Manokotak, Alaska
Wind Resource Report, rev. 1

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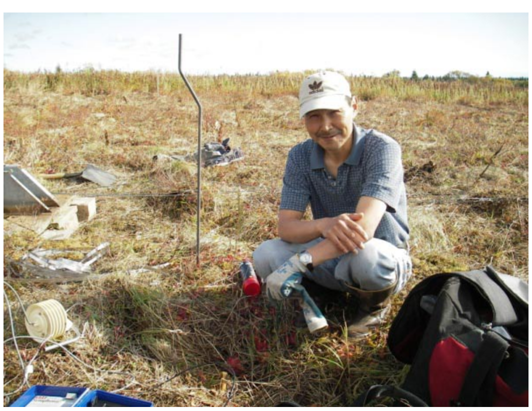
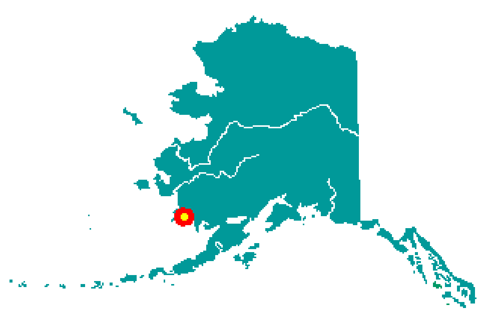
Date of Report: February 10, 2009

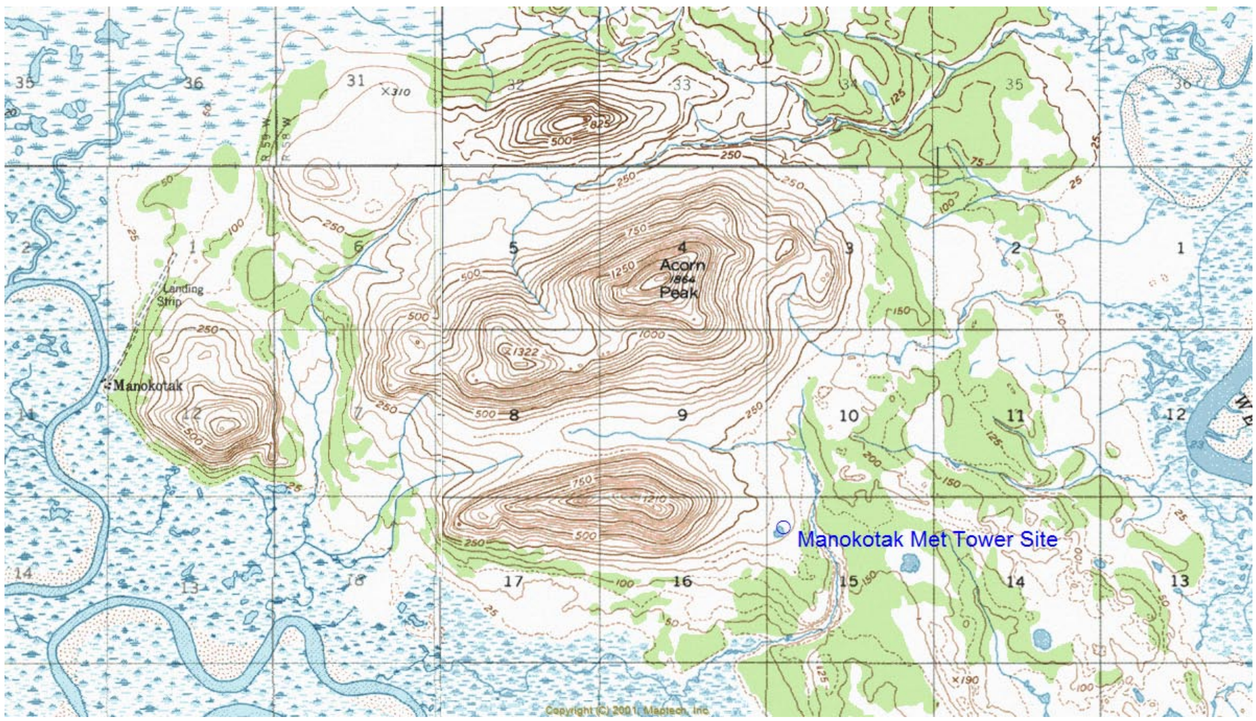




Summary Information

The wind resource at the proposed wind power site in Manokotak shows fair potential for wind energy development as a mid-Class 2 wind power resource with good turbulence behavior. This is a bit lower than expected and it had been thought that the site, chosen with considerable care as the most promising developable wind power site in Manokotak, might yield a better wind resource. Viability for wind power development, though, depends on the price of electricity, so given the high cost of diesel fuel and hence electrical power in Manokotak and despite the lower than desired wind resource, a wind power project may still make good sense for the community. An economic analysis of this question, however, was not within the scope of this study.

Test Site Location



Meteorological Tower Data Synopsis

Wind power class	Class 2 – Marginal
Wind speed annual average (30 meters)	4.95 m/s (11.1 mph)
Maximum 10-minute wind speed avg (30 m)	18.1 m/s
Maximum two second wind gust	26.0 m/s (58.1 mph) (May 2008)
Wind power density (50 meters)	227 W/m^2 (projected)
Wind power density (30 meters)	183 W/m^2 (measured)
IEC 61400-1 3rd edition classification	Class III C-
Weibull distribution parameters	k = 1.62, c = 5.52 m/s
Surface roughness	.0772 m (few trees)
Power law exponent	0.174 (moderate wind shear)

Frequency of calms (4 m/s threshold)	44%
Mean turbulence intensity (30 meters)	0.104 (excellent)
Data start date	September 24, 2007
Data end date	December 15, 2008

Tower Sensor Information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	30 m (A)	0.765	0.35	E
2	NRG #40 anemometer	30 m (B)	0.765	0.35	WSW
3	NRG #40 anemometer	20 m	0.765	0.35	E
7	NRG #200P wind vane	30 m	0.351	325	145° T (SE)
9	NRG #110S Temp C	2 m	0.136	-86.383	N/A

General Site Information

Site number	5262
Site Description	Slightly northeast and uphill of the school in "New Manokotak" (new roads and development not shown in topo map above)
Latitude/longitude	N 58° 58' 4.74", W 158° 56' 54.42", WGS 84
Site elevation	58 meters
Datalogger type	NRG Symphonie
Tower type	NRG 30-meter tall tower, 152 mm (6 in) diameter

Measured Wind Speeds

The 30 meter anemometer annual wind speed averages (anemometer A and B) are 4.91 and 4.92 m/s. The 20 meter anemometer annual average wind speed is 4.58 m/s. The maximum recorded wind gust was 26.0 m/s recorded in May, 2008.

