Wind Resource Assessment For

Atmautluak

Date Last Modified: 8/8/2013

By: Rich Stromberg & Holly Ganser

Site Summary

Station ID: 1045

Latitude: 60° 51’ 53.6” N

Longitude: 162° 16’ 53.6” W

Tower Type: 30-meter NRG Tall Tower

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

Elevation: 4.3m

Monitor Start: October 21st, 2005

Monitor End: December 4th, 2006

In October 2005, Alaska Energy Authority and village residents installed a 30-meter meteorological tower in Atmautluak. The purpose of this monitoring effort is to evaluate the feasibility of utilizing wind energy in the community. 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): 6.4 m/s

Annual Average Wind Speed (30m AGL sensor A): 6.82 m/s

Annual Average Wind Speed (30m AGL sensor B): 6.93 m/s

Predicted by Wind Resource Model (30m AGL): 6.062 m/s

Annual Average Wind Speed (50m AGL calculated): 7.485 m/s

Average Wind Power Density (30 m height):382 W/m^2

Average Wind Power Density (50m AGL calculated): 474 W/m^2

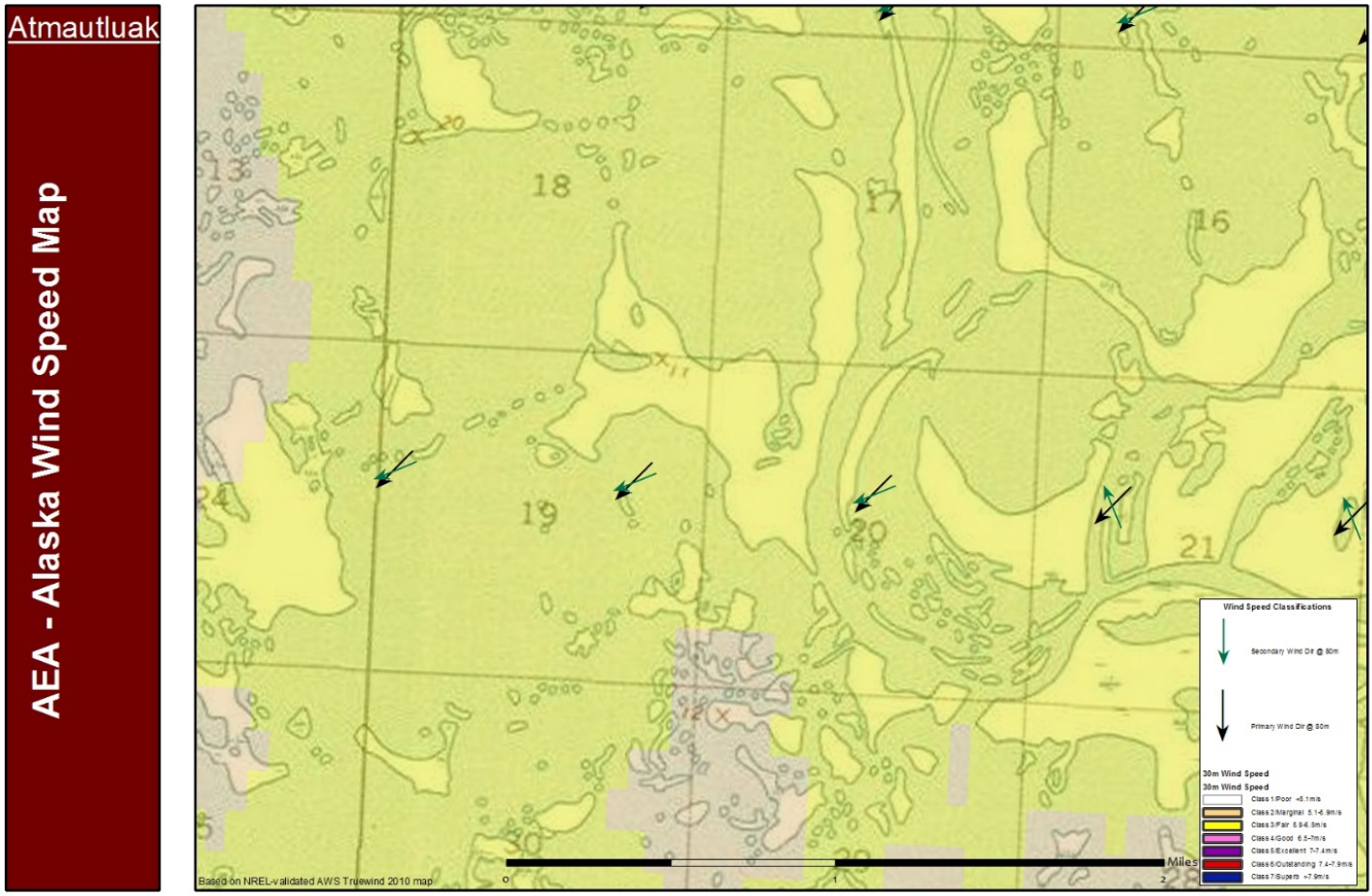
Wind Power Class (range= 1 to 7): 4

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

Prevailing Wind Direction: North & South – model predicts nort

Introduction

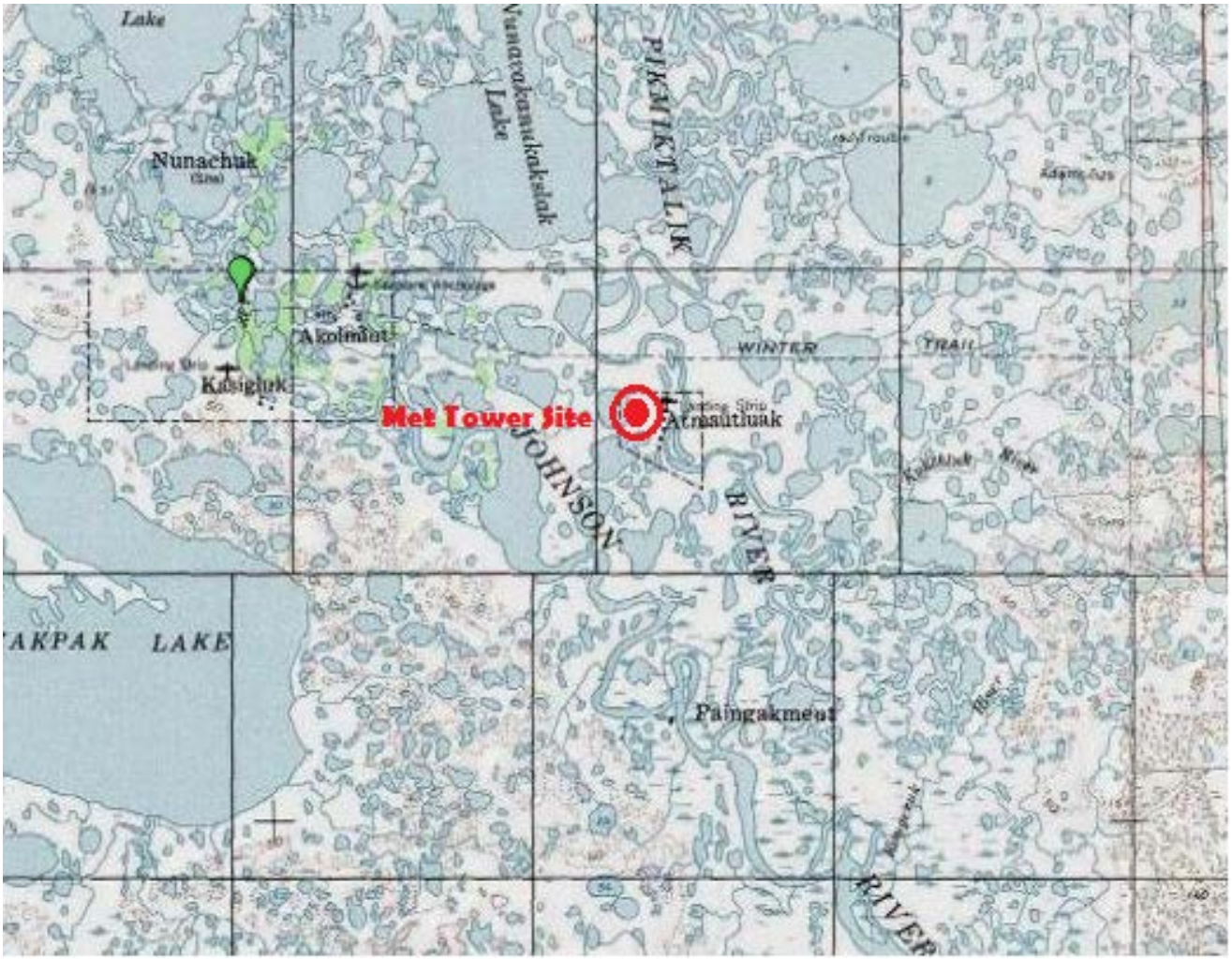
On initial review of the wind resource model, Atmautluak appears to be a “fair” wind candidate. The wind resource model below predicts that the tower location is in an area that experiences Class 3 winds out of the north east. Areas of Class 4 and higher are considered suitable for utility-scale wind power development. The actual winds measured were Class 4 and the wind was primarily from the north and south directions.



Wind Resource Map

Site Description

Atmautluak is located on the west bank of the Pitmiktakik River in Western Alaska. The village is 20 miles northwest of Bethel. The 30-meter tall meteorological tower was constructed at 60° 51’ 53.6” N and 162° 16’ 53.6” W. Below is the location of the tower on a topographical map.

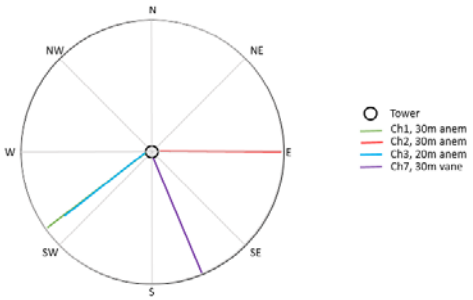


Site Description- continued

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	230° True
2	#40 Anemometer	30m	NRG Standard	90° True
3	#40 Anemometer	20m	NRG Standard	230° True
7	#200 Wind Vane	30m	335° True	155° True
9	#110S Temperature	2m	NRG Standard	-

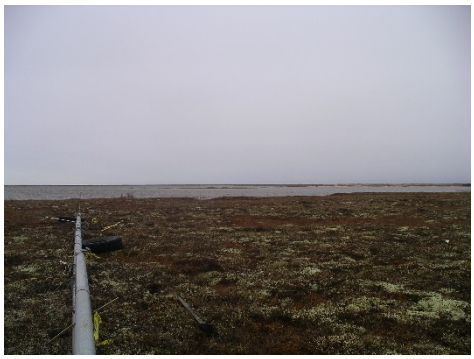


Layout of Sensor Booms

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 free of obstructions and relatively flat.

