Emmonak, Alaska Wind Power Report

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Photos: Doug Vaught

Summary Information

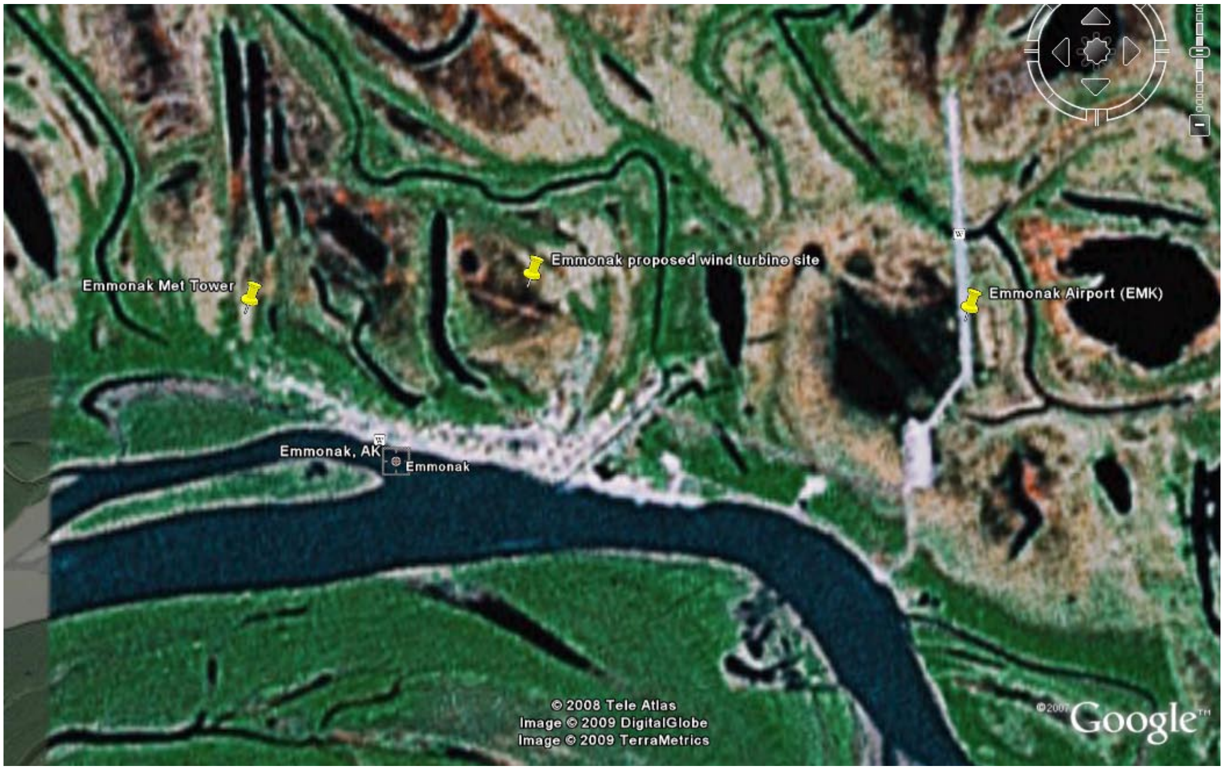
Alaska Village Electric Cooperative (AVEC) is planning a wind power project in the village of Emmonak that will include approximately 400 to 600 kW of installed wind turbine capacity, an electrical intertie to the nearby village of Alakanuk, and a control system to integrate the turbines to the existing power system. In anticipation of this project, a met tower was installed in Emmonak in July, 2007 and continues to collect data. In addition to wind data collection, AVEC collects other information such as electric load and diesel power plant performance data for Emmonak and Alakanuk. This data was analyzed with software tools to evaluate the wind resource itself and to predict the performance of wind turbines and their operation as a wind-diesel hybrid system once connected to the village's existing power system.

The Emmonak met tower site is located on the tundra in a clearing of willow trees just west of the village boundary. This site was selected based on the intended location for wind power development in 2007, but later plans call for turbines to be placed in an open clearing in the north-central portion of the village. Given the uniform terrain characteristics of Emmonak, the met tower site is considered reasonably representative of the new turbine site, although aspects of the data indicate an undesirable influence of the brush surrounding the met tower. If wind turbines are installed at or near the met tower location, plans call for the brush to be cleared sufficiently to mitigate this problem.

Met Tower Data Synopsis

Data dates	September 25, 2007 to April 14, 2010 (31 months; 9 months missing)
IEC 61400-1, 3rd ed. classification	III-b (measured); likely III-c
Power density mean, 30 m	181 W/m^2 (*not* AWOS adjusted)
Wind speed mean, 30 m	5.72 m/s (AWOS data adjusted)
Maximum 10-min wind speed average	19.5 m/s (*not* AWOS adjusted)
Maximum wind gust	29.1 m/s (March 2009)
Weibull distribution parameters	k = 2.13, c = 5.90 m/s (to date)
Roughness class	3.60 (forest)
Power law exponent (α)	0.297 (high wind shear possibly affected by brush; lower α value, more typical of tundra, likely)
Frequency of calms (4 m/s threshold)	35%
Mean turbulence intensity	0.135 (IEC3 turbulence category B; possible brush effect, likely IEC3 turbulence category C)

Google Earth image



Google Earth Image of Emmonak

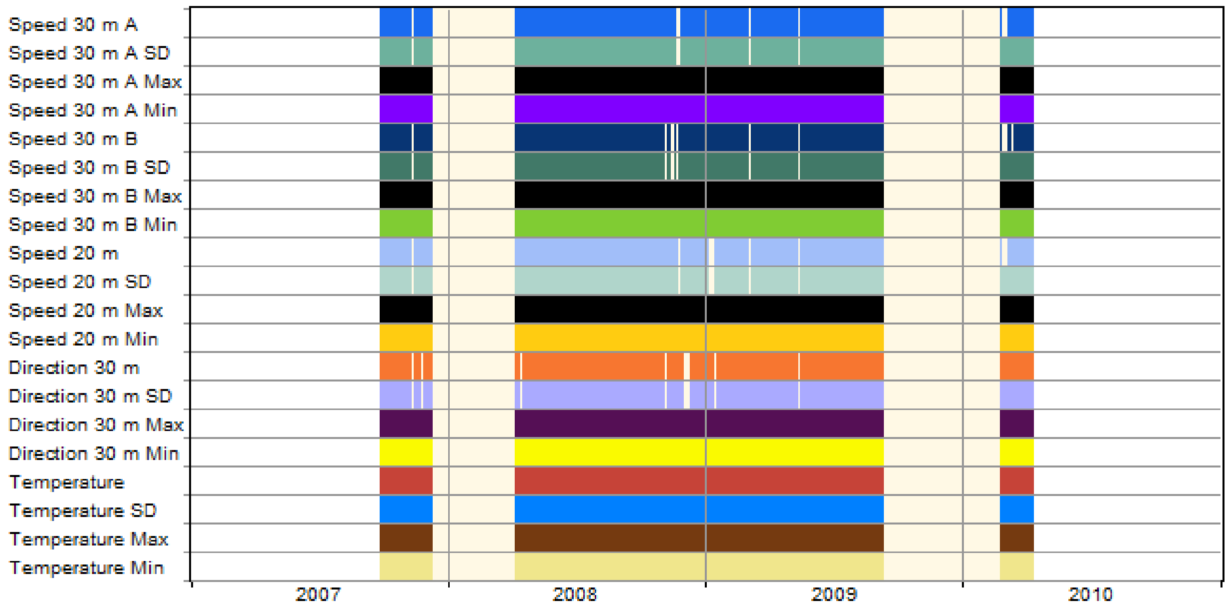
Data Quality Control

Data was filtered to remove obvious icing events. Typically, anemometer icing is identified by non-variant data readings at the sensor offset value for anemometers and a "frozen" heading for wind vanes, a standard deviation of zero, and temperature near or below freezing. The data collected to date in Emmonak indicates a number of icing events typical of freezing rain at a low elevation site. These periods of data loss are shown in the graph below as thin while lines in the colored data fields and are not significant. More substantially, note that nine months of data are missing – from December 11, 2007 to April 5, 2008 and again from September 12, 2009 to February 22, 2010. The first data loss period occurred when a data card failed and data was unrecoverable. The second data loss period is unexplained at present but may indicate a problem with the datalogger. Also note that the met tower was installed in Emmonak on July 20, 2007. The data card containing data logged from July 20 to September 25, 2007 was lost in the mail.