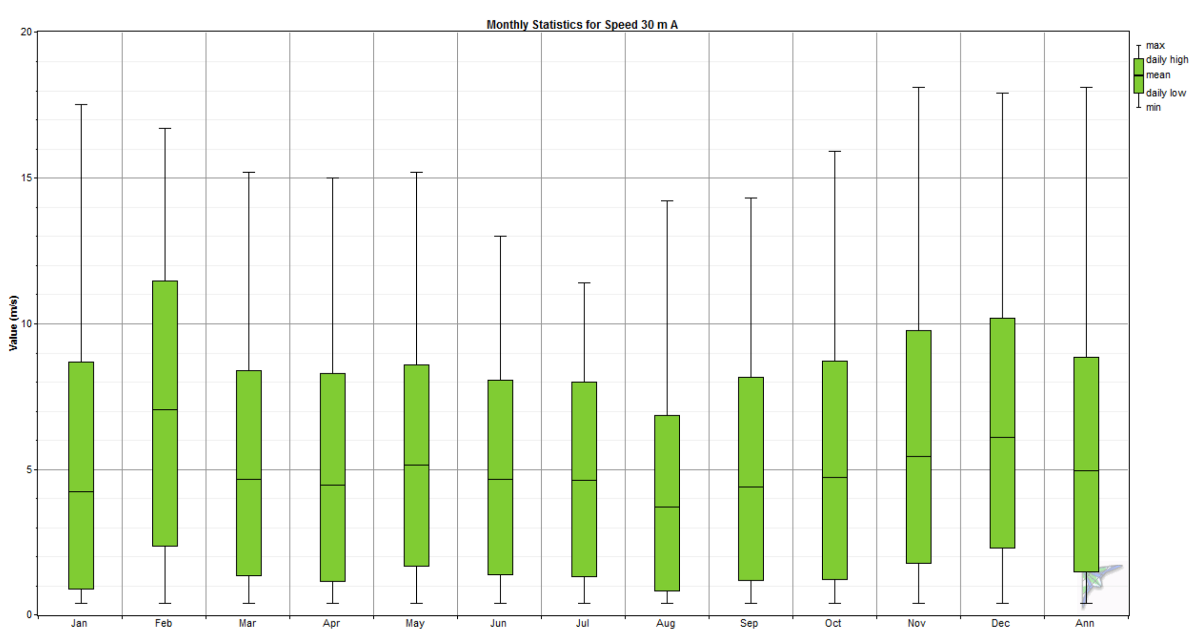
	30 m A speed					30 m B speed		20 m speed	
Month	Mean (m/s)	Max 10 min. avg (m/s)	Max 2 sec. gust (m/s)	Weibull k	Weibull c (m/s)	Mean (m/s)	Max 2 sec. gust (m/s)	Mean (m/s)	Max 10 min. avg (m/s)
Jan	4.23	17.5	23.3	1.28	4.57	4.28	23.7	3.96	16.4
Feb	7.04	16.7	21.8	1.79	7.85	7.10	21.4	6.65	15.6
Mar	4.65	15.2	19.9	1.58	5.18	4.69	19.9	4.39	14.4
Apr	4.44	15.0	19.5	1.73	4.97	4.46	19.1	4.14	14.1
May	5.14	15.2	25.2	1.82	5.78	5.14	26.0	4.79	14.2
Jun	4.65	13.0	19.1	1.94	5.25	4.64	18.7	4.30	12.2
Jul	4.61	11.4	15.6	2.34	5.19	4.64	16.1	4.28	10.5
Aug	3.70	14.2	20.6	1.87	4.16	3.64	20.6	3.39	13.1
Sep	4.39	14.3	20.2	1.73	4.90	4.47	20.2	4.08	13.3

Oct	4.72	15.9	21.8	1.67	5.27	4.67	21.8	4.40	15.1
Nov	5.44	18.1	22.9	1.60	6.07	5.34	22.9	5.09	17.5
Dec	6.10	17.9	23.7	1.59	6.76	6.12	24.0	5.68	17.2
Annual	**4.91**	**18.1**	**25.2**	1.62	5.52	**4.92**	**26.0**	4.58	17.5

Wind Speed Sensor Summary

Variable	Speed 30 m A	Speed 30 m B	Speed 20 m
Mean wind speed (m/s)	4.94	4.95	4.62
MMM wind speed (m/s)	4.91	4.92	4.58
Median wind speed (m/s)	4.50	4.40	4.20
Min wind speed (m/s)	0.4	0.4	0.4
Max wind speed (m/s)	18.1	18.1	17.5
Mean power density (W/m²)	186	187	155
MMM power density (W/m²)	182	184	152
Mean energy content (kWh/m²/yr)	1,628	1,638	1,357
MMM energy content (kWh/m²/yr)	1,597	1,609	1,332
Energy pattern factor	2.39	2.40	2.44
Frequency of calms (%)	44.2	44.4	48.4
1-hr autocorrelation coefficient	0.903	0.905	0.901
Diurnal pattern strength	0.056	0.055	0.064
Hour of peak wind speed	17	17	16

