Chefornak, Alaska Wind Resource Assessment Report

Bernard Mael of Chefornak lifting the met tower, photo by Doug Vaught, June 2012

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Background

The Chefornak wind resource study was funded by the Alaska Energy Authority and managed by the City of Chefornak with the assistance of STG, Inc. The City of Chefornak contracted V3 Energy, LLC to install the met tower in June 2012. Later, STG, Inc. transferred its interest in developing wind power in Chefornak to Intelligent Energy Systems, Inc. (IES). IES contracted V3 Energy, LLC to prepare this wind resource assessment report. IES point of contact is Dennis Meiners (dennis@iesconnect.net).

Summary

The wind resource measured at the Chefornak met tower site is outstanding with measured wind power class 6 by consideration of both mean annual wind speed and mean annual wind power density. Given the cold temperatures in Chefornak, high air density results in a higher wind power density than for the same mean wind speed at standard temperature and pressure. By other measures, Chefornak's wind characteristics are ideal with low turbulence and low wind shear. Because Chefornak experiences cold winter temperatures, energy production of both variable pitch and stall-regulated wind turbines are higher than at standard conditions, but fortuitously, the sea level elevation of the site results in none of the problematic rime icing that have been noted elsewhere in northern Alaska. Simply put, Chefornak has exceptional potential for a wind power project.

Met tower data synopsis

Data dates	June 6, 2012 to July 8, 2013 (13 months); status: met tower still in place but data logger is non-operational
Wind power class	Class 6
Wind power density, mean annual, 30 m	532 W/m^2
Wind speed, mean annual, 30 m	7.55 m/s
Max. 10-min wind speed average	24.5 m/s
Maximum 2-sec. wind gust	31.3 m/s (October, 2012)
Weibull distribution parameters	k = 2.10, c = 8.41 m/s
Wind shear power law exponent	0.146 (low)
Roughness class	1.18 (fallow field)
IEC 61400-1, 3rd ed. (2005) classification	Class III-C
Turbulence intensity, mean	0.082 (at 15 m/s)
Calm wind frequency (at 30 m)	18% (< 4 m/s)

Test Site Location

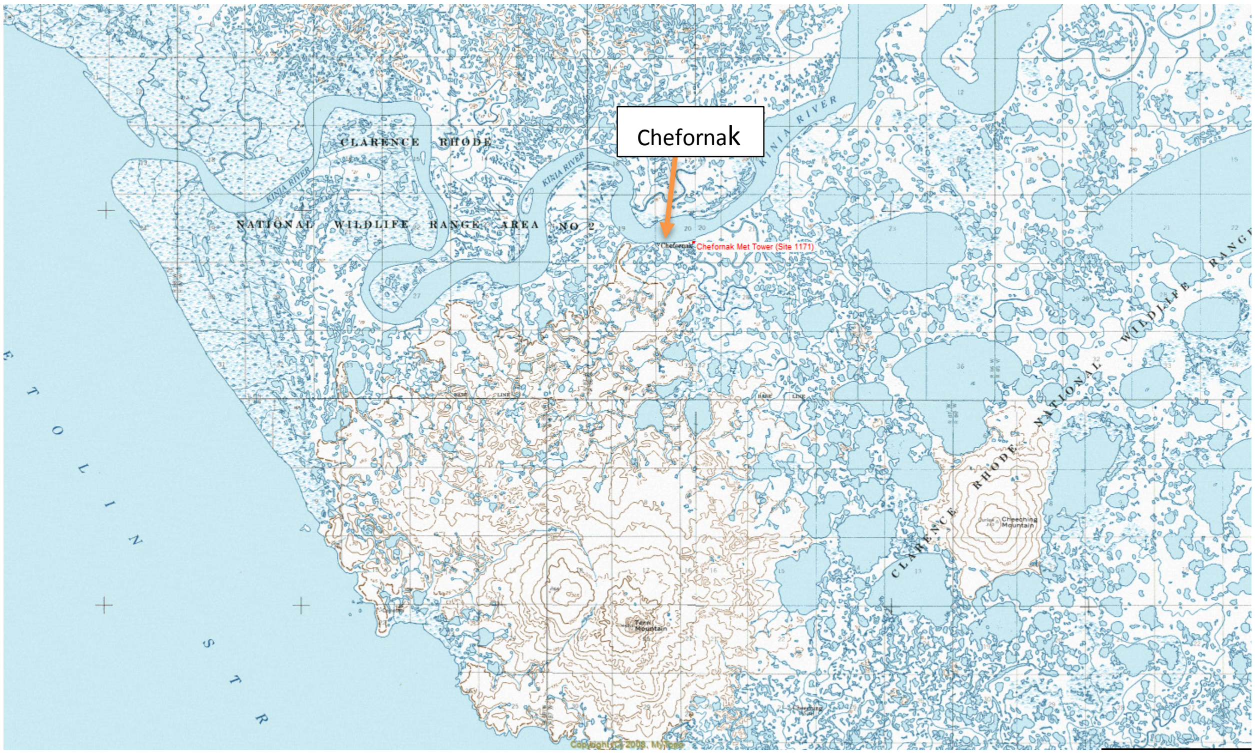
Wind measurement instrumentation was installed on a six-inch diameter 30 meter NRG tubular Tall Tower (met tower) located immediately east of the village of Chefornak and near the south bank of the Kinia River. The tower is located on open tundra and is well exposed to winds from all directions. This site was chosen as a potential wind power site with relatively short connection to existing power distribution. The site is accessible only by boardwalk and trail, however, and this may limit its development appeal. At the time of met tower installation, the old airport was still in use, which precluded met tower site options on the west side of the village. With the new airport now open, other site options are possible. Given the nearly flat, featureless nature of the landscape surrounding Chefornak, data collected at the met tower test location is representative of the wind resource in the near vicinity and orographic modeling can extend the analysis further if desired.

Site information

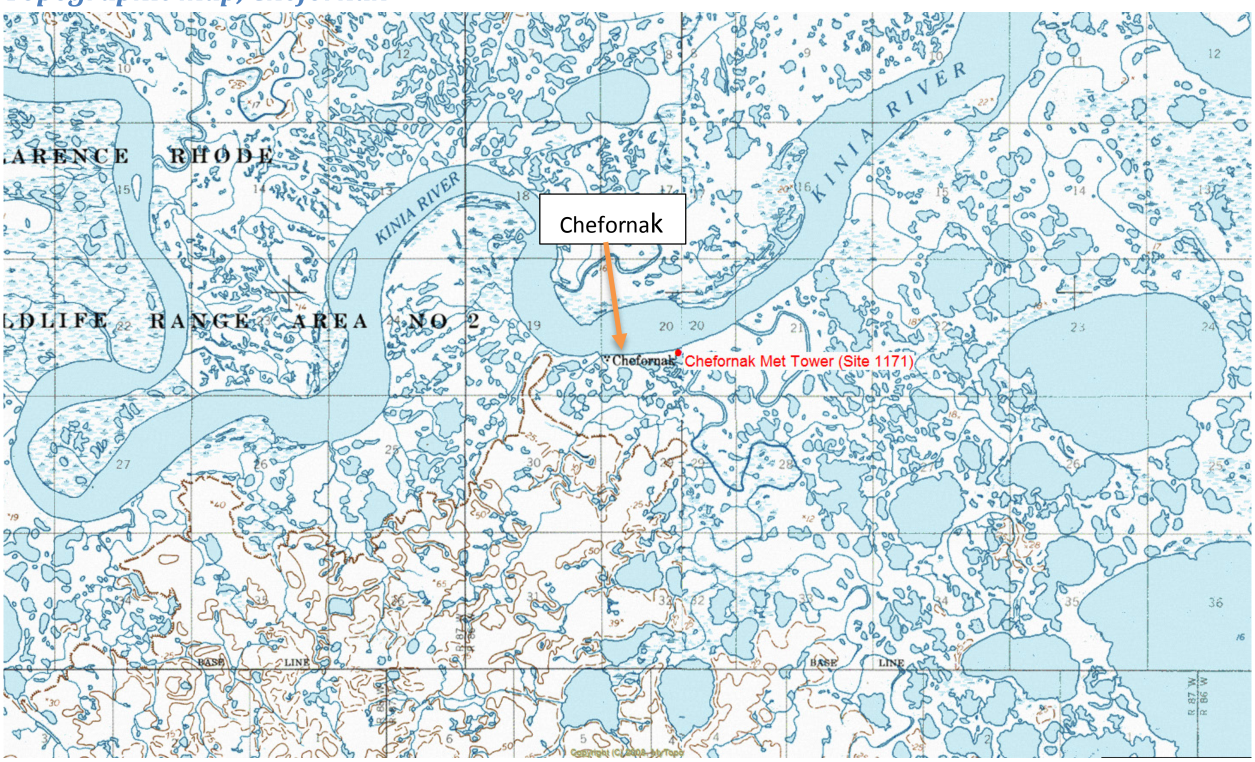
Site number	1171
Latitude/longitude	N 60° 9' 35.24" W 164° 15' 10.81", NAD 83
Elevation	2 meters
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	NRG Tall Tower, 30 meters, six-inch diameter

