1.410	1.355	1.531
Mar	-23.7	-41.1	-12.5	1.413	1.352	1.518
Apr	-11.9	-33.4	0.3	1.349	1.288	1.469
May	-5.3	-19.7	3.2	1.316	1.275	1.390
Jun	4.0	-1.5	19.0	1.272	1.206	1.297
Jul	8.2	0.7	27.2	1.252	1.173	1.286
Aug	6.6	0.9	17.0	1.260	1.214	1.286
Sep	2.1	-9.0	14.3	1.280	1.226	1.334
Oct	-3.7	-15.7	5.2	1.308	1.266	1.368
Nov	-18.5	-35.1	-6.7	1.384	1.322	1.480
Dec	-18.8	-34.3	-0.5	1.386	1.292	1.475
Annual	-9.0	-43.0	27.2	1.337	1.173	1.531

Monthly temperature boxplot



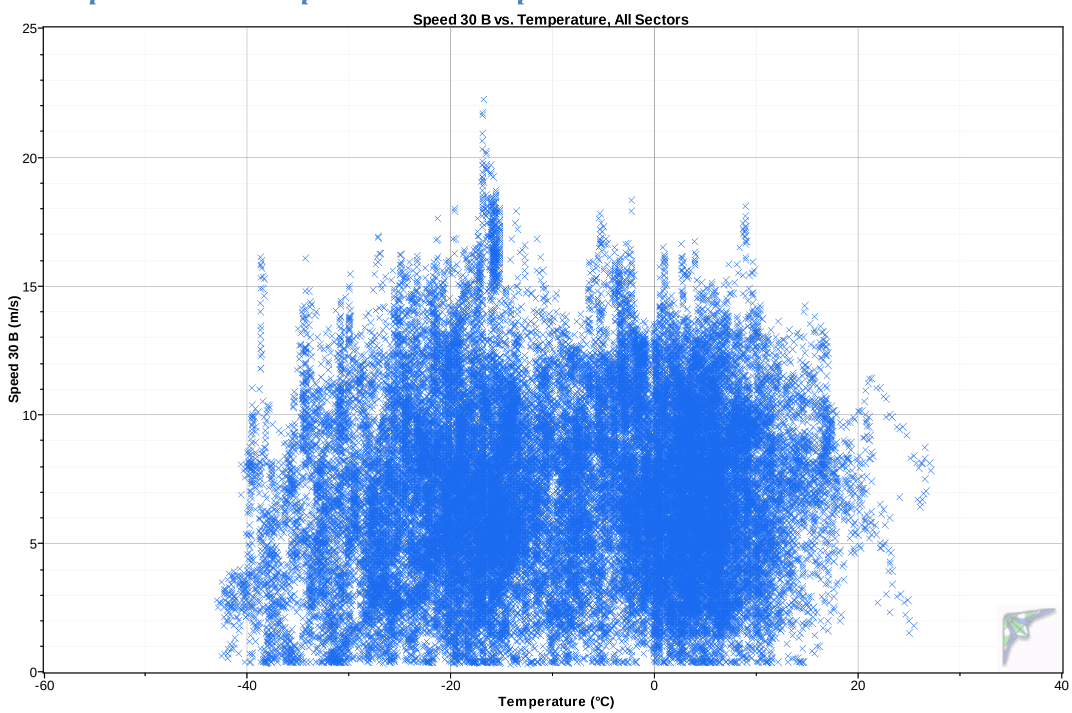
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Wainwright coincides with very cold temperatures, as one would expect given its location on the Chukchi Sea coast. During the met tower test period, temperatures fell below -40°C on a number of occasions.