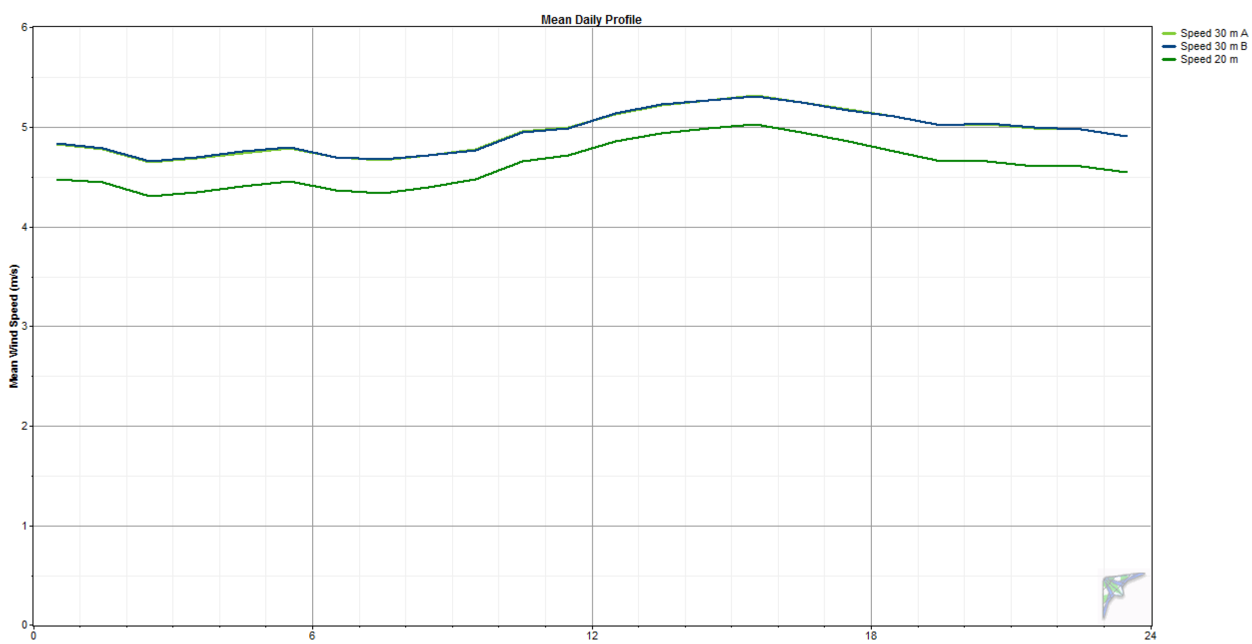
Seasonal Wind Profile

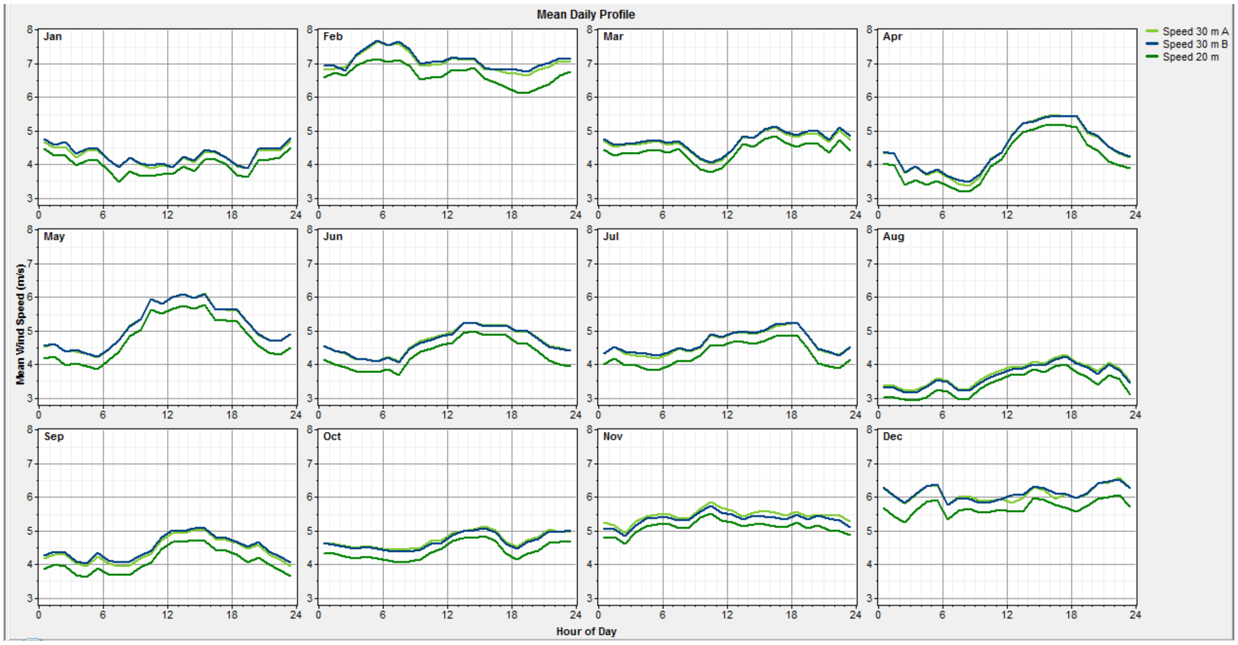


Monthly Time Series of Wind Speed

Daily Wind Profile

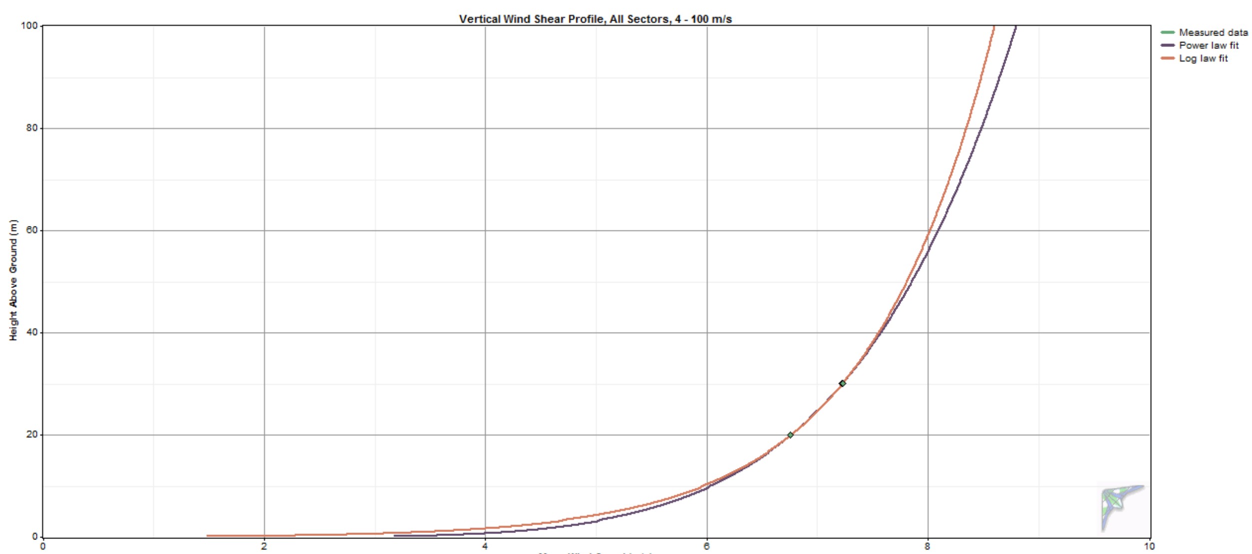
The daily wind profile indicates that the lowest wind speeds of the day occur in the morning hours of 2 a.m. to 9 a.m. and the highest wind speeds of the day occur during the afternoon and evening hours of 12 p.m. to 6 p.m. The daily variation of wind speed is minimal on an annual basis but more pronounced on a monthly basis (second graph).





Wind Shear

The power law exponent was calculated at 0.164 with wind speeds filtered to include only those greater than 4 m/s, the cut-in speed for most turbines, indicating moderate wind shear at the Manokotak met tower site. The practical application of this data is that a higher turbine tower height may be desirable as there will be a worthwhile marginal gain in wind speed and hence power recovery with additional height. A tower height/power recovery/construction cost tradeoff study is advisable.