Data recovery rate summary

Label	Ch	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 30 m A	1	m/s	30 m	134,124	89,797	67.0
Speed 30 m B	2	m/s	30 m	134,124	88,937	66.3
Speed 20 m	3	m/s	20 m	134,124	88,940	66.3
Direction 30 m	7	°	30 m	134,124	89,554	66.8
Temperature	9	°C	2 m	134,124	93,792	69.9

Data coverage chart

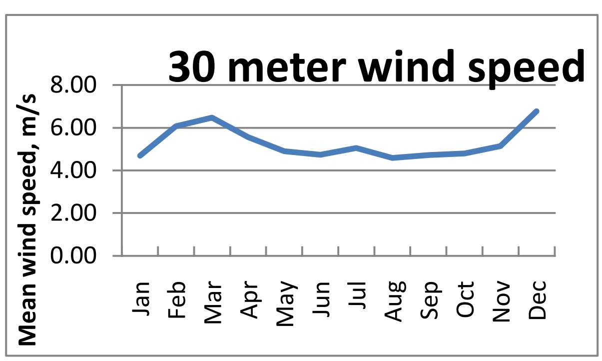


Wind Speed Data Summary

The primary data of interest from the met tower is from the 30 meter anemometer. This data set is used for the wind turbine power generation calculations in this report. An annual summary (mean of monthly means) from the 30 meter A anemometer is presented below.

30 meter anemometer summary

Month	Mean (m/s)	Max (m/s)	Std. Dev. (m/s)
Jan	4.69	16.4	2.68
Feb	6.07	19.2	3.49
Mar	6.48	18.7	2.87
Apr	5.56	15.1	2.46
May	4.89	11.1	1.86
Jun	4.73	13.8	2.07



Jul	5.05	15.5	2.13
Aug	4.58	11.8	1.76
Sep	4.72	13.3	2.05
Oct	4.79	18.7	2.59
Nov	5.13	19.4	3.14
Dec	6.77	19.2	3.06
Annual	5.29	19.4	2.58

Long-term Wind Reference

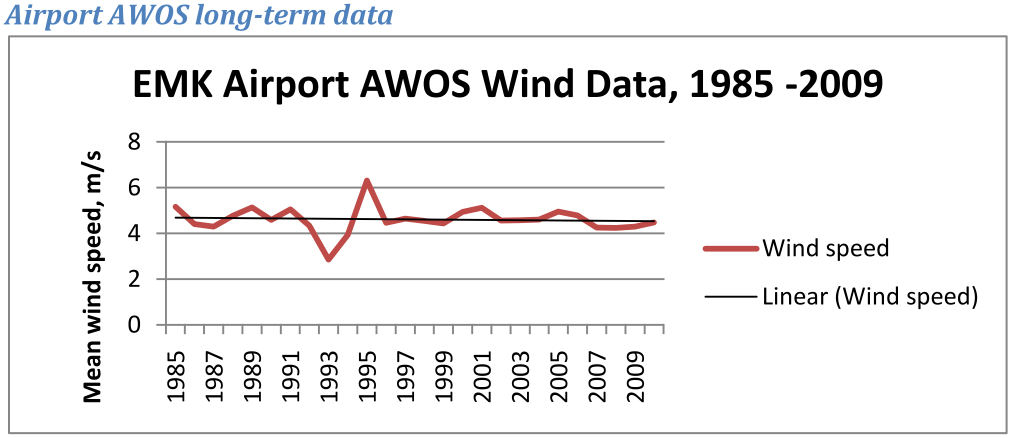
The nearby Emmonak Airport has an Automated Weather Observing System (AWOS) that has collected data for many years. To gain a perspective of wind conditions during the met tower test period, AWOS data from 1985 to present were analyzed. Although some older data (pre-1997) is missing or otherwise appears somewhat inconsistent (especially 1993 and 1995), in general one observes that 2007 through 2009 were relatively low wind years compared to a long-term average (represented by the line titled *Linear (Wind Speed)* in the graph below), representing about 92.5% of the mean wind speed measured from 1985 through 2009 and 92.4% if considering just 1997 through 2009. Note that the long term trend of wind speed appears to be decreasing slightly. This may not necessarily be true with a longer term perspective of wind speeds, but for this study only a twenty-five year period was examined.

To normalize the met tower data to long-term, a simple approach was employed of dividing the measured mean wind speeds by 0.925, which yielded a mean annual wind speed at 30 meters of 5.72 m/s. This changes the Emmonak wind classification from Class 2 to Class 3, without consideration of air density effects on either data set.

Met tower data, AWOS adjusted data table

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
30 m A (m/s)	4.69	6.07	6.48	5.56	4.89	4.73	5.05	4.58	4.72	4.79	5.13	6.77	5.29
30 m A, AWOS corrected ’85 to ’09 (m/s)	5.07	6.57	7.00	6.01	5.29	5.12	5.46	4.95	5.10	5.18	5.55	7.32	5.72

Airport AWOS long-term data



Wind Turbine Performance

It is perhaps counterintuitive that wind power density and wind class do not correlate linearly with turbine power output. This is due to a number of factors, including theoretical limitations of a lift-producing aerodynamic device (the turbine rotor) and practical limitations of generator weight and rated output. For these reasons and others, a wind turbine in a low power class wind regime may still produce sufficient energy to warrant installation of turbines.

A simplistic consideration of possible turbine output in Emmonak is to model power output of a particular turbine with mean of monthly means data collected to date and extrapolating to the turbine hub height. Taking the analysis slightly further, turbine performance estimates was normalized to the long-term average wind as measured by the airport AWOS. Note the this analysis is based on raw data with no synthetic data inserted in place of icing data removed for data quality control or data missing for other reasons.

Turbine performance was analyzed with the HOMER software using the Northern Power Northwind 100 B model (21 meter rotor diameter) and the Aeronautica 29-225 (225 kW, 29 meter rotor diameter). At present the NW100 is AVEC's preferred turbine choice for Emmonak and the Aeronautica 29-225 is an alternate choice. Extrapolating to the 37, 40, and 50 meter hub heights with a power law exponent (α) of 0.14 instead of the met tower derived α of 0.297 (note that this is a more conservative approach as extrapolated wind speeds above 30 meters are less with an α of 0.14 than an α of 0.297; see detailed explanation on page 12 for more information), anticipated turbine performance for 100 percent and 90 percent turbine availabilities is shown in the tables below.

