Noorvik, Alaska (Hotham Peak Quarry Road Site) Wind Resource Report


Aerial view of Noorvik, June 2008; D. Vaught photo

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Summary

The wind resource measured at the Noorvik Hotham Peak Quarry Road met tower site is good with measured low wind power class 4 by measurement of wind power density. Given the very cold temperatures in Noorvik, air density is much higher than standard conditions, leading to the robust annual wind power density average. By other measures important for wind power analysis, the site has a relatively low extreme wind probability and very low turbulence.

Met tower data synopsis

Data dates	October 21, 2010 to January 25, 2012 (15 months); met tower is operational
Wind power class	Class 4 (good), based on wind power density
Wind power density mean, 30 m	334 W/m^2
Wind speed mean, 30 m	5.62 m/s
Max. 10-min wind speed	31.6 m/s
Maximum 2-sec. wind gust	37.5 m/s, November, 2011
Weibull distribution parameters	k = 1.58, c = 6.32 m/s
Wind shear power law exponent	0.160 (high)
Roughness class	1.32 (description: crops)
IEC 61400-1, 3rd ed. classification	Class III-C (at 20 and 30 meters)
Turbulence intensity, mean	0.079 (at 15 m/s)
Calm wind frequency	41% (winds < 4 m/s) (15 mo. measurement period)

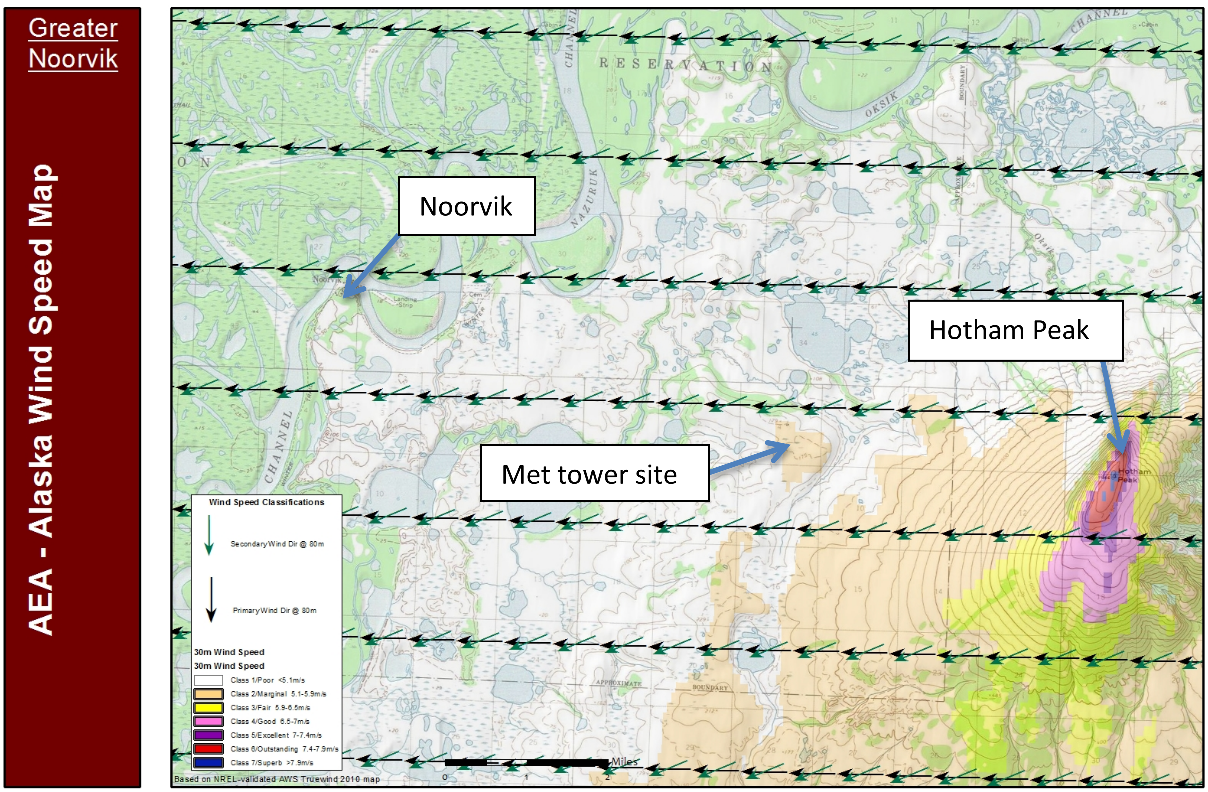
Test Site Location

A 30 meter NRG Systems, Inc. tubular-type meteorological (met) tower is installed approximately 7.25 km (4.5 miles) east of the Noorvik Airport tarmac (easternmost extension of power distribution) on a low, broad, exposed ridge at the foot of Hotham Peak. Distance from the met tower to Noorvik is an additional 1.5 km (0.9 mile). Straight-line distance from the Noorvik power plant to the met tower site is 7.7 km (4.7 miles). The met tower site is accessible via the gravel road from Noorvik that leads to a rock quarry at the base of Hotham Peak. The met tower itself is located approximately 150 meters south of the road.

Hotham Peak is a dominating 460 meter (1500 ft) elevation terrain feature approx. 16 km (10 miles) east of Noorvik. AEA's high resolution State-wide wind map identifies the summit of Hotham Peak as a Class 7 wind resource. The slopes of Hotham Peak are very steep, however, and it would be impractical to build a road to the summit for wind power development. The wind site is located away from the mountain itself on higher-elevation terrain than the rock quarry. AEA's high resolution wind map identifies the met tower site as a higher wind resource than the lower elevation terrain of Noorvik itself and a potentially good compromise between the high wind resource of (inaccessible) Hotham Peak and the predicted low wind resource of the low-lying terrain at Noorvik. Interestingly, the AEA wind map predicts Class 2 winds at the met tower site and low Class 4 winds were measured.

This site has some wind development history in that a met tower had been erected at this location in September 2001 for the Maniilaq Association by Tribal Energy Association of Northwest Alaska (TREANA) and documented in a September 30, 2002 report submitted to Administration for Native Americans (ANA) to complete one of their funding grants. Unfortunately, although the met tower was 30 meters in height and in place for one year, the September 2002 report contained mostly powerplant and load growth information and only cursory summary data from the met tower. An attempt several years ago to obtain from Maniilaq Association the original data files from the 2001 to 2002 met tower project was partially successful in that about five months of data were recovered. Because the September 2002 report inadequately described the wind resource at the site and with incomplete recovery of the data files, it was felt in 2010 that a met tower should be erected again at the site. Because the original anchors were never removed and still secure, the new met tower was erected at the exact location of the previous.