Chefornak met tower (view to east)

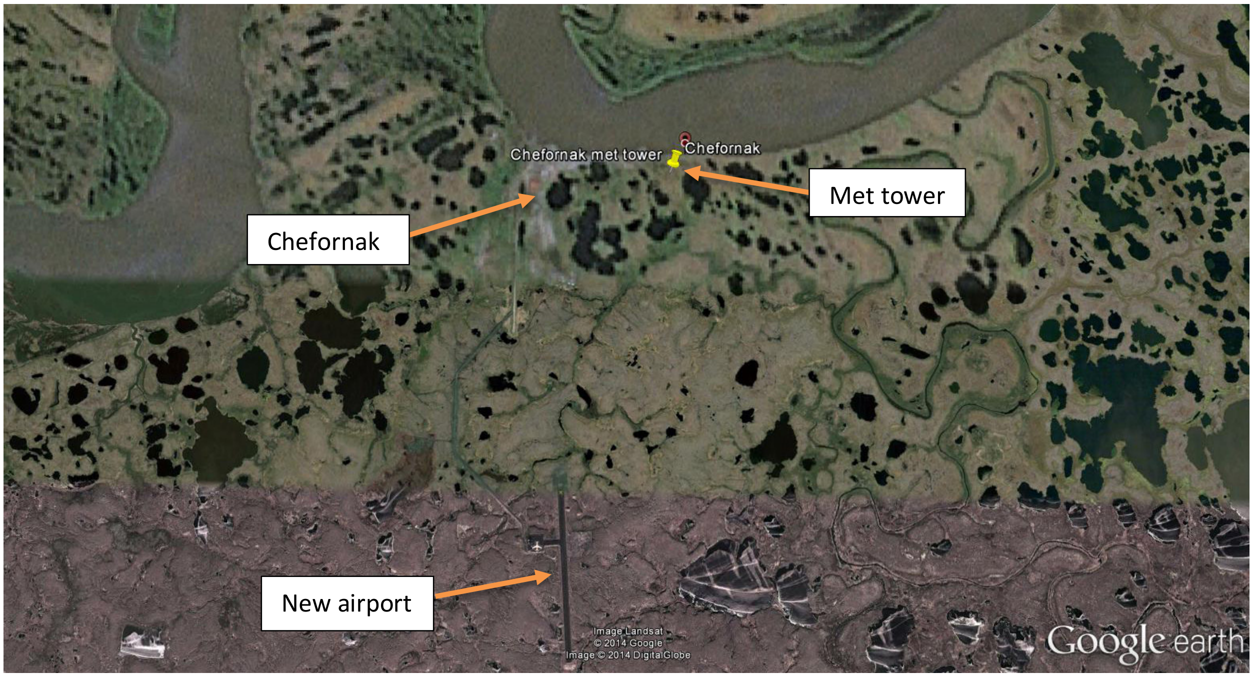
Topographic map, Chefornak and coastal area



Topographic map, Chefornak



Google Earth image



Tower sensor information

Channel	Sensor type	Label	Height	Multiplier	Offset	Orientation
1	SecondWind C3 anemometer	30 m A	28.8 m	0.766	0.324	075° T
2	SecondWind C3 anemometer	30 m B	29.1 m	0.766	0.324	260° T
3	SecondWind C3 anemometer	22 m	21.9 m	0.766	0.324	075° T
7	NRG #200P wind vane	30 m	28.6 m	0.351	000	000° T
8	NRG #200P wind vane	22 m	21.7 m	0.351	355	335° T
10	NRG #110S Temp C		2.0 m	0.138	-86.3	north

Tower sensors photo (view to the southwest)

Data Quality Control

For the measurement period of June 6, 2012 to July 8, 2013, data quality was very good for the anemometers and wind vane but marginal for the temperature sensor, which failed for unknown reasons on March 14, 2013. Also for unknown reasons, the data logger itself failed on July 8, 2014 and no further data was collected from the met tower.

Data loss due to icing conditions was infrequent in Chefornak compared to some coastal sites in western Alaska. Icing conditions in the anemometer data are characterized by output of the anemometer at the minimum offset value of 0.4 m/s, standard deviation of zero, and temperatures less than 1 degree Centigrade. For wind direction data, icing is characterized by non-variant output at the last operable wind direction (standard deviation of zero) and temperature less than 1 degree Centigrade. Icing of the wind vanes was more frequent than the anemometers, but this was not so extensive as to compromise the understanding of prevailing wind directions.

In addition to icing, 30 meter level anemometer pair data was filtered for tower shadow using an algorithm that identifies wind from a 30 degree sector opposite the anemometer and filters that data.

Data flag statistics

Data Column	Possible Records	Icing %	Invalid %	Tower shading %
Speed 30 m A	57,096	2.0%	0.0%	5.1%
Speed 30 m B	57,096	2.3%	0.0%	4.0%
Speed 22 m	57,096	2.3%	0.0%	0.0%
Direction 30 m	57,096	11.2%	0.0%	n/a
Direction 22 m	57,096	9.2%	0.0%	n/a
Temperature	57,096	0.0%	28.9%	n/a

Sensor data recovery

		Anemometers			Wind Vanes		
Year	Month	30 m A Recovery Rate (%)	30 m B Recovery Rate (%)	22 m Recovery Rate (%)	30 m Recovery Rate (%)	22 m Recovery Rate (%)	Temp Recovery Rate (%)
2012	Jun	92.2	97.7	99.9	99.9	99.9	100.0
2012	Jul	89.3	95.2	100.0	100.0	100.0	100.0
2012	Aug	86.0	99.5	100.0	100.0	100.0	100.0
2012	Sep	93.3	94.0	100.0	100.0	100.0	100.0
2012	Oct	99.8	96.4	100.0	100.0	100.0	100.0
2012	Nov	97.5	94.6	97.5	88.8	88.8	100.0
2012	Dec	85.2	77.4	80.0	83.2	83.7	100.0
2013	Jan	96.0	95.6	99.6	68.1	68.1	100.0
2013	Feb	97.0	97.6	99.7	19.7	47.7	100.0
2013	Mar	93.3	88.3	99.0	90.4	90.6	42.9
2013	Apr	94.1	91.0	96.0	98.1	98.4	0.0

		Anemometers			Wind Vanes		
		30 m A Recovery Rate (%)	30 m B Recovery Rate (%)	22 m Recovery Rate (%)	30 m Recovery Rate (%)	22 m Recovery Rate (%)	Temp Recovery Rate (%)
Year	Month						
2013	May	96.1	98.6	98.6	100.0	100.0	0.0
2013	Jun	82.9	91.9	94.3	94.2	94.2	0.0
2013	Jul	93.8	99.9	100.0	100.0	100.0	0.0
All Data		92.5	93.7	97.3	88.3	90.4	70.7

Note: 30 m A & B data recovery percentage includes tower shadow loss

Wind Speed

Anemometer data obtained from the met tower, from perspectives of mean wind speed and mean wind power density, indicates an outstanding wind resource. Mean wind speeds are greater at higher heights on the met tower, as one would expect. Note that the relatively cold mean annual air temperature in Chefornak contributed to a higher wind power density than would be calculated for standard atmospheric conditions of sea level and 15°C.