NW100/21 B, 37 m hub height

			100% turbine avail.		80% turbine avail.	
	30 m mean (m/s)	37 m hub (m/s)	NW100/21 (MWh/yr)	NW100/21 CF (%)	NW100/21 (MWh/yr)	NW100/21 CF (%)
Original data	5.29	5.45	177.2	19.6	141.8	15.7
AWOS-adjusted data	5.72	5.89	211.4	23.4	169.1	18.7

Aeronautica 29-225, 40 m hub height

			100% turbine avail.		80% turbine avail.	
	30 m mean (m/s)	40 m hub (m/s)	NW100/21 (MWh/yr)	NW100/21 CF (%)	NW100/21 (MWh/yr)	NW100/21 CF (%)
Original data	5.29	5.51	349.3	17.7	279.4	14.2
AWOS-adjusted data	5.72	5.95	427.2	21.7	341.8	17.4

Aeronautica 29-225, 50 m hub height

			100% turbine avail.		80% turbine avail.	
	30 m mean (m/s)	50 m hub (m/s)	29-225 (MWh/yr)	29-225 CF (%)	29-225 (MWh/yr)	29-225 CF (%)
Original data	5.29	5.68	384.6	19.5	307.7	15.6
AWOS-adjusted data	5.72	6.14	466.5	23.7	373.2	19.0

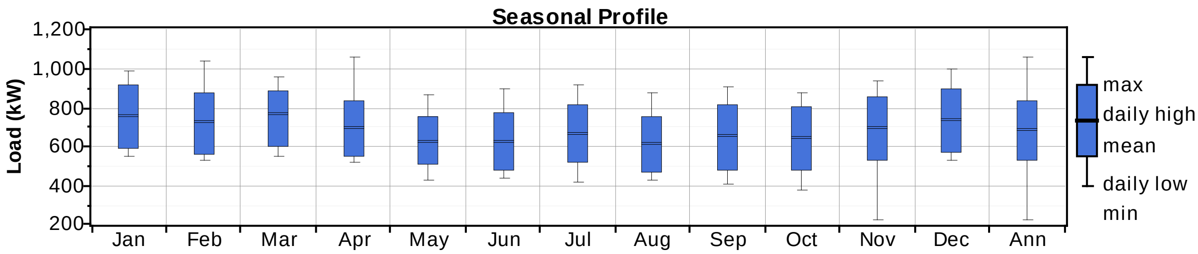
Wind Farm

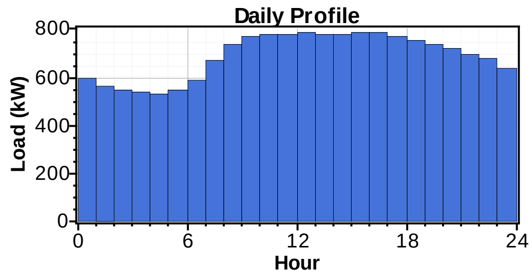
AVEC has proposed construction of an intertie to electrically connect Emmonak to the village of Alakanuk, located approximately twelve kilometers (7.5 miles) southwest of Emmonak on the Alakanuk Pass of the Yukon River. HOMER software was used to create a combined Emmonak-Alakanuk village simulation model.

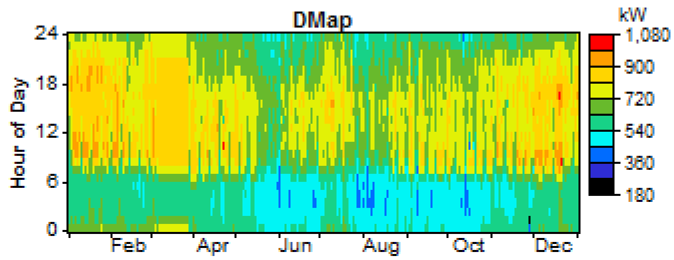
Village Load

A combined Emmonak and Alakanuk hourly load profile was created with total village electric load data that have been collected since July 2009 in Emmonak and June 2010 in Alakanuk. The Emmonak data comprised more than one year and duplicate dates were averaged to create a typical annual load. Because the Alakanuk data represents less than one year of data, the two months of data available were compared corresponding days and times of the Emmonak load and an average ratio calculated. This ratio – 0.512 – was used to scale the Emmonak data up to create a virtual a virtual Emmonak-Alakanuk village with a 687 kW average load, 1,053 kW peak load, approximate 380 kW minimum load, and average daily power usage of 16.5 MWh/day. Seasonal, daily and DMap profiles of the Emmonak-Alakanuk virtual load are shown below.

Load profile graphs







Wind Farm Performance

AVEC plans call for construction of 400 to 600 kW of wind turbine installed power capacity in Emmonak. The likely will be four to six Northwind 100/21 B model (100 kW rated output) wind turbines or alternatively two to three Aeronautica 29-225 (225 kW rated output) wind turbines.

NW100 and Aero 29-225 performance table, 100% turbine availability

Turbine	No.	Hub ht. (m)	Sys. Wind Penetration (%)	Turbine CF (%)	Wind prod. MWh/yr	Displ. fuel (gal)	Excess Energy MWh/yr	Excess Energy (%)
NW100/21	4	37	14.1	23.4	846	55,644	0	0.0
	5	37	17.6	23.4	1,057	69,440	1	0.0
	6	37	21.1	23.4	1,268	82,874	9	0.2
Aero 29-225	2	40	14.2	21.7	854	56,174	0	0.0
	3	40	21.2	21.7	1,281	83,019	22	0.4
	2	50	15.5	23.2	933	61,308	0	0.0
	3	50	23.2	23.3	1,340	90,391	28	0.5

Notes:
1. Wind resource based on Emmonak met tower, EMO-AUK intertied
2. HOMER modeling assumes 100% turbine availability
3. Displaced fuel estimate is for electrical generation only
4. Excess electricity to dump, preferably heat recovery for thermal load
5. SLC may be necessary to avoid curtailment of turbines

NW100 and Aero 29-225 performance table, 80% turbine availability

Turbine	No.	Hub ht. (m)	Sys. Wind Penetration (%)	Turbine CF (%)	Wind prod. MWh/yr	Displ. fuel (gal)	Excess Energy MWh/yr	Excess Energy (%)
NW100/21	4	37	11.3	18.7	437	44,515	0	0.0
	5	37	14.1	18.7	845	55,552	1	0.0
	6	37	16.9	18.7	1,014	66,299	7	0.1
Aero 29-225	2	40	11.4	17.4	683	44,939	0	0.0
	3	40	17.0	17.4	1,025	66,415	18	0.3
	2	50	12.4	18.6	746	49,046	0	0.0
	3	50	18.6	18.6	1,072	72,313	22	0.4