AEA – Alaska Wind Speed Map of Greater Noorvik



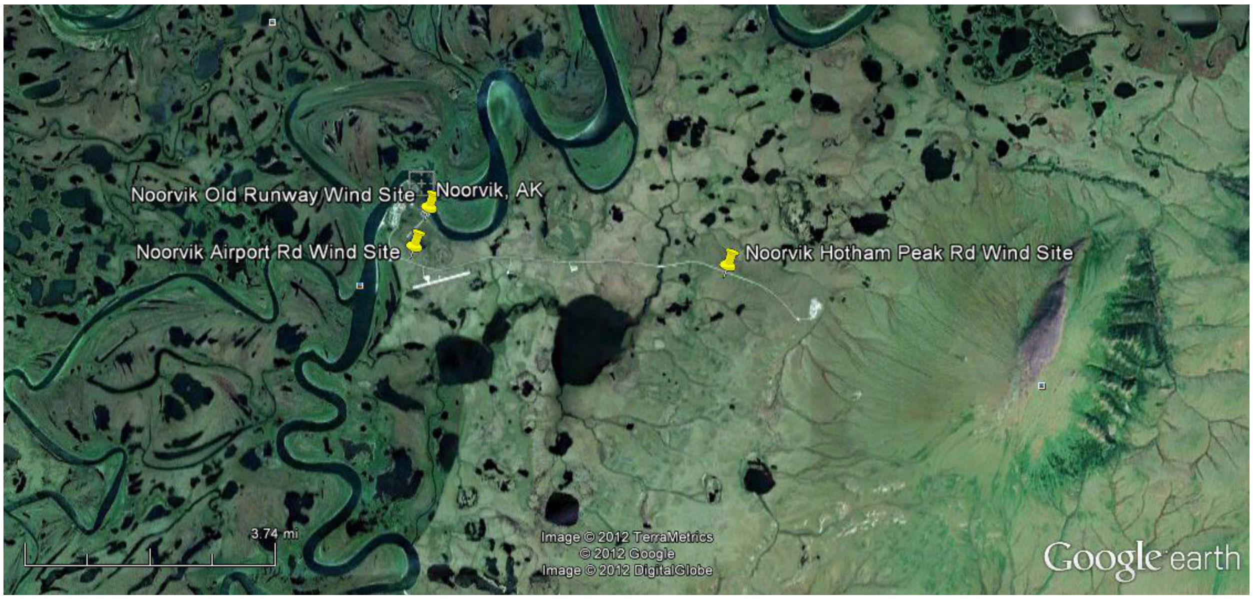
Site information

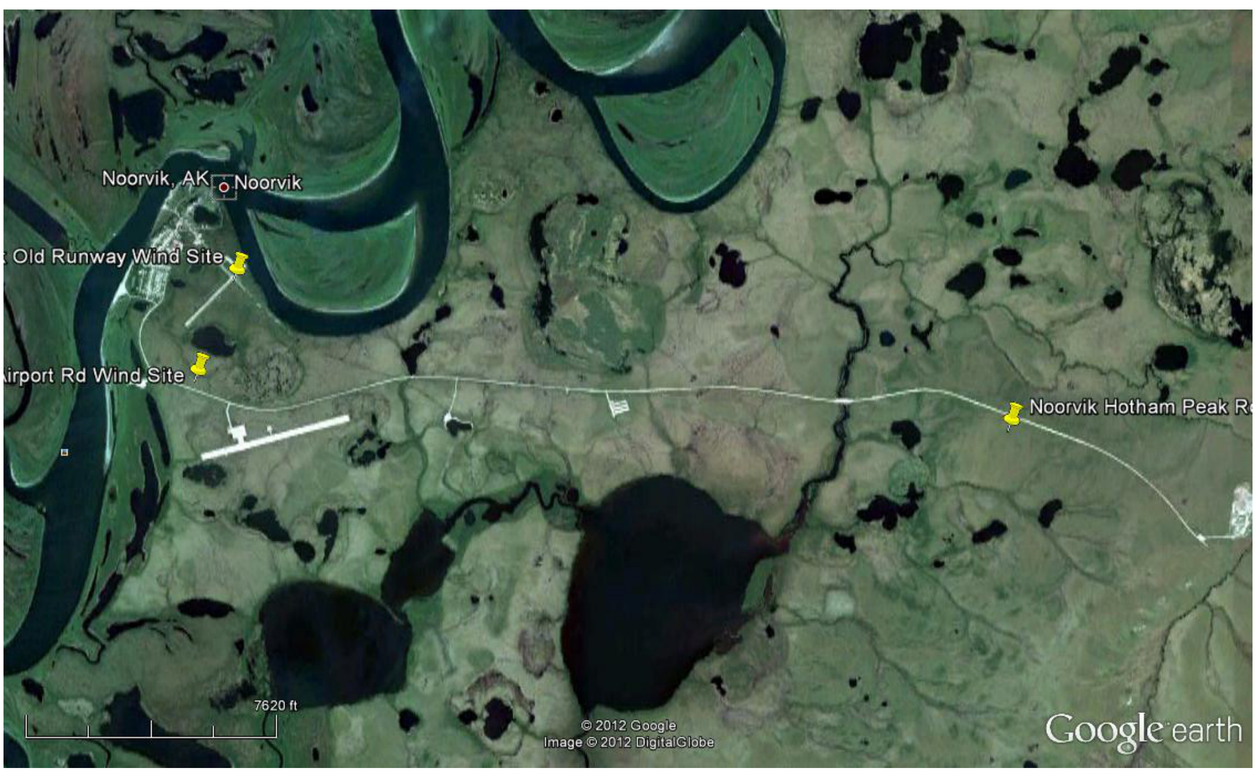
Site number	1002
Latitude/longitude	66° 49’ 11.96” N, 160° 52’ 4.92” W
Time offset	-9 hours from GMT (Yukon/Alaska time zone)
Site elevation	45 meters (148 ft.)
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	Tubular tall tower, 4-inch diameter, 30 meter height

Tower sensor information

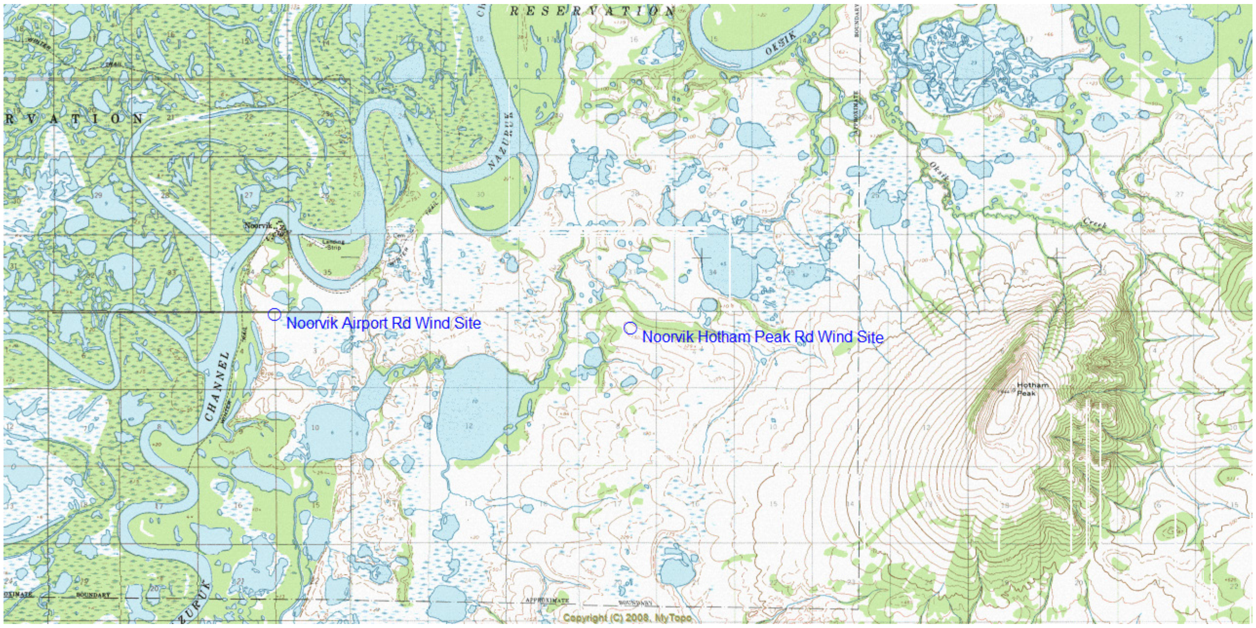
Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	29.11 m	0.765	0.35	157° T
2	NRG #40 anemometer	17.93 m	0.765	0.35	157° T
7	NRG #200P wind vane	25.22 m	0.351	0	359° T
9	NRG #110S Temp °C	2.5 m		-86.3	N

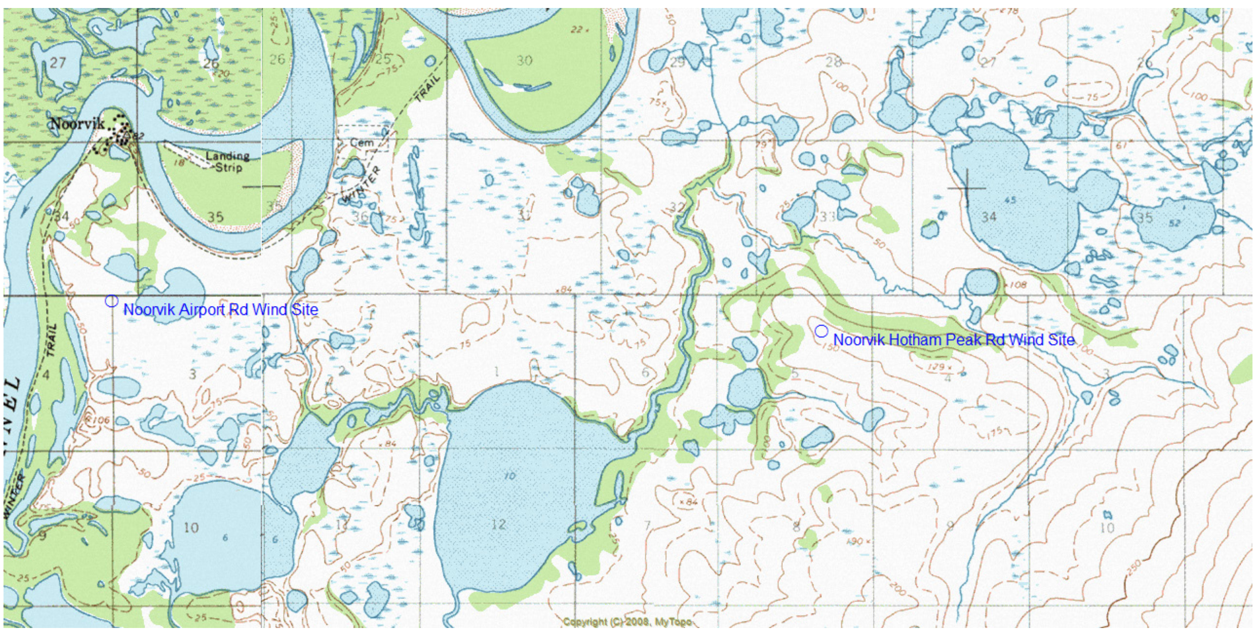
Google Earth images, Noorvik





Topographic maps of Noorvik





Data Quality Control

Data quality is very good with data recovery of both anemometers greater than 97 percent and data recovery of the wind vane nearly 98 percent. Data recovery of the temperatures sensor was 100 percent. Data loss is limited to winter months only and attributable to icing events which are characterized by non-variant output of the anemometers at the offset value (essentially zero) and by non-variant output of the direction vane at the last operable direction. This occurs when the temperature is near or below freezing. Data meeting these criteria were flagged as “icing” and removed from the data set prior to analysis.