North West of Tower Base



North of Tower Base

North East of Tower Base

West of Tower Base

Met Tower

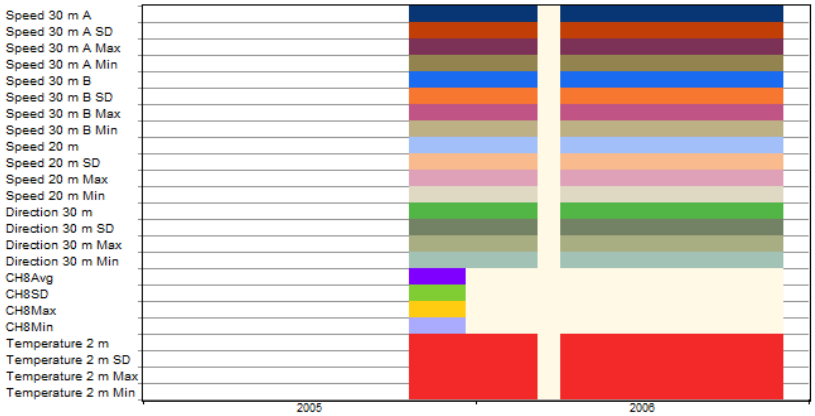
East of Tower Base

South West of Tower Base

South of Tower Base

South East of Tower Base

Raw Wind Data Recovery



Data Coverage Report

Wind data for Atmautluak was measure from October 21st, 2005 to December 4th, 2006. The data coverage report created by Windographer shows that 13 months of data was collected. From March 10, 2006 to April 4th, 2006, data for all sensors was lost.

	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	58,962	55,440	94.03	6.739	0.400	23.100	3.376
2	Speed 30 m A SD	m/s	30 m	58,962	55,440	94.03	0.611	0.000	3.500	0.319
3	Speed 30 m A Max	m/s	30 m	58,962	55,440	94.03	8.268	0.400	30.200	4.067
4	Speed 30 m A Min	m/s	30 m	58,962	55,440	94.03	5.139	0.400	17.200	2.730
5	Speed 30 m B	m/s	30 m	58,962	55,440	94.03	6.799	0.400	23.200	3.569
6	Speed 30 m B SD	m/s	30 m	58,962	55,440	94.03	0.600	0.000	3.600	0.314
7	Speed 30 m B Max	m/s	30 m	58,962	55,440	94.03	8.285	0.400	30.900	4.209
8	Speed 30 m B Min	m/s	30 m	58,962	55,440	94.03	5.224	0.400	17.600	2.944
9	Speed 20 m	m/s	20 m	58,962	55,440	94.03	6.374	0.400	21.200	3.276
10	Speed 20 m SD	m/s	20 m	58,962	55,440	94.03	0.624	0.000	3.600	0.312
11	Speed 20 m Max	m/s	20 m	58,962	55,440	94.03	7.959	0.400	29.800	3.964
12	Speed 20 m Min	m/s	20 m	58,962	55,440	94.03	4.769	0.400	16.800	2.658
13	Direction 30 m	°	30 m	58,962	55,440	94.03	348.0	0.0	359.0	116.3
14	Direction 30 m SD	°	30 m	58,962	55,440	94.03	5.7	0.0	107.0	5.8
15	Direction 30 m Max	°	30 m	58,962	55,440	94.03	188.6	0.0	359.0	116.6
16	Direction 30 m Min	°	30 m	58,962	55,440	94.03	335.0	335.0	335.0	0.0
17	CH8Avg			58,962	8,850	15.01	5.57	0.00	98.00	15.66
18	CH8SD			58,962	8,850	15.01	0.01	0.00	13.00	0.23
19	CH8Max			58,962	8,850	15.01	5.51	0.00	99.00	15.71
20	CH8Min			58,962	8,850	15.01	0	0	0	0
21	Temperature 2 m	°C	2 m	58,962	55,440	94.03	-0.1	-82.2	27.3	12.5
22	Temperature 2 m SD	°C	2 m	58,962	55,440	94.03	0.0	0.0	40.2	0.2
23	Temperature 2 m Max	°C	2 m	58,962	55,440	94.03	0.2	-82.2	54.9	12.6
24	Temperature 2 m Min	°C	2 m	58,962	55,440	94.03	-0.2	-82.2	27.1	12.5
25	Air Density	kg/m³		58,962	58,962	100.00	1.290	1.174	1.847	0.062
26	Speed 30 m A TI			58,962	55,440	94.03	0.10	0.00	1.83	0.07
27	Speed 30 m B TI			58,962	55,440	94.03	0.10	0.00	2.00	0.08
28	Speed 20 m TI			58,962	55,440	94.03	0.11	0.00	1.42	0.07
29	Speed 30 m A WPD	W/m²		58,962	55,440	94.03	362	0	7,793	542
30	Speed 30 m B WPD	W/m²		58,962	55,440	94.03	389	0	7,895	593
31	Speed 20 m WPD	W/m²		58,962	55,440	94.03	317	0	6,151	491

Data Column Table

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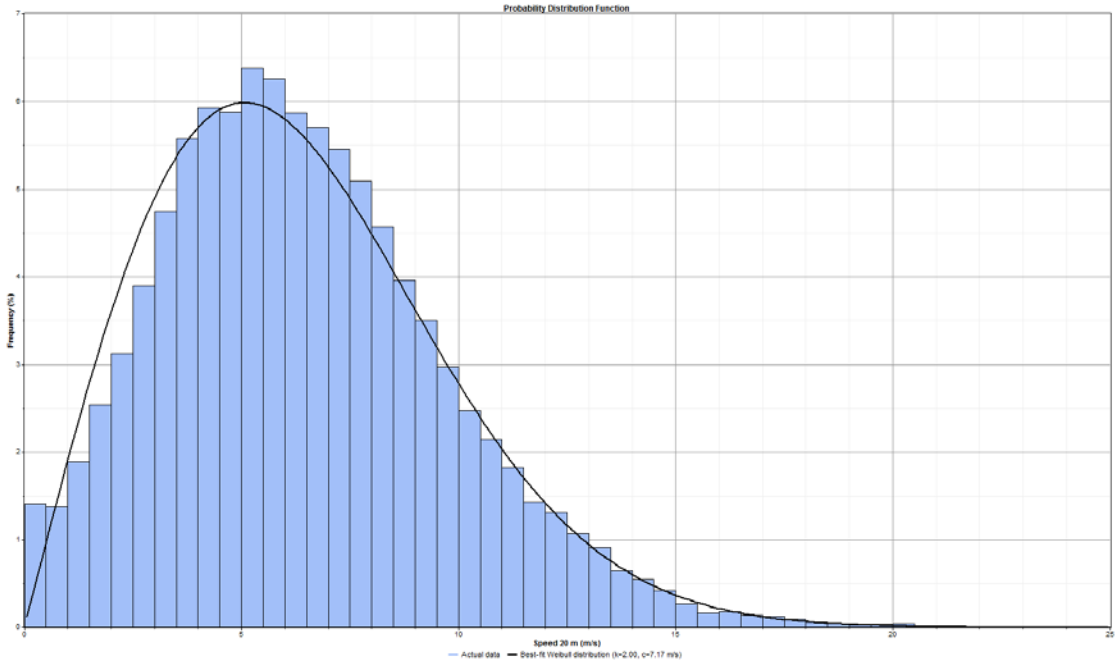
Raw Wind Data Recovery - Continued

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.

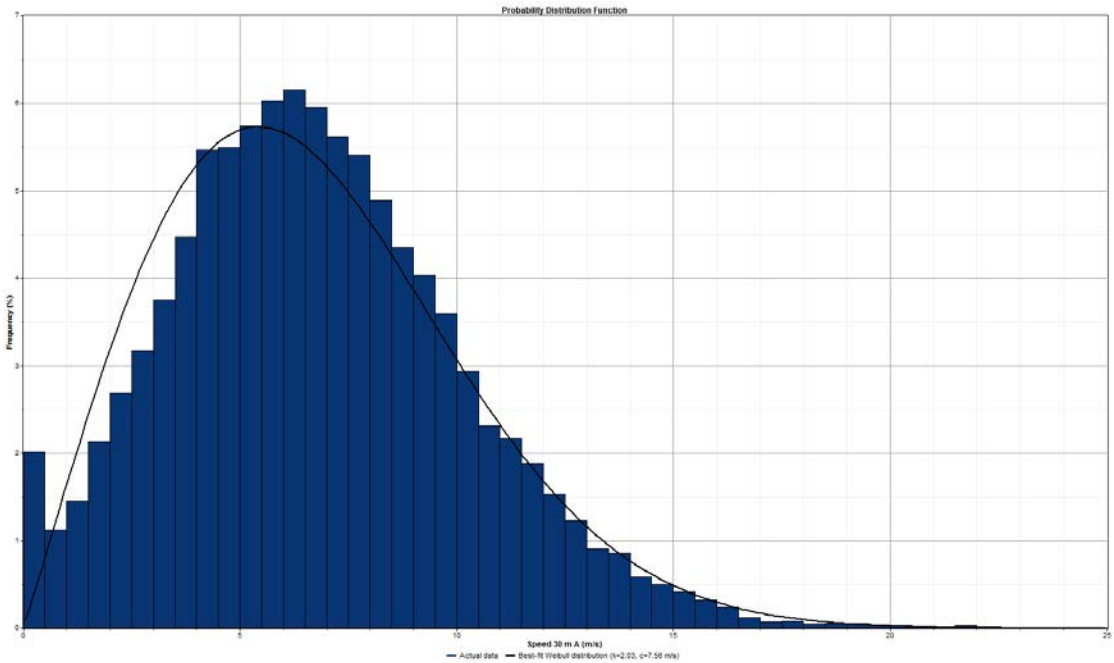
Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20
Mean wind speed (m/s)	6.739	6.800	6.374
MoMM wind speed (m/s)	6.725	6.788	6.349
Median wind speed (m/s)	6.500	6.600	6.000
Min wind speed (m/s)	0.400	0.400	0.400
Max wind speed (m/s)	23.100	23.200	21.200
Weibull k	2.031	1.881	2.001
Weibull c (m/s)	7.559	7.583	7.167
Mean power density (W/m²)	362	389	317
MoMM power density (W/m²)	358	384	312
Mean energy content (kWh/m²/yr)	3,173	3,404	2,777
MoMM energy content (kWh/m²/yr)	3,138	3,364	2,732
Energy pattern factor	1.817	1.895	1.874
Frequency of calms (%)	2.01	3.45	1.40
Possible data points	58,962	58,962	58,962
Valid data points	55,440	55,440	55,440
Missing data points	3,522	3,522	3,522
Data recovery rate (%)	94.03	94.03	94.03

