Wind Resource Assessment For

Palmer UAF Experimental Wind Farm

Date Last Modified: 8/7/2013

By: Rich Stromberg & Holly Ganser

Site Summary

Station ID: 1402

Latitude: 61° 33’ 58.4” N

Longitude: 149° 14’ 30.96” W

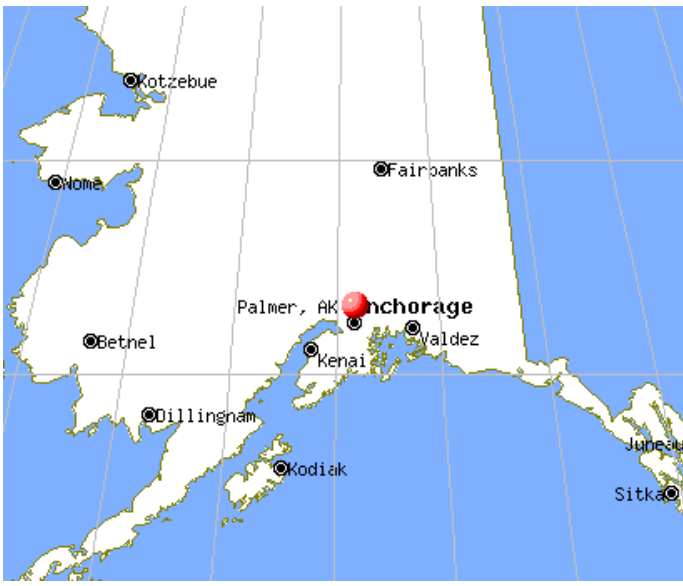
Tower Type: 30-meter NRG Tall Tower

Sensor Heights: Speed: 30m, 20m Dir: 30m Temp: 2m

Elevation: 61 m

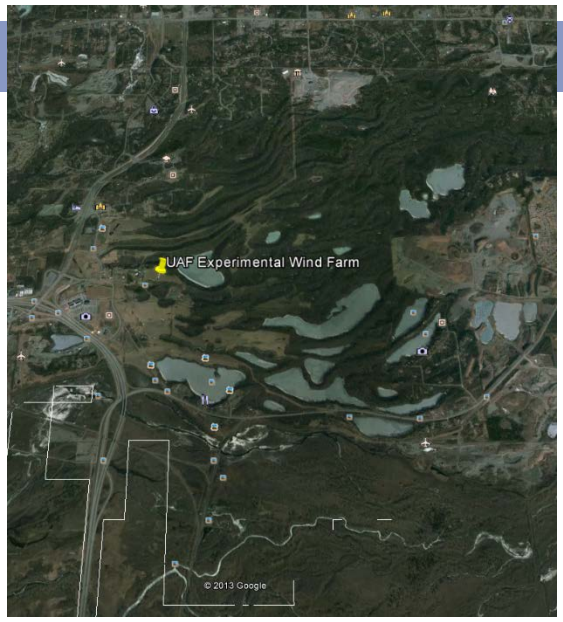
Monitor Start: October 30, 2005

Monitor End: April 18, 2012 (Jan. 12, 2010 / Nov. 30, 2010)



In October 2005, a 30-meter meteorological tower was built in Palmer on UAF land by AEA and UA faculty and students. The purpose of this monitoring effort is to evaluate the feasibility of utilizing wind energy in the area. This report summarizes the wind resource data collected and the long-term energy production potential of the site.

Wind Resource Summary



Annual Average Wind Speed (20m AGL): 2.875 m/s

Annual Average Wind Speed (30m AGL sensor A): 3.43 m/s

Annual Average Wind Speed (30m AGL sensor B): 3.35 m/s

Predicted by Wind Resource Model (30m AGL): 4.11 m/s–model over predicts

Annual Average Wind Speed (50m AGL calculated): 4.408

Average Wind Power Density (30 m height): 114.5 W/m^2

Average Wind Power Density (50m AGL calculated): 190 W/m^2

Wind Power Class (range= 1 to 7): 1

Rating (Poor, Marginal, Fair, Good, Excellent, Outstanding, Superb): Poor

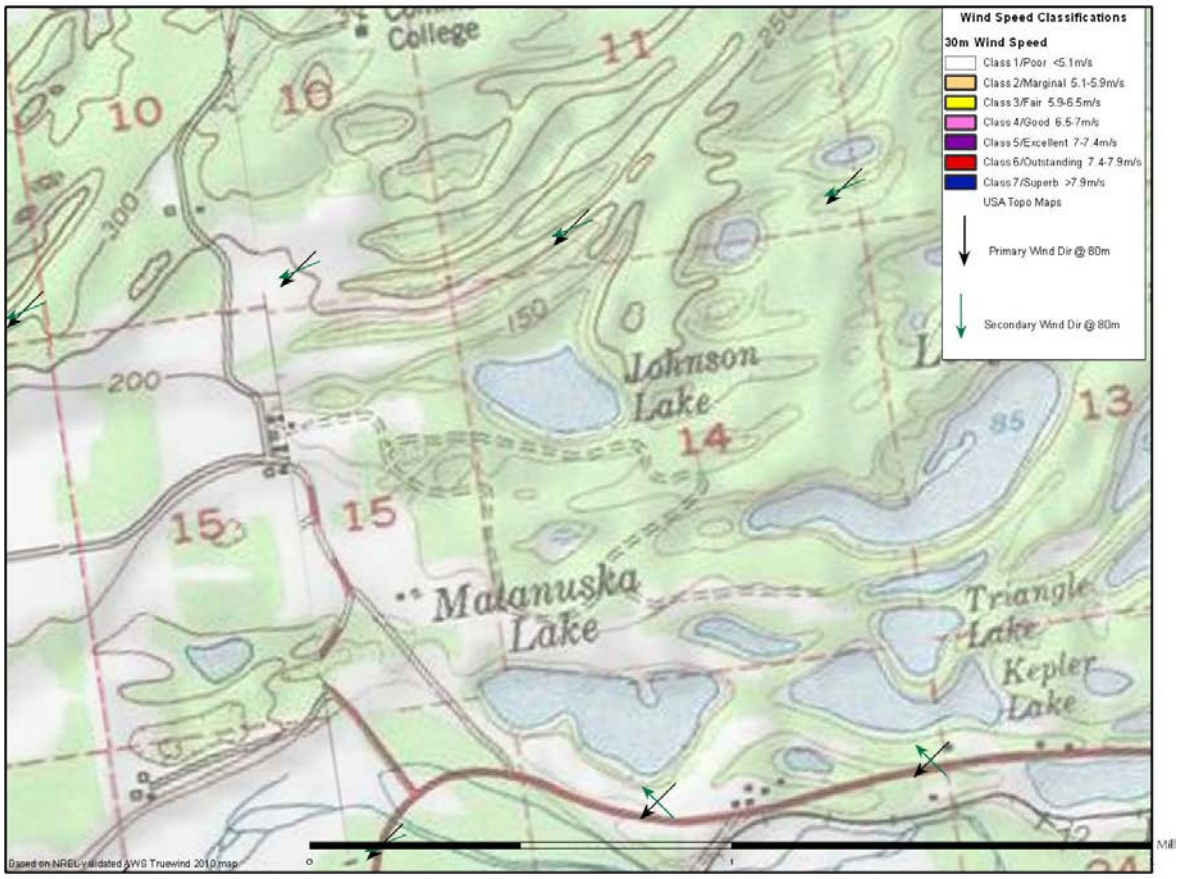
Prevailing Wind Direction: –Northeast model predicts northeast

Introduction

On initial review of the wind resource model, Palmer site appears to be a “poor” wind candidate. The wind resource model below predicts that the location is in an area that experiences Class 1 winds out of the north east. Areas of Class 4 and higher are considered suitable for utility-scale wind power development. The actual winds measured were Class 1 out of the northeast, which confirms the wind resource model. A low wind resource was found and turbulence at the met tower site is above desirable levels. This location is not recommended for wind energy development. Additional reconnaissance work should be conducted in the region to find a more suitable site.

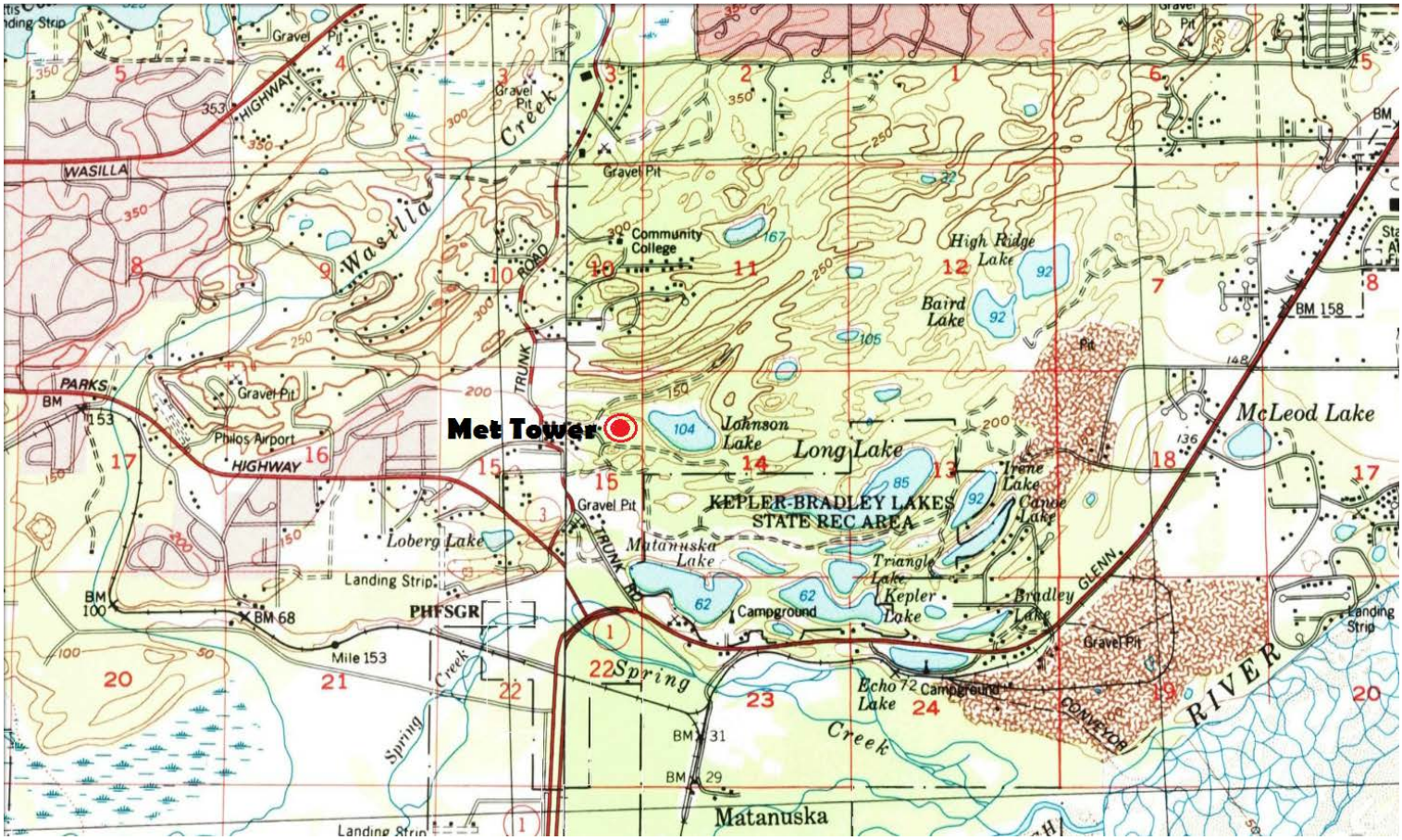
Palmer

AEA - Alaska Wind Speed Map



Site Description

Palmer is located in the Matanuska Valley, 42 miles northeast of Anchorage on the Glenn Highway. The 30-meter tall meteorological tower was constructed at 61° 33’ 58.4” N and 149° 14’ 30.96” W, on UAF owned land between Palmer and Wasilla. Below is the location of the met tower on a topographical map.