Sensor data recovery table

Year	Month	Possible Records	Valid Records	30 m Recovery Rate (%)	18 m Recovery Rate (%)	Vane Recovery Rate (%)	Temp Recovery Rate (%)
2010	Oct	1,584	1,584	100.0	100.0	100.0	100.0
2010	Nov	4,320	3,130	72.5	86.0	68.8	100.0
2010	Dec	4,464	4,320	96.8	100.0	98.2	100.0
2011	Jan	4,464	4,464	100.0	100.0	100.0	100.0
2011	Feb	4,032	3,722	92.3	92.5	100.0	100.0
2011	Mar	4,464	4,464	100.0	100.0	100.0	100.0
2011	Apr	4,320	4,320	100.0	100.0	100.0	100.0
2011	May	4,464	4,464	100.0	100.0	100.0	100.0
2011	Jun	4,320	4,320	100.0	100.0	100.0	100.0
2011	Jul	4,464	4,464	100.0	100.0	100.0	100.0
2011	Aug	4,464	4,464	100.0	100.0	100.0	100.0
2011	Sep	4,320	4,320	100.0	100.0	100.0	100.0
2011	Oct	4,464	4,430	99.2	99.3	96.7	100.0
2011	Nov	4,320	4,270	98.8	98.5	100.0	100.0
2011	Dec	4,464	4,464	100.0	100.0	100.0	100.0
2012	Jan	3,552	3,552	100.0	100.0	100.0	100.0
All data		66,480	64,752	97.4	98.5	97.6	100.0

Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a very good wind resource, especially for an inland site. Note that cold temperatures contributed to a higher wind power density than standard conditions would yield for the measured mean wind speeds.

Anemometer data summary

Variable	Speed 30 m	Speed 18 m
Measurement height (m)	29.1	17.9
Mean wind speed (m/s)	5.69	5.24
MMM wind speed (m/s)	**5.62**	**5.18**
Max wind speed (m/s)	31.6	29.2
Weibull k, annual	1.39	1.40
Weibull c (m/s), annual	6.21	5.73
Mean power density (W/m²)	358	288
MMM power density (W/m²)	**334**	**268**
Mean energy content (kWh/m²/yr)	3,139	2,520
MMM energy content (kWh/m²/yr)	2,924	2,347
Energy pattern factor	2.95	3.04
Frequency of calms (%)	40.8	45.1
Hour of peak wind speed	15	15

MMM = mean of monthly mean, or *annualized*

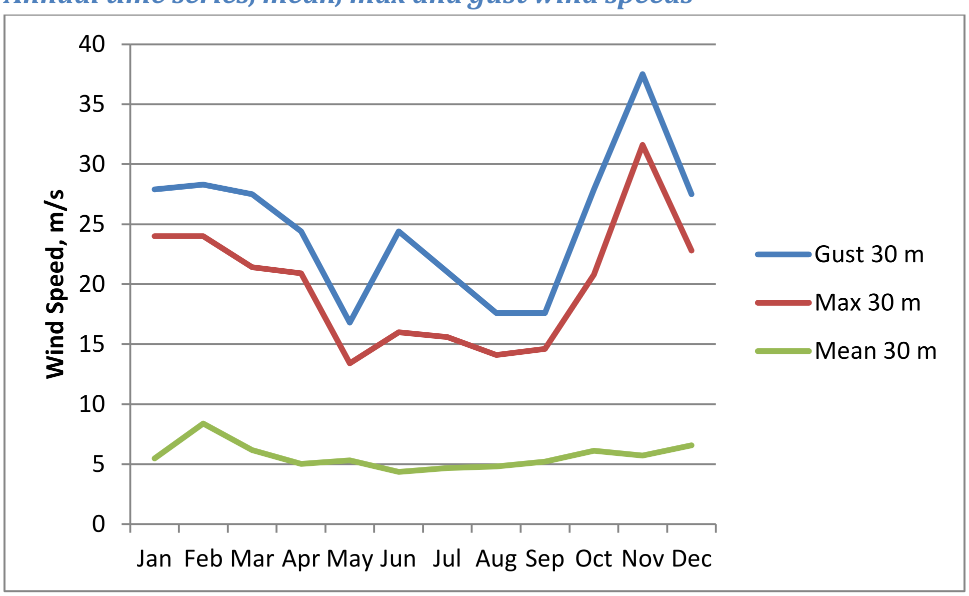
Time Series

Time series calculations indicate higher wind speeds during the winter months with more moderate wind speeds during summer months. This is typical of other wind power sites in Alaska and correlates well with the a typical village load profile where winter months have a high electric load and heat demand and summer months have a much lower demand for electricity and heat. The month-specific daily wind profiles indicate relatively even wind speeds throughout the day with slightly higher wind speeds during afternoon hours.