Anemometer data summary

Variable	Speed 30 m A	Speed 30 m B	Speed 22 m
Measurement height (m)	28.8	29.1	21.9
Mean wind speed (m/s)	7.46	7.42	7.08
MoMM wind speed (m/s)	7.55	7.53	7.19
Median wind speed (m/s)	7.10	7.00	6.60
Max 10-min avg wind speed (m/s)	24.2	24.5	23.3
Max gust (m/s)	31.3	31.3	23.3
Weibull k	2.10	2.13	2.09
Weibull c (m/s)	8.41	8.37	7.99
Mean power density (W/m²)	532	522	462
Mean energy content (kWh/m²/yr)	4,664	4,575	4,045
Energy pattern factor	1.80	1.79	1.82
Frequency of calms (%)	19.2	19.0	20.7

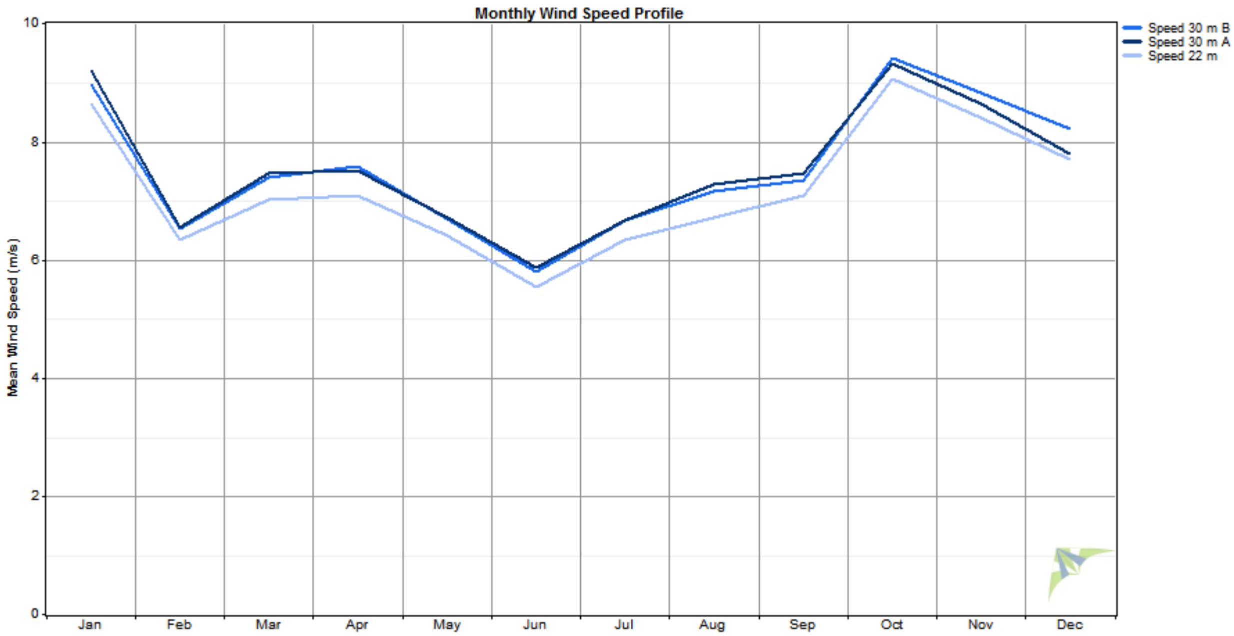
Time series calculations indicate high mean wind speeds during the winter months with more moderate, but still quite high, mean wind speeds during summer months. This correlates well with the typical village load profile with high winter-time electric and thermal energy demand and lower summer-time energy demand.

30 m A anemometer data summary

Year	Month	Mean (m/s)	Max 10-min avg (m/s)	Max Gust (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2012	Jun	5.50	13.6	16.4	2.31	2.53	6.19
2012	Jul	6.62	16.4	21.0	3.05	2.28	7.46

Year	Month	Mean (m/s)	Max 10-min avg (m/s)	Max Gust (m/s)	Std. Dev. (m/s)	Weibull k	Weibull c (m/s)
2012	Aug	7.29	17.0	23.3	3.35	2.32	8.23
2012	Sep	7.47	17.1	22.6	3.78	1.98	8.36
2012	Oct	9.31	23.6	31.3	3.89	2.55	10.48
2012	Nov	8.65	18.1	22.9	3.77	2.46	9.75
2012	Dec	7.79	20.5	25.2	3.44	2.34	8.73
2013	Jan	9.20	24.2	28.7	4.46	2.15	10.36
2013	Feb	6.54	17.5	21.4	3.40	1.97	7.35
2013	Mar	7.46	18.3	22.1	3.75	2.08	8.41
2013	Apr	7.52	16.1	19.9	3.07	2.66	8.46
2013	May	6.71	18.1	21.8	3.64	1.90	7.55
2013	Jun	6.22	17.2	21.8	3.54	1.83	7.00
2013	Jul	6.84	14.4	17.9	2.38	3.06	7.65
All Data		7.46	24.2	31.3	3.70	2.10	8.41
Annual		7.55					

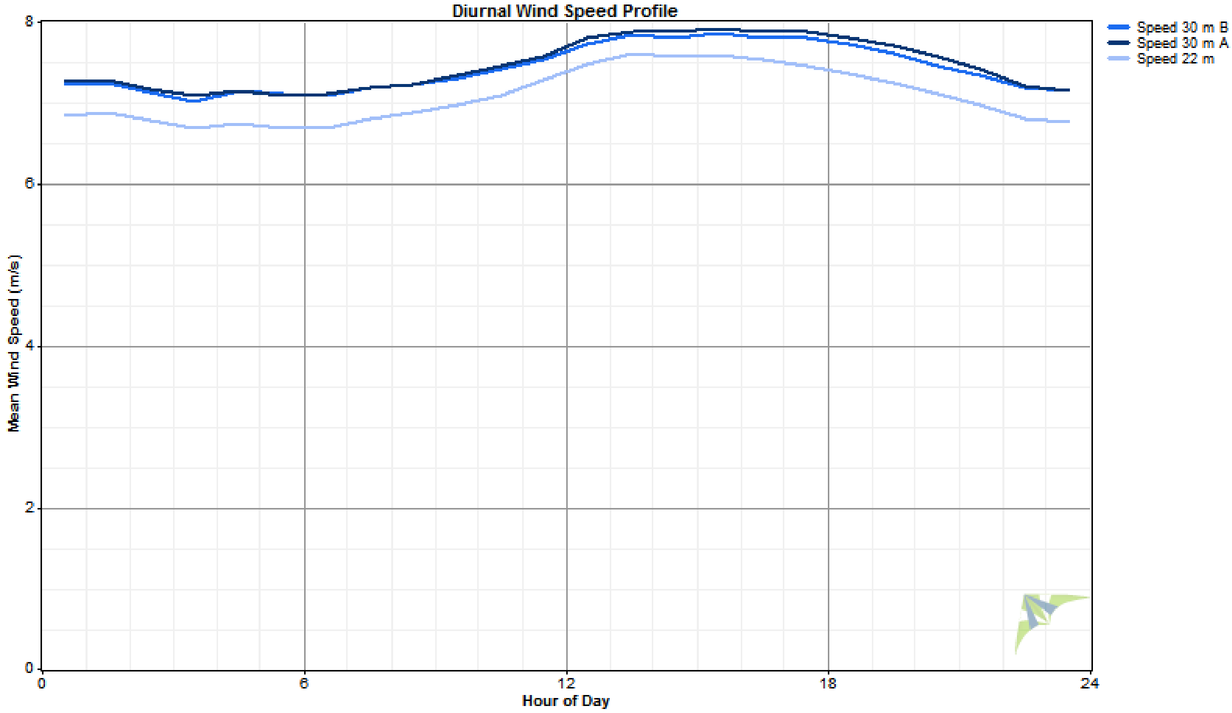
Wind speed time series graph



Diurnal Profile

The a diurnal profile indicates quite stable wind speeds throughout the day with a “valley” of wind speeds during the morning hours and a minor “peak” of wind speeds during afternoon. This correlates reasonably well with typical diurnal electrical load demand of lower loads during the night and morning hours followed by higher demand in the afternoon and evening hours.