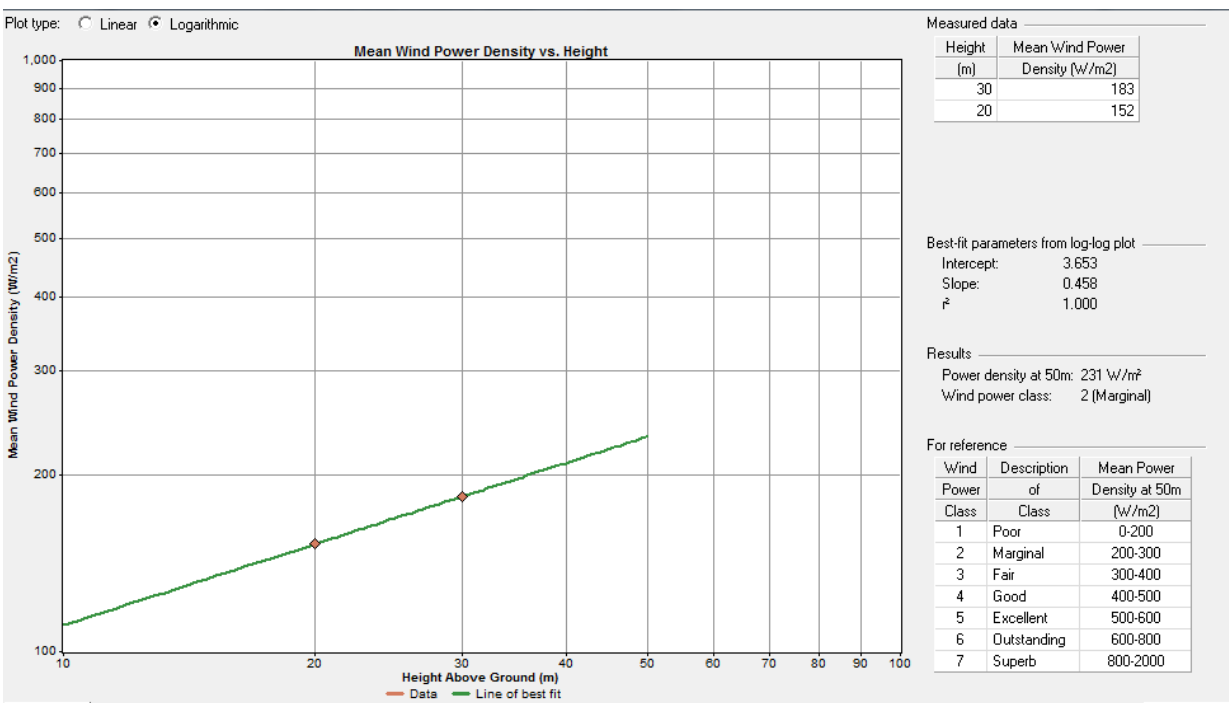


Wind Power Density

Another view of wind shear is wind power density by height above ground level. Wind power density is defined as the power per unit area of the wind with units of Watts per square meter. It is calculated by multiplying ½ times the air density times the wind speed cubed for each time step. The equation is $P/A = ½*\rho*U^3$. The time step values are averaged to produce an overall wind power density.

The wind power density at 50 meters elevation is a wind industry standard method of comparing and evaluating sites. If the anemometer measurement heights are at other than 50 meters, the wind analysis software uses the power law exponent derived from the two (or more) measurement heights to extrapolate up or down.

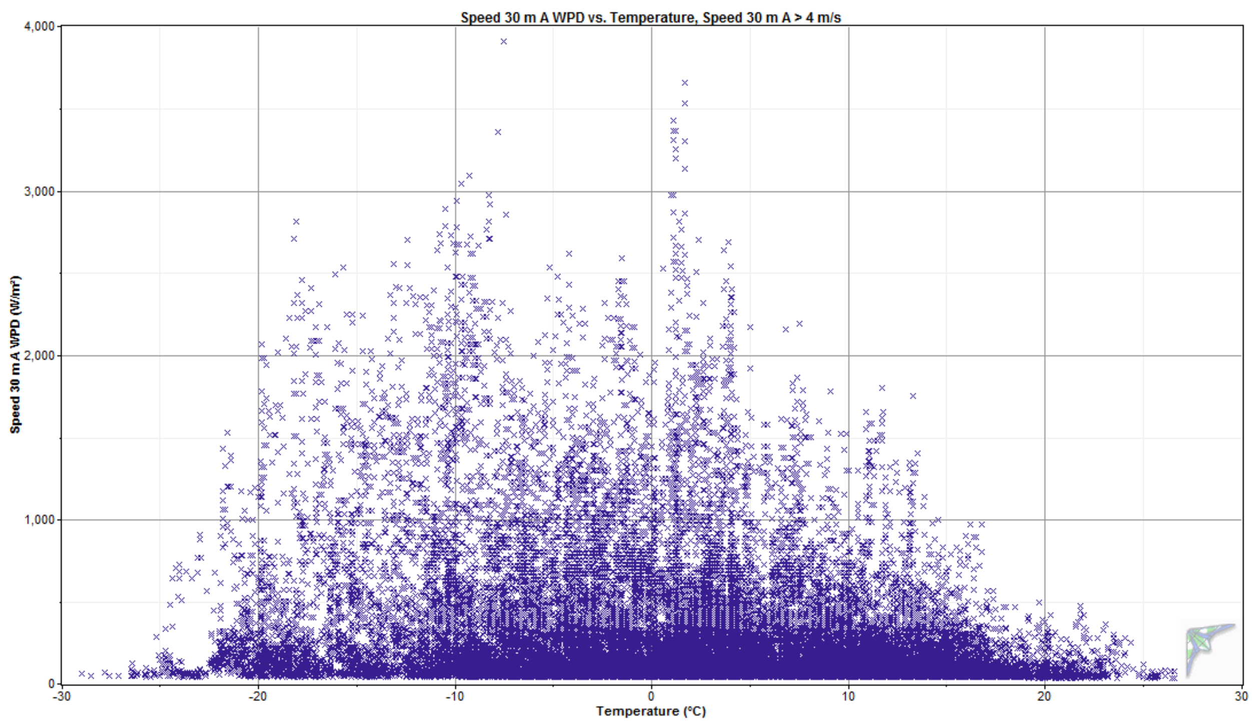
As can be seen in the figure below, power density and hence potential turbine power production increases substantially with turbine hub height in Manokotak, as is true at most sites. Note that the measured power densities in the figure below differ from those reported in the data summary table on page 2 of this report. The figure below uses all collected data (September 2007 through December 2008) while in the summary table these data are presented as annual averages.



Scatterplot

An observation of some interest is to compare by scatterplot the power density and, separately, the mean wind speed to temperature. As one can see below, the power producing winds (winds greater than 4 m/s, the typical wind turbine cut-in speed) are present through all temperature ranges, even as low as -30° C, although high winds at extreme low temperatures are uncommon in Manokotak. A turbine selected for Manokotak should be capable of operation to -25° C.

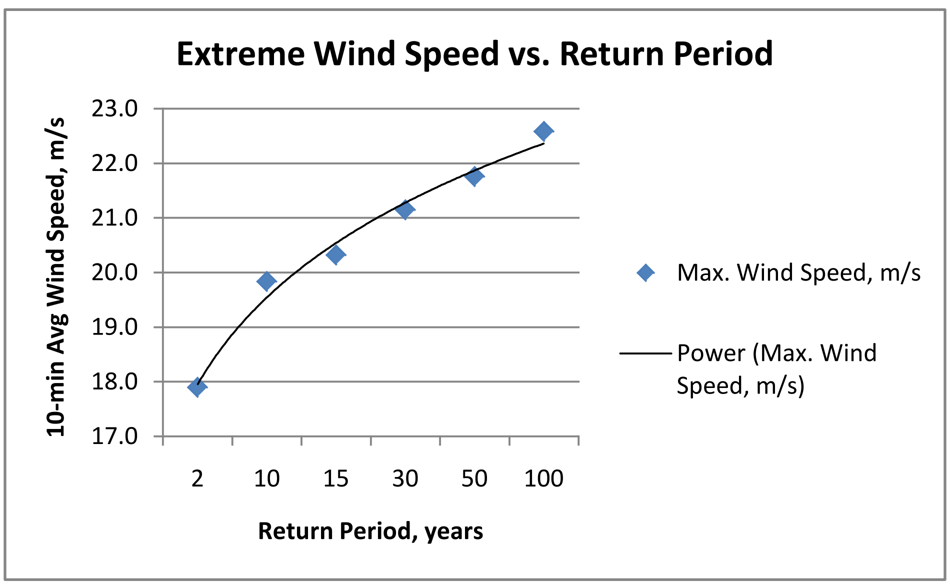

Speed 30 m A vs. Temperature, Speed 30 m A 4 m/s - 30 m/s
Speed 30 m A (m/s)
Temperature (°C)