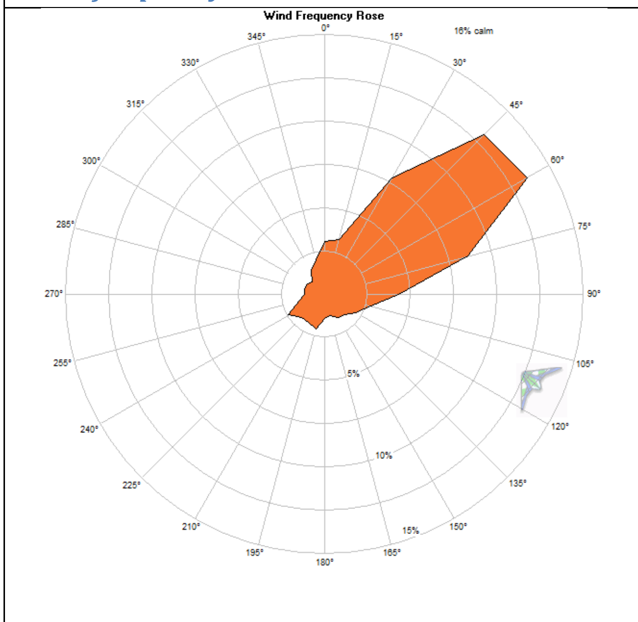
Wind speed versus temperature scatterplot



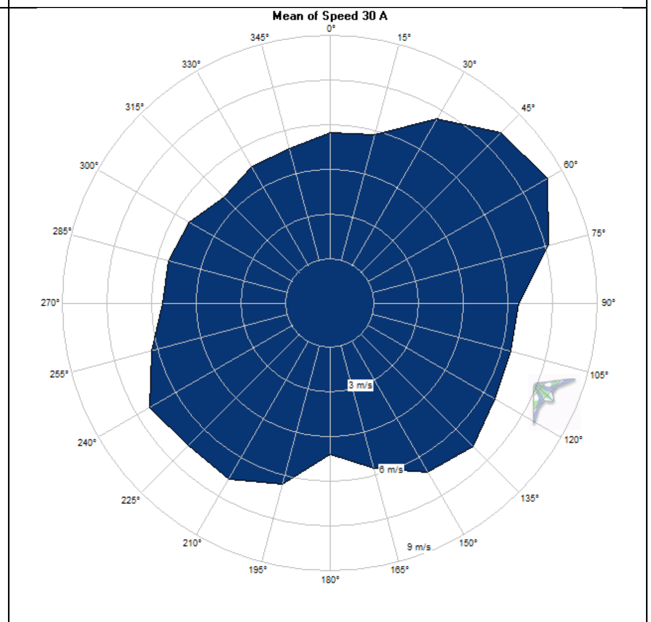
Wind Direction

Wind frequency rose data indicates highly directional winds from northeast to east-northeast. Power density rose data (representing the power in the wind) indicates power winds are strongly directional, from 345°T to 025°T and to a lesser extent from 130°T. Calm frequency (percent of time that winds at 30 meter level are less than 3.5 m/s) was 16 percent during the met tower test period.