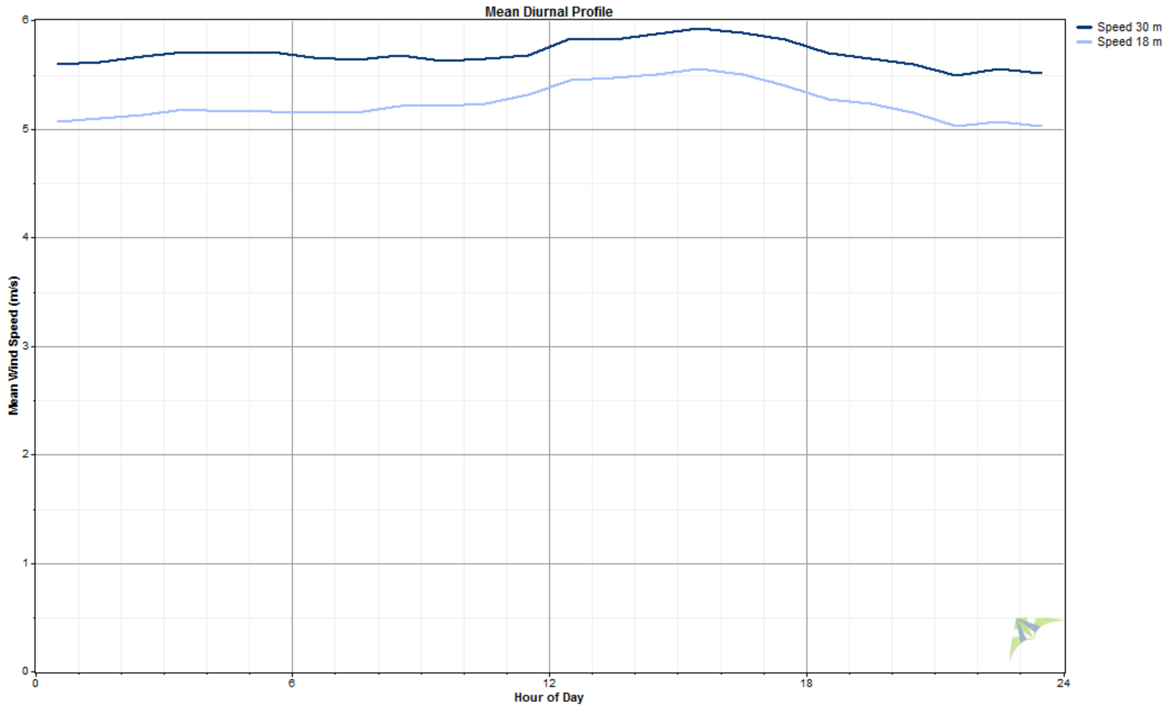
30 m anemometer data summary

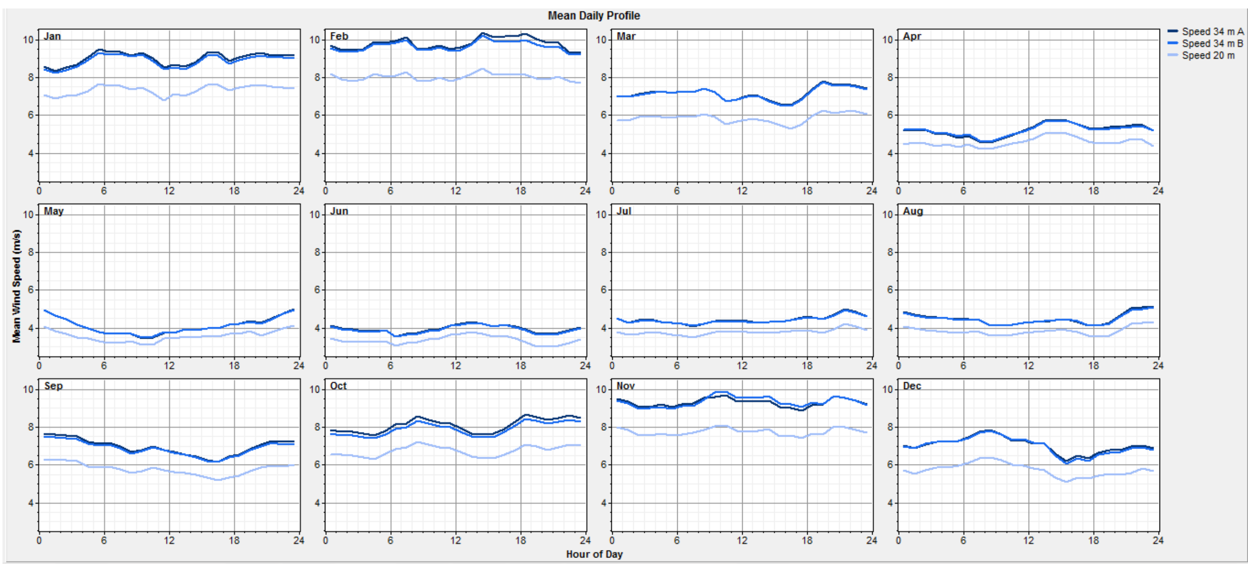
Month	Mean (m/s)	Max 10-min avg (m/s)	Gust (2 sec) (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
Jan	5.47	24.0	27.9	4.54	1.08	5.60
Feb	8.38	24.0	28.3	5.54	1.42	9.14
Mar	6.18	21.4	27.5	4.26	1.36	6.69
Apr	5.03	20.9	24.4	3.91	1.31	5.45
May	5.31	13.4	16.8	2.69	2.06	5.99
Jun	4.36	16.0	24.4	2.23	2.05	4.93
Jul	4.67	15.6	21.0	2.45	1.96	5.26
Aug	4.82	14.1	17.6	2.66	1.83	5.39
Sep	5.21	14.6	17.6	2.87	1.80	5.82
Oct	6.11	20.8	27.9	3.69	1.68	6.83
Nov	5.73	31.6	37.5	4.40	1.27	6.14
Dec	6.56	22.8	27.5	4.95	1.24	6.99
Annual	5.62	31.6	37.5	3.68	1.59	6.18

Annual time series, mean, max and gust wind speeds



Daily wind profiles (annual and by month)

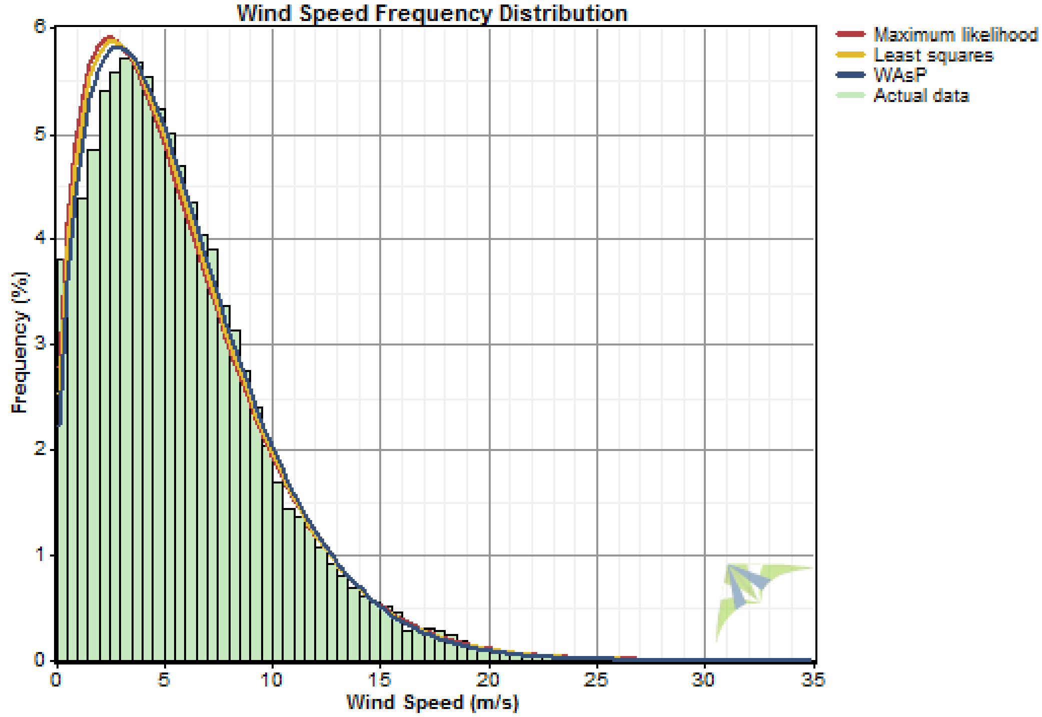




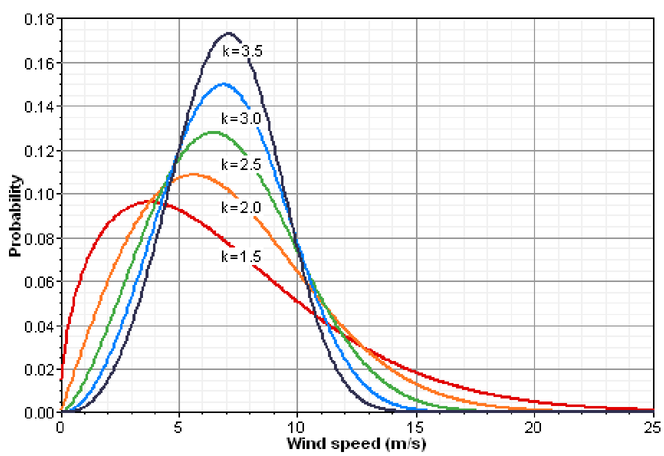
Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Noorvik met tower wind speed indicates a shape curve dominated by lower wind speeds with a Weibull k shape factor value of 1.59. This compares to a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis. As observed in the PDF of the 30 m anemometer, the most frequently occurring wind speeds are between 3 and 5 m/s with a few wind events exceeding 25 m/s (the cutout speed of most wind turbines; see following wind speed statistical table).

PDF of 30m anemometer (15 months' data)



Weibull k shape curve table



Occurrence by wind speed bin (30 m anemometer)

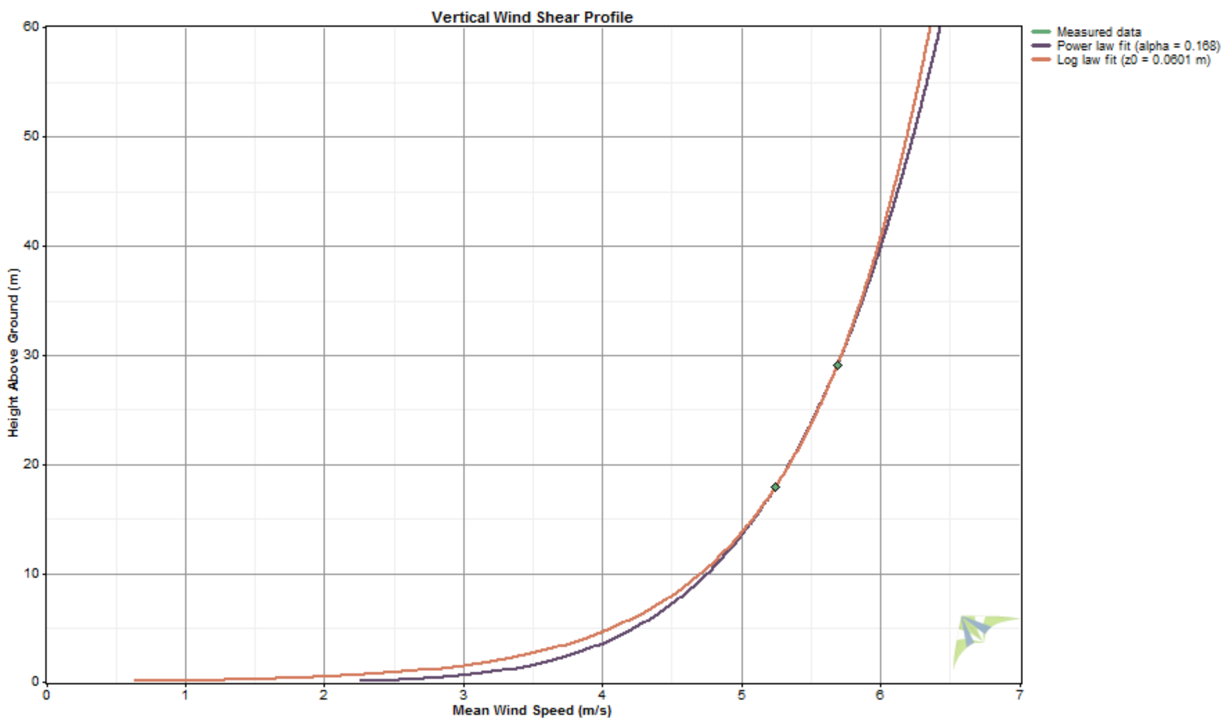
Bin Endpoints (m/s)		Occurrences			Bin Endpoints (m/s)		Occurrences		
Lower	Upper	No.	Percent	Cumul.	Lower	Upper	No.	Percent	Cumul.
0	1	5,265	8.13	8.1	16	17	390	0.60	98.2
1	2	5,983	9.24	17.4	17	18	386	0.60	98.8
2	3	7,106	10.97	28.3	18	19	296	0.46	99.2
3	4	7,374	11.39	39.7	19	20	175	0.27	99.5
4	5	6,966	10.76	50.5	20	21	106	0.16	99.7