Speed 30 m A WPD vs. Temperature, Speed 30 m A > 4 m/s
Speed 30 m A WPD (W/m²)
Temperature (°C)

Extreme Wind Analysis

Using a modified Gumbel distribution, one can predict the probability of winds exceeded a certain value within a defined period of time. Another way to consider the analysis though is by the concept of return period. In other words, in a defined period of time, typically 50 years, one can determine the maximum wind speed likely to occur. This is important when selecting a wind turbine as manufacturers classify their turbines by International Electrotechnical Commission (IEC) standards of Class (per IEC 61400-1, edition 3). At the Manokotak test site, the maximum predicted 50 year wind speed (ten minute average) at 30 meters is 21.8 m/s, and the maximum predicted 50 year wind gust (two second average) at 30 meters is 29.9 m/s. The 50 year return period, ten minute wind speed average prediction qualifies the site as IEC Class III, the lowest and most common extreme wind designation.

RETURN PERIOD SPEED		Average Gust Factor	1.38
Manokotak	RETURN YR	10 min average, m/s	2 sec gust, m/s
30 meter	2	17.9	24.6
	10	19.8	27.3
	15	20.3	28.0
	30	21.1	29.1
	50	21.8	29.9
	100	22.6	31.1

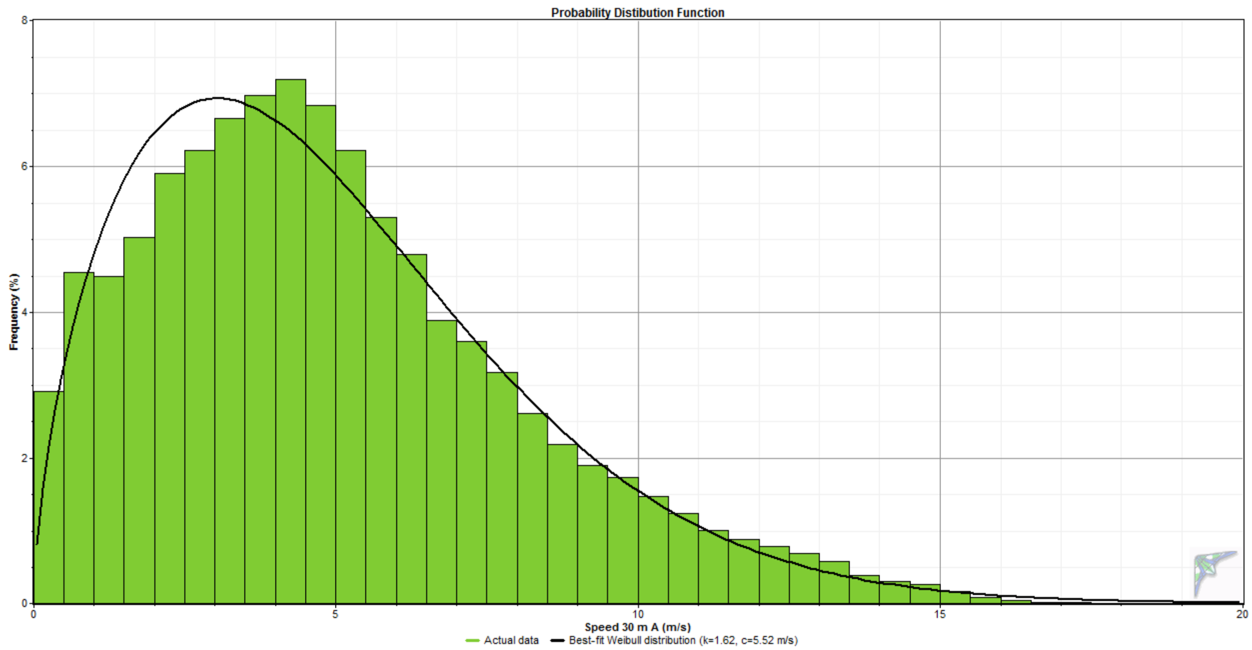


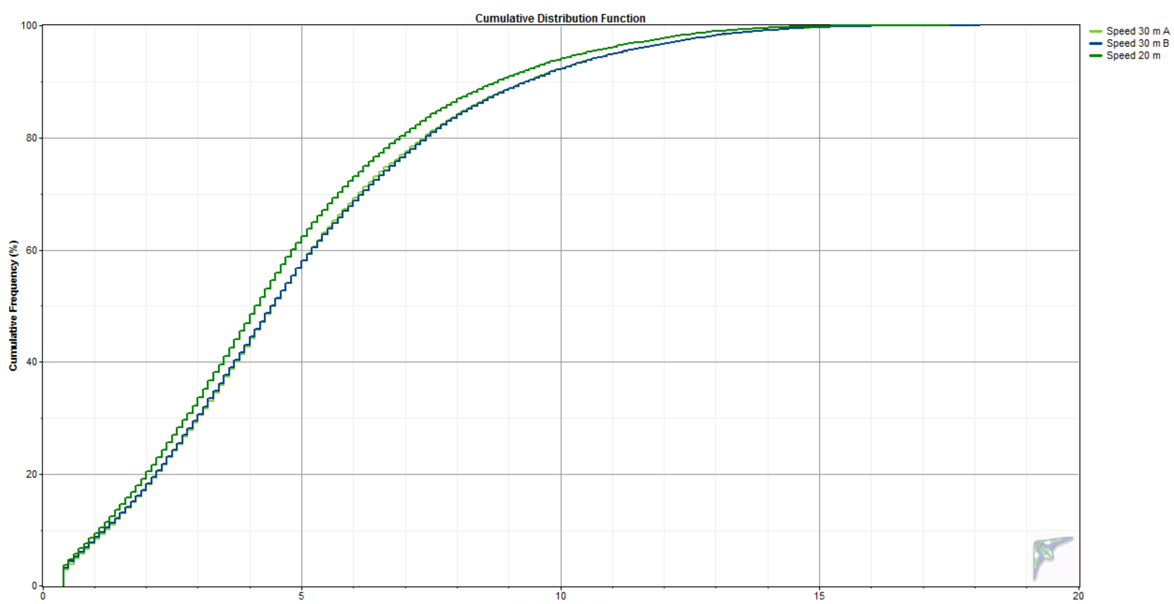
Probability Distribution Function

The probability distribution function provides a visual indication of measured wind speeds in one meter per second "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. At the 30 meter level, Weibull parameters are k = 1.62 and c = 5.52 m/s ("k" is the shape factor and "c" is the scale factor) for the data period. This shape factor is indicative of a normal wind distribution for wind power sites.

The PDF information is shown visually in another manner in the second graph, the Cumulative Distribution Function. In this view, one can see that about 45 percent of winds (at 30 meters) are less than 4 m/s, the standard cut-in speed of most turbines and 100 percent of the winds are less than 25 m/s, the standard high wind cut-out speed for most turbines.