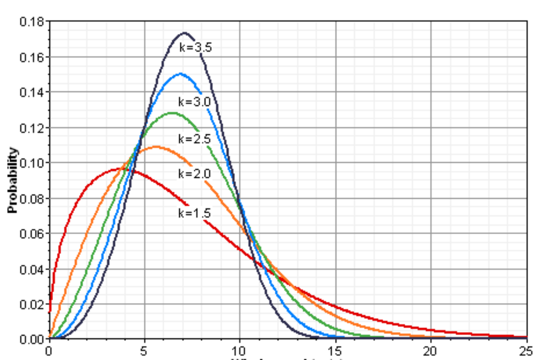
Diurnal profile



Wind Speed Distribution

The probability distribution function gives the probability that a variable, in this case wind speed, will take on the value *x*. It is graphically displayed as a frequency histogram, which give the frequency with which the variable falls within certain ranges or bins. For wind speed, the shape of the distribution curve describes the Weibull k value, with k = 2.0 defined as the Rayleigh distribution, or "normal" shape curve, for wind power analysis (see below).

Weibull k shape curve table



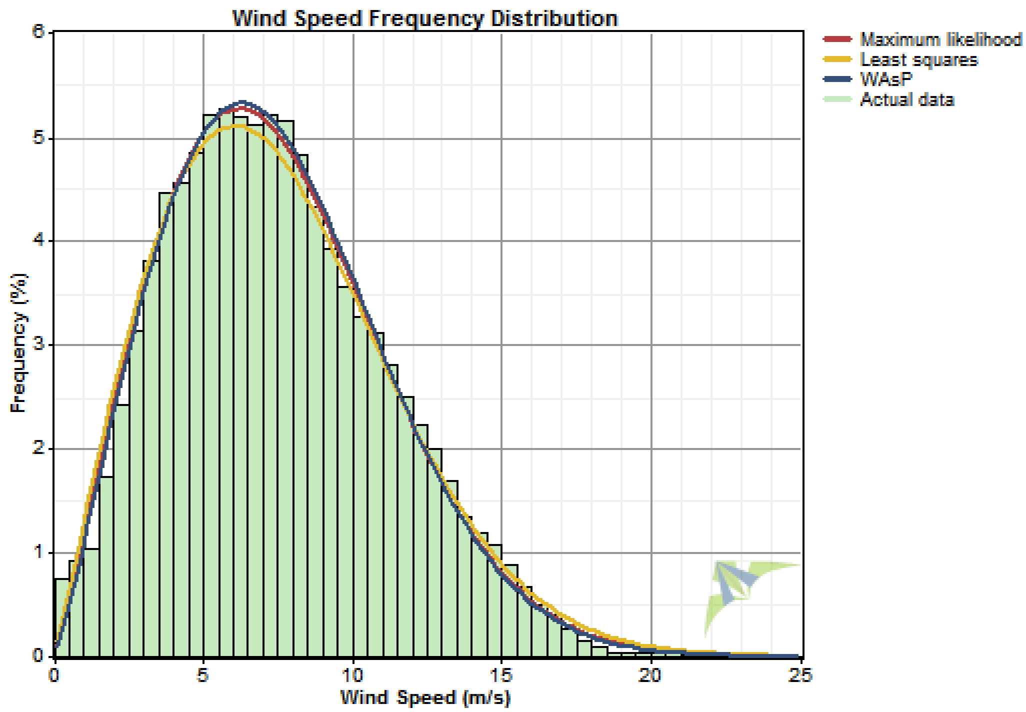
The wind speed distribution of the Chefornak 30 m A anemometer data wind speed data indicates a near normal, or k = 2.0, shape curve as calculated by three methods: maximum likelihood, least squares, and WAsP (software). All approximate the actual data with some variation due to calculation methods.

Weibull comparison table

Algorithm	Weibull k (-)	Weibull c (m/s)	Mean (m/s)	Proportion Above 7.462 m/s	Power Density (W/m2)	R Squared (-)
Maximum likelihood	2.10	8.41	7.45	46.0%	461	0.993
Least squares	2.03	8.48	7.51	46.2%	489	0.992
WAsP	2.14	8.44	7.47	46.3%	457	0.993
Actual data	(52,814 time steps)		7.46	46.3%	457	

As one can see in the following graph, the most frequently occurring wind speeds are between 4 and 8 m/s with very few wind events exceeding 25 m/s, the cutout speed of most wind turbines. See the *Occurrence by wind speed bin* table for additional information.

Wind speed distribution of 30 m A anemometer



Occurrence by wind speed bin

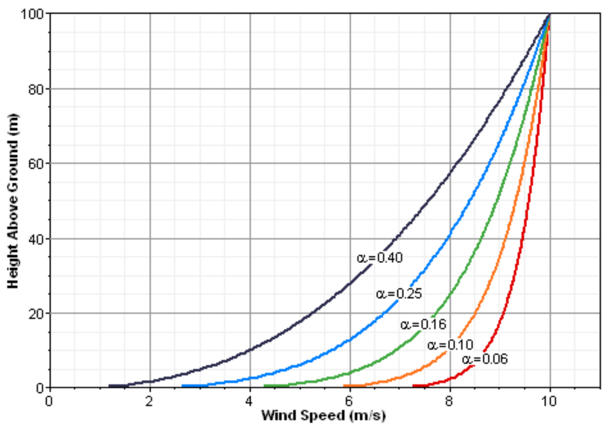
Bin Endpoints (m/s) Lower	Upper	Occurrences No.	Percent	Bin Endpoints (m/s) Lower	Upper	Occurrences No.	Percent
0	1	883	1.7%	14	15	1,201	2.3%
1	2	1,468	2.8%	15	16	825	1.6%
2	3	2,930	5.5%	16	17	475	0.9%
3	4	4,375	8.3%	17	18	227	0.4%
4	5	4,968	9.4%	18	19	77	0.1%
5	6	5,530	10.5%	19	20	45	0.1%
6	7	5,439	10.3%	20	21	41	0.1%

Bin Endpoints (m/s)		Occurrences		Bin Endpoints (m/s)		Occurrences	
Lower	Upper	No.	Percent	Lower	Upper	No.	Percent
7	8	5,469	10.4%	21	22	17	0.0%
8	9	4,840	9.2%	22	23	21	0.0%
9	10	3,957	7.5%	23	24	12	0.0%
10	11	3,371	6.4%	24	25	1	0.0%
11	12	2,801	5.3%	all		52,814	100.0%
12	13	2,237	4.2%				
13	14	1,604	3.0%				