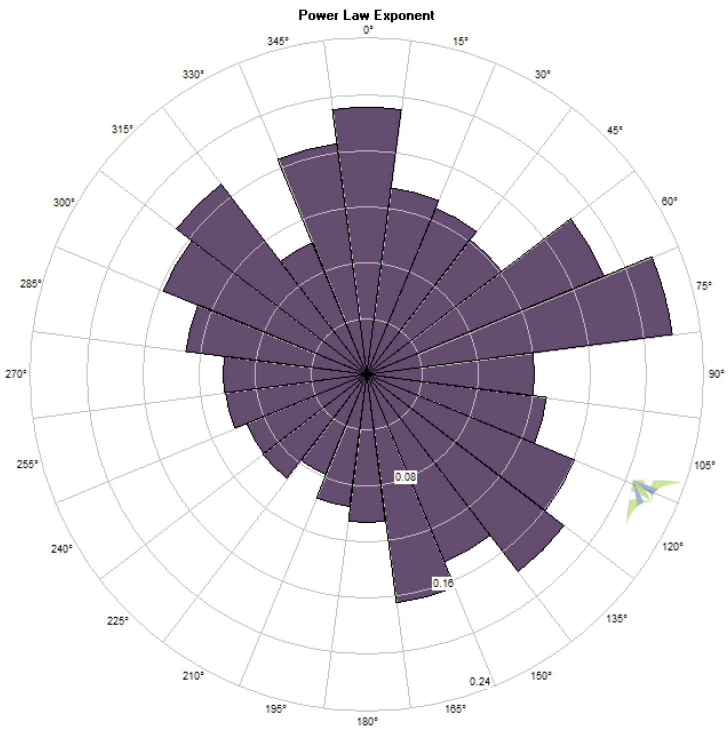
5	6	6,268	9.68	60.2	21	22	77	0.12	99.8
6	7	5,428	8.38	68.6	22	23	56	0.09	99.9
7	8	4,715	7.28	75.8	23	24	21	0.03	99.9
8	9	3,818	5.90	81.7	24	25	12	0.02	99.9
9	10	2,874	4.44	86.2	25	26	13	0.02	99.9
10	11	2,027	3.13	89.3	26	27	10	0.02	100.0
11	12	1,712	2.64	91.9	27	28	12	0.02	100.0
12	13	1,295	2.00	93.9	28	29	7	0.01	100.0
13	14	967	1.49	95.4	29	30	7	0.01	100.0
14	15	756	1.17	96.6	30	31	4	0.01	100.0
15	16	625	0.97	97.6	31	32	1	0.00	100.0

Wind Shear and Roughness

A wind shear power law exponent (α) of 0.168 indicates low wind shear at the site. Related to wind shear, a calculated surface roughness of 0.0601 meters (indicating the height above ground level where wind velocity would be zero) indicates fairly smooth terrain (roughness description: crops) surrounding the met tower. In the power law exponent wind rose graphic, wind shear coefficients variability by wind direction is noted.

Vertical wind shear profile





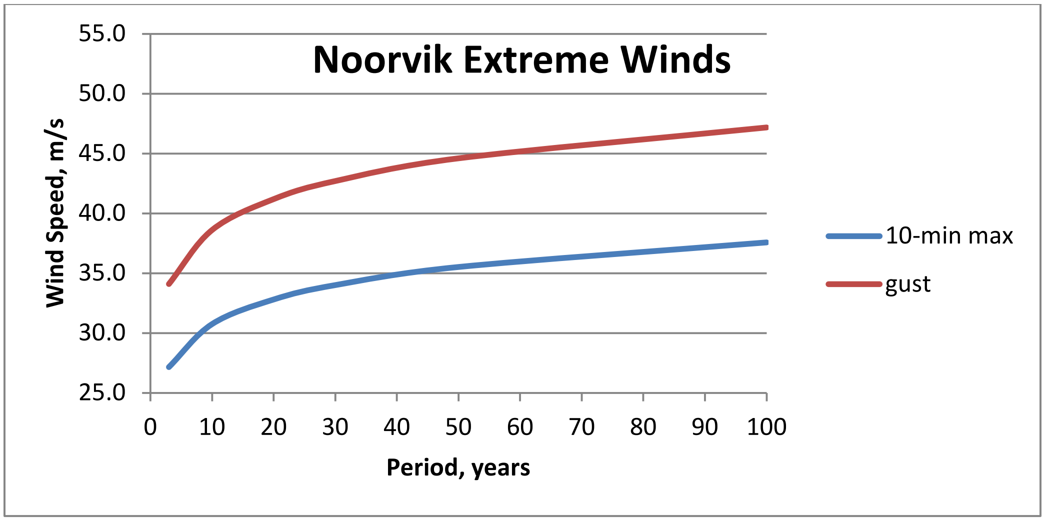
Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds instead of annual maximum winds, was used to predict extreme winds at the Noorvik met tower site. Fifteen months of data though are minimal at best and hence results should be viewed with caution and updated when more data is available. Nevertheless, with data available the predicted Vref (maximum ten-minute average wind speed) in a 50 year return period (in other words, predicted to occur once every 50 years) is 35.5 m/s. This result classifies the site as Class III by International Electrotechnical Commission 61400-1, 3rd edition (IEC3) criteria. IEC extreme wind probability classification is one criteria – with turbulence the other – that describes a site with respect to suitability for particular wind turbine models. Note that the IEC3 Class III extreme wind classification, which appears to apply to the Noorvik met tower site, is the lowest and most common classification. All wind turbines are designed to operate in IEC3 Class III sites.

Site extreme wind probability table, 30 m data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
3	27.1	34.1	I	50.0
10	30.7	38.6	II	42.5
20	32.8	41.2	III	37.5
30	34.0	42.7	S	designer-specified
50	35.5	44.6		
100	37.6	47.2		
average gust factor:	1.26			