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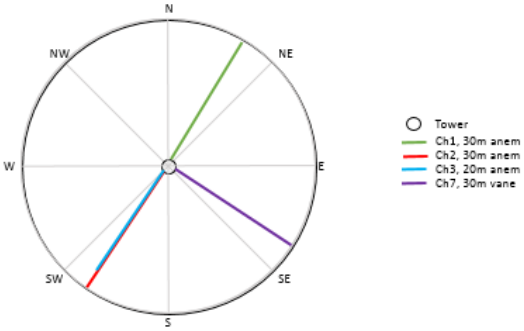
Site Description- continued

Construction of met tower by AEA and UAF faculty and students

The table below lists the data logger channels where each sensor is wired and the orientation that they are mounted on the tower. The layout of the sensor booms on the tower is also shown below.

Data Logger Channels

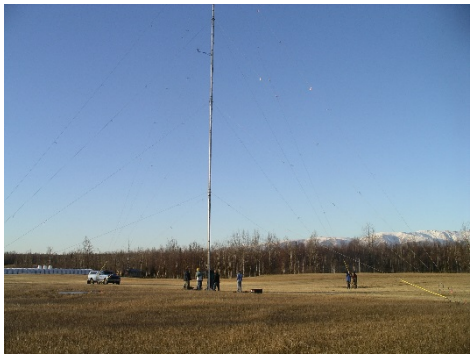
Ch #	Sensor Type	Height	Offset	Boom Orientation
1	#40 Anemometer	30m	NRG Standard	30° True
2	#40 Anemometer	30m	NRG Standard	210° True
3	#40 Anemometer	20m	NRG Standard	210° True
7	#200P Wind Vane	30m	315° True	120° True
9	#110S Temperature		NRG Standard	-



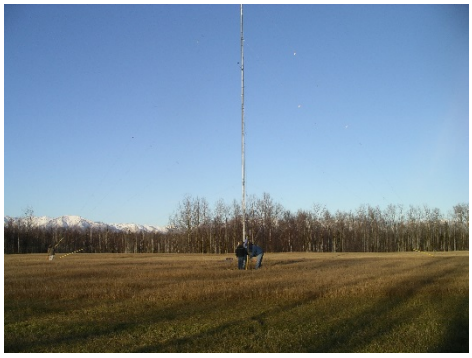
Layout of Sensor Booms

Site Description- continued

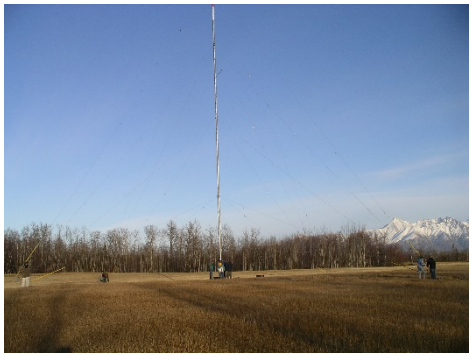
The photos below illustrate the surrounding ground cover and any major obstructions, which could have an effect on how the wind flows over the terrain from a particular direction. As shown, the landscape surrounding the met tower site is a relatively flat field surrounded by trees.



North West



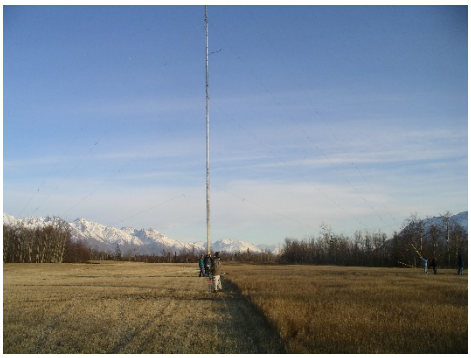
North



North East

West

Met Tower



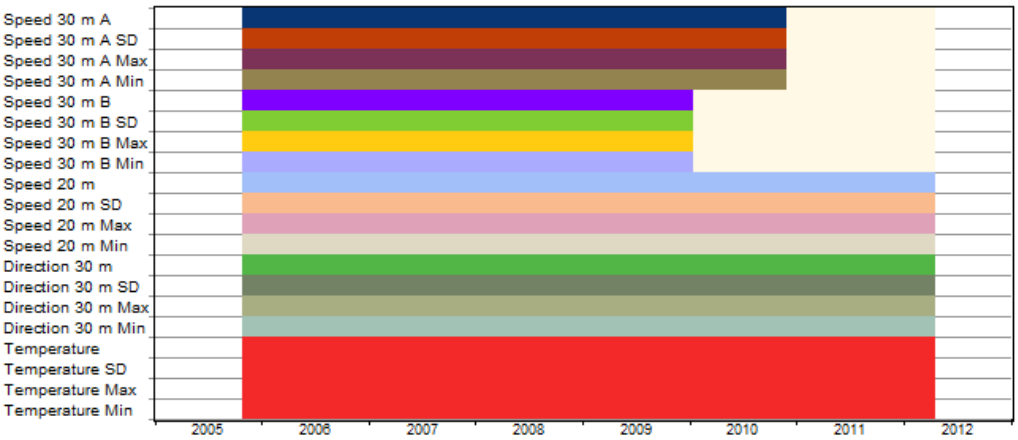
East

South West

South

South East

Raw Wind Data Recovery



Data Coverage Report

Wind data for the Palmer-UAF site was measured from October 30, 2005 to April 18, 2012. The data coverage report created by Windographer shows that 6.5 years of data was collected. After November 30th, 2010, the 30m A anemometer data was determined to be invalid. After January 12th, 2010, the 30m B anemometer data was also found to be invalid. The invalid data was not included in the analysis.

	Label	Units	Height	Possible Data Points	Valid Data Points	Recovery Rate (%)	Mean	Min	Max	Std. Dev
1	Speed 30 m A	m/s	30 m	340,200	267,126	78.52	3.278	0.400	24.000	3.063
2	Speed 30 m A SD	m/s	30 m	340,200	267,126	78.52	0.751	0.000	5.400	0.635
3	Speed 30 m A Max	m/s	30 m	340,200	267,126	78.52	5.220	0.400	39.000	4.685
4	Speed 30 m A Min	m/s	30 m	340,200	267,126	78.52	1.516	0.400	13.700	1.552
5	Speed 30 m B	m/s	30 m	340,200	220,758	64.89	3.178	0.400	23.100	2.933
6	Speed 30 m B SD	m/s		340,200	220,758	64.89	0.757	0.000	5.100	0.640
7	Speed 30 m B Max	m/s		340,200	220,758	64.89	5.15	0.40	38.60	4.62
8	Speed 30 m B Min	m/s		340,200	220,758	64.89	1.42	0.40	13.00	1.43
9	Speed 20 m	m/s	20 m	340,200	339,918	99.92	2.746	0.400	20.300	2.665
10	Speed 20 m SD	m/s	20 m	340,200	339,918	99.92	0.766	0.000	5.400	0.666
11	Speed 20 m Max	m/s	20 m	340,200	339,918	99.92	4.849	0.400	36.300	4.549
12	Speed 20 m Min	m/s	20 m	340,200	339,918	99.92	1.095	0.400	10.300	1.161
13	Direction 30 m	°	30 m	340,200	339,918	99.92	53.4	0.0	359.0	92.8
14	Direction 30 m SD	°	30 m	340,200	339,918	99.92	14.7	0.0	133.0	12.7
15	Direction 30 m Max	°	30 m	340,200	339,918	99.92	145.2	0.0	359.0	106.4
16	Direction 30 m Min	°	30 m	340,200	339,918	99.92	300.0	300.0	300.0	0.0
17	Temperature	°C	2 m	340,200	339,918	99.92	4.0	-32.3	31.5	11.2
18	Temperature SD	°C	2 m	340,200	339,918	99.92	0.1	0.0	3.9	0.1
19	Temperature Max	°C	2 m	340,200	339,918	99.92	4.2	-32.0	31.8	11.2
20	Temperature Min	°C	2 m	340,200	339,918	99.92	3.8	-33.2	31.2	11.2
21	Air Density	kg/m³		340,200	340,200	100.00	1.266	1.149	1.454	0.052
22	Speed 30 m A TI			340,200	267,126	78.52	0.26	0.00	1.56	0.16
23	Speed 20 m TI			340,200	339,918	99.92	0.30	0.00	1.56	0.16
24	Speed 30 m A WPD	W/m²		340,200	267,126	78.52	114	0	9,153	396
25	Speed 30 m B WPD	W/m²		340,200	220,758	64.89	102	0	8,161	348
26	Speed 20 m WPD	W/m²		340,200	339,918	99.92	74	0	5,505	254

Data Summary

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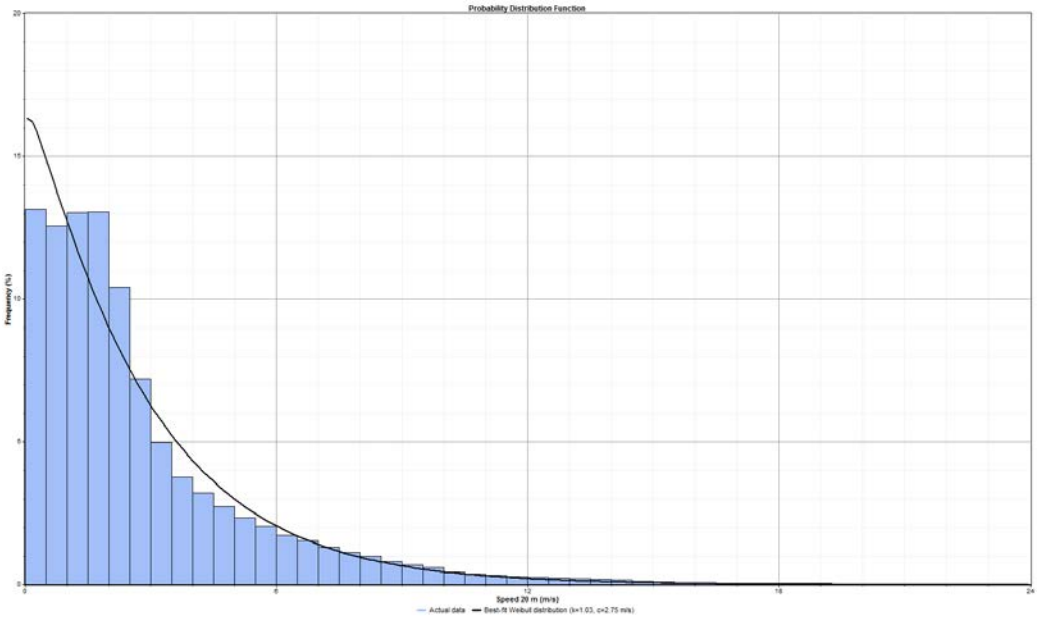
Raw Wind Data Recovery - Continued