Wind Shear and Roughness

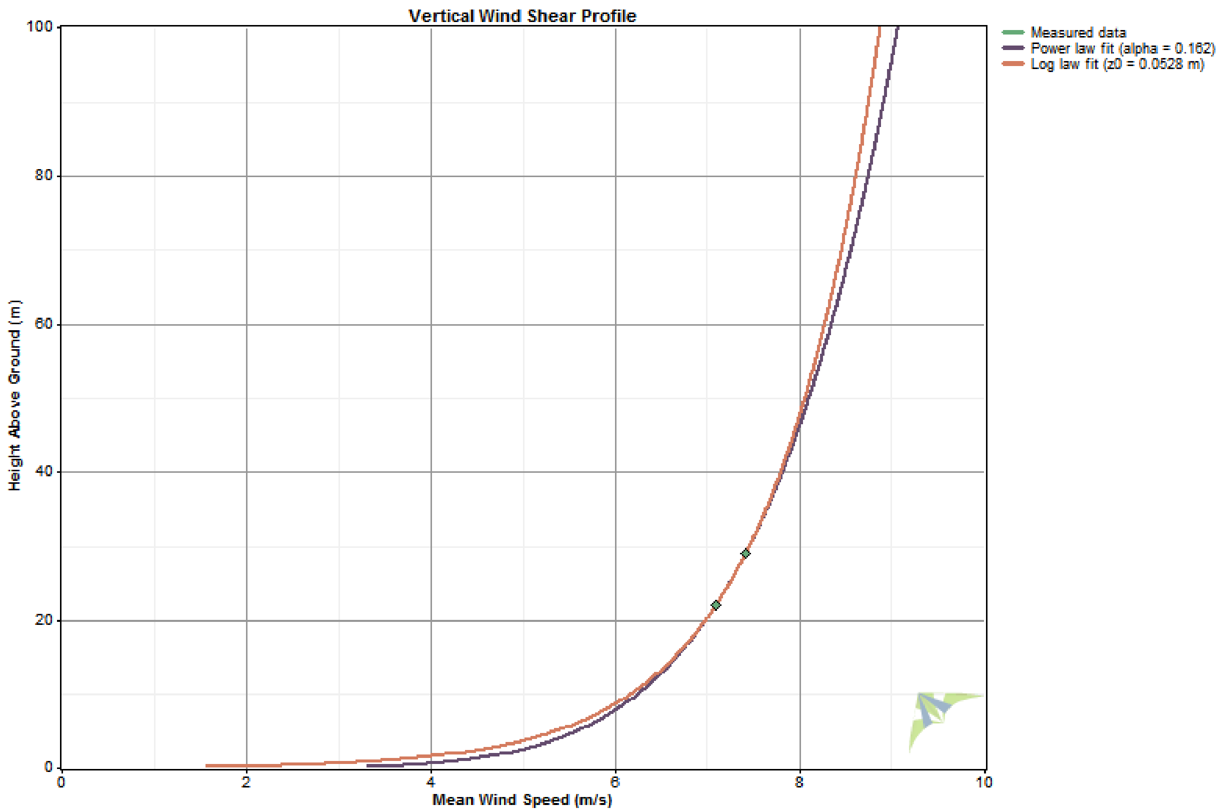
The power law exponent (*alpha*, α), also referred to as the power law coefficient, is a number that characterizes the wind shear, or the change in wind speed with height above ground level. The power law equation to calculate wind speed with increasing height uses the power law exponent as a parameter. The graph below shows comparative wind shear profiles with varying α values.

Comparative wind shear profiles



A wind shear α of 0.162, calculated with non-flagged 30 m A and 22 m anemometer data, indicates moderate wind shear at the Chefornak met tower site. Related to wind shear, a calculated surface roughness of 0.053 meters (indicating the height above ground level where wind velocity would be zero) indicates relatively smooth terrain (roughness description: fallow field) surrounding the met tower. The practical implication of this data is that increased turbine hub height is likely to be beneficial from a benefit-to-cost perspective.

Vertical wind shear profile



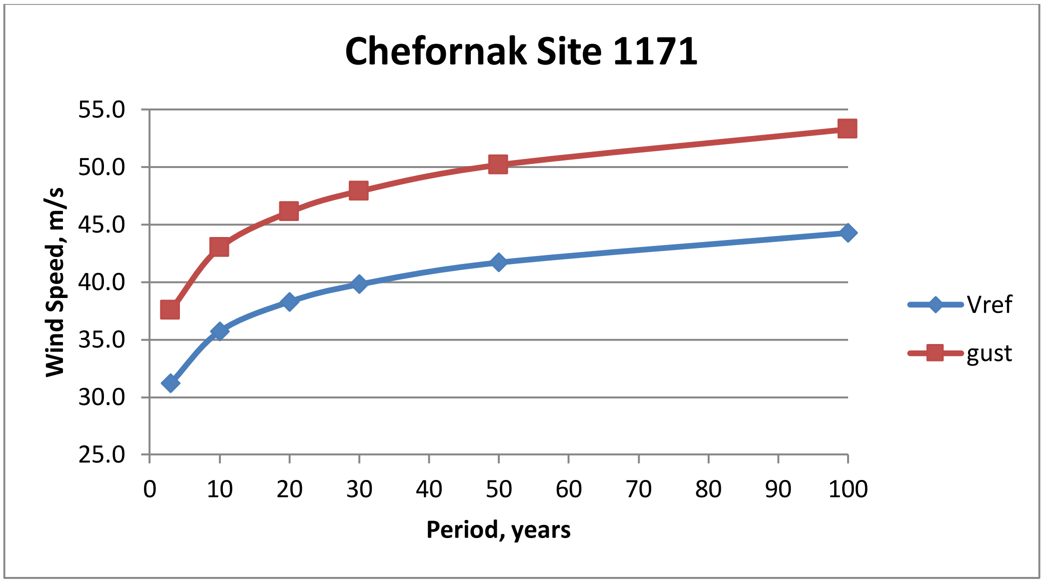
Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Chefornak met tower site. Industry standard reference of extreme wind is the 50 year probable (50 year return period) ten-minute average wind speed, referred to as V_{ref}. For Chefornak, this calculates to 30.7 m/s (at 30 meters), which qualifies as an International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria Class III site, the lowest defined. All wind turbines are designed for IEC 61400-1 Class III conditions.

Extreme wind probability table, 30 m A data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	24.4	30.7	I	50.0
10	27.1	34.1	II	42.5
20	28.6	36.0	III	37.5
30	29.5	37.1	S	designer-specified
50	30.7	38.5		
100	32.2	40.4		
average gust factor:	1.26			

Extreme wind graph



Temperature and Density

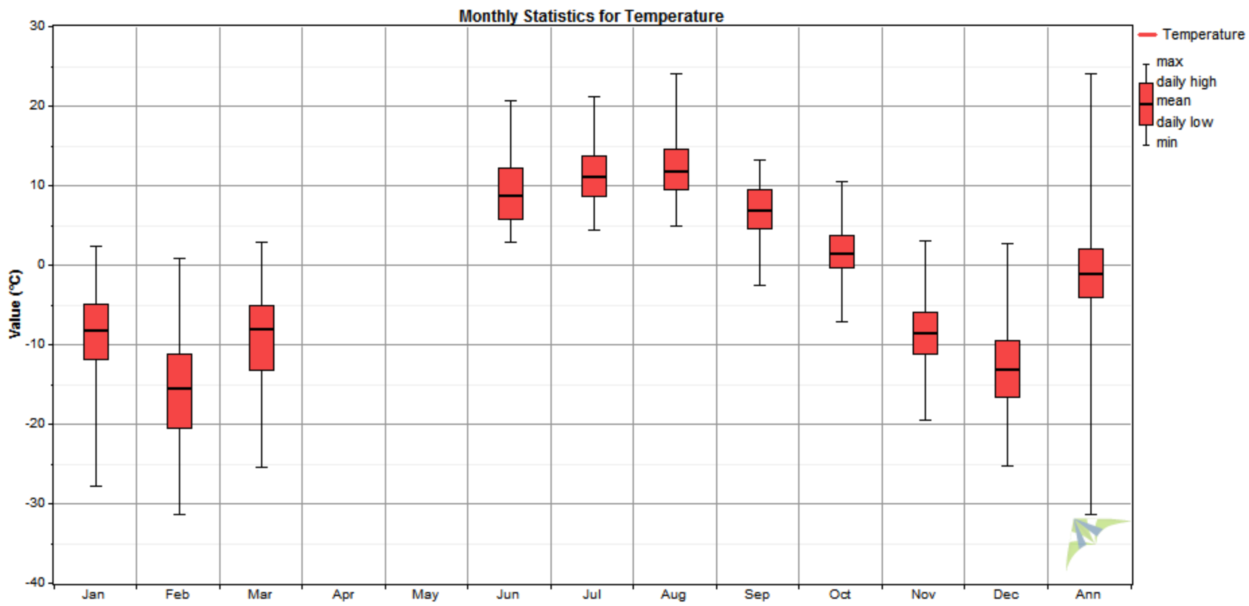
Chefornak experiences moderately cool summers and cold winters with resulting higher than standard air density. The measured mean annual temperature of -0.9°C was compromised however by failure of the temperature sensor in mid-March, 2013. With inclusion of late March thru July, 2013 data, the mean annual temperature would be higher than indicated. Calculated annual mean air density during the met tower test period exceeds by 5.9 percent the 1.225 kg/m^3 standard air density at a 2 meter elevation. This is advantageous in wind power operations as wind turbines typically produce more power at low temperatures/high air density than at standard temperature and density. Again, though, this calculation does not include data from the warmer summer months so the mean air density should be considered with some caution as it is likely high.