Extreme wind graph, by return period



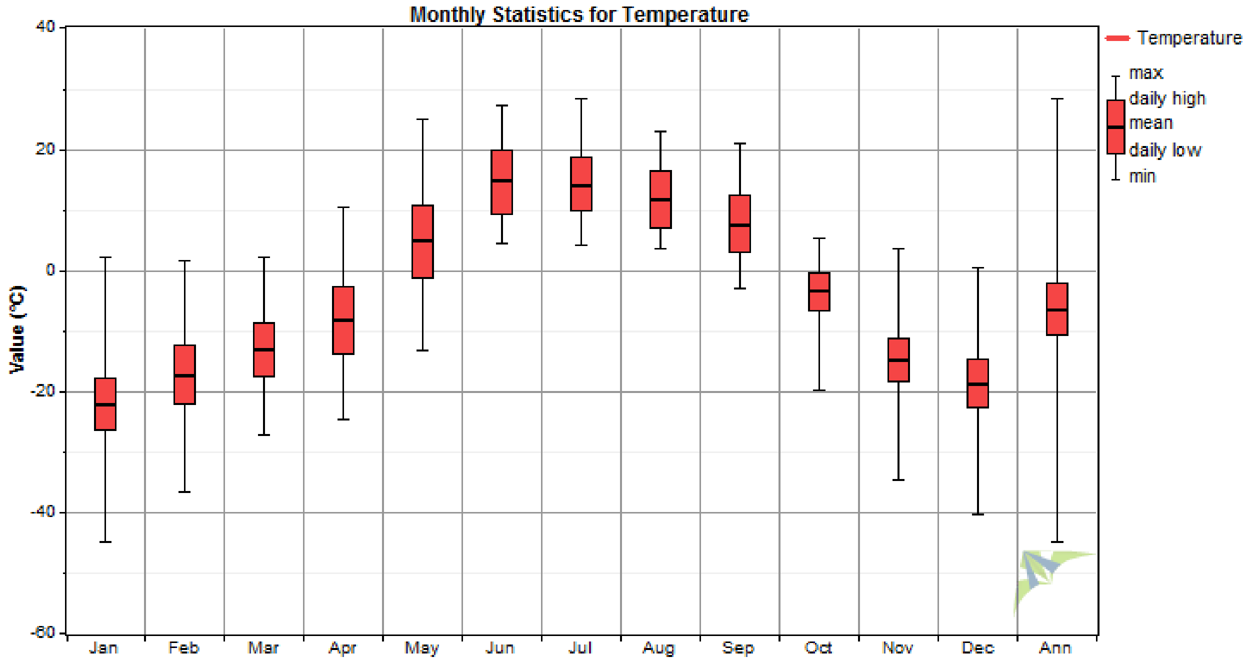
Temperature and Density

The Noorvik met tower site experiences cool summers and extremely cold winters with resulting higher than standard air density. Calculated mean-of-monthly-mean (or annual) air density during the met tower test period exceeds the 1.219 kg/m^3 standard air density for a 47 meter elevation by 7.1 percent. This is advantageous in wind power operations as wind turbines produce more power at low temperatures (high air density) than at standard temperature and density. Note that winter 2011/2012 has been exceptionally cold by recent standards and typical winters of the past few decades have been less extreme.

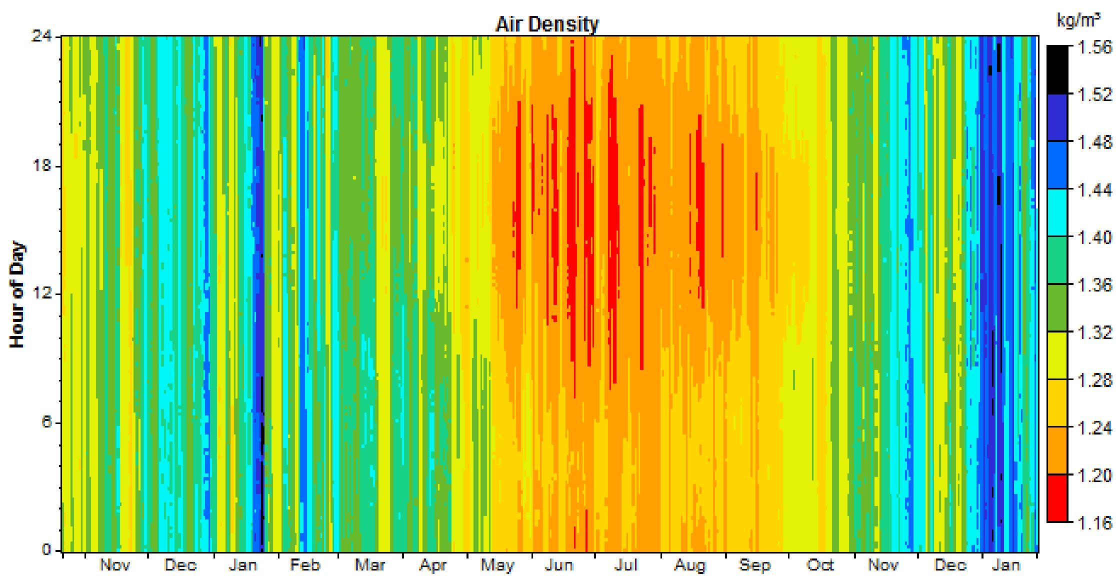
Temperature and density table

	Temperature			Air Density		
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)
Jan	-22.2	-44.9	2.2	1.402	1.275	1.538
Feb	-17.2	-36.7	1.5	1.373	1.278	1.485
Mar	-13.0	-27.2	2.1	1.350	1.275	1.427
Apr	-8.2	-24.8	10.3	1.326	1.238	1.413
May	5.0	-13.2	25.0	1.263	1.177	1.350
Jun	14.9	4.4	27.2	1.219	1.169	1.265
Jul	14.2	4.0	28.3	1.222	1.164	1.267
Aug	11.9	3.6	23.0	1.232	1.185	1.268
Sep	7.5	-3.0	20.8	1.251	1.194	1.299
Oct	-3.3	-19.8	5.1	1.301	1.262	1.386
Nov	-14.8	-34.7	3.4	1.360	1.269	1.472
Dec	-18.6	-40.2	0.5	1.381	1.283	1.507
Annual	-3.6	-44.9	28.3	1.306	1.164	1.538

Temperature annual boxplot graph



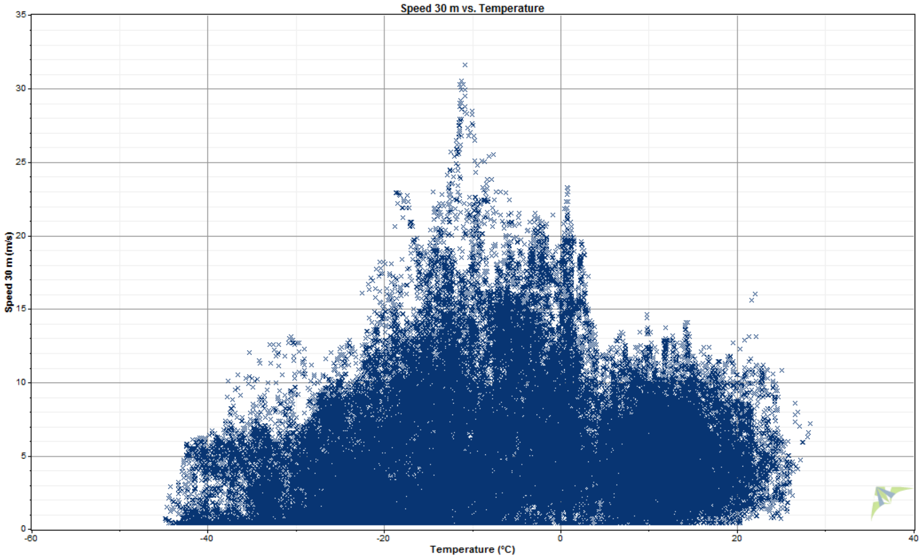
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates very cold temperatures at the Noorvik met tower site with highest wind speeds occurring at temperatures between approximately -20° C and 3° C. During the met tower test periods, temperatures fell below -40° C on a number of occasions. Note that arctic-capable wind turbines are rated to -40°C, hence some power production would be lost due to low temperature shutdown of the turbine. But, wind speeds at -40° C and less are very low, hence loss of power production would be minimal.

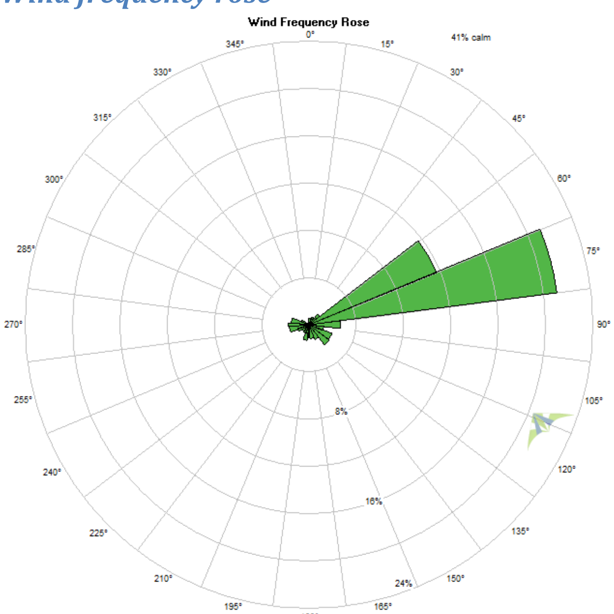
Wind speed/temperature scatterplot



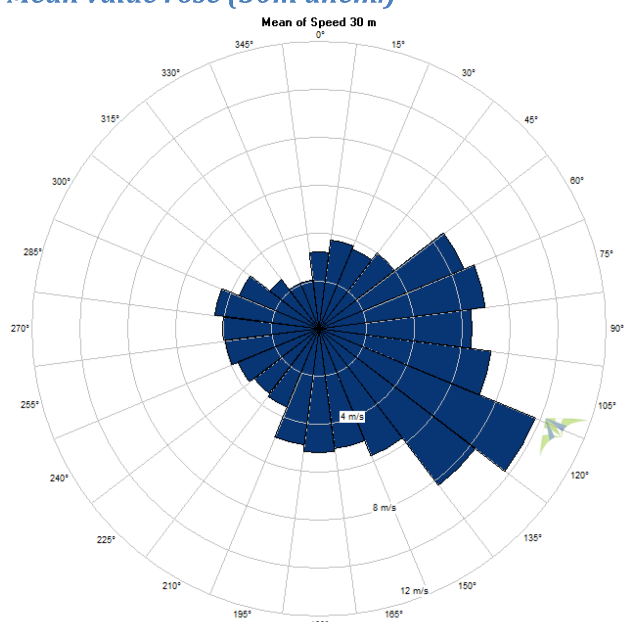
Wind Direction

Wind frequency rose data indicates that winds at the Noorvik met tower site highly directional, with east-northeast winds predominating. The mean value rose indicates that southeasterly winds, when they do occur, are of high energy and hence likely are storm winds. The wind energy rose indicates that for wind turbine operations, power-producing winds are dominated by ENE winds with a lesser component of SE winds. Calm frequency (the percent of time that winds at the 30 meter level are less than 4 m/s, a typical cut-in speed of larger wind turbines) was a relatively high 41 percent during the met tower test period (15 months of data).