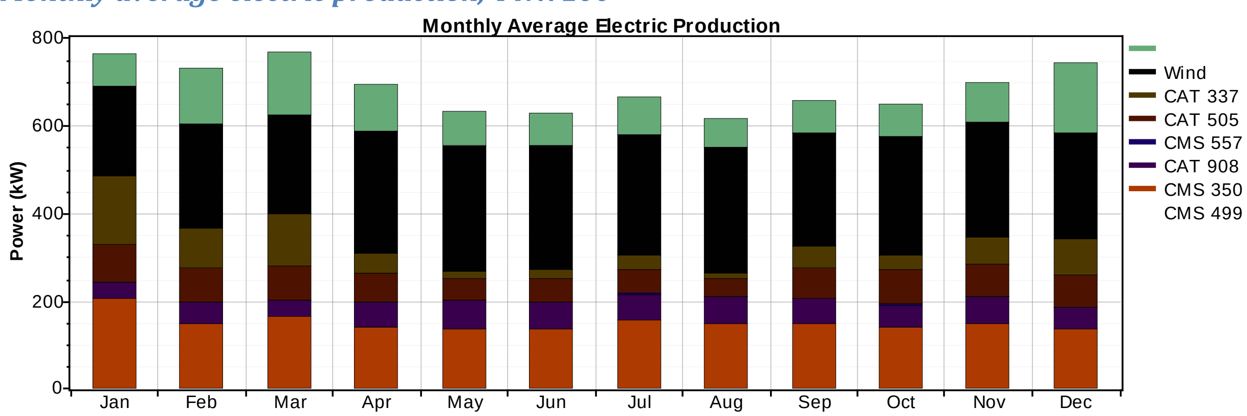
Notes:

1. Wind resource based on Emmonak met tower, EMO-AUK intertied
2. 80% turbine availability assumed
3. Displaced fuel estimate is for electrical generation only
4. Excess electricity to dump, preferably heat recovery for thermal load
5. SLC may be necessary to avoid curtailment of turbines

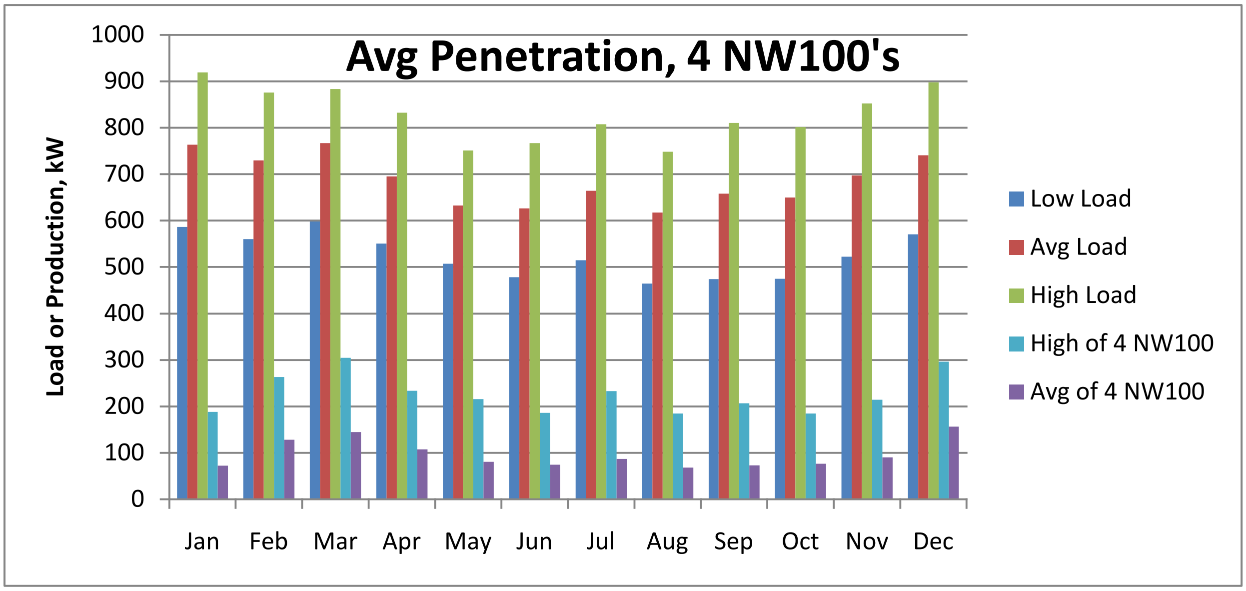
Loads and Energy Production, Four (4) NW100/21 Turbines

The graphs below indicate predicted energy production of four (4) NW100/21 turbines operating to supply a combined Emmonak-Alakanuk village load with existing diesel generation capacity. Note the assumption of 100 percent turbine availability.

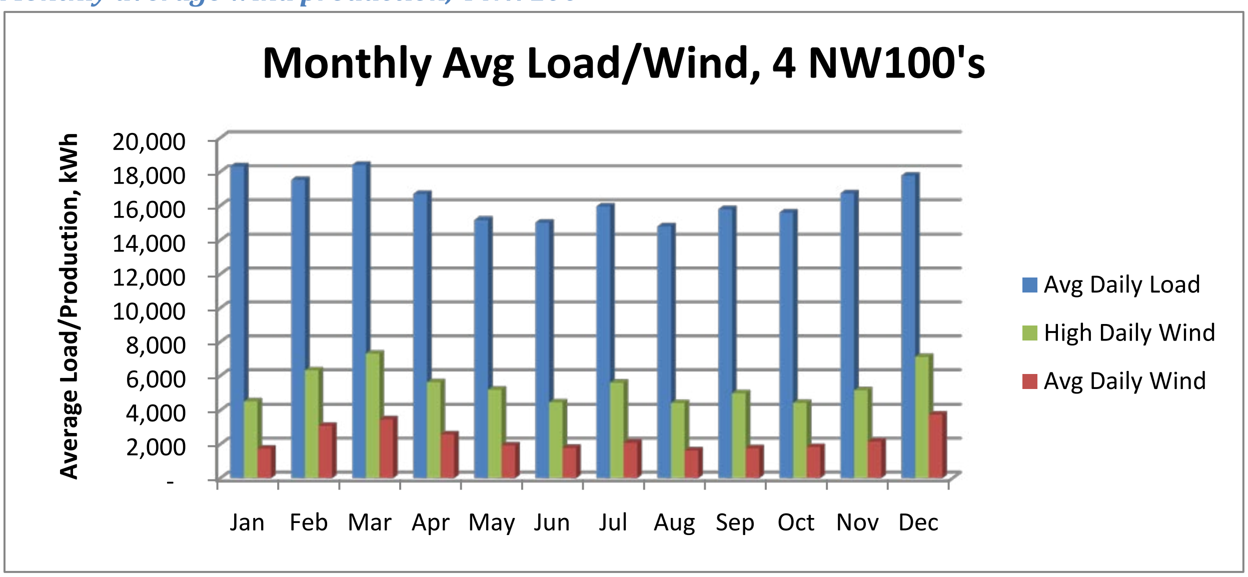
Monthly average electric production, 4 NW100



Monthly average wind penetration, 4 NW100



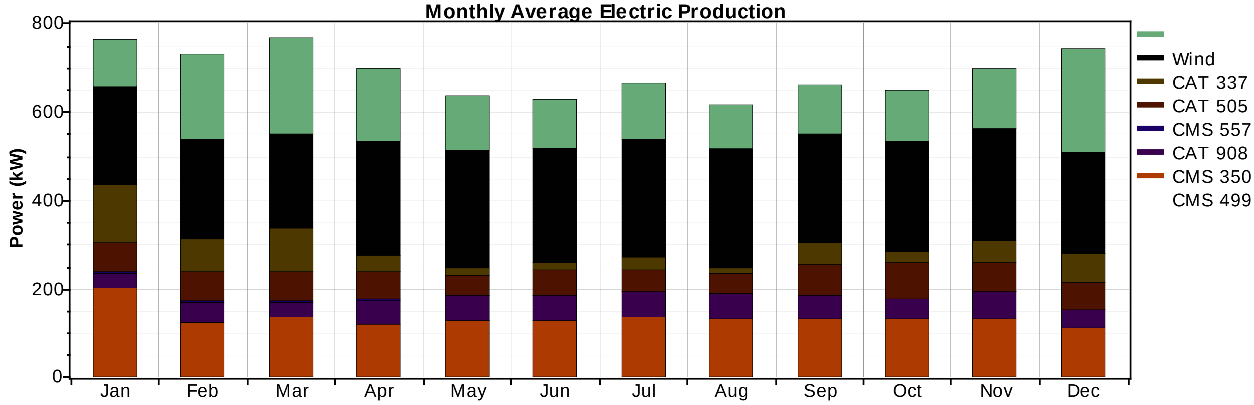
Monthly average wind production, 4 NW100