Temperature and density table

			Temperature °C			Temperature °F			Density,
		Recovery	Mean	Min	Max	Mean	Min	Max	Mean
Year	Month	Rate (%)	(°C)	(°C)	(°C)	(°F)	(°F)	(°F)	(kg/m^3)
2012	Jun	100.0	8.8	2.9	20.7	47.8	37.2	69.3	1.251
2012	Jul	100.0	11.1	4.4	21.2	52.0	39.9	70.2	1.241
2012	Aug	100.0	11.9	4.9	24.1	53.5	40.8	75.4	1.238
2012	Sep	100.0	7.0	-2.6	13.3	44.6	27.3	55.9	1.259
2012	Oct	100.0	1.5	-7.1	10.5	34.7	19.2	50.9	1.285
2012	Nov	100.0	-8.5	-19.5	3.0	16.8	-3.1	37.4	1.333
2012	Dec	100.0	-13.0	-25.3	2.7	8.6	-13.5	36.9	1.357
2013	Jan	100.0	-8.2	-27.8	2.3	17.3	-18.0	36.1	1.333
2013	Feb	100.0	-15.5	-31.3	0.9	4.2	-24.3	33.6	1.370
2013	Mar	42.9	-8.0	-25.4	2.9	17.6	-13.7	37.2	1.332
2013	Apr	0.0							

			Temperature °C			Temperature °F			Density,
Year	Month	Recovery Rate (%)	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)	Mean (kg/m^3)
2013	May	0.0							
2013	Jun	0.0							
2013	Jul	0.0							
All Data		70.7	-0.9	-31.3	24.1	30.3	-24.3	75.4	1.298

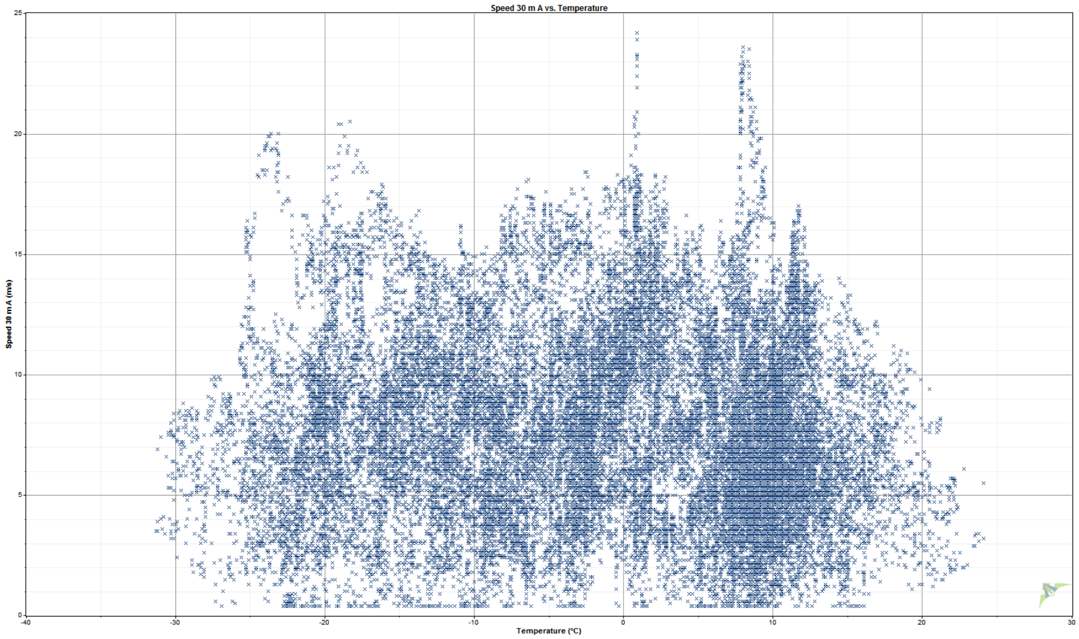
Annual temperature boxplot



Wind Speed-Temperature Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Chefornak coincides with cold temperatures as one would expect. During the met tower test period, temperatures rarely fell below -30°C and never below -40°C, the minimum operating temperature of arctic-capable wind turbines. Note, however, that nearly four months of temperature data are missing from the data set and hence not represented in the scatter plot.

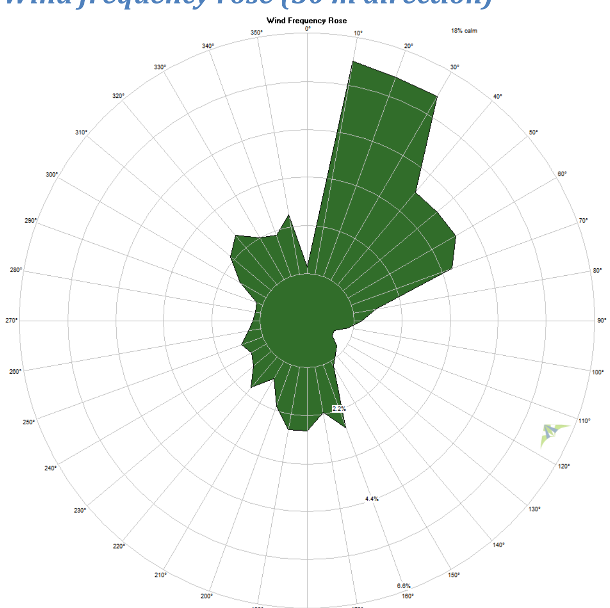
Wind speed/temperature



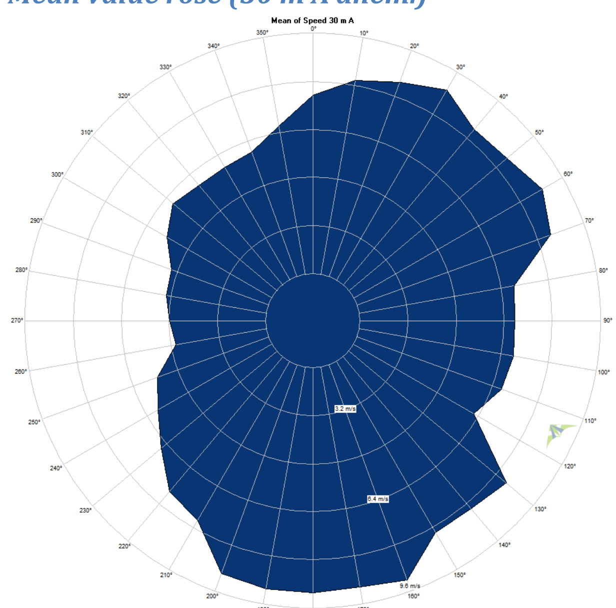
Wind Direction

Wind frequency rose data indicates that Chefornak winds are fairly directional, with north-northeasterly winds predominating and southwesterly and northwesterly winds contributing less significantly. Interestingly, the mean value rose indicates that northeasterly and southwesterly winds are of highest intensity. This results in the wind energy rose which indicates that power production winds are strongly northeasterly and to a lesser extent southwesterly. Calm frequency (percent of time that winds at the 30 meter level are less than 4 m/s) was a remarkably low 18 percent during the met tower test period.