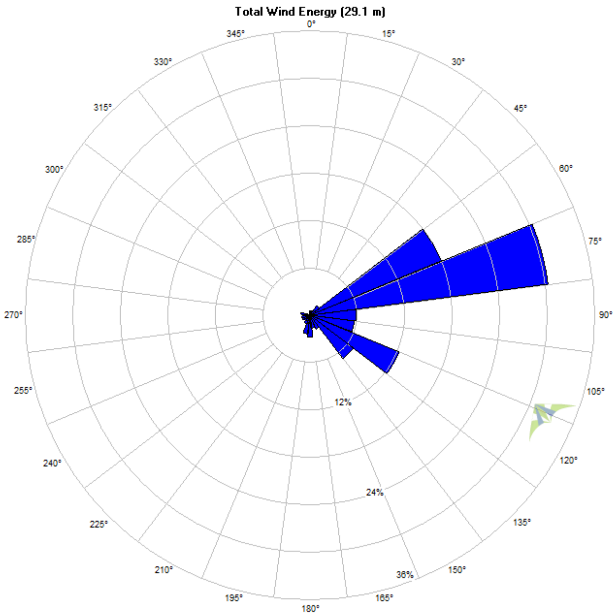
Wind frequency rose



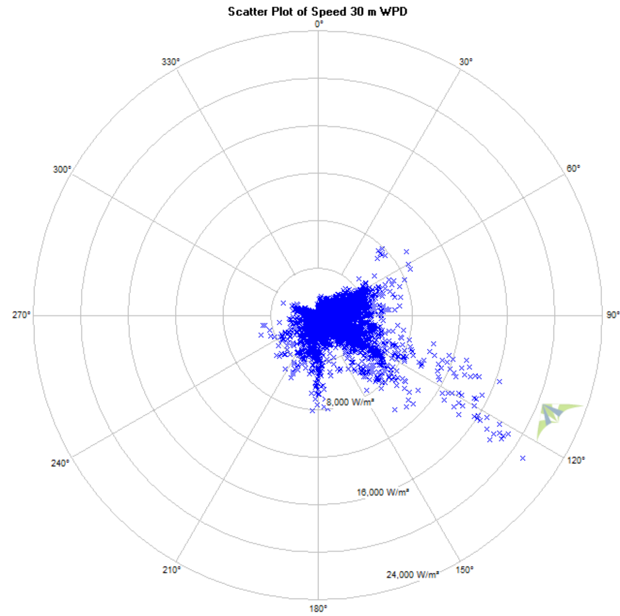
Mean value rose (30m anem.)



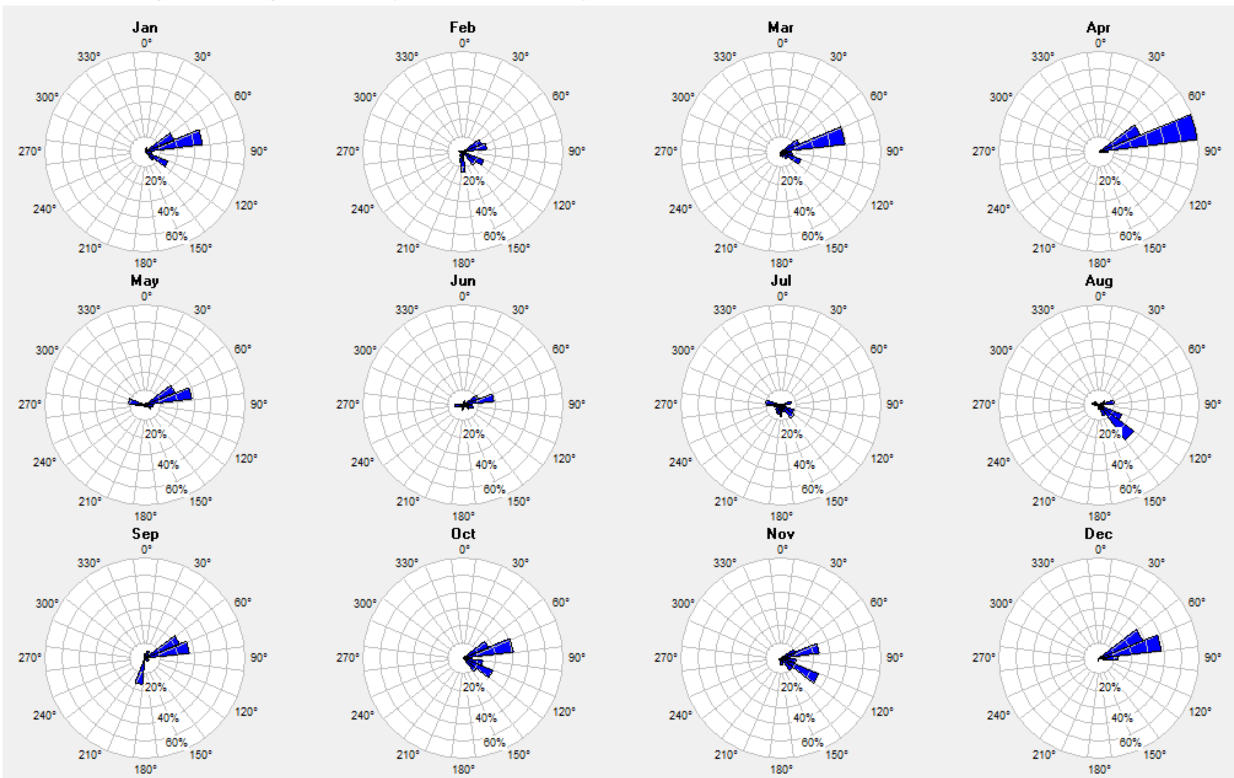
Wind energy rose (30 m anem.)



Scatterplot rose of 30m wind power density



Wind density roses by month (common scale)



Turbulence

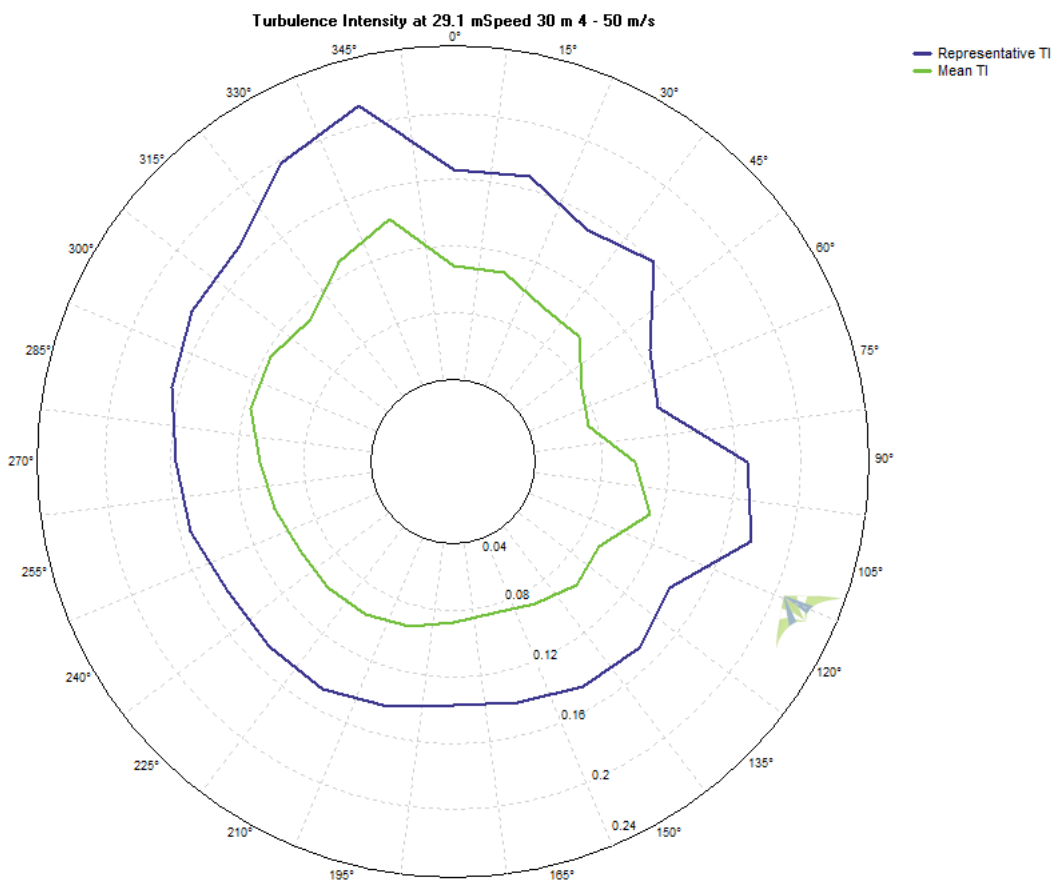
Turbulence intensity (TI) at the Noorvik met tower site is low with an IEC 61400-1, 3rd edition (IEC3) classification of turbulence category C, which is the lowest defined. A review of TI coefficients by sector indicates that low turbulence wind occurs from all wind sectors, except for NNW winds where TI appears to be somewhat high, but winds from this direction occur very infrequently and are of little consequence.