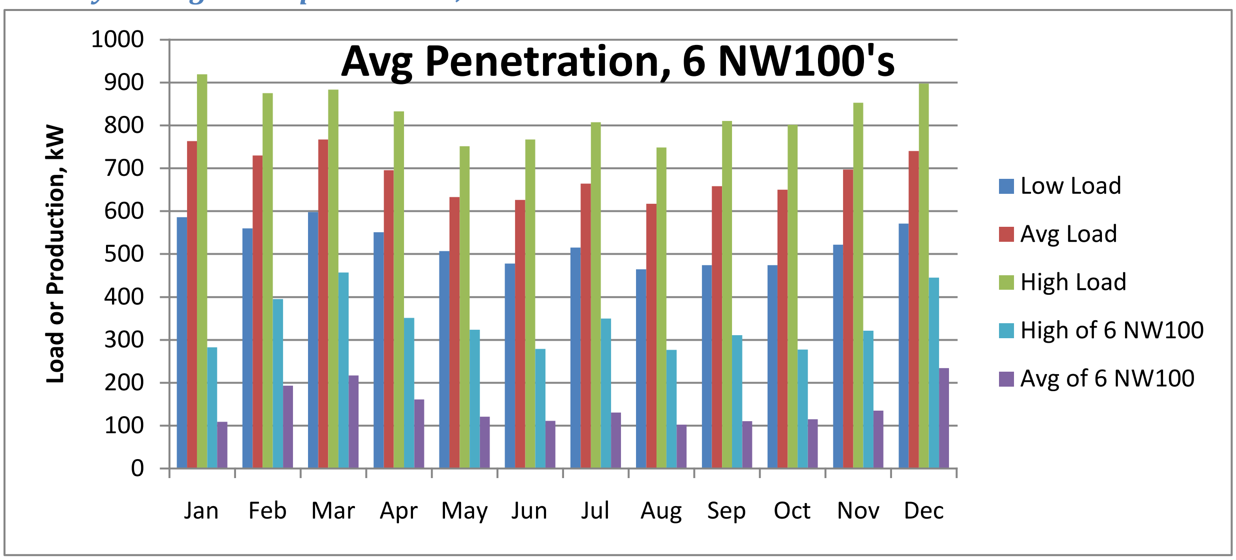
Loads and Energy Production, Six (6) NW100/21 Turbines

The graphs below indicate predicted energy production of six (6) NW100/21 turbines operating to supply a combined Emmonak-Alakanuk village load with existing diesel generation capacity. Note the assumption of 100 percent turbine availability.

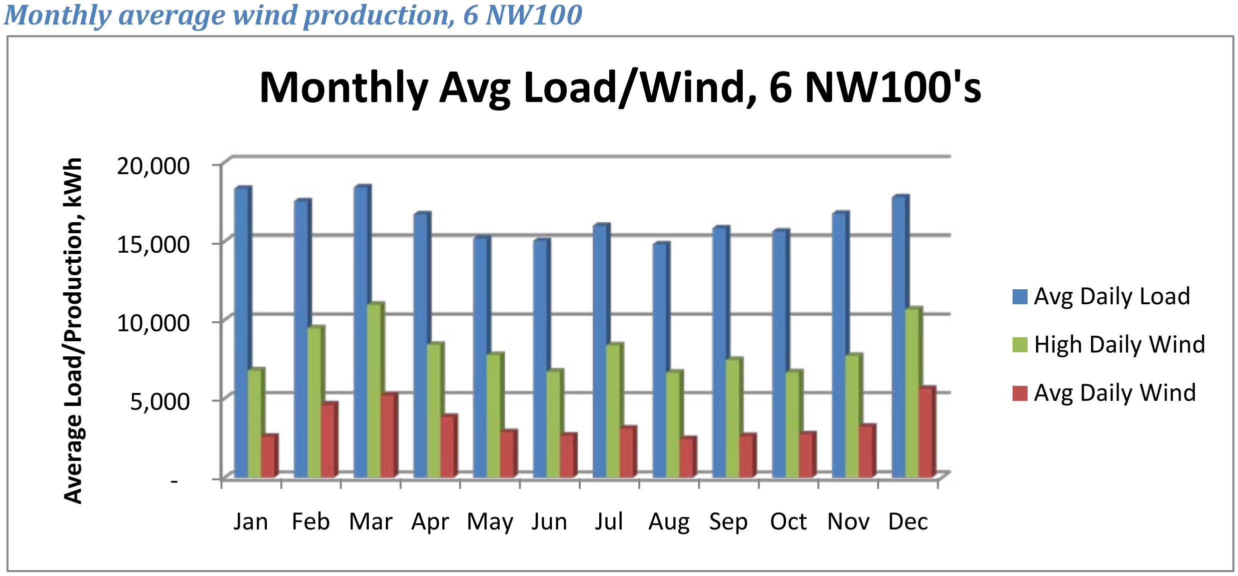
Monthly average electric production, 6 NW100



Monthly average wind penetration, 6 NW100



Monthly average wind production, 6 NW100



Met Tower Data

Presented below is information regarding the met tower installed in 2007 in Emmonak and pertinent technical information regarding data results.

Met tower location summary information

Site number	0007
Site Description	Tundra clearing among willow brush northwest of Emmonak
Latitude/longitude	N 62° 46.964', W 164° 33.447', WGS 84
Site elevation	3 meters
Datalogger/modem type	NRG Symphonie/no modem
Tower type	NRG 30-meter tall tower, 102 mm (4 inch) diameter
Anchor type	Buried plate

Tower sensor information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40C anemometer	30 m (A)	0.765	0.35	North
2	NRG #40C anemometer	30 m (B)	0.765	0.35	East
3	NRG #40C anemometer	20 m	0.765	0.35	North
7	NRG #200P wind vane	30 m	0.351	080	West
9	NRG #110S Temp C	2 m	0.136	-86.383	