Wind Speed Sensor Summary Report

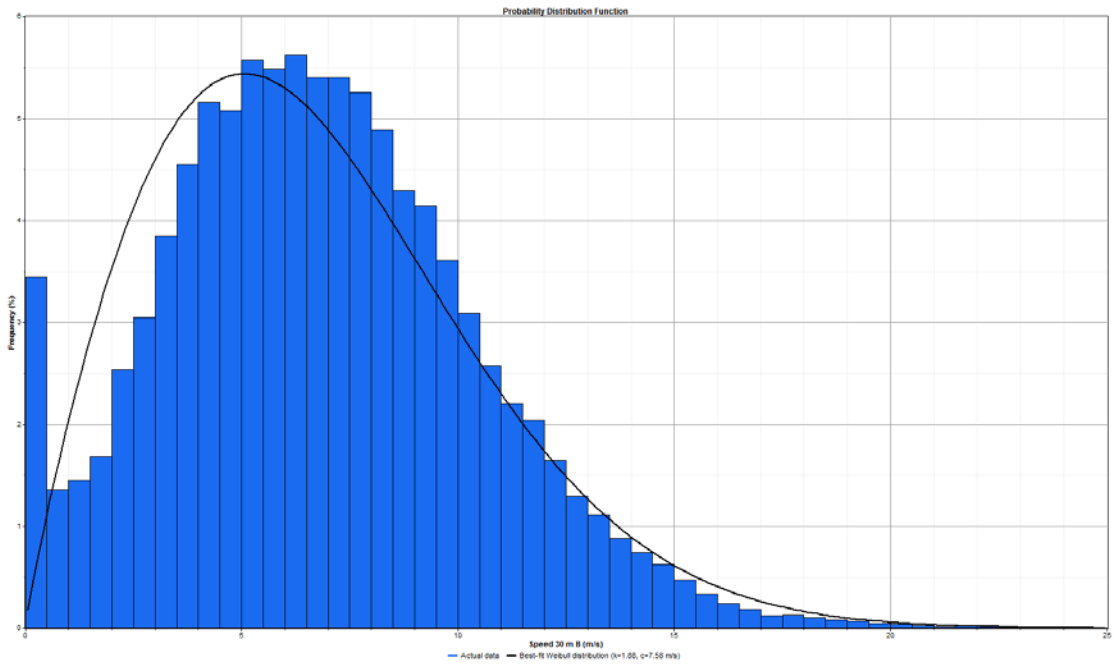


Probability Distribution Function of the 20m

Raw Wind Data Recovery - Continued



Probability Distribution Function of the 30m A anemometer



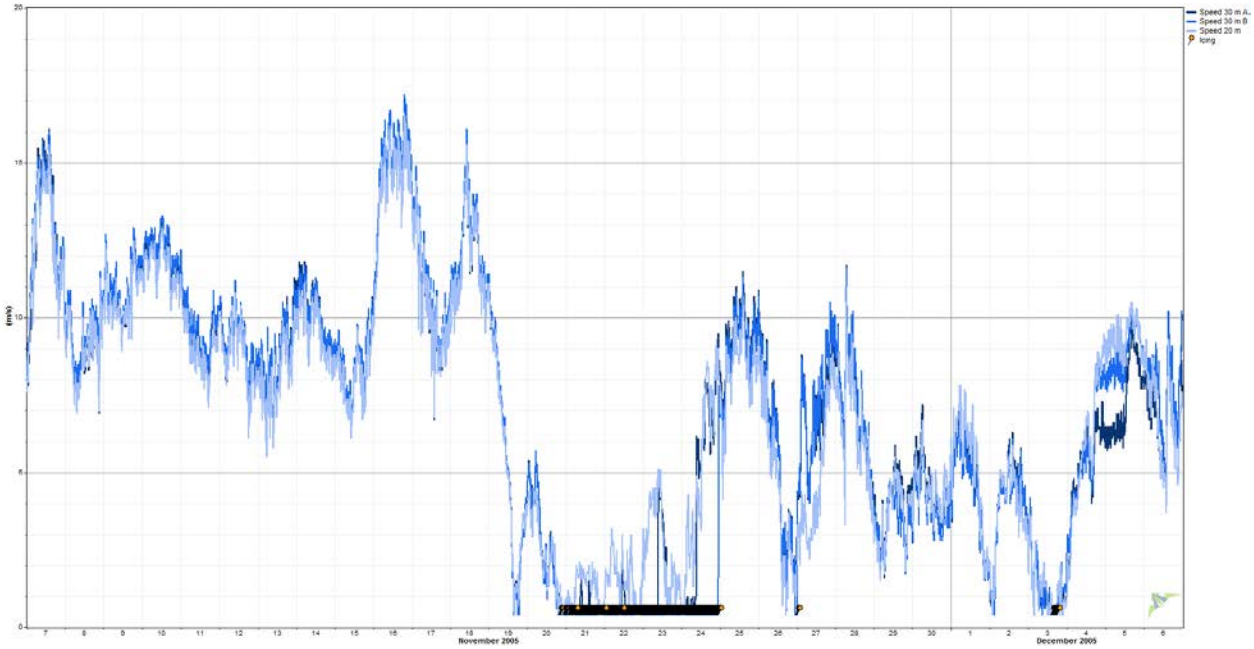
Probability Distribution Function of the 30m B anemometer

Wind Speed Data – Flagging Data

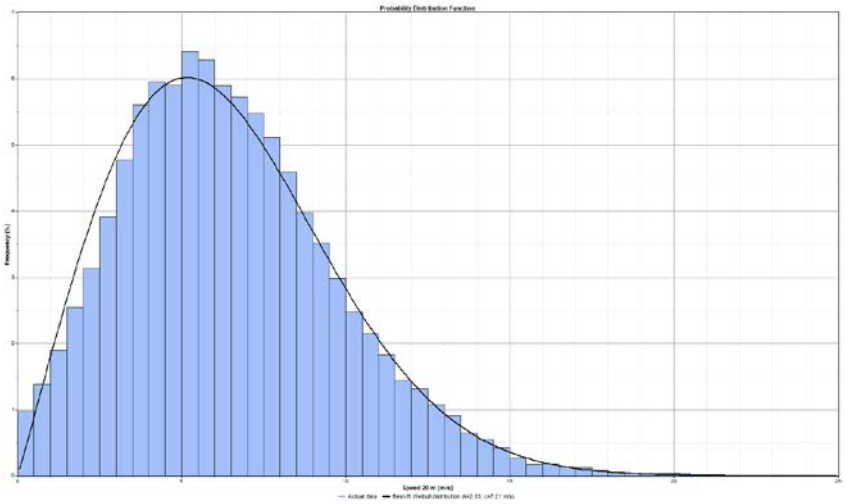
Once the data set was filtered for invalid data points and icing occurrences, the high number of zero wind occurrences was reduced. Rules were created to flag icing events. These rules included flagging the anemometer data anytime the temperature was below 4° C, the standard deviation of the anemometer was equal to zero and the speed was less than 0.5 m/s. After the rules were applied it was found that icing was flagged on the 30m A sensor 1.16%, 30m A 1.94%, and 20m 0.32% of the time it was recording data. Data at the beginning of the collection was also flagged as invalid because the sensors recorded values that were not feasible.

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20
Mean wind speed (m/s)	6.821	6.934	6.400
MoMM wind speed (m/s)	6.790	6.892	6.374
Median wind speed (m/s)	6.500	6.700	6.100
Min wind speed (m/s)	0.400	0.400	0.400
Max wind speed (m/s)	23.100	23.200	21.200
Weibull k	2.139	2.042	2.034
Weibull c (m/s)	7.683	7.791	7.207
Mean power density (W/m²)	367	397	318
MoMM power density (W/m²)	362	391	313
Mean energy content (kWh/m²/yr)	3,214	3,476	2,789
MoMM energy content (kWh/m²/yr)	3,171	3,422	2,743
Energy pattern factor	1.775	1.824	1.859
Frequency of calms (%)	0.75	1.43	0.97
Possible data points	58,962	58,962	58,962
Valid data points	54,731	54,299	55,198
Missing data points	4,231	4,663	3,764
Data recovery rate (%)	92.82	92.09	93.62