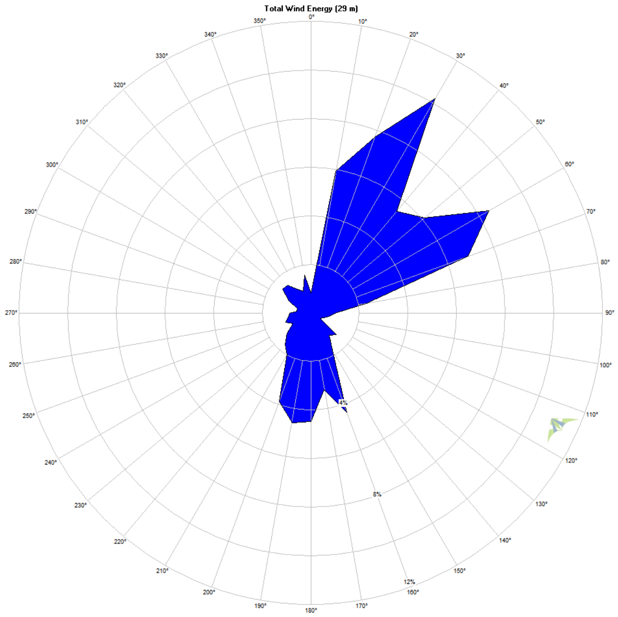
Wind frequency rose (30 m direction)



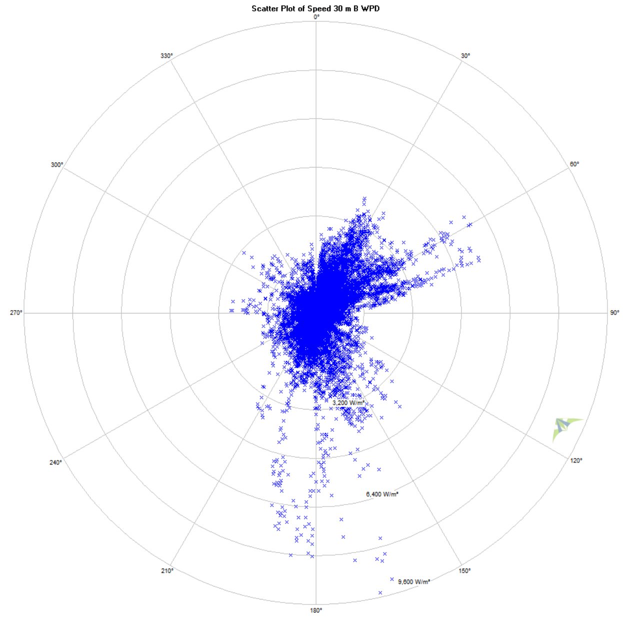
Mean value rose (30 m A anem.)



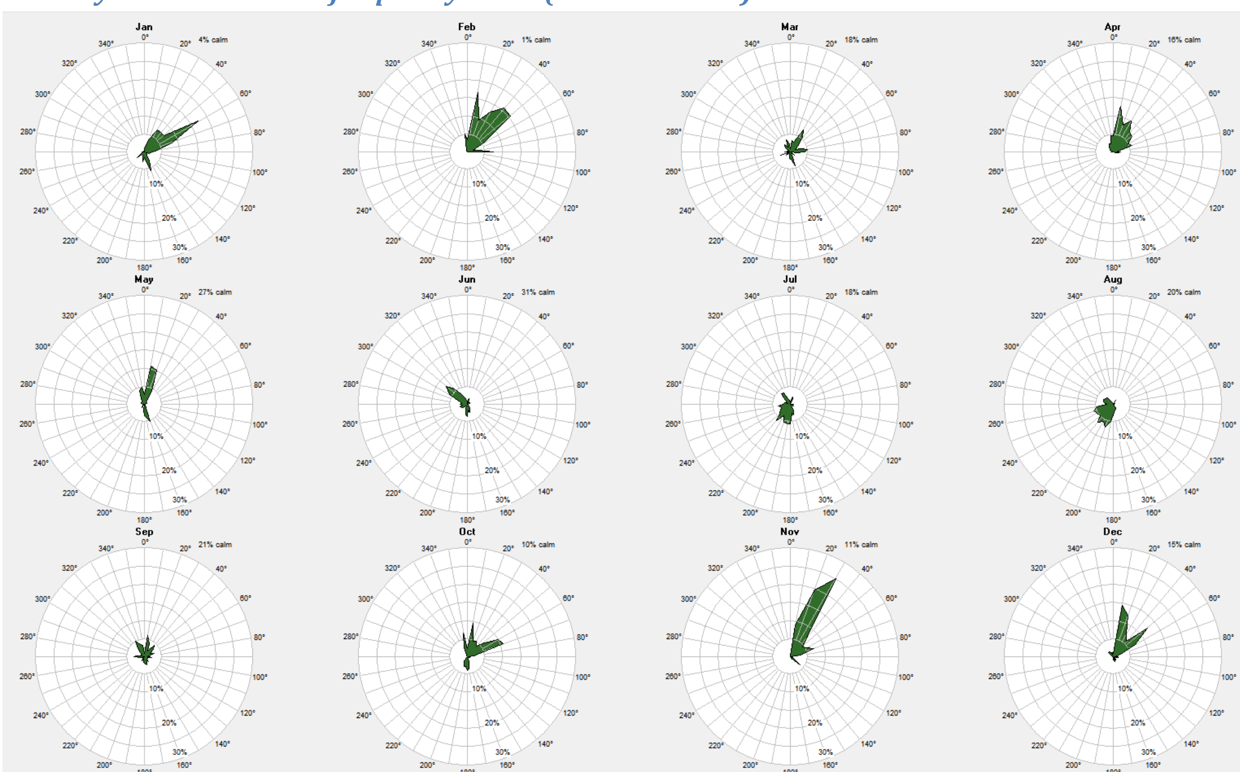
Wind energy rose (30 m A anem.)



Scatterplot rose of 30m A wind power density

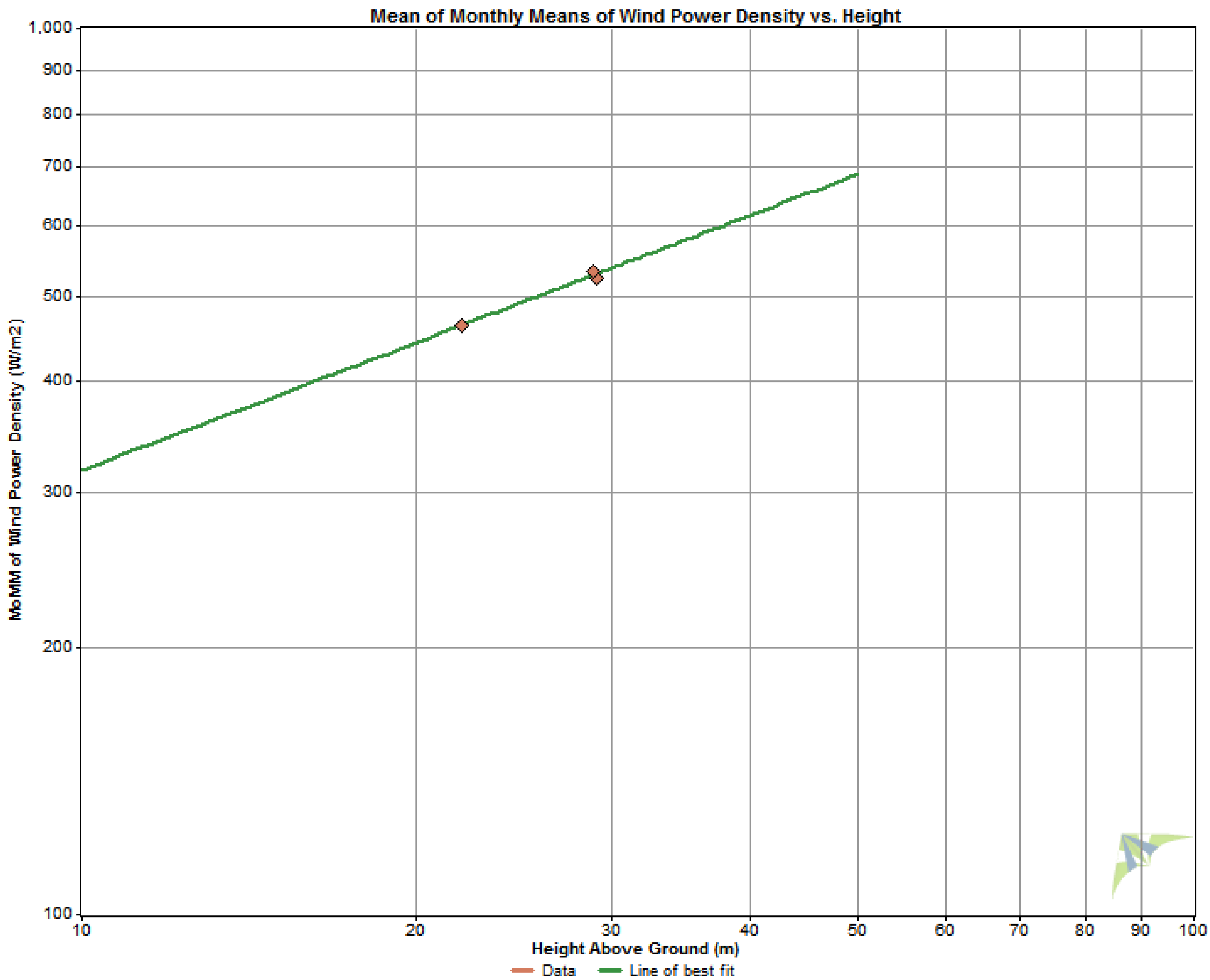


Monthly 30 m vane wind frequency roses (common scale)