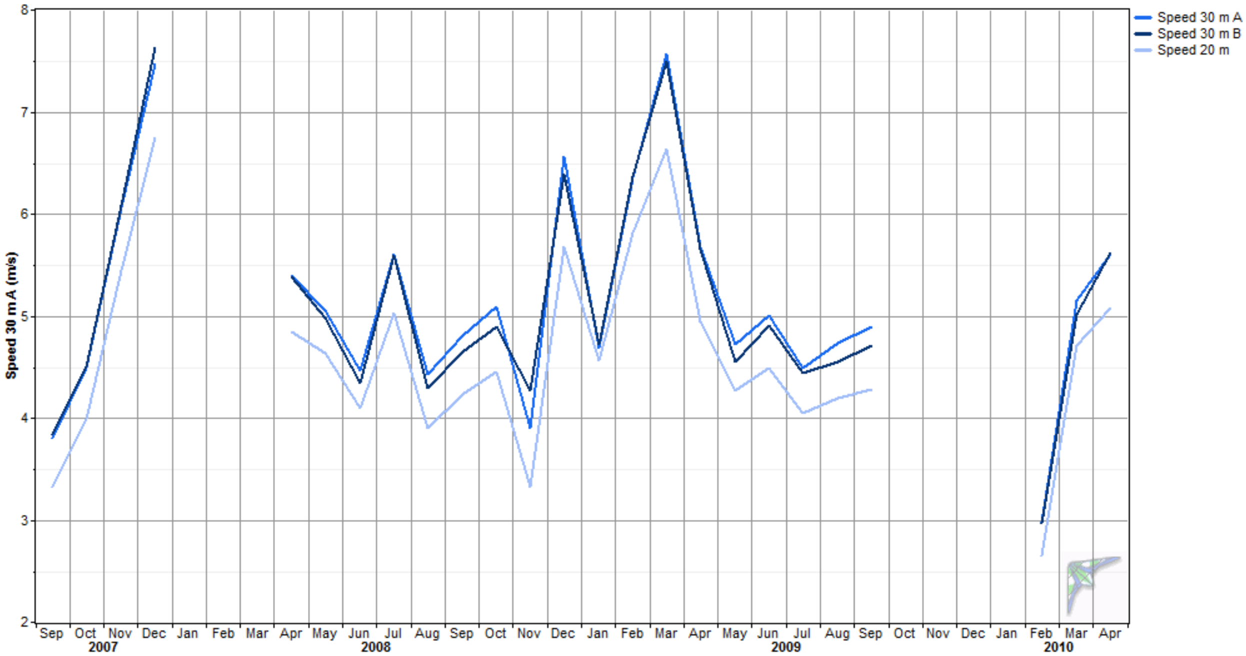
Anemometer Data

Met tower anemometer data is presented below, although note that the met tower test period of late 2007 to 2009 apparently was dominated by lower than long-term average winds (see earlier discussion).

Anemometer summary data

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Measurement height (m)	30.0	30.0	20.0
Annual mean wind speed (m/s)	5.29	5.24	4.74
Max wind speed (m/s) (10-min)	19.4	19.5	18.0
Max wind speed (m/s) (gust)	28.3	29.1	26.8
Weibull k	2.13	2.05	2.08
Weibull c (m/s)	5.91	5.83	5.28
Annual mean power density (W/m²)	181	180	134
Mean energy content (kWh/m²/yr)	1,584	1,578	1,172
Energy pattern factor	1.83	1.89	1.89
Frequency of calms (%)	34.3	35.2	43.6
1-hr autocorrelation coefficient	0.923	0.922	0.922
Diurnal pattern strength	0.067	0.074	0.109
Hour of peak wind speed	18	18	17

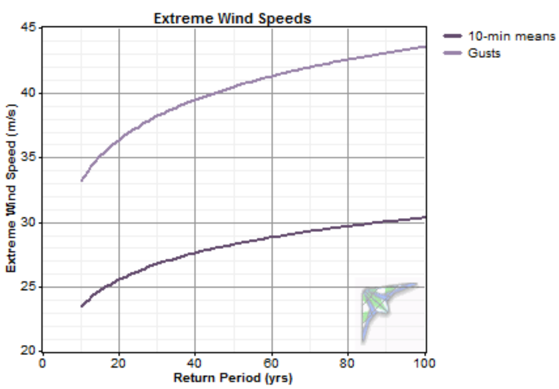
Anemometer Monthly Time Series



Extreme Winds

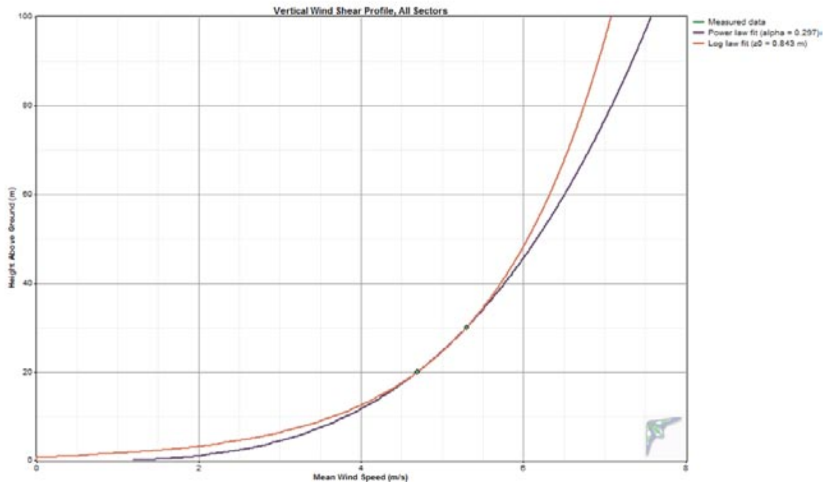
Emmonak classifies as IEC 61400-1, 3rd edition Class III, the most common category of extreme wind classification and that for which most wind turbines are designed.

Return Period (yr)	Extreme Wind Speed (m/s) 10-min means	Extreme Wind Speed (m/s) Gusts	IEC 50-year extreme wind Class	IEC 50-year extreme wind V_{ref} (10 min, m/s)
20	25.5	36.3	I	50.0
25	26.2	37.4	II	42.5
50	28.3	40.5	III	37.5
100	30.3	43.5	S	mfr specified



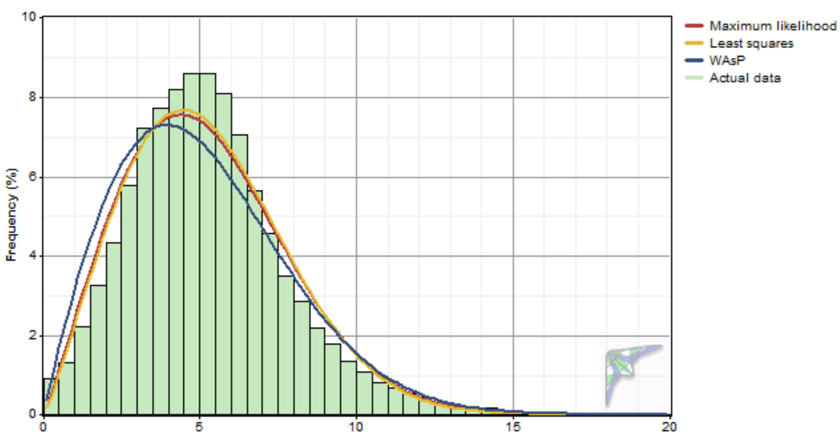
Wind Shear

The power law exponent was calculated at 0.297 for all wind directions, indicating higher than expected wind shear at the Emmonak test site. Note however that the measured high wind shear is very likely influenced by the brush surrounding the test site. If turbines are installed in more open terrain and at hub heights exceeding 30 meters, it is likely that shear values will be less than calculated. To extrapolate data to levels higher than 30 meters, a power law exponent (α) value of 0.14, typical of open tundra terrain, was used throughout this report.



Probability Distribution Function

The probability distribution function (PDF) provides a visual indication of measured wind speeds in one meter per second or smaller "bins". Note that most wind turbines do not begin to generate power until the wind speed at hub height reaches 4 m/s, known as the "cut-in" wind speed. The black line in the graph is a best fit Weibull distribution. The Weibull shape factor (k) value of 2.13 is near the "normal" shape curve k value of 2.0, also known as the Raleigh distribution.