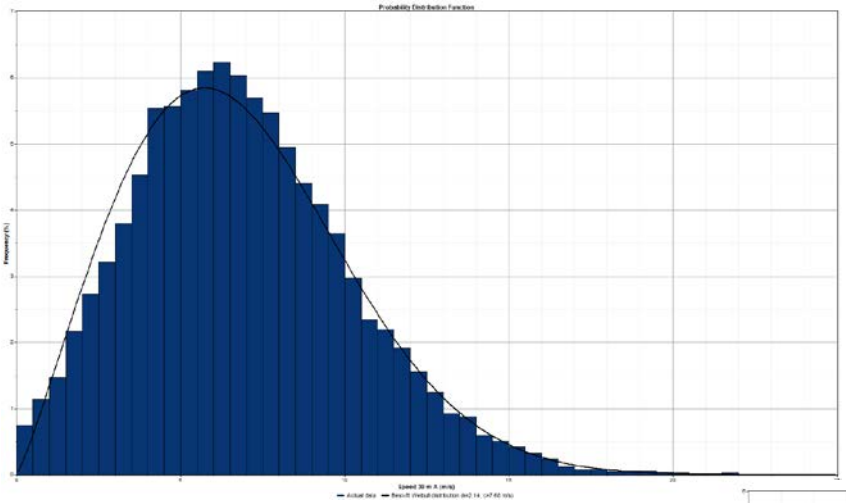
Wind Speed Sensor Summary Report



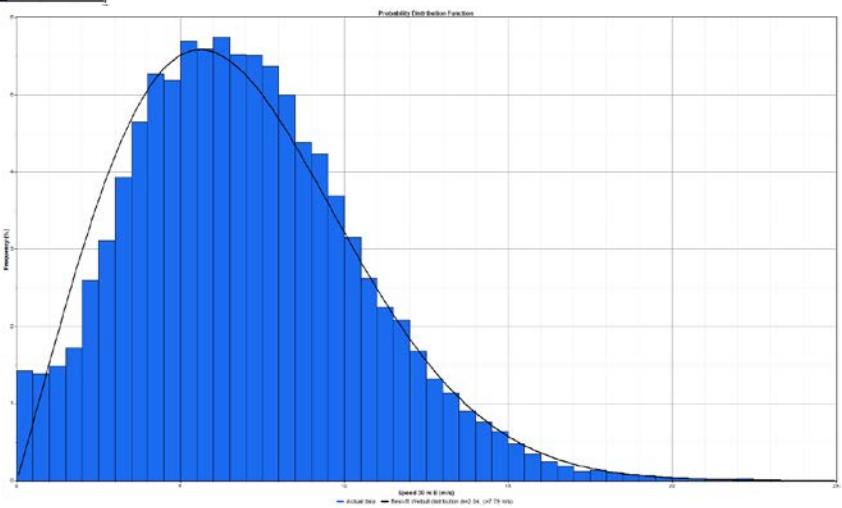
Wind Speed Data – Flagging Data Continued



Probability Distribution Function of the 20m anemometer



Probability Distribution Function of the 30m A anemometer

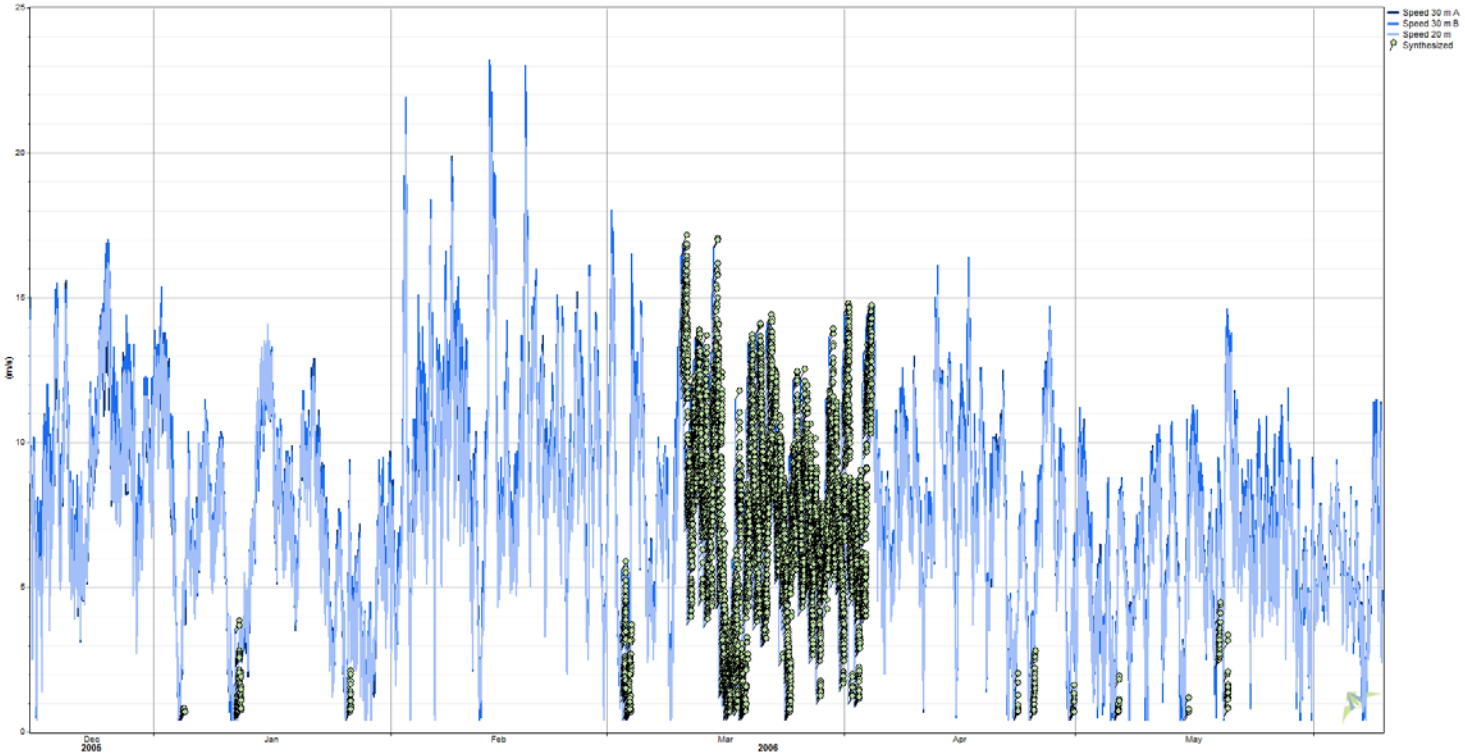


Probability Distribution Function of the 30m B anemometer

Wind Speed Data – Synthesized Data

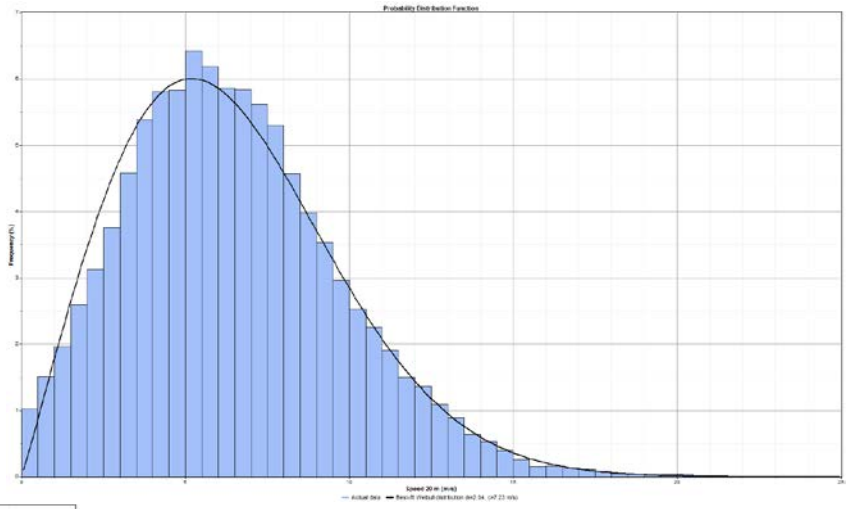
After the data was flagged for icing, it was deleted and synthesized to fill in the gaps. The missing data in March and April was also synthesized. The resulting summary and probability distribution functions can be found below. The resulting mean wind speeds of each anemometer are lower than that of the flagged data. The synthesized data was not used in the analysis unless otherwise indicated due to the increased risk of uncertainty in replacing long stretches of missing data – more than a few days.

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30	30	20
Mean wind speed (m/s)	6.808	6.879	6.423
MoMM wind speed (m/s)	6.794	6.862	6.403
Median wind speed (m/s)	6.600	6.664	6.100
Min wind speed (m/s)	0.400	0.400	0.398
Max wind speed (m/s)	23.100	23.200	21.200
Weibull k	2.108	1.991	2.037
Weibull c (m/s)	7.663	7.717	7.231
Mean power density (W/m²)	368	393	320
MoMM power density (W/m²)	365	389	316
Mean energy content (kWh/m²/yr)	3,223	3,443	2,807
MoMM energy content (kWh/m²/yr)	3,194	3,407	2,769
Energy pattern factor	1.785	1.847	1.848
Frequency of calms (%)	0.71	1.55	0.95
Possible data points	58,962	58,962	58,962
Valid data points	58,960	58,960	58,960
Missing data points	2	2	2
Data recovery rate (%)	100.00	100.00	100.00

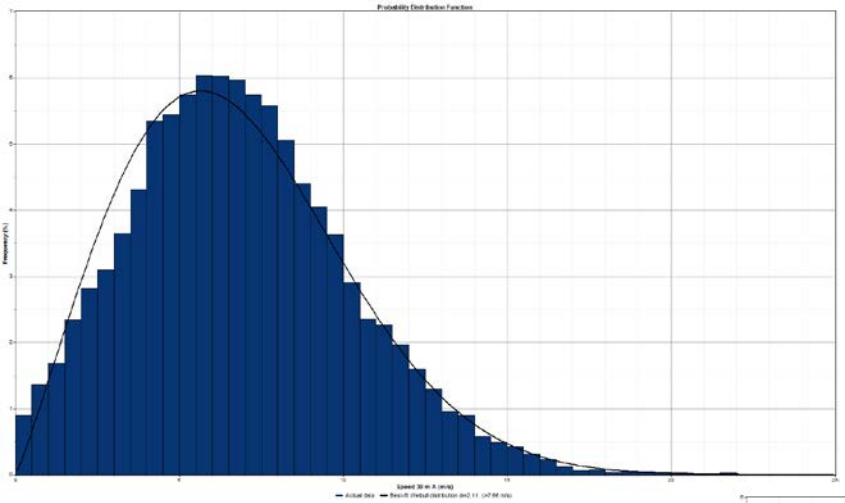


Example of synthesized data

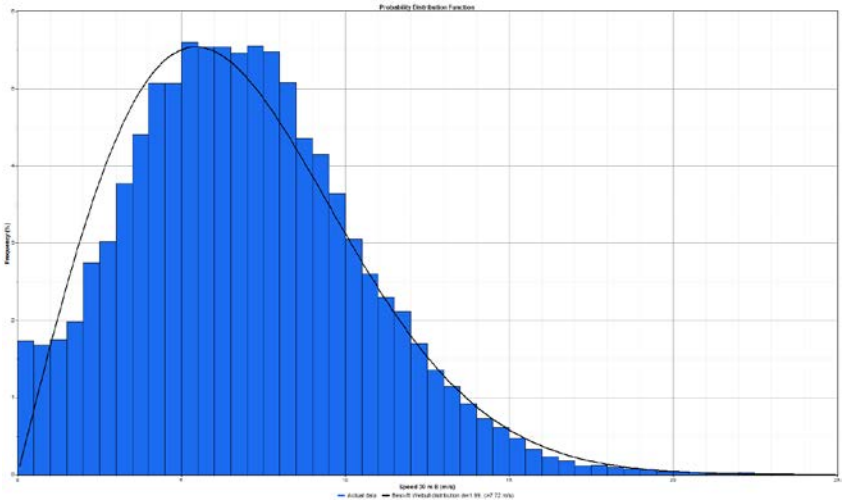
Wind Speed Data – Synthesized Data Continued