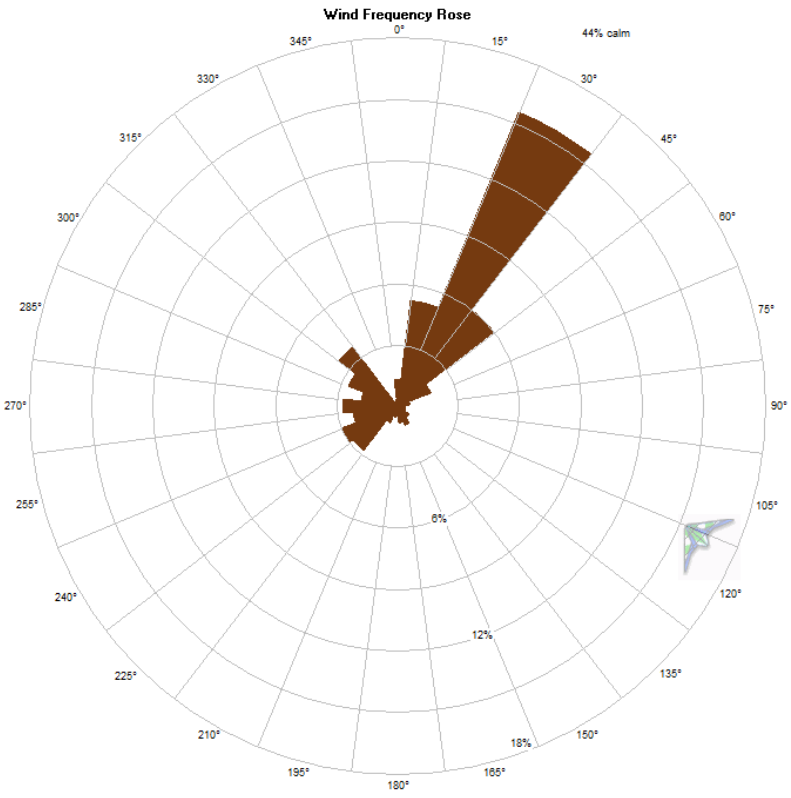


Wind Roses

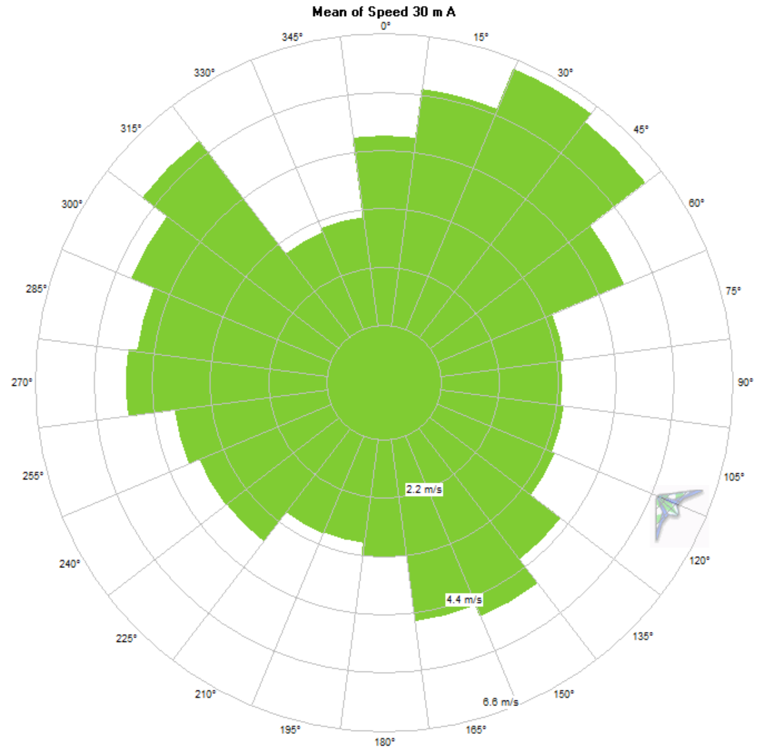
Manokotak's winds are highly directional with the wind frequency rose indicating mostly northeast winds with a minor component of westerly winds. This observation is reinforced with reference to the mean value and total value power density roses. Although the wind is nearly equal strength from all directions, the power producing winds are entirely northeasterly due to the dominance of wind frequency from that sector. The practical application of this information is that a wind turbine site should be selected with adequate freedom from ground interference to the northeast and if more than one turbine is installed, the turbines should aligned along an axis of 120° to 300°, perpendicular to the power wind direction of 030° (true bearings).

Note also 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, Manokotak experienced 44 percent calm conditions during the measurement period (see wind frequency roses below).