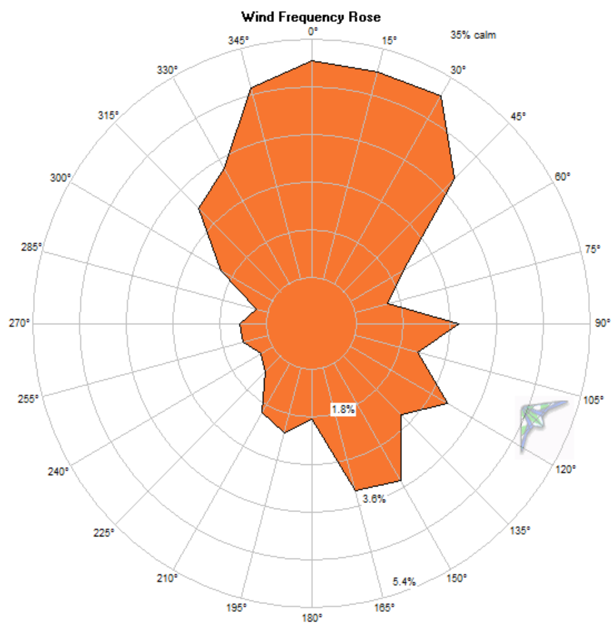


Wind Roses

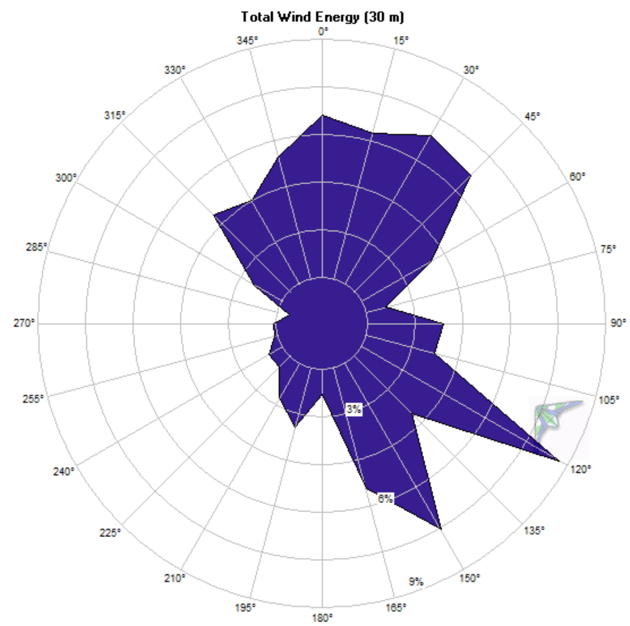
Winds at the Emmonak met tower test site are primarily northerly to northeasterly and to a lesser extent easterly to southeasterly winds. Importantly though, southeasterly winds are higher strength, hence the power density rose indicates an approximately equal share of northerly, northeasterly and southeasterly power-producing winds at the met tower site.

Note that a wind threshold of 4 m/s was selected for the definition of calm winds. This wind speed represents the cut-in wind speed of most wind turbines. By this definition, the Emmonak site experienced 35 percent calm conditions during the measurement period (see wind frequency rose below). This percentage was not adjusted based on adjustment to the AWOS long-term average; if it were to be, calm condition percentage likely would be lower.

Wind Frequency Rose



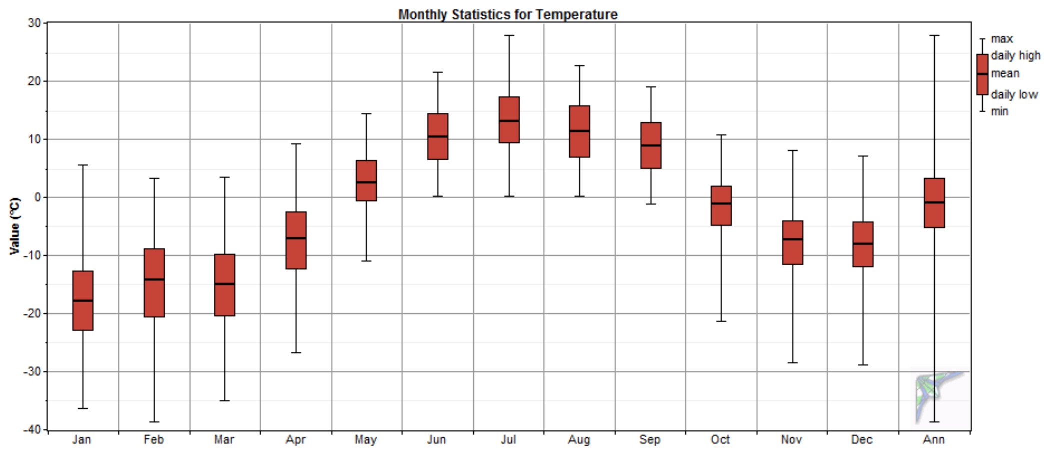
Total value (power density) rose



Air Temperature and Density

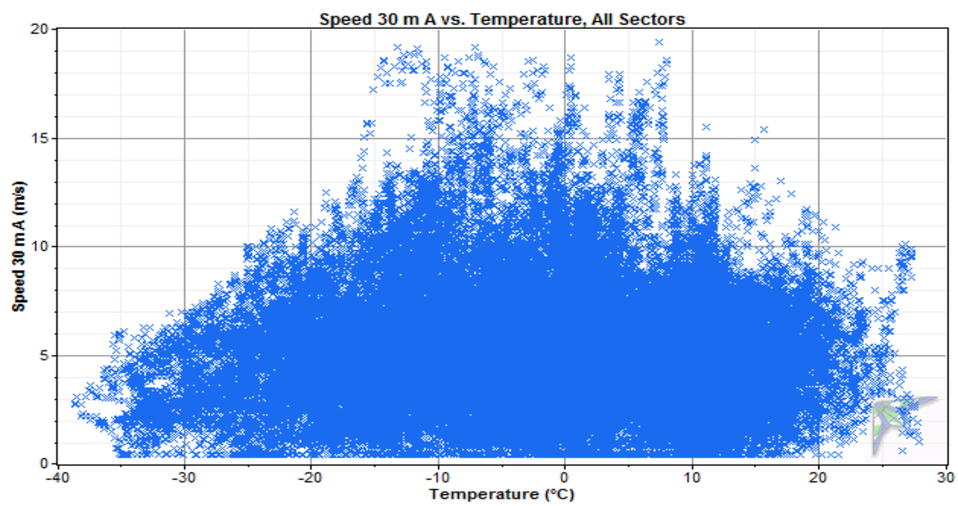
During the measurement period, Emmonak experienced an average temperature of -1.9° C. The minimum recorded temperature during the measurement period was –38.6° C (February) and the maximum temperature was 27.9° C (July).

Consequent to Emmonak's cool temperatures, the average air density of 1.272 kg/m^3 is approximately four percent higher than the standard air density of 1.225 kg/m^3 (15.0° C and 101.2 kPa standard temperature and pressure) at 3 m elevation, indicating that Emmonak has denser air than the standard air density used to calculate turbine power curves.