Probability Distribution Function of the 20m anemometer



Probability Distribution Function of the 30m A anemometer



Probability Distribution Function of the 30m B anemometer

Wind Speed Data – Analysis

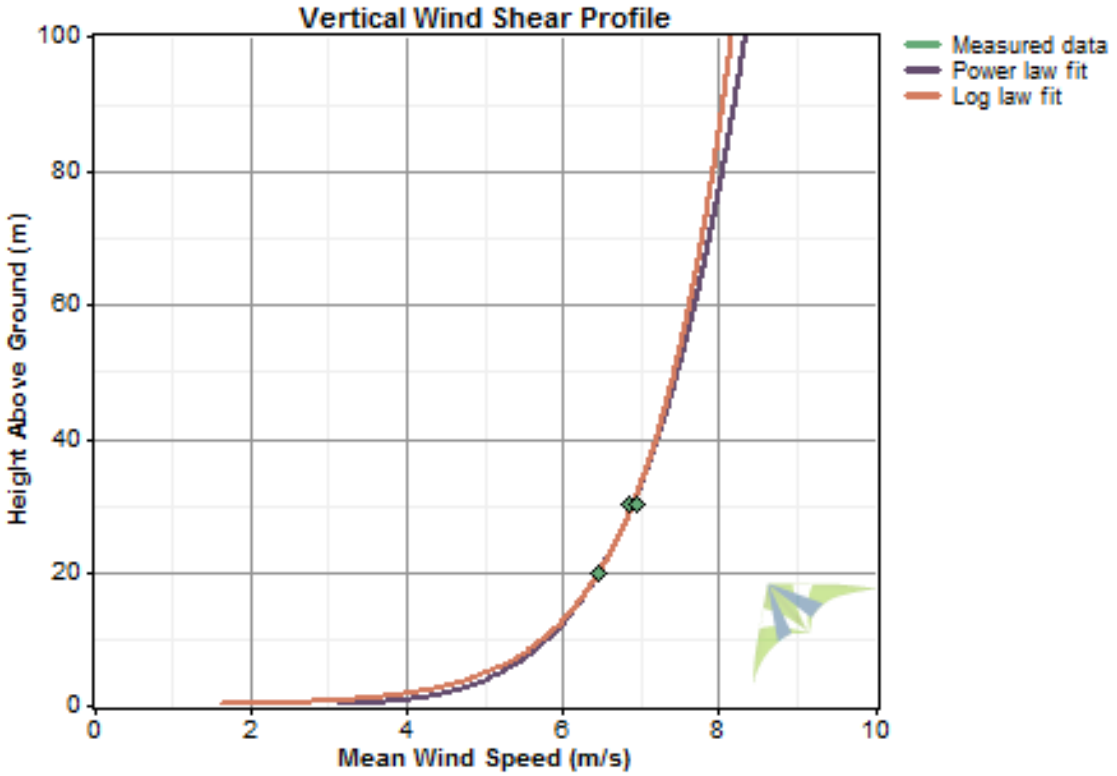
The filtered data produced a 30m-AGL power density of 382 W/m^2 and 50-m AGL power density at 474 W/m^2. At this density the wind power is Class 4. Windographer calculated a power law exponent of 0.158 and a surface roughness of 0.0432m. The wind shear is close to a **typical** power law exponent value 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

Wind power coefficients

Power density at 50m:	474 W/m²
Wind power class:	4 (Good)

Wind shear coefficients

Power law exponent:	0.158
Surface roughness:	0.0432 m
Roughness class:	1.30



Wind Shear Profile Graph

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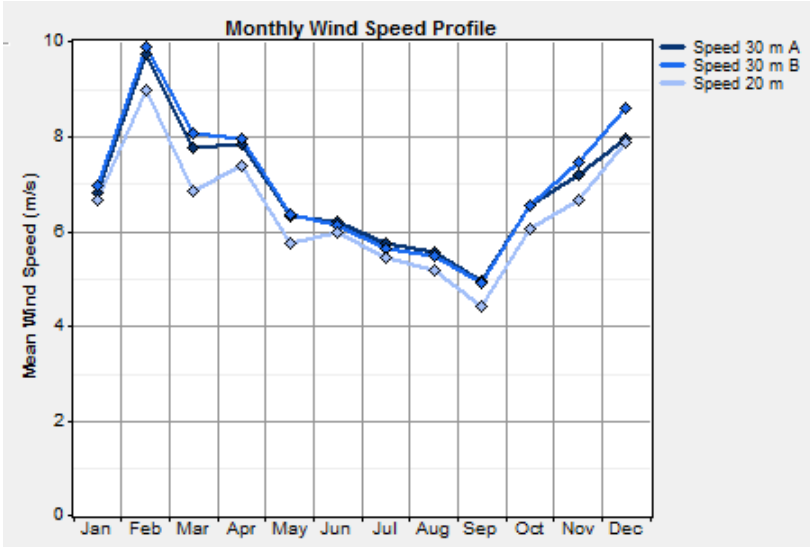
Wind Speed Data – Analysis

The synthesized data produced a power density at 50m of 470 W/m^2. This value is slightly lower than the flagged data calculation. Windographer calculated the same power law exponent of 0.156 and surface roughness of 0.0408m.

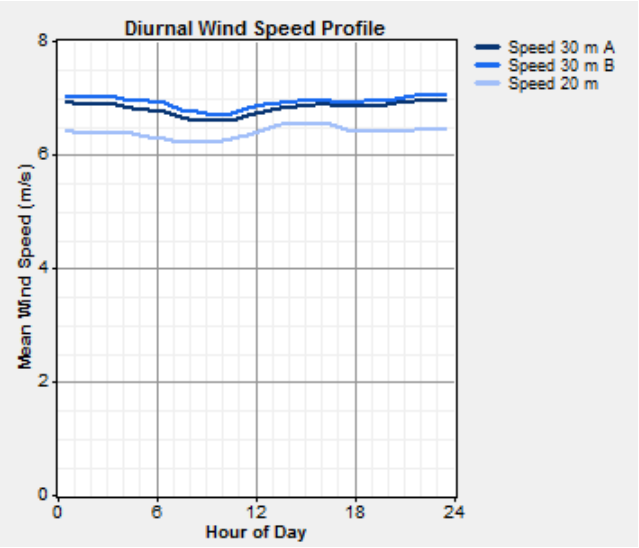
Wind power coefficients	
Power density at 50m:	470 W/m²
Wind power class:	4 (Good)
Wind shear coefficients	
Power law exponent:	0.156
Surface roughness:	0.0408 m
Roughness class:	1.26

Wind Speed Data – Analysis Continued

The monthly wind speed profile follows the standard pattern of wind speeds higher in the winter months than in the summer months. The lowest monthly wind speeds occur in September. The diurnal wind speed profile shows that wind speeds stay fairly constant throughout the day but drop slightly in the morning hours. The wind shear analysis by month reveals that in January and June the surface roughness is less than half the annual average. These months also have the lowest power law exponents. February experiences the highest 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	4,391	6.810	6.954	6.678	0.074	0.000035
Feb	4,032	9.730	9.900	8.956	0.226	0.291894
Mar	1,234	7.861	8.073	7.245	0.234	0.340898
Apr	3,827	7.912	7.982	7.416	0.171	0.069894
May	4,410	6.362	6.331	5.792	0.225	0.288160
Jun	4,320	6.199	6.125	5.977	0.075	0.000040
Jul	4,464	5.736	5.631	5.431	0.112	0.003293
Aug	4,464	5.561	5.479	5.182	0.156	0.039874
Sep	4,320	4.938	4.891	4.398	0.274	0.631028
Oct	5,965	6.550	6.549	6.038	0.201	0.166845
Nov	7,907	7.359	7.439	7.020	0.130	0.010930
Dec	4,936	7.958	8.611	7.928	0.109	0.002447