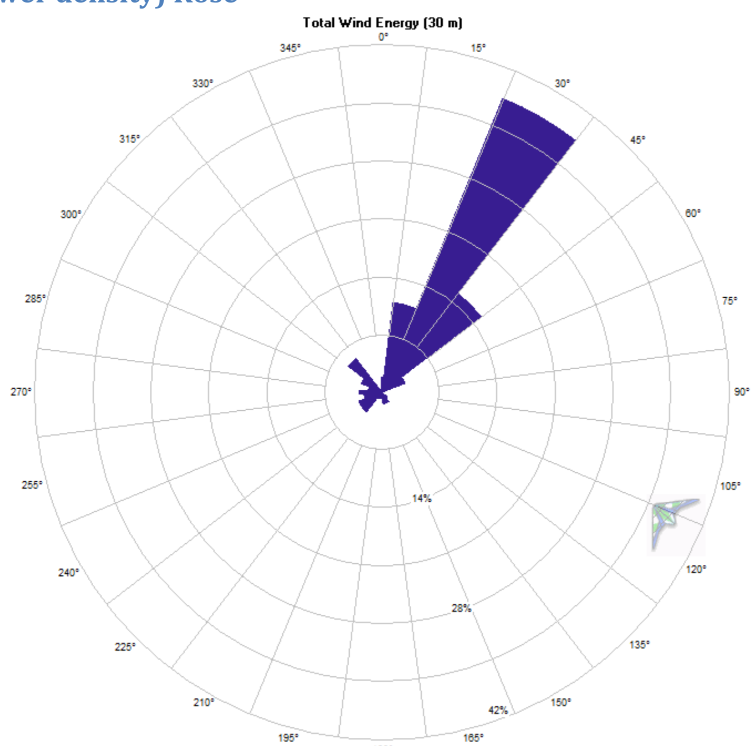
Wind Frequency Rose



Mean Value Rose



Total Value (power density) Rose



Turbulence Intensity

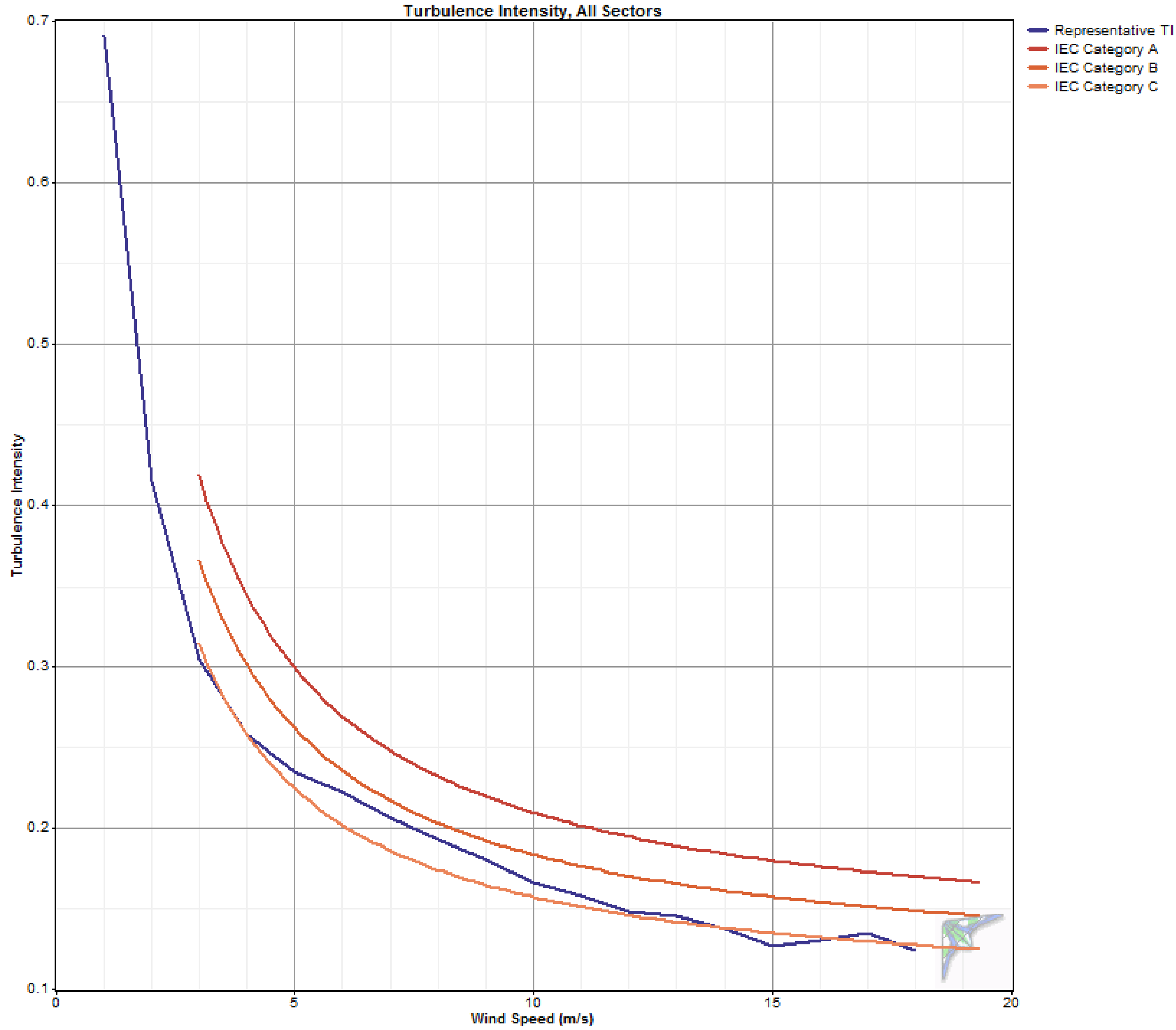
The turbulence intensity is acceptable with a mean turbulence intensity of 0.102 and a representative turbulence intensity of 0.127 at 15 m/s wind speed, indicating quite smooth air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 3rd Edition (2005) turbulence category C, which is the lowest defined category.

Turbulence Table

Turbulence Intensity (TI) Table, 30 m A speed

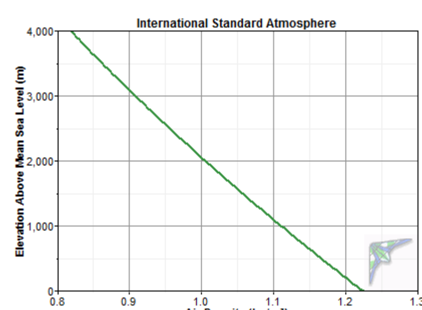
Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records In Bin	Mean TI	Standard Deviation of TI	Representative TI	Peak TI
1	0.5	1.5	5,654	0.467	0.175	0.691	1.429
2	1.5	2.5	6,847	0.250	0.129	0.415	1.000
3	2.5	3.5	8,066	0.185	0.093	0.304	0.880
4	3.5	4.5	8,871	0.162	0.075	0.258	0.722
5	4.5	5.5	8,177	0.151	0.065	0.234	0.553
6	5.5	6.5	6,320	0.145	0.060	0.222	0.534
7	6.5	7.5	4,678	0.138	0.054	0.206	0.492
8	7.5	8.5	3,614	0.130	0.049	0.193	0.398
9	8.5	9.5	2,551	0.124	0.044	0.180	0.424
10	9.5	10.5	2,006	0.117	0.038	0.166	0.396
11	10.5	11.5	1,404	0.111	0.037	0.158	0.290
12	11.5	12.5	1,045	0.105	0.033	0.148	0.303
13	12.5	13.5	788	0.104	0.032	0.146	0.304
14	13.5	14.5	429	0.102	0.028	0.137	0.226
15	14.5	15.5	264	0.102	0.019	0.127	0.191
16	15.5	16.5	80	0.107	0.018	0.131	0.148
17	16.5	17.5	17	0.117	0.014	0.135	0.135
18	17.5	18.5	5	0.117	0.006	0.124	0.123
19	18.5	19.5	0				