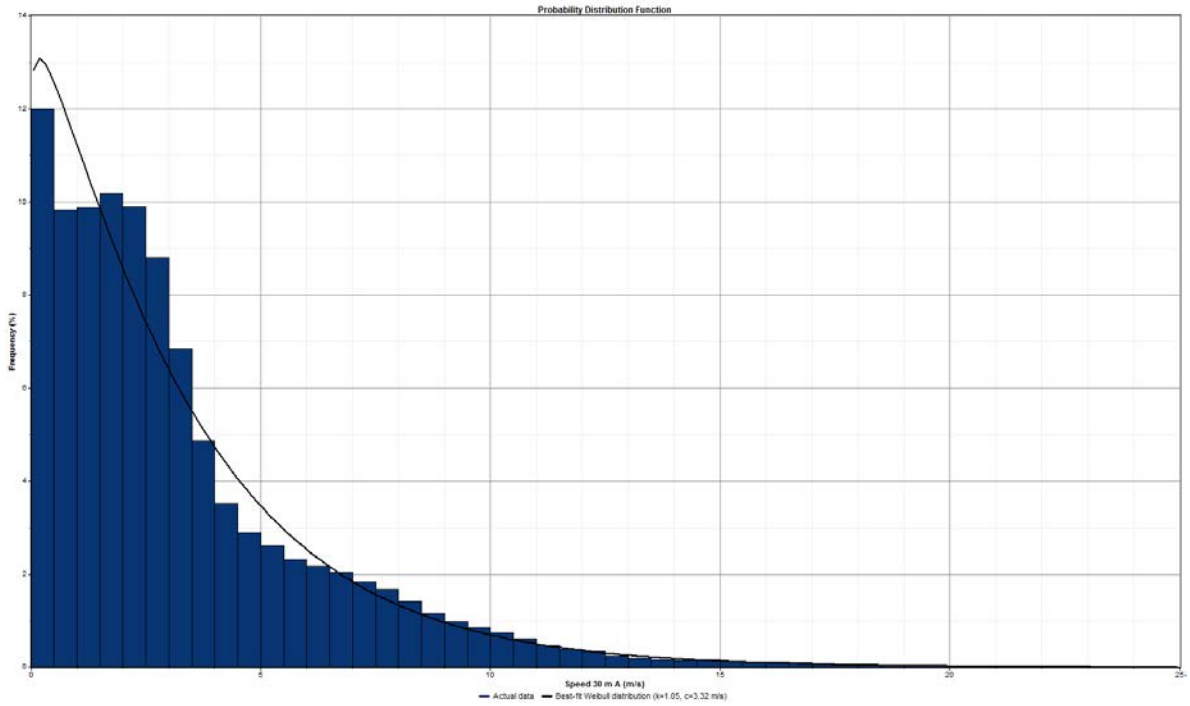
The wind speed summary and probability distribution function chart show the distribution of the raw data for each anemometer. At initial review the data for the 30 meter anemometers show higher frequencies of zero wind speeds. This indicates that there are areas in the data set that need to be filtered for icing conditions or other areas of invalid/questionable data.

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20
Mean wind speed (m/s)	3.277	3.177	2.745
MoMM wind speed (m/s)	3.273	3.170	2.726
Median wind speed (m/s)	2.400	2.300	1.900
Min wind speed (m/s)	0.400	0.400	0.400
Max wind speed (m/s)	24.000	23.100	20.300
Weibull k	1.049	1.052	1.031
Weibull c (m/s)	3.316	3.215	2.753
Mean power density (W/m²)	114	102	74
MoMM power density (W/m²)	113	99	71
Mean energy content (kWh/m²/yr)	1,002	890	647
MoMM energy content (kWh/m²/yr)	989	863	623
Energy pattern factor	5.112	4.978	5.615
Frequency of calms (%)	12.00	12.85	13.13
Possible data points	340,200	340,200	340,200
Valid data points	267,126	220,758	339,918
Missing data points	73,074	119,442	282
Data recovery rate (%)	78.52	64.89	99.92

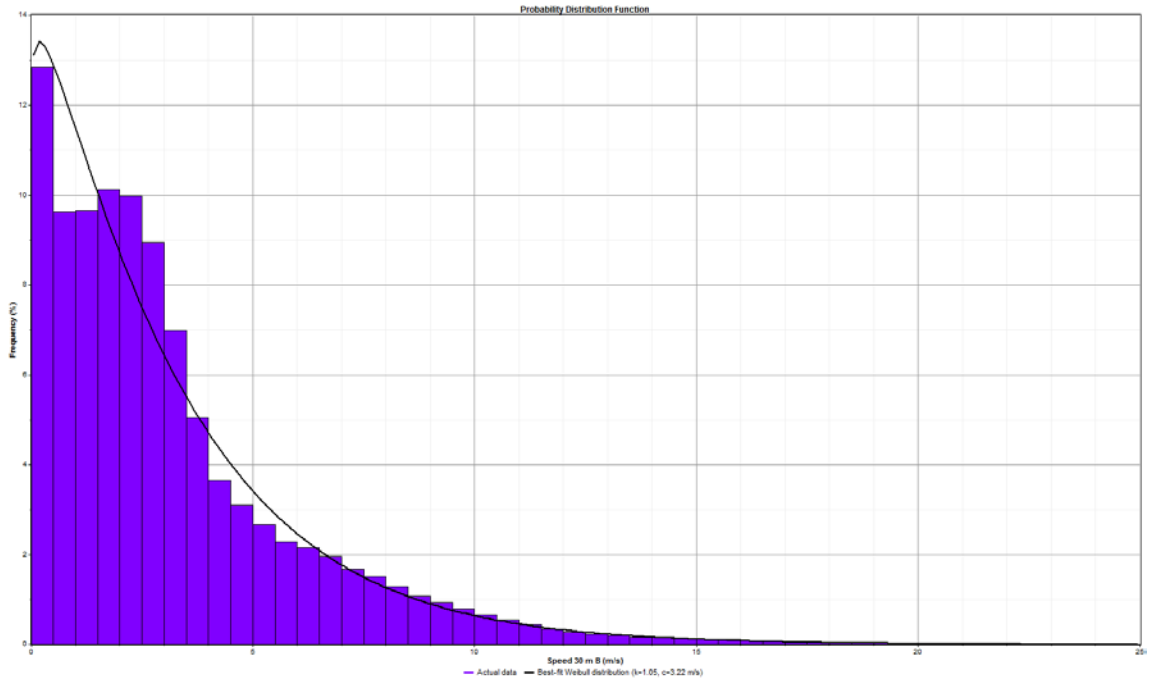


Probability Distribution Function of the 20m anemometer

Raw Wind Data Recovery - Continued



Probability Distribution Function of the 30m A anemometer

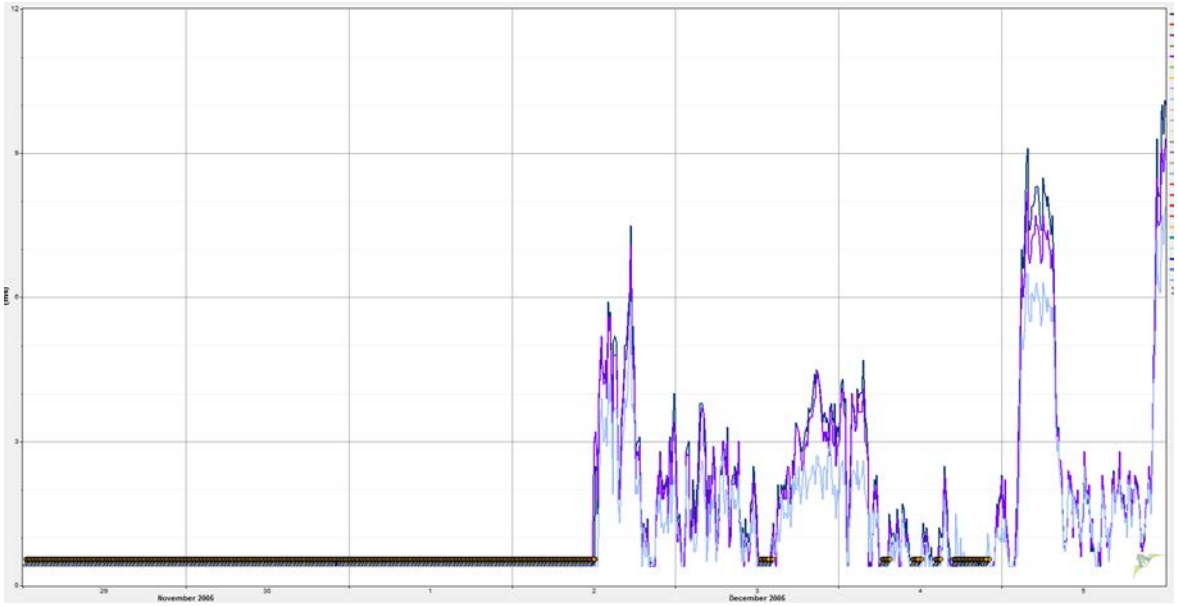


Probability Distribution Function of the 30m B anemometer

Wind Speed Data – Flagging Data

Once the data set was filtered for invalid data points and icing occurrences, the high number of zero wind occurrences was reduced. Rules were created to flag icing events. These rules included flagging the anemometer data anytime the temperature was below 5° C, the standard deviation of the anemometer was equal to zero and the speed was less than 0.5 m/s. Even after the icing rules filtered out the data, the 30m B anemometer still showed high occurrences of zero. Another rule was applied that flagged 30m B data when the temperature was above 5°C, the standard deviation equaled zero, and the speed was less than 0.5m/s for at least 3 hours. After the rules were applied, it was found that approximately 5% of each anemometer data set was flagged for icing. There were numerous incidences where icing occurred over several days.

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20
Mean wind speed (m/s)	3.431	3.345	2.875
MoMM wind speed (m/s)	3.443	3.343	2.866
Median wind speed (m/s)	2.500	2.500	2.000
Min wind speed (m/s)	0.400	0.400	0.400
Max wind speed (m/s)	24.000	23.100	20.300
Weibull k	1.146	1.162	1.120
Weibull c (m/s)	3.591	3.515	2.988
Mean power density (W/m²)	121	108	78
MoMM power density (W/m²)	123	108	78
Mean energy content (kWh/m²/yr)	1,056	943	683
MoMM energy content (kWh/m²/yr)	1,077	946	682
Energy pattern factor	4.691	4.524	5.155
Frequency of calms (%)	7.30	7.61	8.31
Possible data points	340,200	340,200	340,200
Valid data points	253,589	208,235	322,029
Missing data points	86,611	131,965	18,171
Data recovery rate (%)	74.54	61.21	94.66



Sample of the data that was flagged for icing conditions with temperature data.