Monthly Wind Shear Analysis by month

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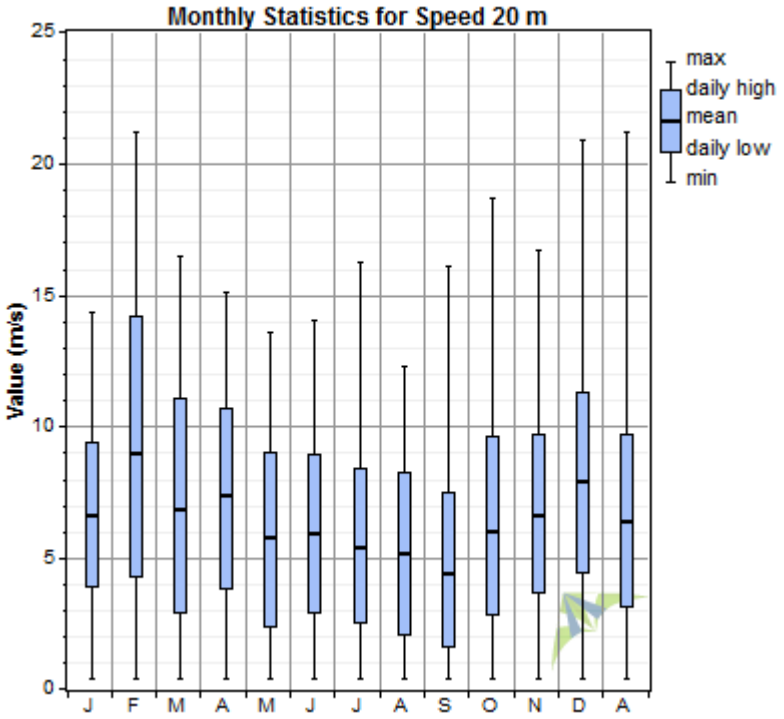
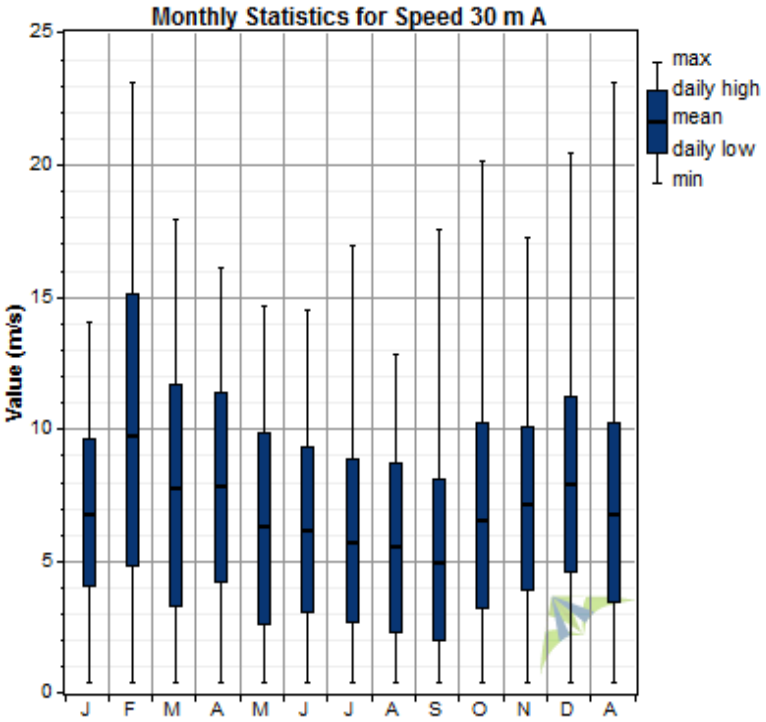
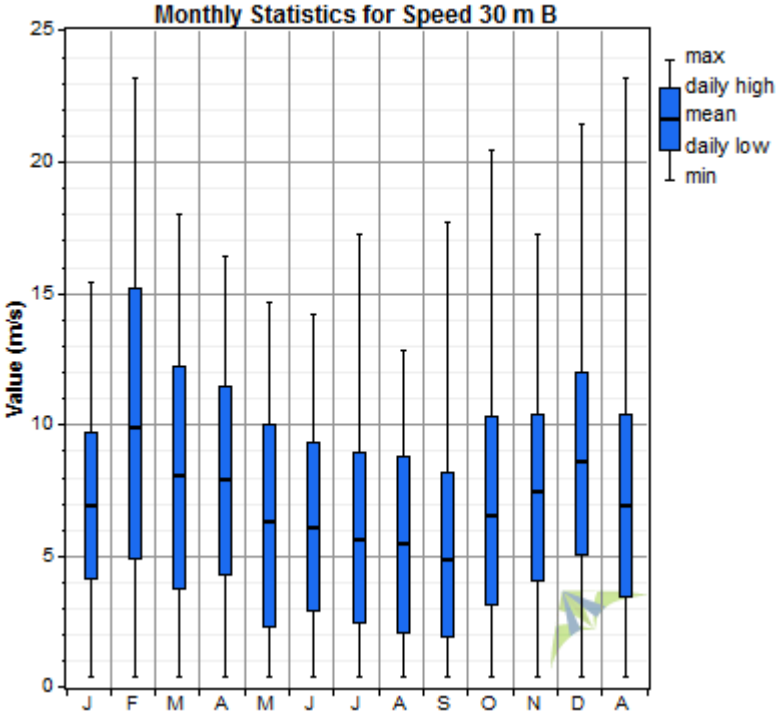
Wind Speed Data – Analysis Continued

The monthly statistics boxplots for each anemometer indicate the mean, daily high, daily low, maximum, and minimum wind speeds for each month. Across all anemometers February recorded the highest wind speed and has the highest mean wind speed. Mean wind speeds for February were approximately 9.5 m/s. December recorded the second highest mean wind speeds of approximately 8.5 m/s.







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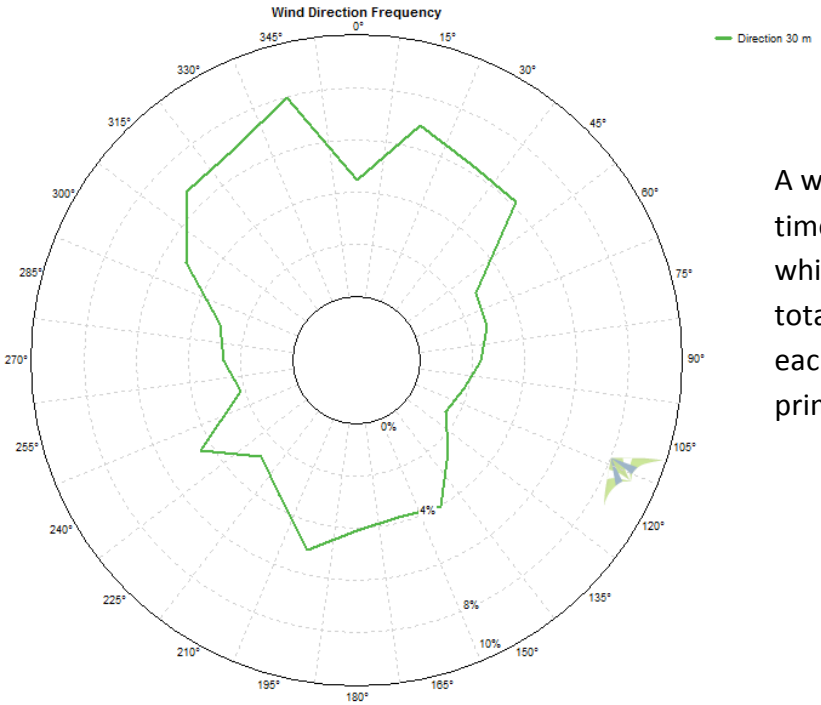
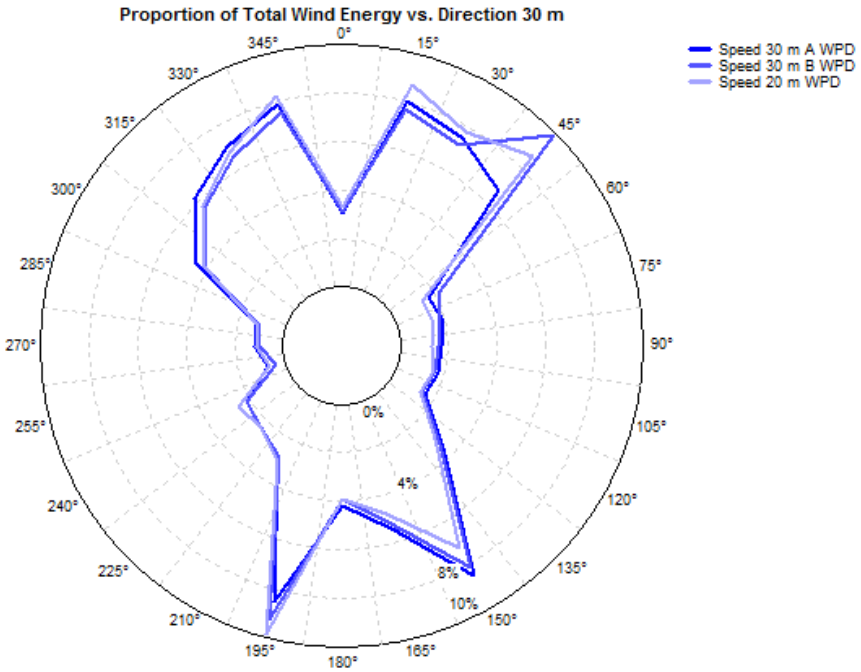
Wind Direction and Energy Production



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. Atmautluak experiences winds primarily from the north and south directions.

The wind energy rose shows the proportion of energy generated by the wind from each direction. The total wind energy is generated from the north and south directions.



Total Wind Energy Rose

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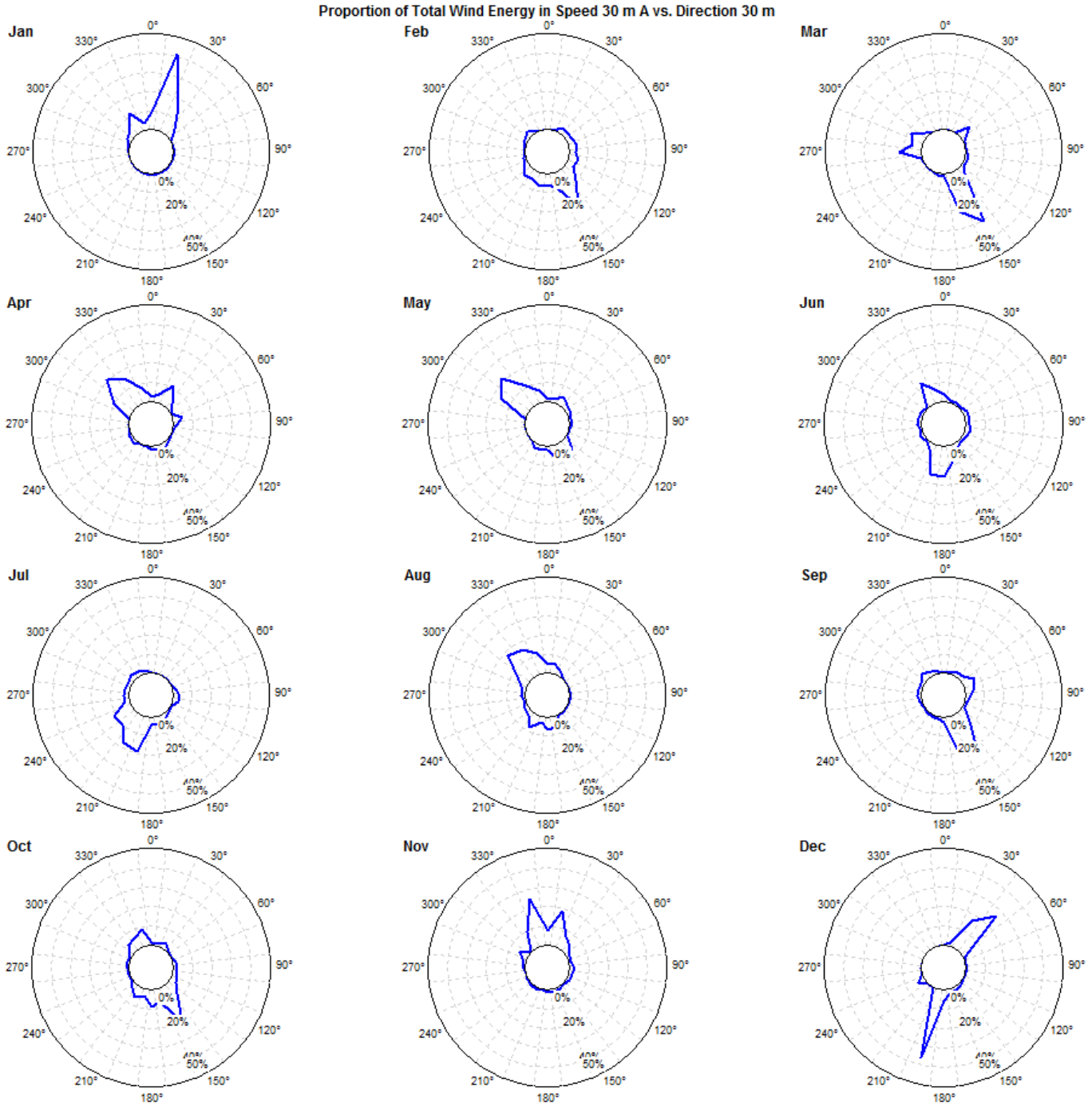
Wind Direction and Energy Production Continued

The monthly wind energy charts indicate that the direction the wind energy is generated changes from month to month.