Speed vs. Temperature Scatterplot

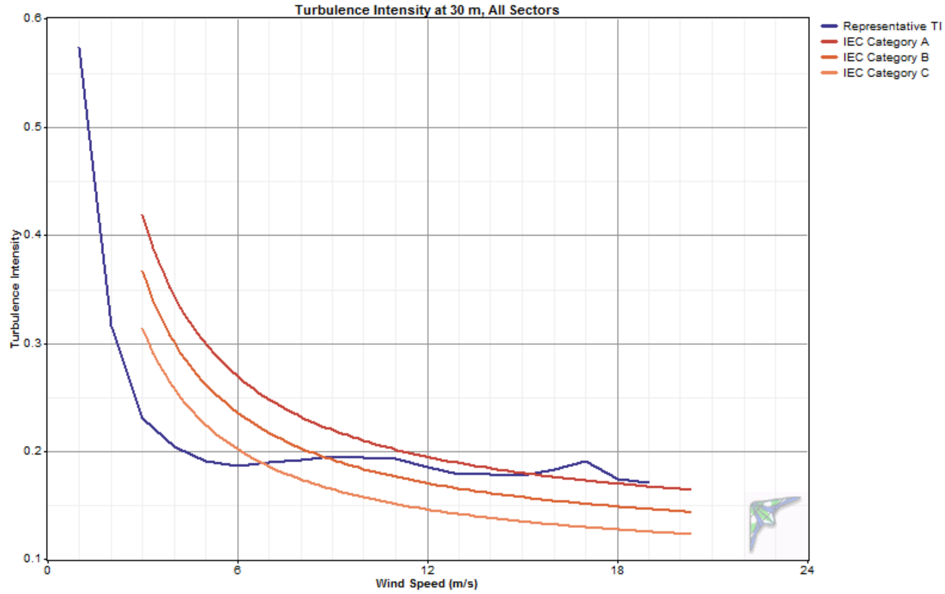
A scatterplot of 30m A anemometer wind speed versus temperature indicates that the higher wind ranges where wind turbine power production becomes substantial generally occur at temperatures warmer than -30° C. Although a wind turbine installed in Emmonak should be rated to -40° C, little power production will occur during periods of severe cold.



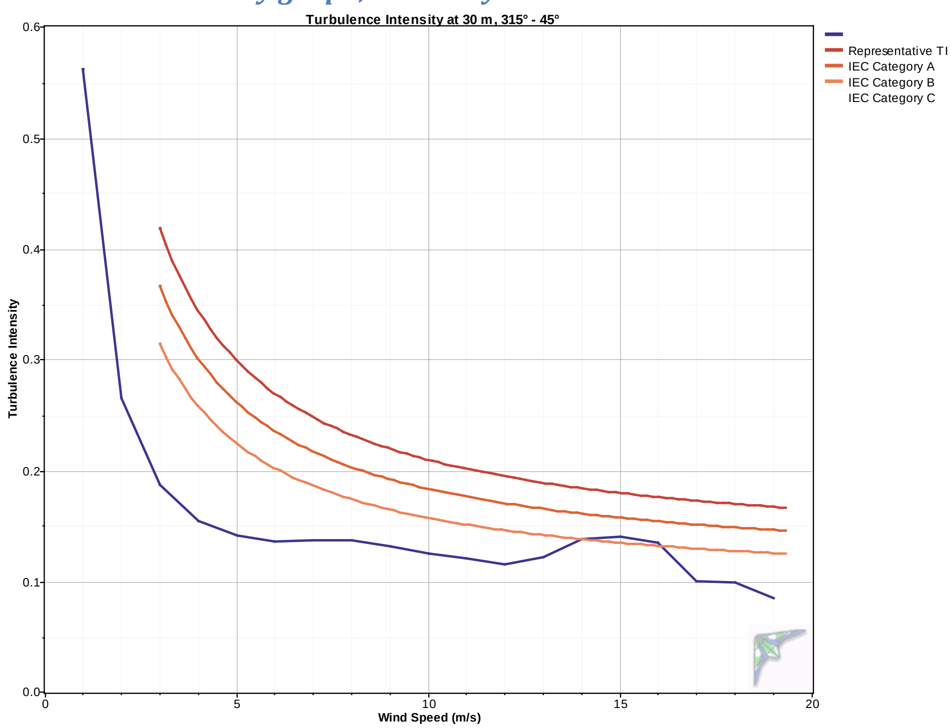
Turbulence

Air turbulence at the Emmonak test site during the measurement period is somewhat high, exceeding International Electrotechnical Commission (IEC) Category C criteria and classifying as IEC 3rd Edition turbulence category B at the 30 meter level and as IEC turbulence category A at the 20 meter level. Turbulent air is highly unusual in open tundra environments and in this case is likely due to effects of the brush and vegetation surrounding the met tower. This assumption can be noted in the turbulence rose (turbulence vs. wind direction) graph which shows higher turbulence with southerly and westerly winds, the directions toward which heavy brush exists at the met tower site. It is presumed that wind turbines at hub heights exceeding 30 meters at the test location, or if located elsewhere in Emmonak less dominated by brush, will experience less turbulence, likely within category C criteria. Note also that turbulence from northerly winds (second graph) is substantially less than when considering all wind sectors (first graph).

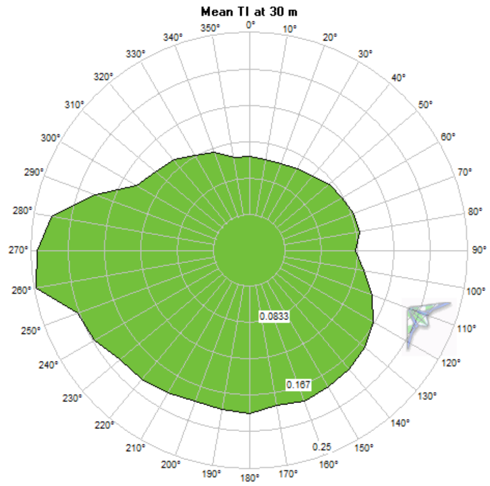
Turbulence intensity graph



Turbulence intensity graph, northerly winds



Turbulence vs. wind direction



Turbulence Table

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Bin Endpoints Upper (m/s)	Records In Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	0.5	1.5	3,166	0.364	0.164	0.573	1.143
2	1.5	2.5	6,830	0.192	0.096	0.316	0.882
3	2.5	3.5	11,666	0.144	0.068	0.231	0.774
4	3.5	4.5	14,265	0.129	0.059	0.204	0.583
5	4.5	5.5	15,423	0.120	0.055	0.190	0.511
6	5.5	6.5	13,586	0.117	0.054	0.187	0.500
7	6.5	7.5	9,182	0.123	0.052	0.189	0.370
8	7.5	8.5	5,689	0.130	0.049	0.192	0.329
9	8.5	9.5	3,558	0.134	0.047	0.195	0.282
10	9.5	10.5	2,157	0.134	0.047	0.194	0.324
11	10.5	11.5	1,317	0.135	0.045	0.193	0.292
12	11.5	12.5	877	0.129	0.044	0.186	0.422
13	12.5	13.5	490	0.128	0.039	0.178	0.246
14	13.5	14.5	305	0.134	0.035	0.178	0.234
15	14.5	15.5	159	0.135	0.033	0.177	0.259
16	15.5	16.5	144	0.145	0.030	0.183	0.199
17	16.5	17.5	83	0.147	0.034	0.190	0.213
18	17.5	18.5	59	0.128	0.036	0.174	0.206
19	18.5	19.5	23	0.125	0.036	0.171	0.177
20	19.5	20.5	0				