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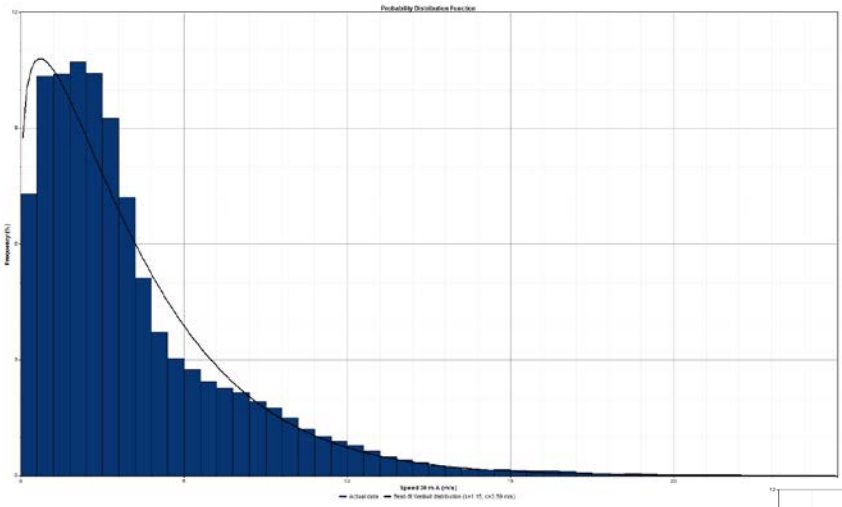
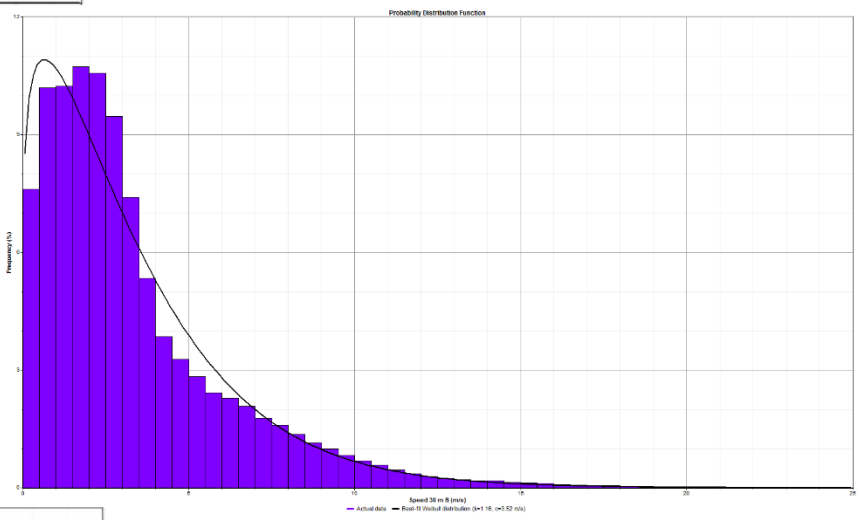
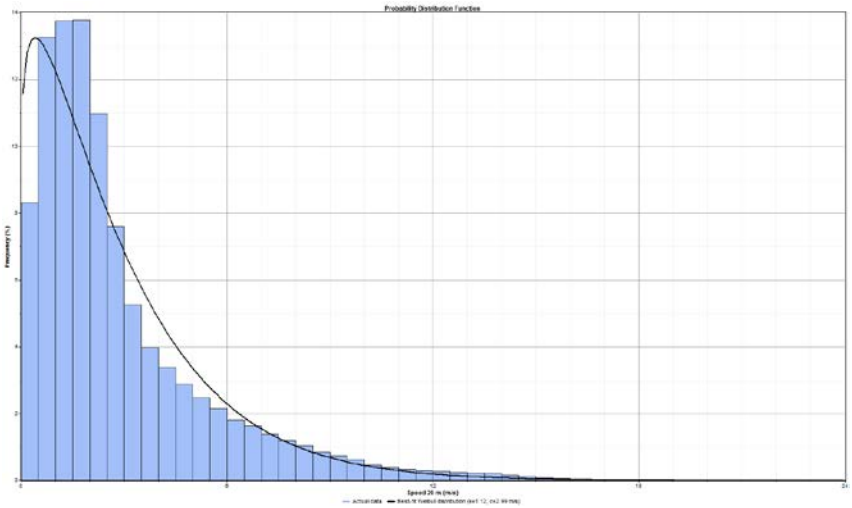
Wind Speed Data – Flagging Data Continued



Probability Distribution Function of the 30m A anemometer



Probability Distribution Function of the 30m B anemometer

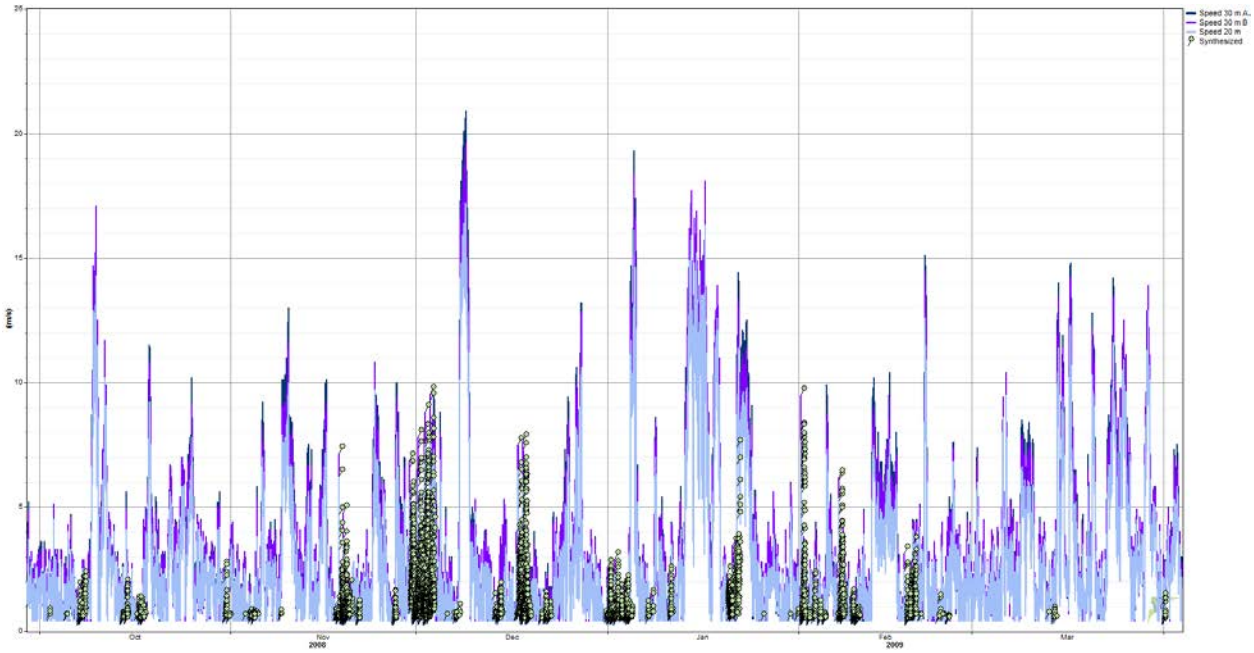


Probability Distribution Function of the 20m anemometer

Wind Speed Data – Synthesized Data

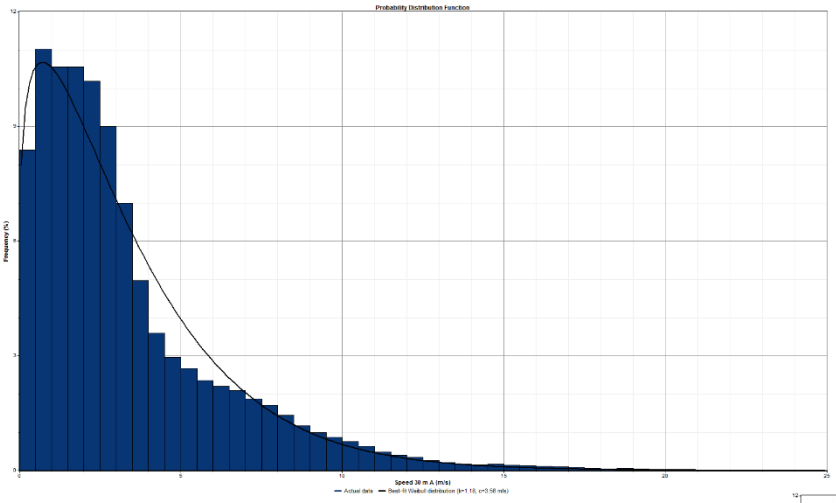
After the data was flagged for icing, it was deleted and synthesized to fill in the gaps. The resulting summary and probability distribution functions can be found below. The resulting mean wind speeds of each anemometer are lower than that of the flagged data. The synthesized data was not used in the analysis unless otherwise indicated.

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20
Mean wind speed (m/s)	3.354	3.250	2.823
MoMM wind speed (m/s)	3.348	3.234	2.803
Median wind speed (m/s)	2.400	2.400	1.900
Min wind speed (m/s)	0.294	0.294	0.232
Max wind speed (m/s)	24.000	23.100	20.300
Weibull k	1.178	1.184	1.161
Weibull c (m/s)	3.564	3.459	2.992
Mean power density (W/m²)	118	106	76
MoMM power density (W/m²)	116	102	74
Mean energy content (kWh/m²/yr)	1,030	925	669
MoMM energy content (kWh/m²/yr)	1,019	895	651
Energy pattern factor	4.894	4.828	5.329
Frequency of calms (%)	7.72	8.38	9.20
Possible data points	340,200	340,200	340,200
Valid data points	265,759	221,112	333,958
Missing data points	74,441	119,088	6,242
Data recovery rate (%)	78.12	64.99	98.17

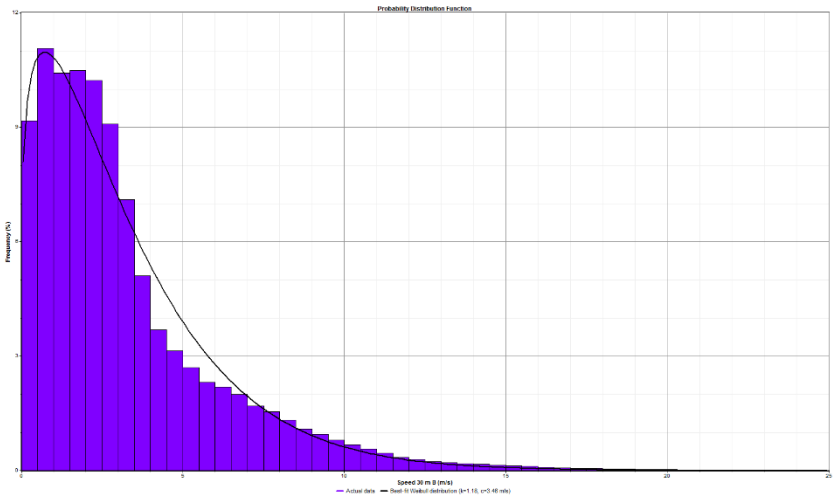


Example of Synthesized Data

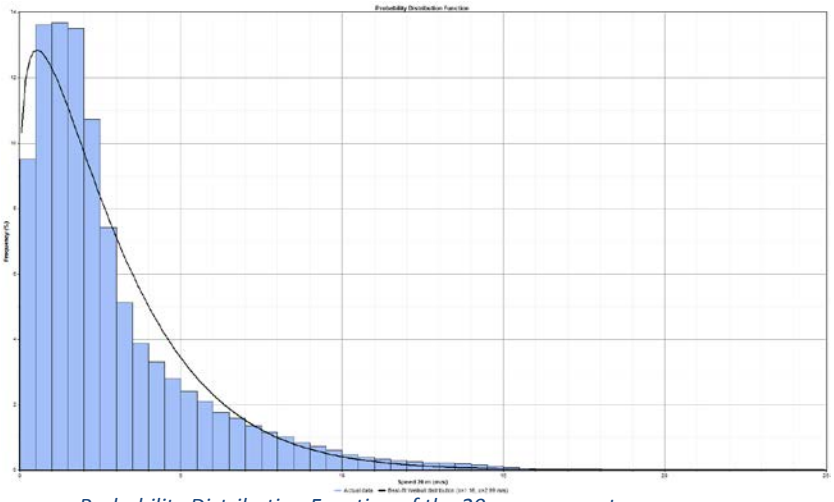
Wind Speed Data – Synthesized Data Continued