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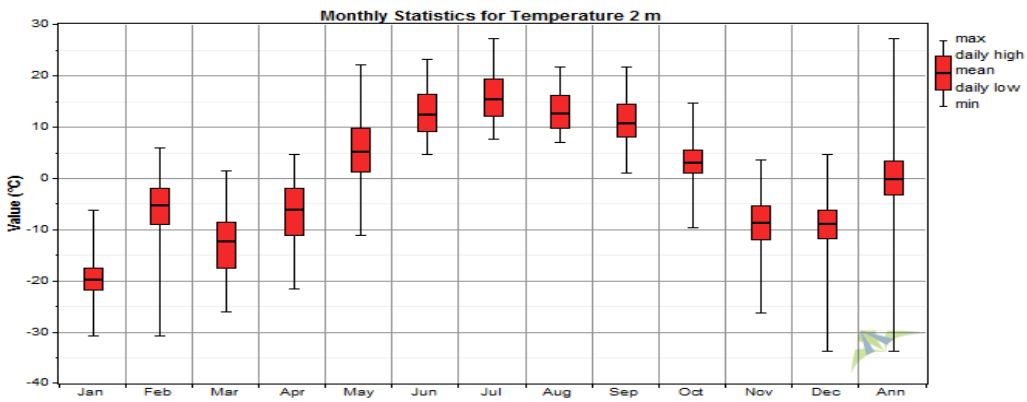
Temperature

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 13 months of observation was 0.01°C (32°F). The mean air pressure was 101.2 kPa and the mean air density was 1.289 kg/m^3, which is 1.052x or 5.2% denser than the standard of 1.225 kg/m^3.



Monthly Statistics for Temperature

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 for 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	35.743
Method of Independent Storms	25.291
EWTS II (Exact)	26.407
EWTS II (Gumbel)	26.765
EWTS II (Davenport)	29.105

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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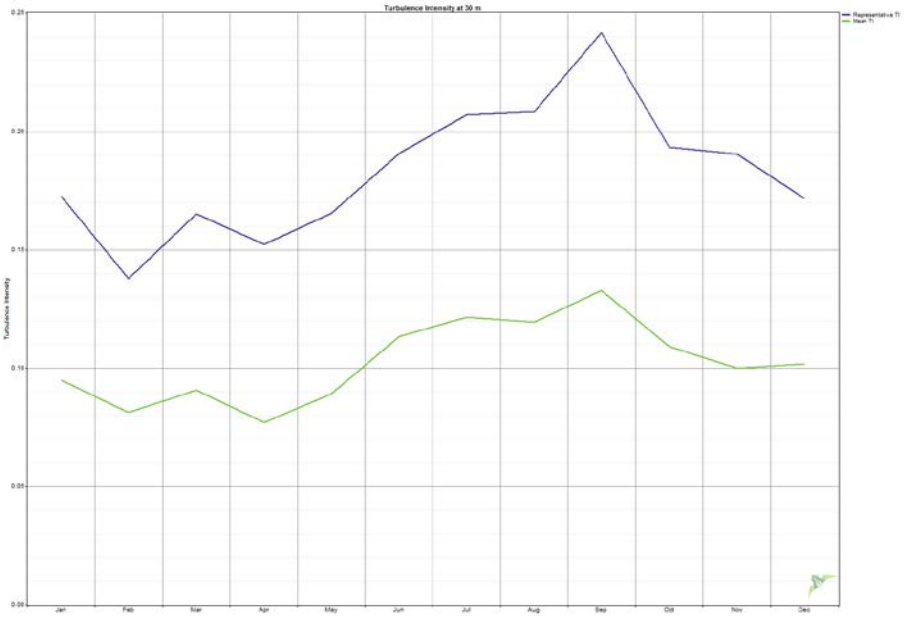
Wind Turbulence

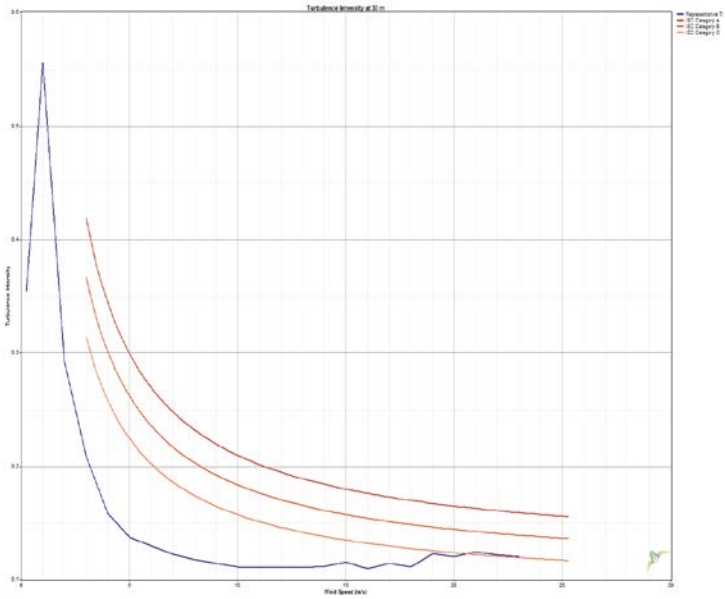
Analysis of the turbulence intensity (TI) indicated that the met tower was in a location that is below IEC standard 61200-1 3rd ed. (IEC3) turbulence category C.

Quantity	Value
Data points in 15 m/s bin	510
Mean TI at 15 m/s	0.09
Representative TI at 15 m/s	0.12
IEC3 turbulence category	C

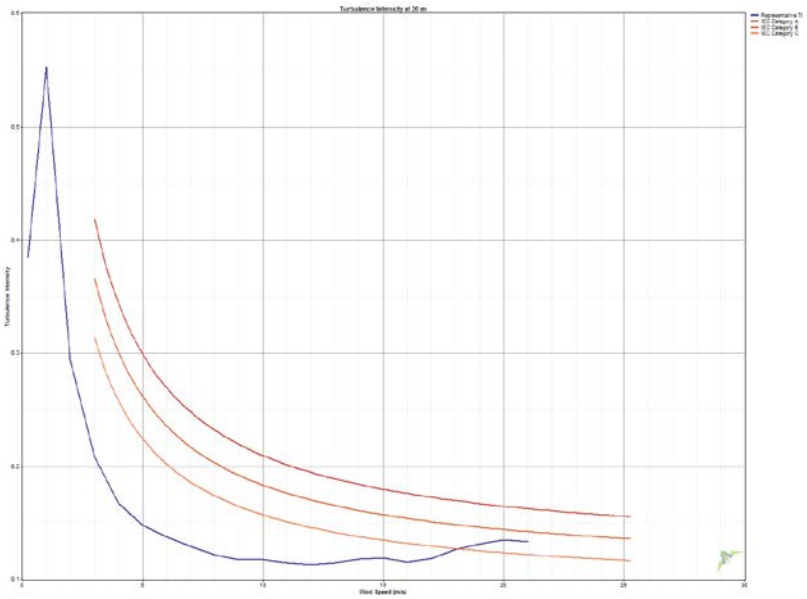
30m Turbulence Intensity Calculations



30m Turbulence Intensity by Month



30m Turbulence Intensity

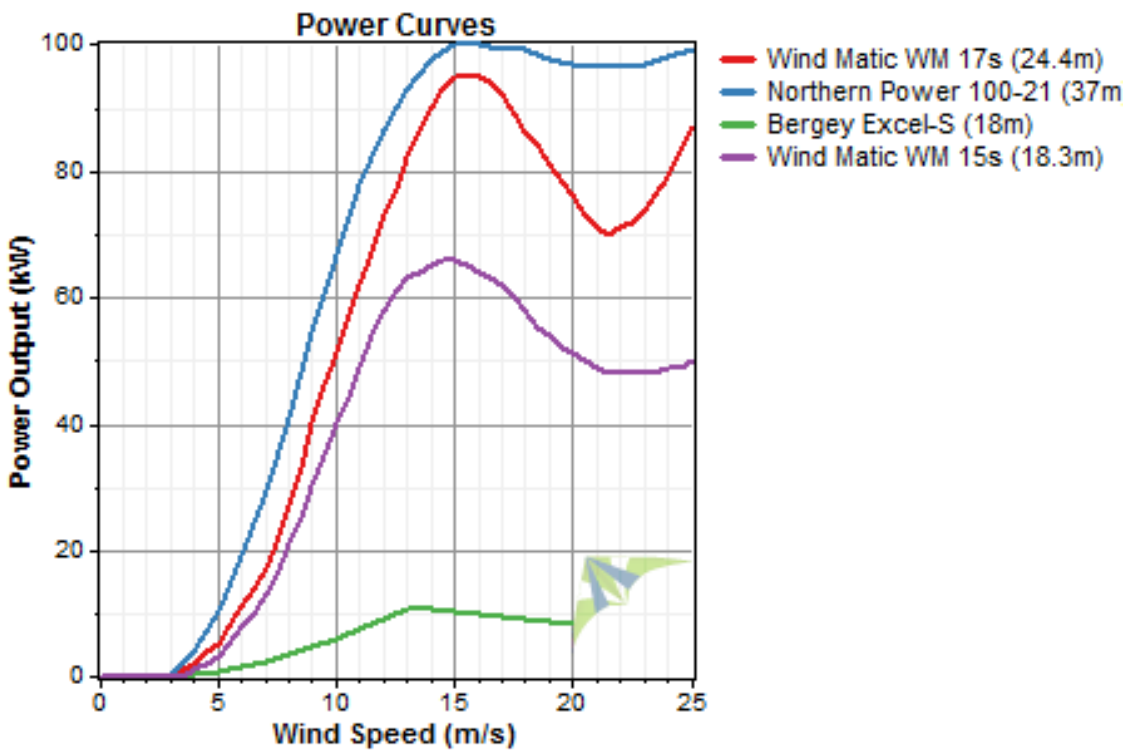


20m Turbulence Intensity and Wind Speed

Estimated Turbine Outputs

Four wind turbine models 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 4 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.