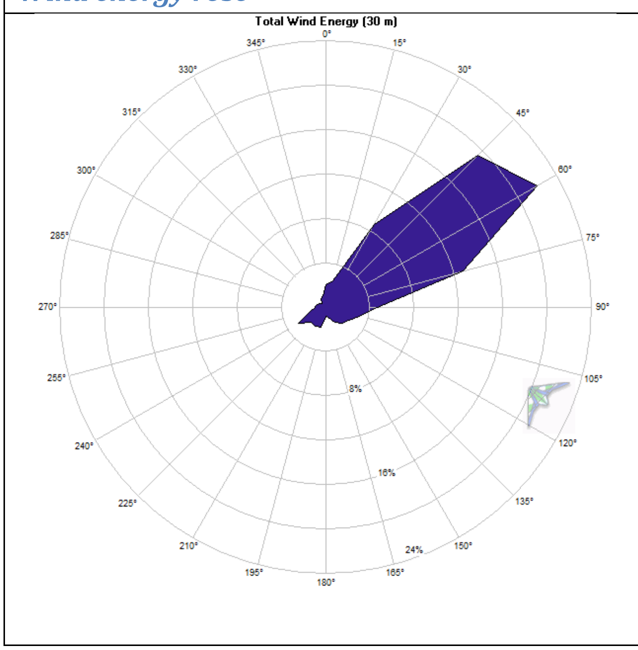
Wind frequency rose



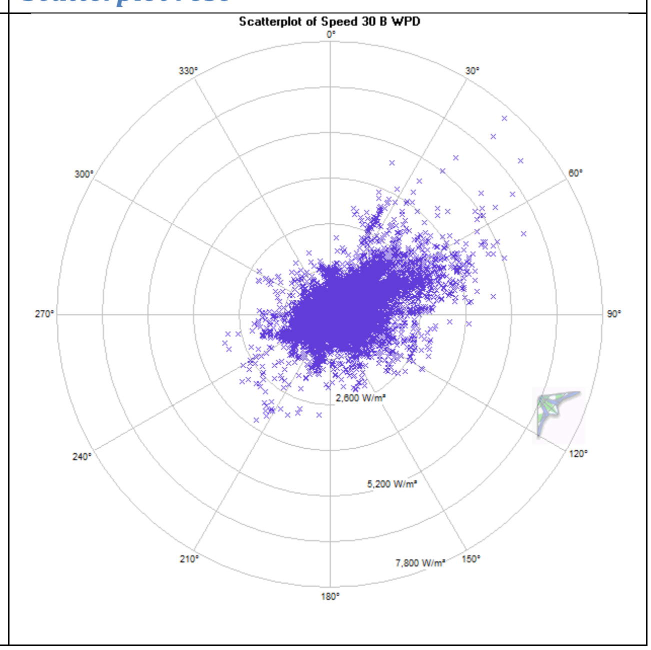
Mean value rose



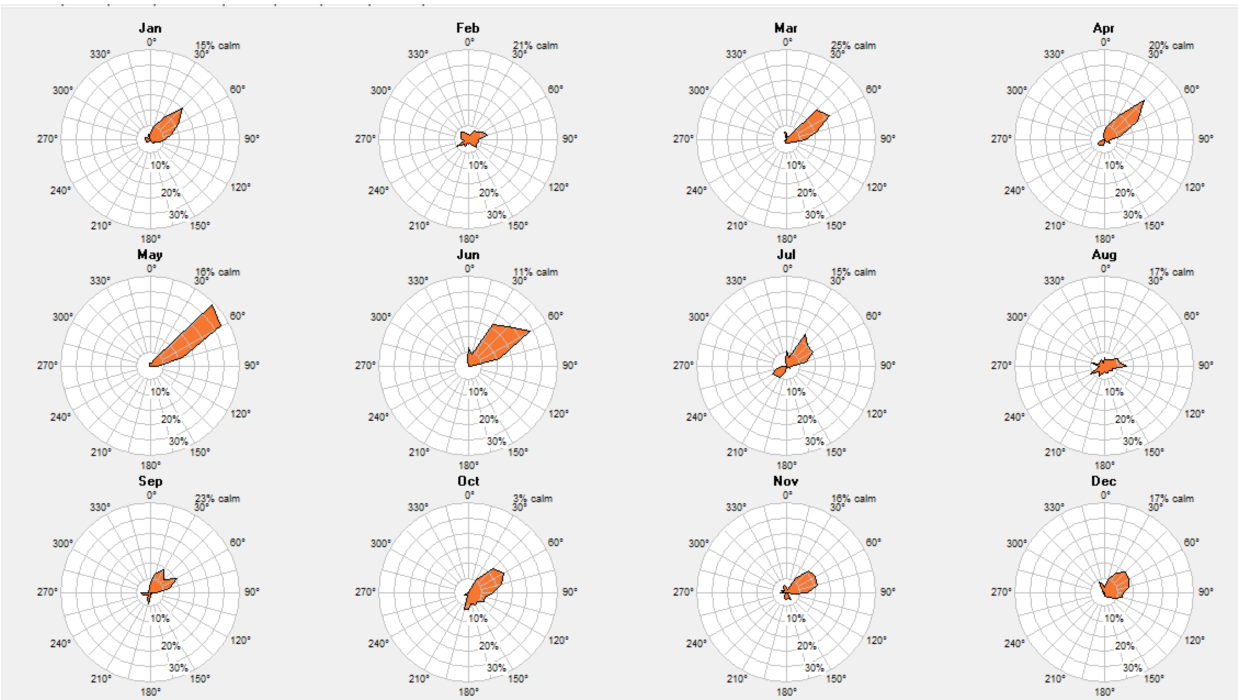
Wind energy rose



Scatterplot rose