IEC 3rd Edition Turbulence Category Graph



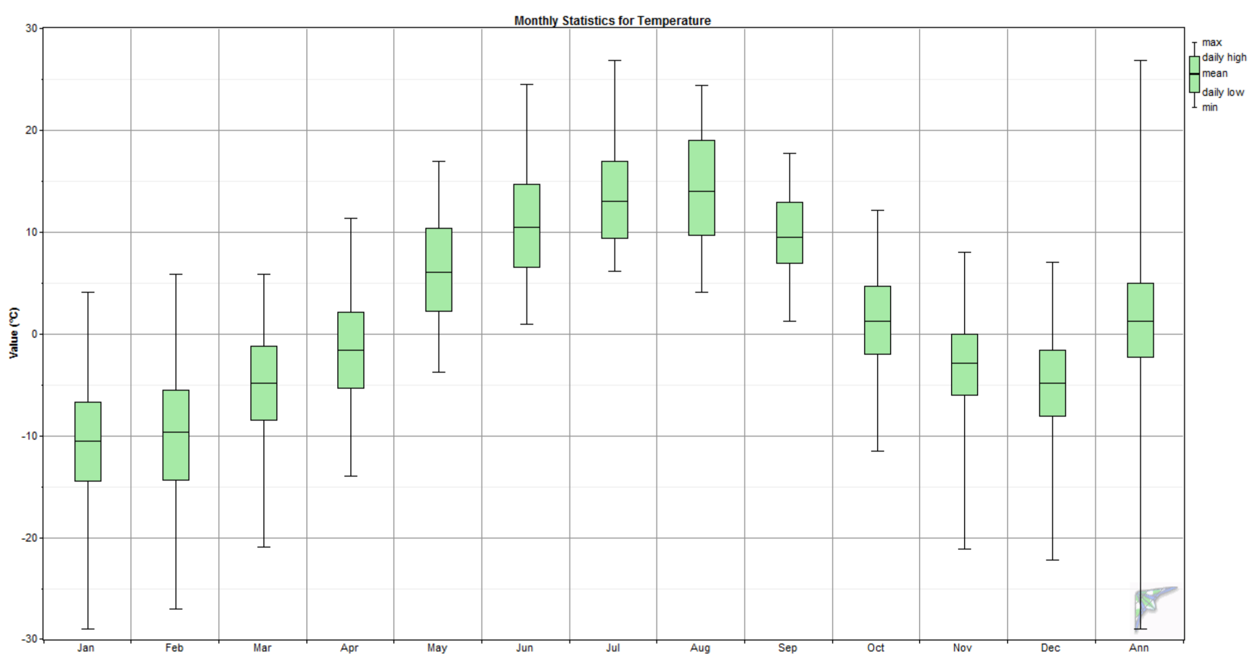
Air Temperature and Density

Over the reporting period, Manokotak had an average temperature of 1.7° C. The minimum recorded temperature during the measurement period was -29.0° C and the maximum temperature was 26.9° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations.



Consequent to Manokotak's cool temperatures, the average air density of 1.277 kg/m^3 is nearly five percent higher than the standard air density of 1.218 kg/m^3 (14.6° C and 100.6 kPa standard temperature and pressure at 58 m elevation), indicating that Manokotak has denser air than the standard air density used to calculate turbine power curves (note that all turbine power curves are calculated at a sea level standard of 15° C and 101.3 kPa pressure).

	Temperature			Air Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-10.5	-29.0	4.1	1.336	1.264	1.436
Feb	-9.6	-27.1	5.8	1.331	1.256	1.424
Mar	-4.9	-21.0	5.8	1.307	1.256	1.390
Apr	-1.6	-14.0	11.3	1.291	1.232	1.352
May	6.1	-3.8	16.9	1.256	1.208	1.301
Jun	10.4	0.9	24.5	1.236	1.178	1.279
Jul	13.0	6.1	26.9	1.225	1.168	1.255
Aug	14.0	4.1	24.4	1.221	1.178	1.264
Sep	9.5	1.2	17.7	1.240	1.205	1.278
Oct	1.2	-11.5	12.1	1.278	1.229	1.340
Nov	-2.9	-21.2	8.0	1.298	1.247	1.391
Dec	-4.8	-22.2	7.0	1.307	1.251	1.397
Annual	**1.7**	-29.0	26.9	**1.277**	1.168	1.436



Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data. Data that met the following criteria were filtered: wind speed < 1 m/s, wind speed standard deviation = 0, and temperature < 3 °C. Other obvious icing event data not meeting these criteria were filtered manually. In general, data recovery from the Manokotak met tower was very good, with some icing loss presumably due to freezing rain during the autumn through spring months.

		Ch 1, 30m A		Ch 2, 30 m B		Ch 3, 20 m	
Year	Month	Records	Recovery Rate, %	Records	Recovery Rate, %	Records	Recovery Rate, %
2007	Sep	1,008	100.0	1,008	100.0	1,008	100.0
2007	Oct	4,440	99.5	4,360	97.7	4,360	97.7
2007	Nov	3,858	89.3	3,822	88.5	3,887	90.0
2007	Dec	4,324	96.9	4,420	99.0	4,389	98.3
2008	Jan	4,464	100.0	4,337	97.2	4,284	96.0
2008	Feb	3,969	95.0	3,972	95.1	3,966	95.0
2008	Mar	4,464	100.0	4,464	100.0	4,464	100.0
2008	Apr	4,191	97.0	4,191	97.0	4,191	97.0
2008	May	4,411	98.8	4,411	98.8	4,411	98.8
2008	Jun	4,320	100.0	4,320	100.0	4,320	100.0
2008	Jul	4,464	100.0	4,464	100.0	4,464	100.0
2008	Aug	4,464	100.0	4,464	100.0	4,464	100.0
2008	Sep	4,320	100.0	4,320	100.0	4,320	100.0
2008	Oct	4,257	95.4	4,220	94.5	4,227	94.7
2008	Nov	4,250	98.4	4,250	98.4	4,091	94.7
2008	Dec	1,438	69.5	1,469	71.0	1,453	70.2
All data		62,642	97.0	62,492	96.8	62,299	96.5

		Ch 7, vane		Ch 9, temp	
Year	Month	Records	Recovery Rate, %	Records	Recovery Rate, %
2007	Sep	1,008	100.0	1,008	100.0
2007	Oct	4,354	97.5	4,464	100.0
2007	Nov	3,570	82.6	4,320	100.0
2007	Dec	4,197	94.0	4,464	100.0
2008	Jan	3,952	88.5	4,464	100.0
2008	Feb	4,109	98.4	4,176	100.0
2008	Mar	4,333	97.1	4,464	100.0
2008	Apr	4,234	98.0	4,320	100.0
2008	May	4,399	98.5	4,464	100.0
2008	Jun	4,320	100.0	4,320	100.0

2008	Jul	4,464	100.0	4,464	100.0
2008	Aug	4,464	100.0	4,464	100.0
2008	Sep	4,320	100.0	4,320	100.0
2008	Oct	4,228	94.7	4,464	100.0
2008	Nov	3,808	88.2	4,320	100.0
2008	Dec	1,519	73.4	2,070	100.0
All data		61,279	94.9	64,566	100.0

Turbine Analysis

Estimating turbine performance in Manokotak's wind regime can be accomplished by matching the turbine manufacturer's power curve to each ten-minute average wind speed to derive a corresponding power output. This output is adjusted for increased or decreased air density due to temperature and summed as an annual energy output in kilowatt-hours. Output can also be reported as capacity factor, defined as the percent of maximum possible power output a turbine is capable of delivering (if it were operating at 100% power, 100% of the time). Typical capacity factors for wind sites vary from perhaps 15% at a low wind resource site to 50% at a very high wind resource site.

Based on data collected in this study, wind turbines operating in Manokotak's wind regime, depending on the model, hub heights, and blade pitch technology, are estimated to operate at 15 to 20 percent capacity factor. To estimate potential annual turbine energy output, multiply the turbine's rated power (maximum kW output) X 8,760 (number of hours per year) X the capacity factor expressed as a unitless ratio X the turbine availability (percent of time it is available for normal operation), also expressed as a unitless ratio. For instance, if one were to consider a turbine rated at 100 kW, assume an 18% capacity factor, and assume that the turbine availability is 90%, then the expected annual energy production would be:

$$Energy\left(\frac{kWhr}{yr}\right) = 100\ kW * 8{,}760\frac{hr}{yr} * 0.18 * 0.90 = 141{,}900\frac{kWhr}{yr}$$

If two or more identical 100 kW turbines will be installed, multiply the annual energy result by the number of turbines. A precise estimate of turbine capacity factor at the Manokotak wind site can be calculated once a specific wind turbine is identified.