Probability Distribution Function of the 30m A anemometer



Probability Distribution Function of the 30m B anemometer

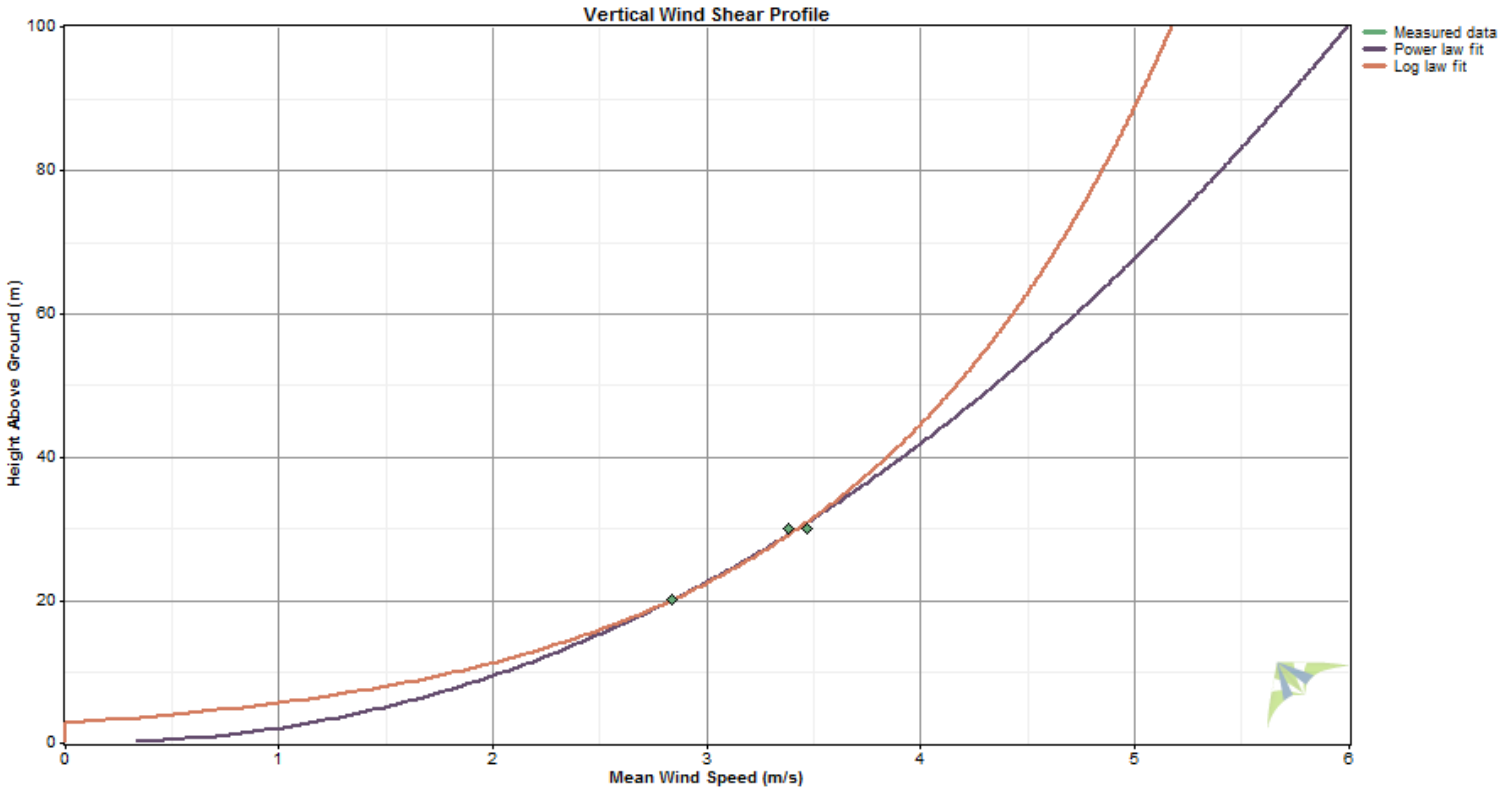


Probability Distribution Function of the 20m anemometer

Wind Speed Data – Analysis

The flagged data produced a power density at 50m of 190 W/m^2. At this density the wind power class is a class 1 or poor winds. Windographer calculated a power law exponent of 0.464 and a surface roughness of 2.82m. The wind shear is high when compared to a **typical** power law exponent value of 0.14. From this wind shear value, the mean wind speed for heights that were not measured can be estimated. The *estimated* mean wind speed for heights up to 100m can be found below.

Wind power coefficients	
Power density at 50m:	190 W/m²
Wind power class:	1 (Poor)
Wind shear coefficients	
Power law exponent:	0.464
Surface roughness:	2.82 m
Roughness class:	4.77



Wind Speed Data – Analysis Continued

The synthesized data produced a power density at 50m of 178 W/m^2, which was lower than with the power density of the flagged data. Windographer calculated the same power law exponent of 0.464 and a surface roughness of 2.82m as with the flagged data.

Wind power coefficients	
Power density at 50m:	178 W/m²
Wind power class:	1 (Poor)
Wind shear coefficients	
Power law exponent:	0.464
Surface roughness:	2.82 m
Roughness class:	4.77

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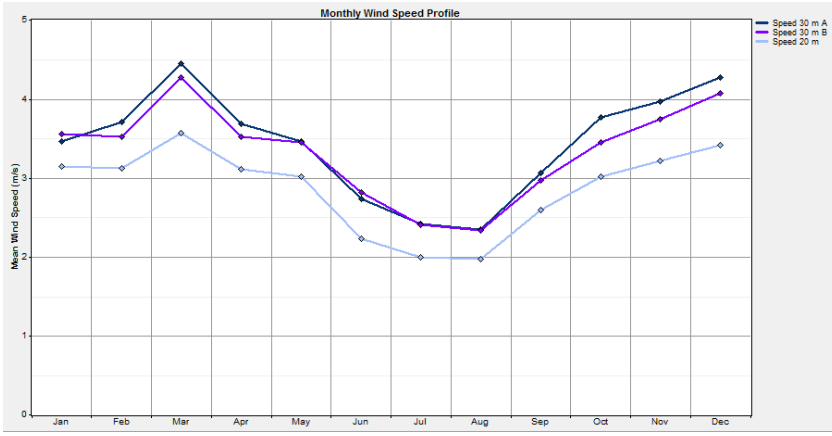
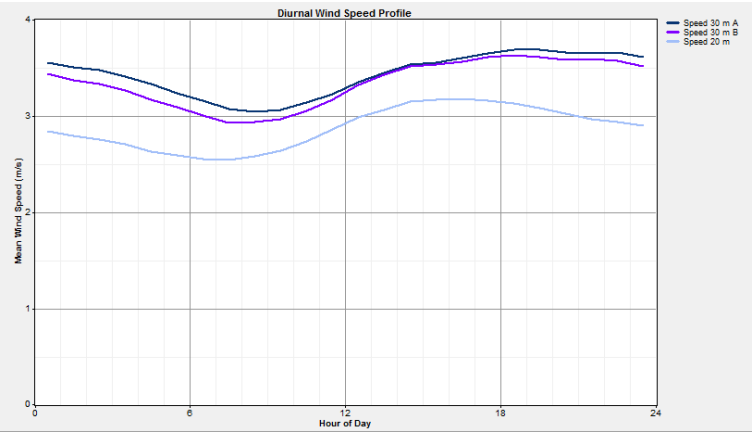
Wind Speed Data – Analysis Continued

The monthly wind speed profile follows the common pattern of wind speeds that are higher in the winter months than the summer months. The diurnal wind speed profile indicates that the UAF-Palmer site experiences average wind speeds from 2.6 m/s to 3.5 m/s in the morning which increase to speeds of 3.6 m/s at 6pm. This diurnal pattern is true up to 40m. At heights of 50m and higher the pattern may be inverted with stronger winds at nighttime. The wind shear analysis by month reveals that in August the surface roughness was the highest at 4.34. August also has the highest power law exponent and it recorded the lowest mean wind speeds.



Monthly Wind Speed Profile



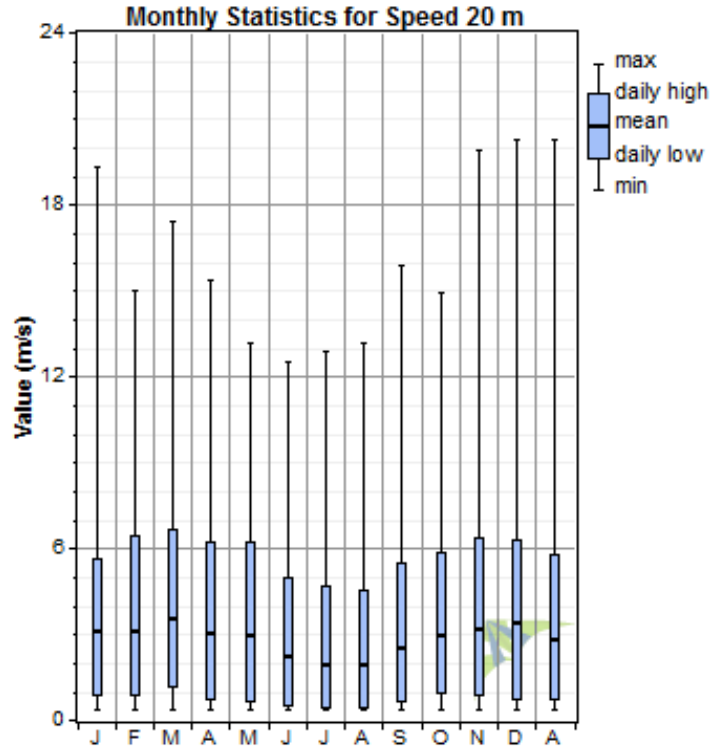
Diurnal Wind Speed Profile

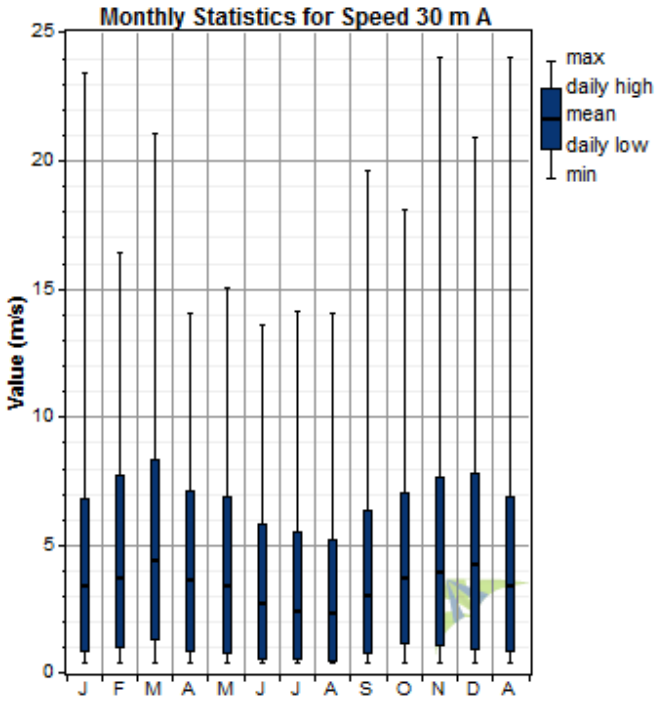
Month	Time Steps	Mean Wind Speed (m/s)			Best-Fit	
		Speed 30 m A	Speed 30 m B	Speed 20 m	Power Law Exp	Surface Roughness (m)
Jan	13,844	3.851	3.729	3.087	0.506	3.365678
Feb	14,822	3.741	3.630	3.024	0.488	3.130212
Mar	17,684	4.385	4.276	3.657	0.417	2.209133
Apr	16,816	3.539	3.551	3.052	0.369	1.621462
May	17,837	3.476	3.456	3.009	0.349	1.384671
Jun	17,280	2.840	2.813	2.436	0.367	1.592997
Jul	17,796	2.450	2.411	2.053	0.416	2.206267
Aug	17,856	2.402	2.331	1.870	0.581	4.340787
Sep	17,190	3.022	2.977	2.435	0.514	3.479962
Oct	16,998	3.643	3.515	2.885	0.532	3.709431
Nov	18,671	3.979	3.789	3.151	0.515	3.494490
Dec	18,166	4.429	4.210	3.483	0.531	3.700830