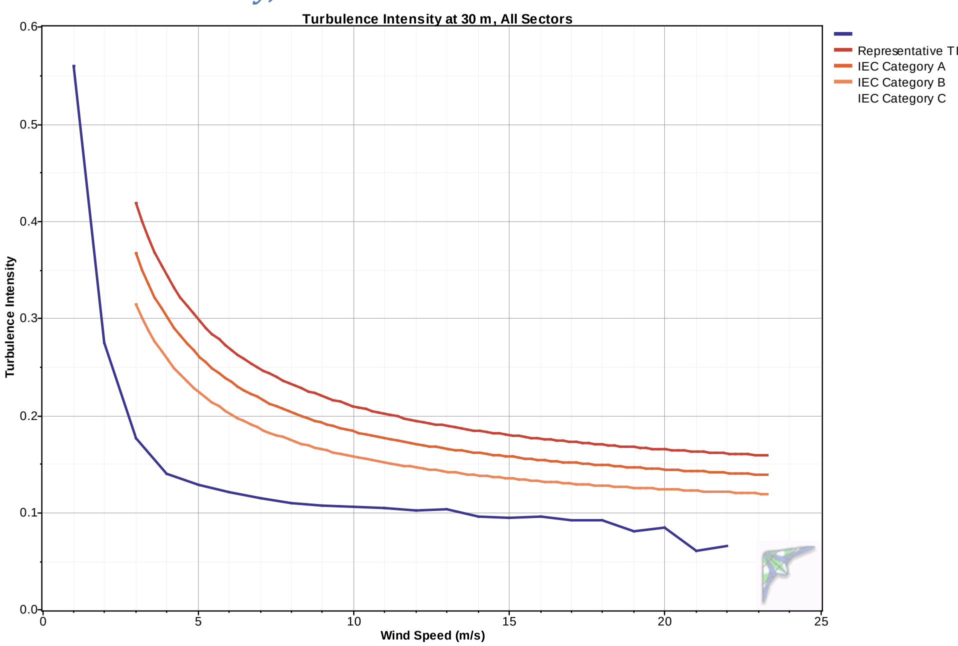
Wind density roses by month



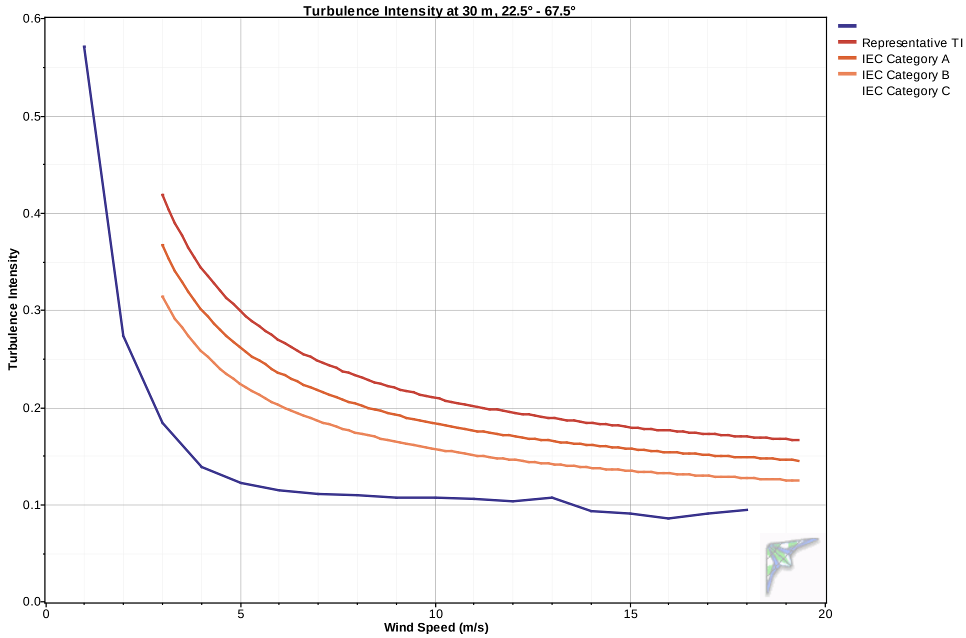
Turbulence

Turbulence intensity at the Wainwright 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 0.072.