Turbulence synopsis

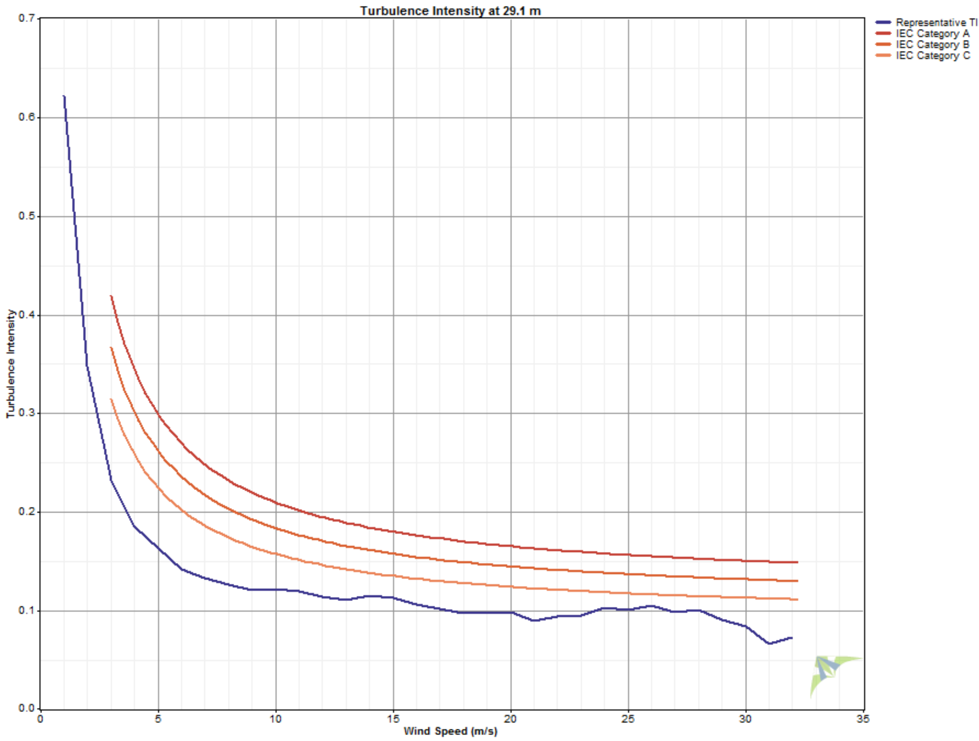
	30 m speed			18 m speed			Legend	
Sector	Mean TI at 15 m/s	Repres. TI at 15 m/s	IEC3 Category	Mean TI at 15 m/s	Repres. TI at 15 m/s	IEC3 Category	IEC3 Categ.	Mean TI at 15 m/s
all	0.079	0.112	C	0.086	0.120	C	S	>0.16
315° to 045°	0.073	0.086	C	0.074	0.079	C	A	0.14-0.16
045° to 135°	0.081	0.117	C	0.247	0.088	C	B	0.12-0.14
135° to 225°	0.071	0.089	C	0.077	0.098	C	C	0-0.12
045° to 135°	0.092	0.113	C	0.099	0.12	C		

TI = turbulence intensity

Turbulence rose, 30 m anemometer



Turbulence intensity, 30 m, all direction sectors



Turbulence table, 30 m data, all sectors, > 4 m/s

Bin Midpoint (m/s)	Bin Endpoints Lower (m/s)	Upper (m/s)	Records in Bin	Mean TI	SD of TI	Repres. TI	Peak TI
1	0.5	1.5	0				
2	1.5	2.5	0				
3	2.5	3.5	0				
4	3.5	4.5	3,583	0.108	0.054	0.177	0.452
5	4.5	5.5	6,615	0.099	0.049	0.162	0.667
6	5.5	6.5	5,854	0.089	0.041	0.142	0.421
7	6.5	7.5	5,142	0.085	0.037	0.132	0.378
8	7.5	8.5	4,218	0.081	0.035	0.126	0.383
9	8.5	9.5	3,341	0.077	0.034	0.121	0.364
10	9.5	10.5	2,413	0.078	0.034	0.122	0.373
11	10.5	11.5	1,818	0.079	0.032	0.120	0.267
12	11.5	12.5	1,520	0.077	0.029	0.114	0.333
13	12.5	13.5	1,119	0.077	0.026	0.110	0.248
14	13.5	14.5	848	0.079	0.028	0.115	0.243
15	14.5	15.5	685	0.079	0.026	0.112	0.226
16	15.5	16.5	481	0.076	0.024	0.106	0.222
17	16.5	17.5	404	0.075	0.020	0.101	0.159
18	17.5	18.5	353	0.073	0.019	0.097	0.153

19	18.5	19.5	221	0.073	0.018	0.097	0.154
20	19.5	20.5	134	0.073	0.020	0.099	0.128
21	20.5	21.5	94	0.068	0.016	0.089	0.117
22	21.5	22.5	72	0.067	0.021	0.094	0.144
23	22.5	23.5	36	0.070	0.020	0.095	0.116
24	23.5	24.5	14	0.078	0.020	0.103	0.104
25	24.5	25.5	10	0.091	0.007	0.100	0.102
26	25.5	26.5	10	0.092	0.010	0.104	0.106
27	26.5	27.5	12	0.089	0.007	0.098	0.103
28	27.5	28.5	11	0.089	0.008	0.100	0.099
29	28.5	29.5	7	0.084	0.005	0.091	0.093
30	29.5	30.5	7	0.076	0.006	0.084	0.086
31	30.5	31.5	1	0.066	0.000	0.066	0.066
32	31.5	32.5	1	0.073	0.000	0.073	0.073

Wind Turbine Performance

The selection of suitable wind turbines for a wind power project in Noorvik is beyond the scope of this report, but for initial planning purposes, predicted annual energy output and capacity factor for the 100 kW Northwind 100 B model (21 meter rotor, 37 meter hub height) is presented below. Note that the Alaska Energy Authority considers 82 percent turbine availability (percent of time that the turbine is operational and available to produce power, irrespective of wind speed) as the default value for planning of village wind-diesel power projects.

Wind turbine performance, NW100B/21

	100% availability Northwind 100B/21				82% availability Northwind 100B/21			
Month	Hub Height Wind Speed (m/s)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)	Hub Height Wind Speed (m/s)	Mean Net Power Output (kW)	Mean Net Energy Output (kWh/yr)	Net Capacity Factor (%)
Jan	5.8	30.1	22,410	30.1	5.8	24.7	18,376	24.7
Feb	8.7	51.7	34,719	51.7	8.7	42.4	28,470	42.4
Mar	6.5	35.9	26,691	35.9	6.5	29.4	21,886	29.4
Apr	5.3	24.0	17,254	24.0	5.3	19.7	14,149	19.7
May	5.5	21.5	15,992	21.5	5.5	17.6	13,113	17.6
Jun	4.5	12.4	8,958	12.4	4.5	10.2	7,346	10.2
Jul	4.9	15.7	11,658	15.7	4.9	12.8	9,559	12.8
Aug	5.1	17.9	13,298	17.9	5.1	14.7	10,904	14.7
Sep	5.5	22.9	16,524	22.9	5.5	18.8	13,549	18.8
Oct	6.5	31.0	23,031	31.0	6.5	25.4	18,885	25.4
Nov	6.0	28.7	20,649	28.7	6.0	23.5	16,932	23.5
Dec	7.0	38.8	28,846	38.8	7.0	31.8	23,654	31.8
Annual	5.9	27.6	240,030	27.6	5.9	22.6	196,823	22.6