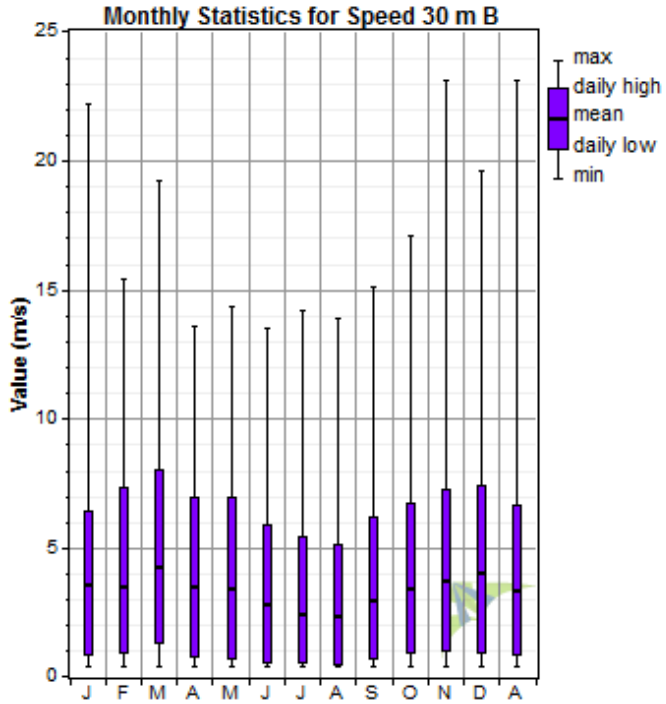
Monthly Wind Shear Analysis

Wind Speed Data – Analysis Continued

The monthly statistics boxplots for each anemometer indicate the mean, daily high, daily low, maximum, and minimum wind speeds for each month. November had the highest recorded wind speed for the 30m anemometers at approximately 23 m/s, while December recorded the highest for the 20m anemometer at approximately 20 m/s. Across all the anemometers March had the highest mean wind speeds around 4 m/s.







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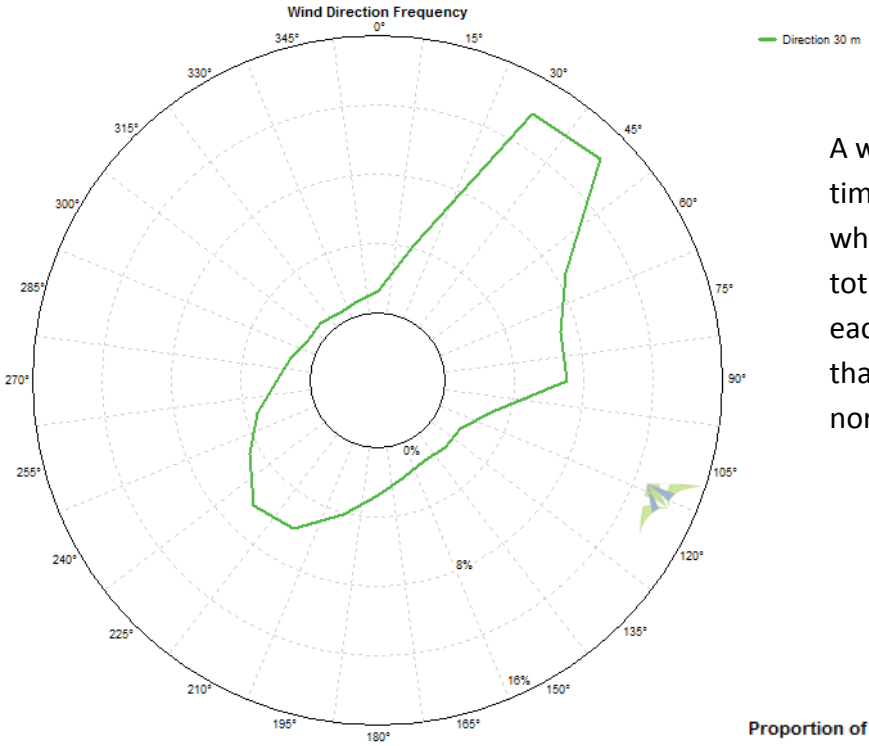
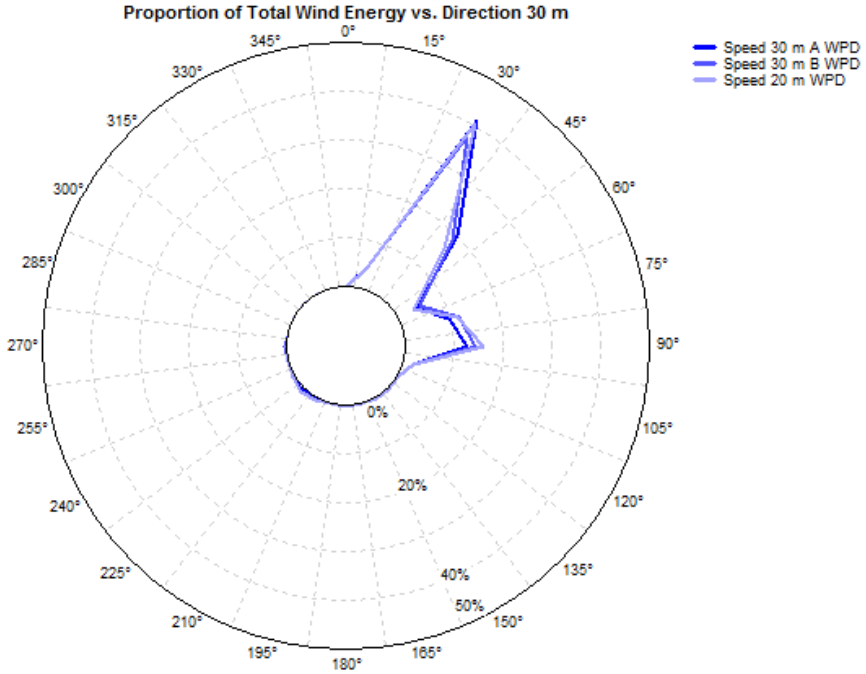
Wind Direction and Energy Production



Wind Frequency Rose

A wind frequency rose shows the percent of the time that the wind blows from each direction, while the wind power roses show the percent of total power that is available in the wind from each direction. The wind direction rose shows that the primary wind directions are from the northeast and southwest.

The wind energy rose shows the proportion of energy generated by the wind from each direction. The total wind energy rose shows that for about 40% of the time energy is generated from 30° and 15% of the time the energy comes from 90°.



Total Wind Energy Rose

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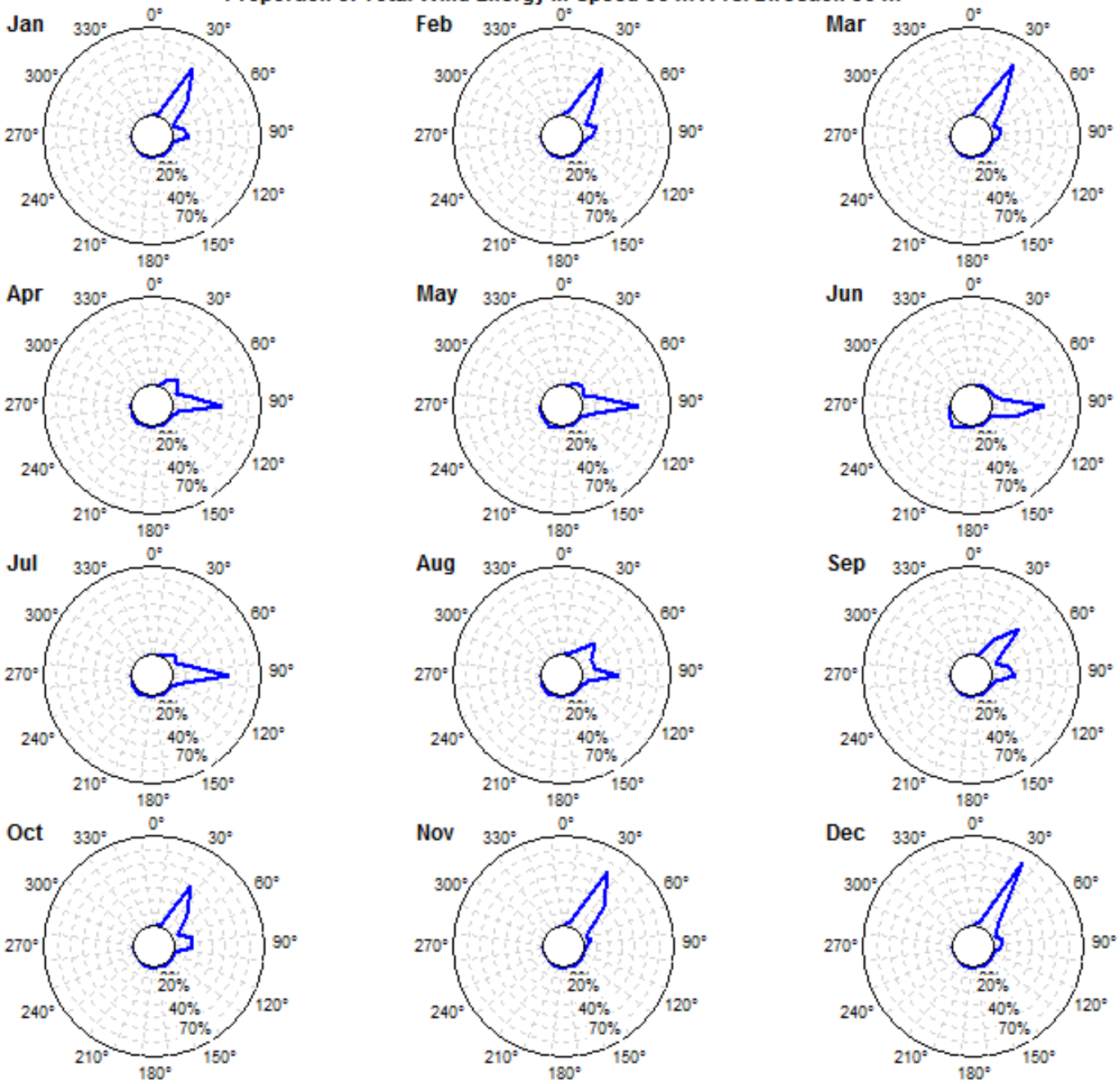
Wind Direction and Energy Production Continued

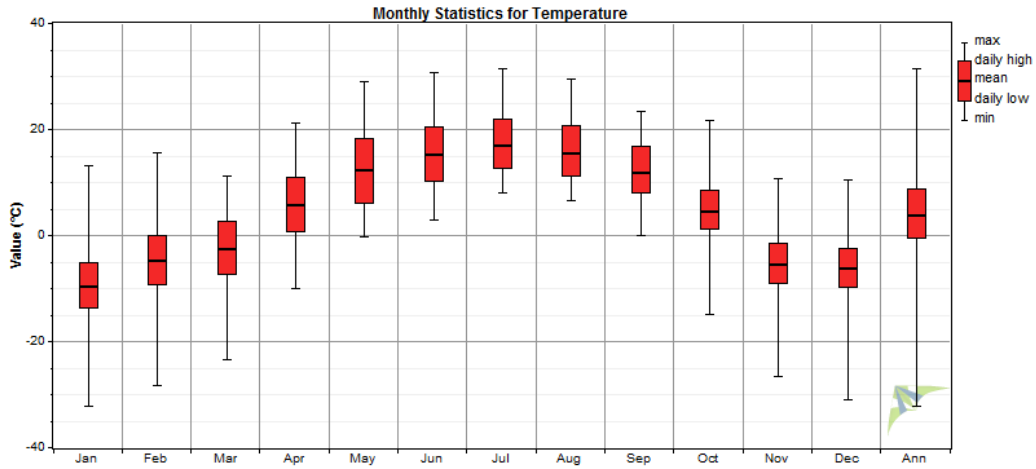
The monthly wind energy charts indicate that for the winter months of January, February, March, October, November, and December the primary wind energy is generated from 30°. While in April, May, June, July, and August the primary wind energy direction is 90°. In September, the primary wind direction is from 45°.