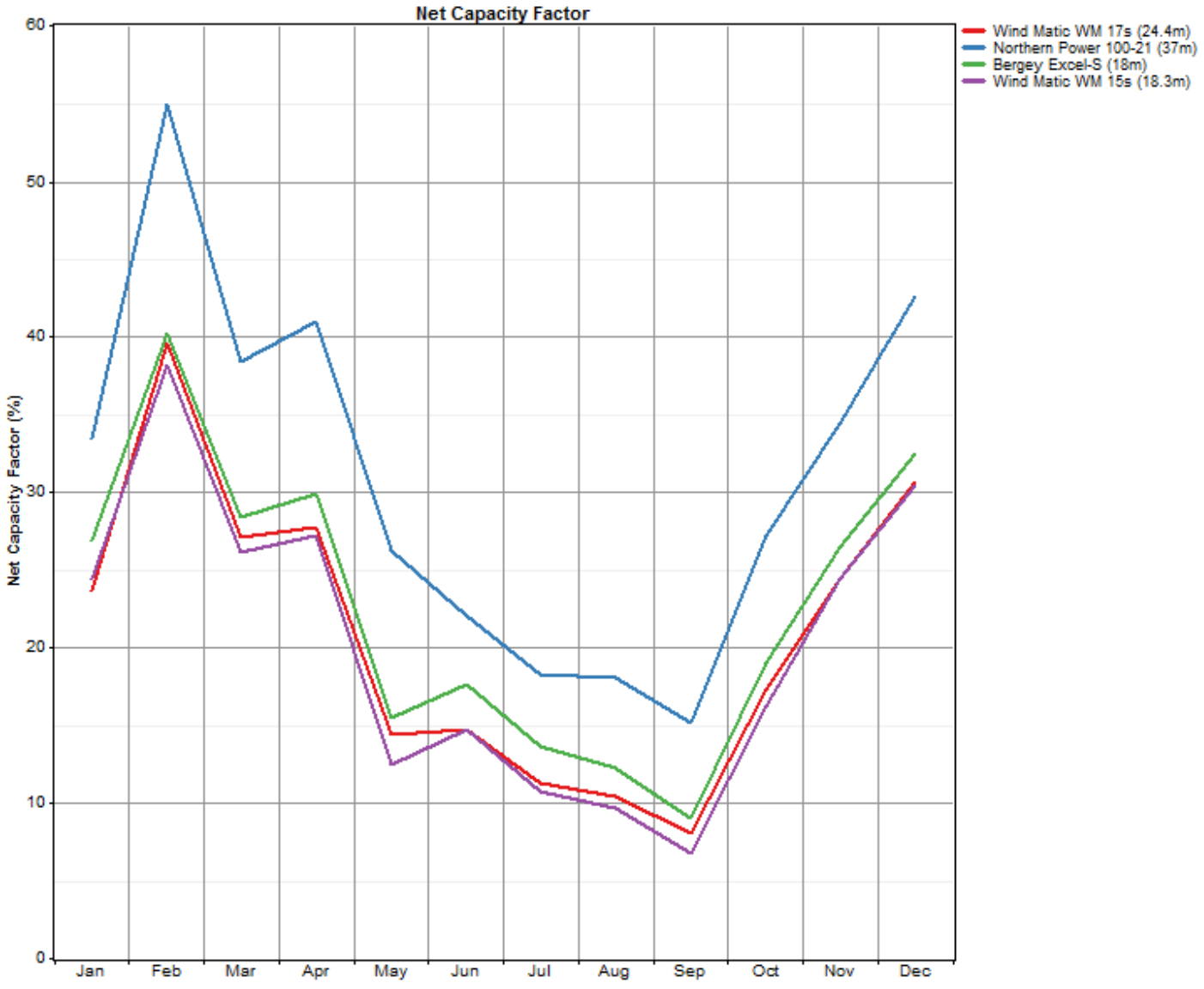
Turbine	Valid Time Steps	Hub Height Wind Speed (m/s)	Percentage Of Time At Zero Power	Percentage Of Time At Rated Power	Simple Mean Net Power (kW)	Simple Mean Net AEP (kWh/yr)	Simple Mean NCF (%)	Mean of Monthly Means Net Power (kW)	Mean of Monthly Means Net AEP (kWh/yr)	Mean of Monthly Means NCF (%)
Wind Matic WM 17s (24.4m)	55,241	6.59	13.66	2.20	19.5	170,676	20.51	19.2	167,824	20.17
Northern Power 100-21 (37m)	55,241	7.08	6.41	5.14	30.6	267,818	30.57	30.2	264,744	30.22
Bergey Excel-S (18m)	55,241	6.27	7.61	4.39	2.2	19,634	22.41	2.2	19,324	22.06
Wind Matic WM 15s (18.3m)	55,241	6.29	20.22	3.55	13.2	115,231	19.93	12.9	112,962	19.54



Power Curves of Turbines

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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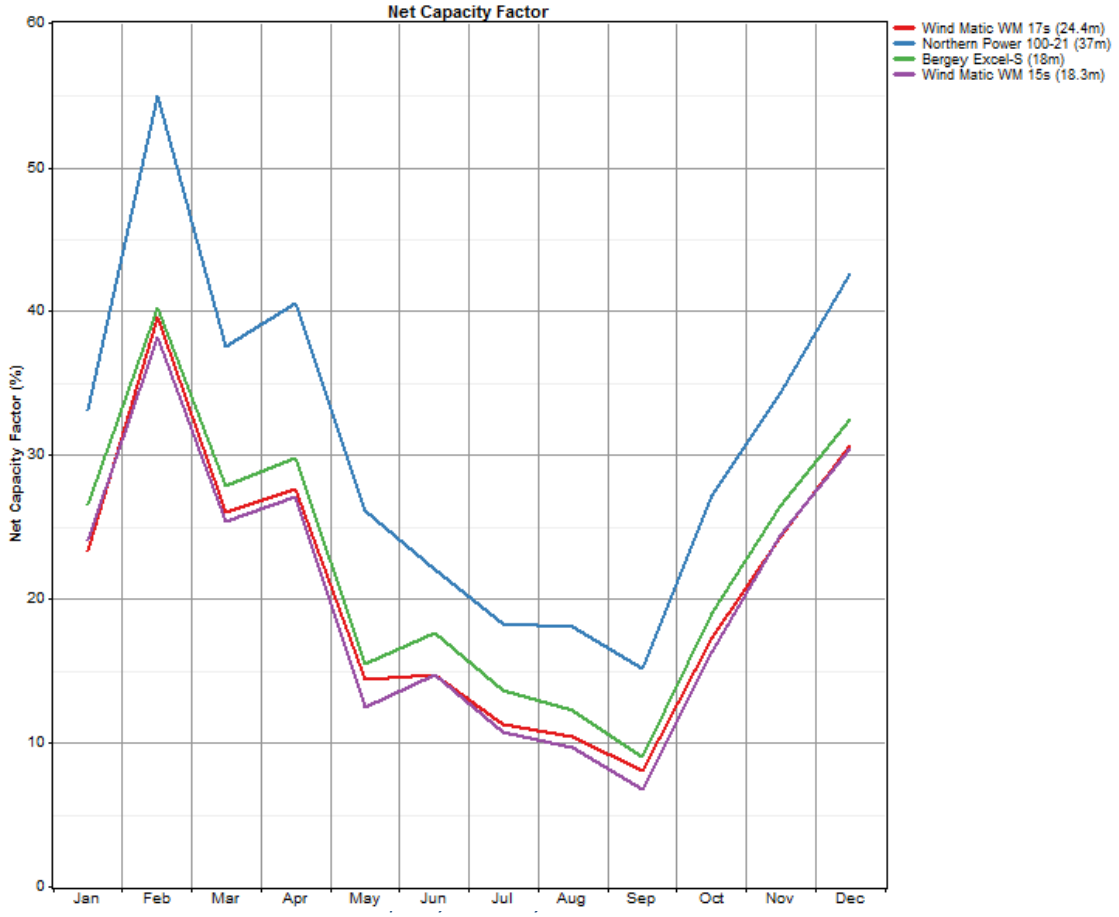
Estimated Turbine Outputs

The output for the four 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 higher than the net capacity factors of the flagged data. The percentage at zero is also slightly higher for all turbines except for the Wind Matic WM 15s.

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)	58,960	6.62	13.70	2.16	19.7	172,998	20.79	19.5	170,679	20.51
Northern Power 100-21 (37m)	58,960	7.11	6.56	5.31	30.9	270,935	30.93	30.7	268,515	30.65
Bergey Excel-S (18m)	58,960	6.30	7.74	4.42	2.3	19,895	22.71	2.2	19,644	22.42
Wind Matic WM 15s (18.3m)	58,960	6.32	19.98	3.55	13.3	116,927	20.22	13.1	115,060	19.90



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Summary

The met tower at Atmautluak measured average wind speeds of 6.88 m/s at a 30 meter height. The winds measured at this site generated a wind power density of 474 W/m^2 at 50 meters, making this site a wind class 4. The greater than 30-percent capacity factor for the Northern Power Systems 100 at 37 meters AGL actually meets AEA guidelines for a class 5 wind site. The extreme winds calculated would allow an IEC Class IV turbine. There was very little icing observed. This location experiences low turbulence, allowing for IEC class C turbine.

The 13 month study revealed a wind class that was higher than what was predicted with the wind resource map. The direction was also found to be from both the north and south directions as opposed to mainly the north east as stated by the map.