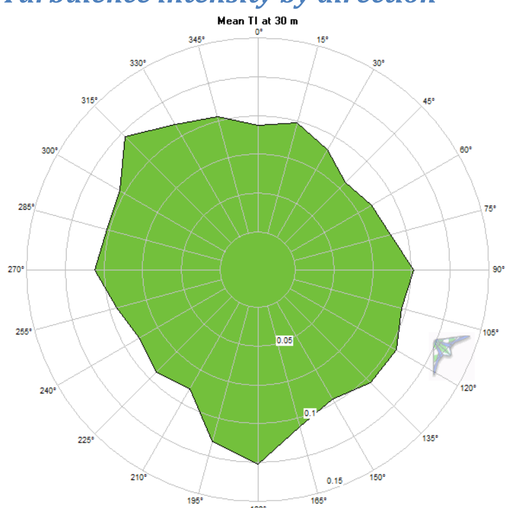
Turbulence intensity, all wind sectors



Turbulence intensity, northeast (prevailing) wind sector



Turbulence intensity by direction



Turbulence table

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	1,073	0.347	0.166	0.559	1.167
2	1.5	2.5	2,164	0.160	0.089	0.274	1.235
3	2.5	3.5	3,123	0.109	0.053	0.177	0.536
4	3.5	4.5	3,742	0.090	0.040	0.140	0.389
5	4.5	5.5	4,541	0.081	0.036	0.128	0.563

6	5.5	6.5	4,883	0.080	0.032	0.120	0.435
7	6.5	7.5	4,779	0.078	0.029	0.115	0.303
8	7.5	8.5	4,722	0.076	0.027	0.110	0.320
9	8.5	9.5	4,186	0.078	0.023	0.108	0.298
10	9.5	10.5	3,404	0.078	0.021	0.106	0.182
11	10.5	11.5	2,690	0.078	0.021	0.105	0.274
12	11.5	12.5	1,955	0.078	0.019	0.102	0.168
13	12.5	13.5	1,138	0.079	0.019	0.104	0.157
14	13.5	14.5	545	0.073	0.018	0.095	0.148
15	14.5	15.5	401	0.072	0.017	0.094	0.132
16	15.5	16.5	283	0.074	0.016	0.095	0.135
17	16.5	17.5	152	0.075	0.013	0.092	0.127
18	17.5	18.5	82	0.074	0.013	0.092	0.117
19	18.5	19.5	18	0.070	0.008	0.081	0.086
20	19.5	20.5	11	0.071	0.010	0.084	0.090
21	20.5	21.5	2	0.055	0.004	0.061	0.058
22	21.5	22.5	3	0.063	0.002	0.065	0.065
23	22.5	23.5	0				

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. Wainwright Airport (ICAO station identifier: PAWI) data was first collected in 1973 by an AWOS which was later upgraded to ASOS.

The AEA report documents data from AWOS/ASOS sensor, which is 8 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 0.142. 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/ASOS data. This would account for the higher wind class prediction of the met tower (high Class 4/low Class 5) over the airport data (low Class 4). There may be a number of reasons for this discrepancy, including closer proximity of the met tower to the coast and extrapolation errors in translating the eight meter airport data to thirty meters. Comparison discrepancies aside, the Wainwright airport data confirms the robust wind resource recorded by the met tower.

Airport/met tower data comparison

	Wainwright Airport		Met Tower, 30m B anem.	
	AWOS/ASOS, 8 m sensor (m/s)	Data adj. to 30 m (m/s)	Collected data (m/s)	Synthesized data (m/s)
Jan	5.50	6.64	7.78	7.19
Feb	5.00	6.03	7.98	8.11
Mar	5.30	6.39	7.55	6.76
Apr	5.30	6.39	6.27	6.19
May	5.40	6.51	7.48	7.32
Jun	4.70	5.67	7.97	7.98
Jul	5.10	6.15	7.03	7.02
Aug	5.20	6.27	6.39	6.39
Sep	4.70	5.67	6.21	6.21
Oct	4.90	5.91	7.68	7.80
Nov	4.60	5.55	5.88	6.00
Dec	4.80	5.79	6.46	6.62
Annual	5.04	6.08	7.05	6.97