Proportion of Total Wind Energy in Speed 30 m A vs. Direction 30 m



Temperature

Temperature was measured over the entire monitoring period. A box plot of the monthly averages with each month's maximum and minimum can be found below. The mean for the 6.5 years of observation was 3.97°C (39.15°F). The mean air pressure is 100.5kPa and the mean air density is 1.266 kg/m^3, which is 1.033% denser than the standard of 1.225 kg/m^3.



Extreme Winds

The 50 year wind extreme (V_{ref}) was calculated using the 10 minute mean wind speed. Three different algorithms were used to calculate the V_{ref}, the Periodic Maxima (using 1 month maximums), the Method of independent Storms, and the European Wind Turbine Standards II (EWTS II) algorithm. The resulting V_{ref} for each algorithm can be found in the table below. This would allow an IEC Class IV wind turbine. It is important to note that extreme winds are best calculated using multiple years' worth of data. Continued monitoring of wind sites is recommended to calculate more accurate extreme winds.

Method	Vref (50 yr) (m/s)
Periodic Maxima	33.287
Method of Independent Storms	28.149
EWTS II (Exact)	35.924
EWTS II (Gumbel)	36.123
EWTS II (Davenport)	37.151

Extreme Wind Calculations

IEC Wind Turbine Classes								
Wind Speed Parameters for Wind Turbine Classes								
	I	II	III	IV				
Reference Wind Speed, U_{ref} (m/s)	50	42.5	37.5	30				
Annual Average Wind Speed U_{ave} (m/s)	10	8.5	7.5	6				
50-year Return Gust Speed, 1.4 U_{ref} (m/s)	70	59.5	52.5	42				
1-year Return Gust Speed, 1.05 U_{ref} (m/s)	52.5	44.6	39.4	31.5				
Notes: 10-minute averages, hub height wind speed. Air density: 1.225 kg/m3.								
Turbulence Intensity Classes	I		II		III		III	IV
	A	B	A	B	A	B	A	B
I_{15} (Turbulence Intensity at 15 m/s)	18%	16%	18%	16%	18%	16%	18%	16%
a	2	3	2	3	2	3	2	3
I_u (Turbulence Intensity)	0.210	0.180	0.226	0.191	0.240	0.200	0.270	0.220
I_u (Turbulence Intensity) = $I_{15}(a=15/U_{ave})/(a+1)$								
Source: IEC 61400-1; cited in Wind Energy Handbook, Tony Burton, et al, John Wiley & Sons UK), 2001, ISBN: 0-471-48997-2, p. 210.								
Caution: Verify with current IEC 61400-1 for all parameters and criteria.								

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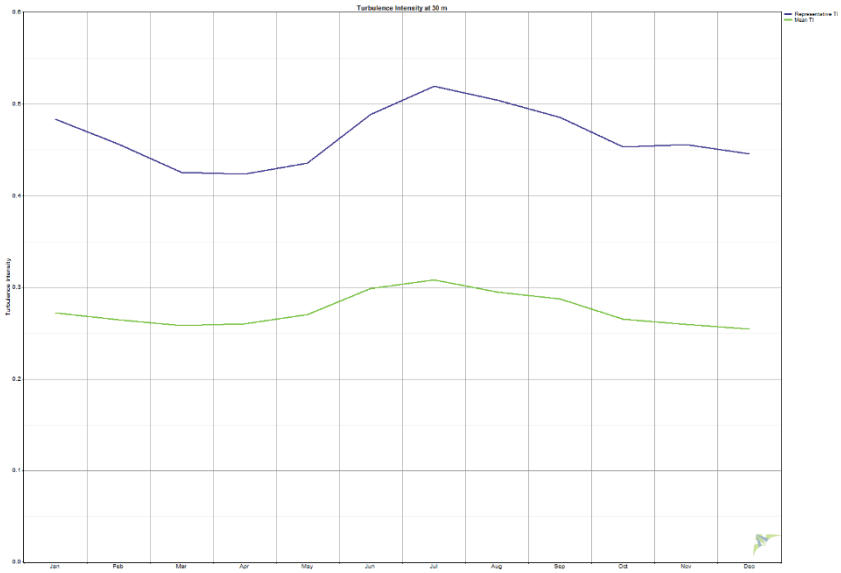
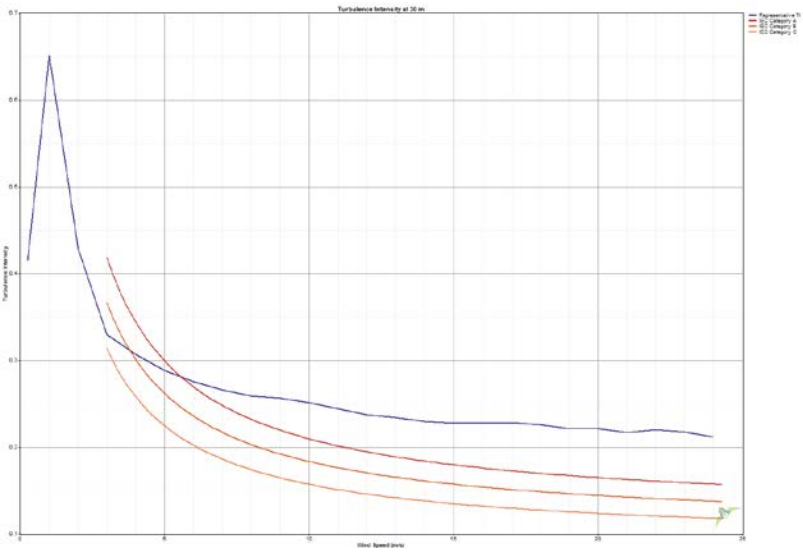
Wind Turbulence

Analysis of the turbulence intensity (TI) indicated that the met tower was in a location that exceeds] IEC standard 61200-1 3rd ed. (IEC3) turbulence category A. With low wind regimes, sometimes the turbulence intensity calculates at a high level. It is possible that the TI value would be in a more acceptable range if a class 4 or higher wind site could be found in the region.

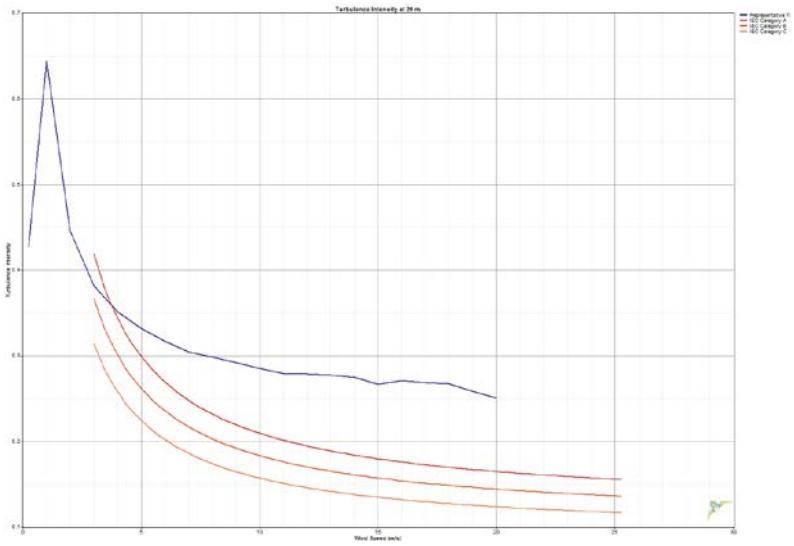
Quantity	Value
Data points in 15 m/s bin	772
Mean TI at 15 m/s	0.20
Representative TI at 15 m/s	0.23
IEC3 turbulence category	S



30m Turbulence Intensity by Month



30m Turbulence Intensity and Wind Speed



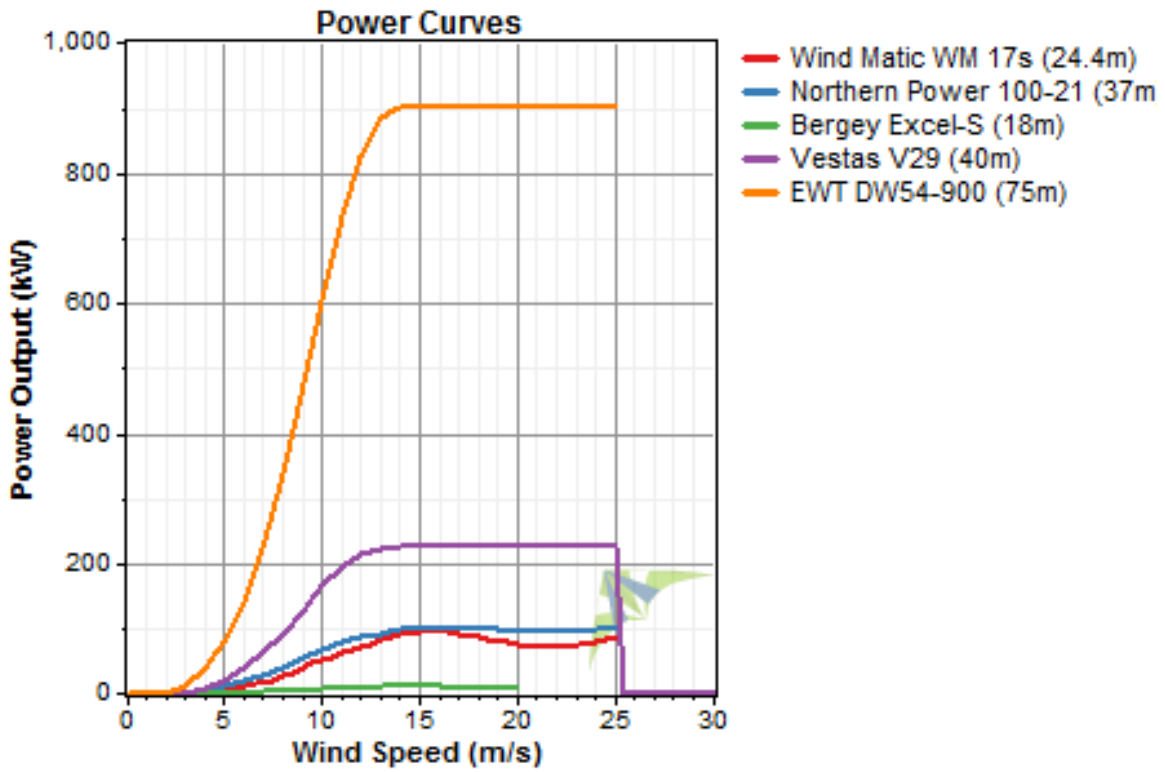
20m Turbulence Intensity and Wind Speed

Estimated Turbine Outputs

Five wind turbines were used in the comparison of the estimated wind turbine output. The wind turbines were selected because of their previous success in Alaska. In order to calculate the outputs at the individual turbine hub heights, Windographer used synthesized wind speed data calculated from the wind shear value for each time step in the data set. The resulting outputs can be found below. The power curves for each of the 5 compared turbines can also be found below. The net capacity factor assumes total turbine losses of availability, icing, array effects and other factors to be 18 percent. Thus, the net CF is 82% of the gross CF.