Wind Power Classification

The graph below is a least squares regression best fit of wind power density versus height above ground level. This can be used to extrapolate or interpolate wind power density at heights of interest than measured.



Turbulence

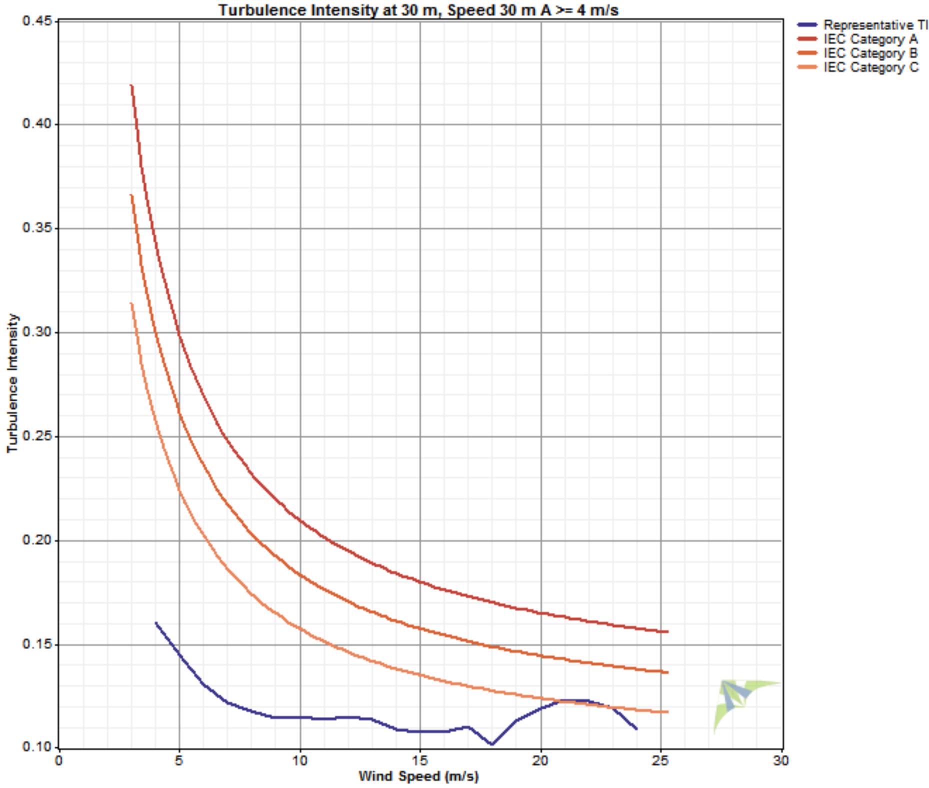
Turbulence intensity (TI) is a dimensionless number defined as the standard deviation of the wind speed within a time step divided by the mean wind speed of that time step.

Turbulence intensity at the Chefornak met tower site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. The mean TI at 15 m/s is 0.082 and the representative TI at 15 m/s is 0.107 (30 m A anemometer), both which can be considered very low and hence highly desirable for wind turbine operations.

Turbulence categories defined in IEC 61400-1, 3rd edition

Category	Mean TI at 15 m/s
S	> 0.16
A	0.14-0.16
B	0.12-0.14
C	<0.12

Turbulence intensity, 30 m A anemometer, all direction sectors



Turbulence table, 30 m A anemometer data

Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
0.5	1.5	1,041	0.408	0.169	0.624	1.600
1.5	2.5	2,194	0.191	0.101	0.321	1.053
2.5	3.5	3,665	0.130	0.060	0.207	0.607
3.5	4.5	4,769	0.109	0.049	0.171	0.528
4.5	5.5	5,308	0.096	0.038	0.145	0.500
5.5	6.5	5,523	0.088	0.033	0.131	0.364
6.5	7.5	5,446	0.084	0.030	0.122	0.275
7.5	8.5	5,271	0.081	0.028	0.117	0.244
8.5	9.5	4,365	0.079	0.027	0.114	0.409
9.5	10.5	3,605	0.081	0.026	0.115	0.200
10.5	11.5	3,126	0.080	0.026	0.114	0.266
11.5	12.5	2,503	0.083	0.025	0.115	0.190
12.5	13.5	1,950	0.084	0.024	0.114	0.169
13.5	14.5	1,345	0.083	0.020	0.109	0.156
14.5	15.5	1,036	0.082	0.020	0.107	0.170
15.5	16.5	621	0.083	0.019	0.108	0.160
16.5	17.5	351	0.083	0.021	0.110	0.162

Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
17.5	18.5	138	0.077	0.019	0.101	0.131
18.5	19.5	50	0.088	0.019	0.113	0.130
19.5	20.5	41	0.091	0.022	0.119	0.134
20.5	21.5	28	0.102	0.016	0.123	0.131
21.5	22.5	18	0.100	0.017	0.122	0.118
22.5	23.5	21	0.095	0.018	0.119	0.120
23.5	24.5	4	0.081	0.022	0.109	0.102

WAsP Modeling

WAsP (Wind Atlas Analysis and Application Program) and is PC-based software for predicting wind climates, wind resources and power production from wind turbines and wind farms and was used to model the Chefornak area terrain and wind turbine performance.

WAsP software calculates gross and net annual energy production (AEP) for turbines contained within wind farms, such as an array of two or more turbines in proximity to each other. For s single turbine array, WAsP calculates gross AEP. With one turbine, net AEP is identical to gross AEP as there is no wake loss to consider.

Orographic Modeling

WAsP modeling begins with import of a digital elevation map (DEM) of the subject site and surrounding area and conversion of coordinates to Universal Transverse Mercator (UTM). UTM is a geographic coordinate system that uses a two-dimensional Cartesian coordinate system to identify locations on the surface of Earth. UTM coordinates reference the meridian of its particular zone (60 longitudinal zones are further subdivided by 20 latitude bands) for the easting coordinate and distance from the equator for the northing coordinate. Units are meters. Elevations of the DEMs are converted to meters if necessary for import into WAsP software.

A met tower reference point is added to the digital elevation map, wind turbine locations identified, and a wind turbine(s) selected to perform the calculations. WAsP considers the orographic (terrain) effects on the wind (plus surface roughness and obstacles) and calculates wind flow increase or decrease at each node of the DEM grid. The mathematical model has a number of limitations, including an assumption that general wind regime of the turbine site is the same as the met tower reference site, prevailing weather conditions are stable over time, and the surrounding terrain at both sites is sufficiently gentle and smooth to ensure laminar, attached wind flow. WAsP software is not capable of modeling turbulent wind flow resulting from sharp terrain features such as mountain ridges, canyons, shear bluffs, etc.

Orographic modeling of the wind across the site, with the Chefornak met tower as the reference site, indicates an outstanding wind resource in Chefornak itself, with even higher winds speeds on the higher elevation terrain along the access road to the new airport. This may provide wind turbine site location opportunities beyond the met tower location.

Orographic WAsP modeling of Chefornak, plan view