Turbine	Valid Time Steps	Hub Height Wind Speed (m/s)	Percentage Of Time At Zero Power	Percentage Of Time At Rated Power	Simple Mean Net Power (kW)	Simple Mean Net AEP (kWh/yr)	Simple Mean NCF (%)	Mean of Monthly Means Net Power (kW)	Mean of Monthly Means Net AEP (kWh/yr)	Mean of Monthly Means NCF (%)
Wind Matic WM 17s (24.4m)	326,192	3.12	65.12	0.87	5.2	45,126	5.42	5.1	44,537	5.35
Northern Power 100-21 (37m)	326,192	3.80	37.63	2.27	10.5	91,901	10.49	10.4	90,815	10.37
Bergey Excel-S (18m)	326,192	2.72	53.12	0.92	0.5	4,501	5.14	0.5	4,447	5.08
Vestas V29 (40m)	326,192	3.94	35.89	2.55	25.2	220,478	11.19	24.9	217,907	11.06
EWT DW54-900 (75m)	326,192	5.44	28.02	6.06	163.1	1,429,034	18.13	161.7	1,416,779	17.97

Estimated Turbine Output Summary Chart



Power Curves of Turbines

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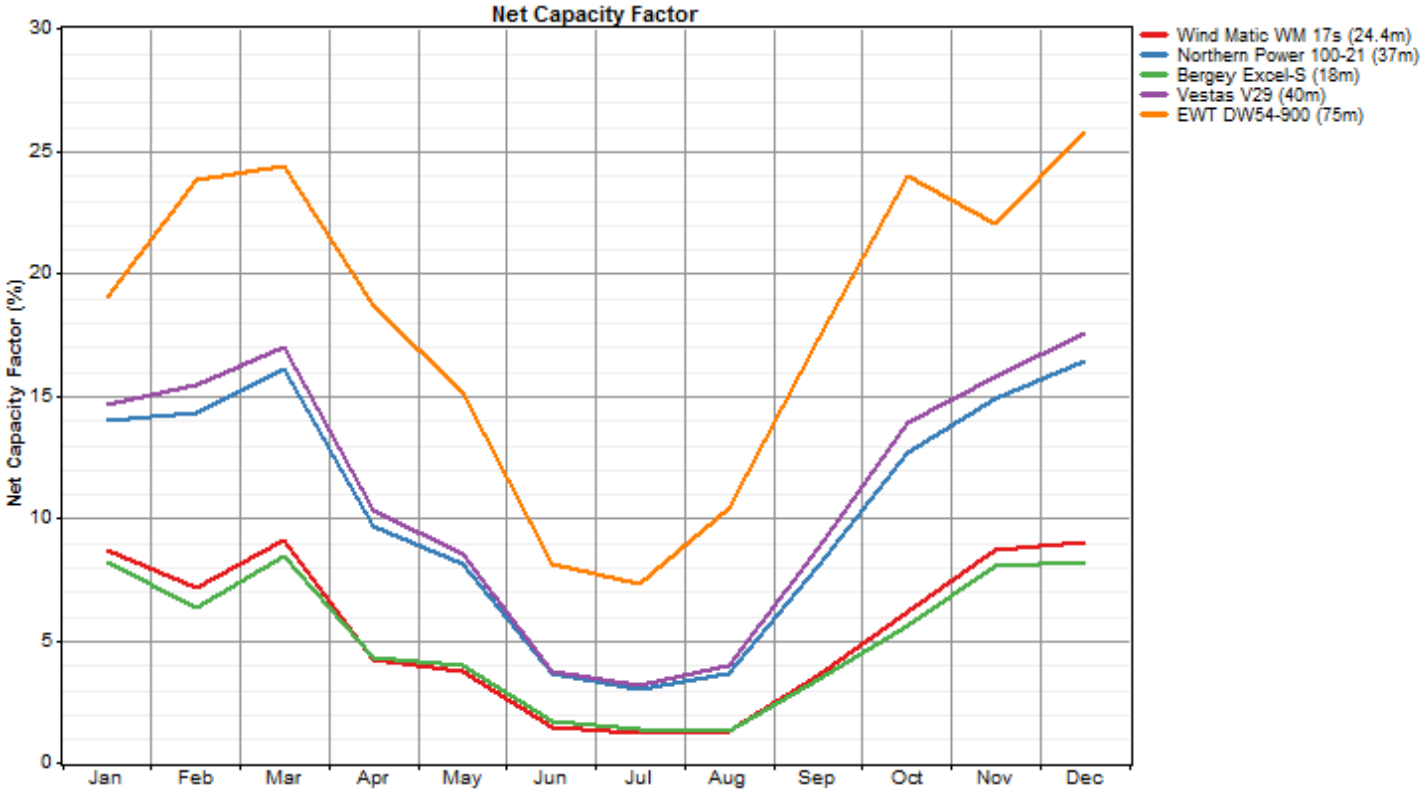
Estimated Turbine Outputs Continued

The net capacity factor graph shows the estimated monthly capacity factor of each of the compared turbines.



Net Capacity Factor by Month

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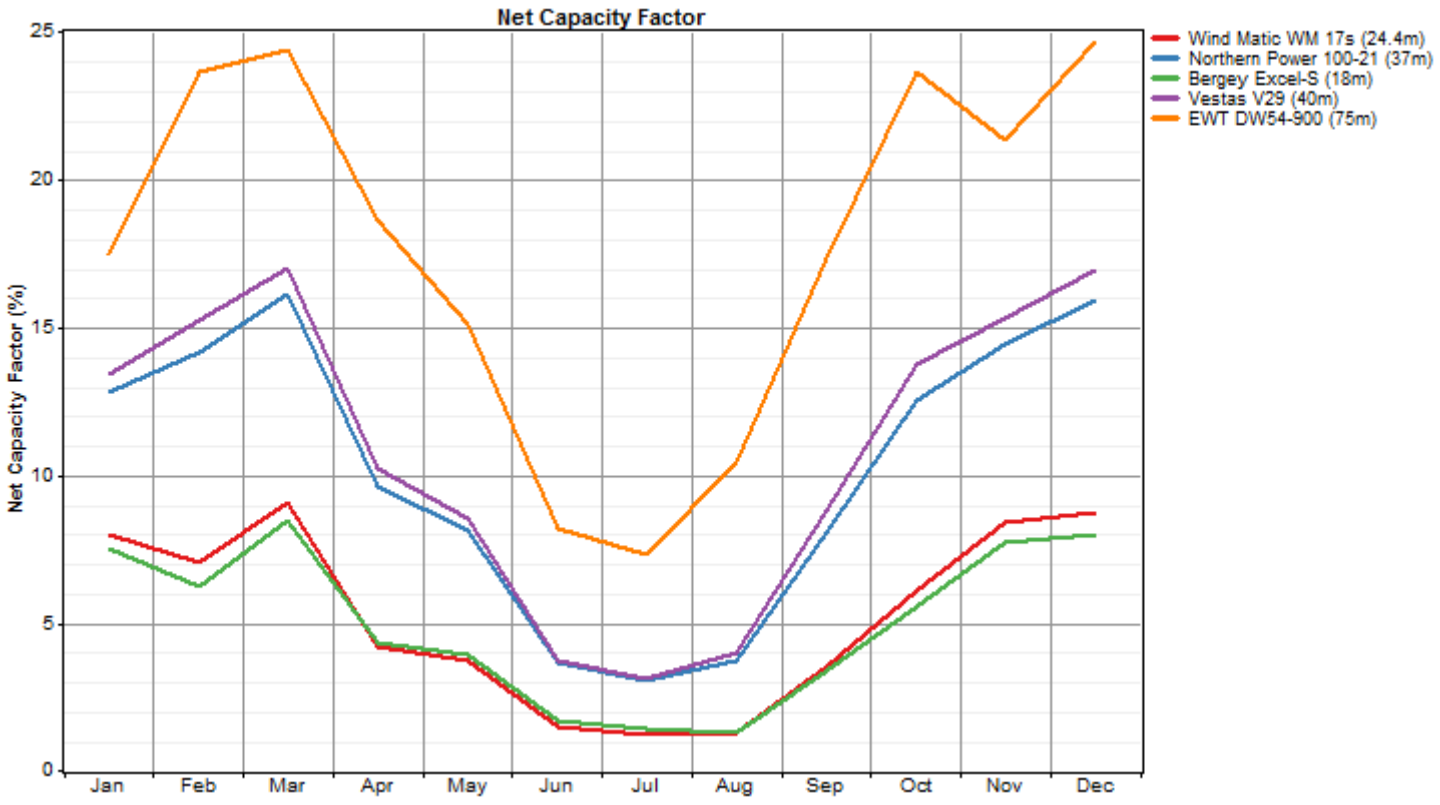
Estimated Turbine Outputs Continued

The output for the five turbines was estimated again using the synthesized data. This allows for a comparison between the outputs with icing and without icing. The same turbines and conditions were used in each estimate. It can be noted that the net capacity factors for the synthesized data is slightly lower than the net capacity factors of the flagged data. While the percentage of time a zero power is higher for the synthesized data than that of the flagged data.

Turbine	Valid Time Steps	Hub Height Wind Speed (m/s)	Percentage Of Time At Zero Power	Percentage Of Time At Rated Power	Simple Mean Net Power (kW)	Simple Mean Net AEP (kWh/yr)	Simple Mean NCF (%)	Mean of Monthly Means Net Power (kW)	Mean of Monthly Means Net AEP (kWh/yr)	Mean of Monthly Means NCF (%)
Wind Matic WM 17s (24.4m)	334,777	3.09	65.59	0.86	5.1	44,692	5.37	5.0	43,503	5.23
Northern Power 100-21 (37m)	334,777	3.76	38.48	2.27	10.4	90,921	10.38	10.2	88,967	10.16
Bergey Excel-S (18m)	334,777	2.69	53.75	0.90	0.5	4,455	5.09	0.5	4,345	4.96
Vestas V29 (40m)	334,777	3.90	36.71	2.53	24.9	217,991	11.06	24.4	213,356	10.82
EWT DW54-900 (75m)	334,777	5.38	28.79	6.02	161.1	1,411,356	17.90	158.9	1,391,974	17.66



Net Capacity Factor by Month

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Summary

The met tower at the Palmer-UAF site measured average wind speeds of 3.43 m/s at a 30 meter height. The winds measured at this site generated a wind power density of 190 W/m^2 at 50 meters, making this site a wind class 1. The extreme winds calculated would allow an IEC Class IV turbine. Icing was observed over several multi-day periods throughout the winter. This location experiences turbulence higher than an IEC Class A. AEA dos not recommend building at this location because of the low wind class and the high turbulence.

The 6.5 year study revealed a wind class and direction that was similar to what was predicted with the wind resource map. AEA recommends additional reconnaissance work at nearby locations to find if a potential site for a wind turbine exists and to further verify the wind resource model.