Mountain Village, Alaska Wind Resource Report

Mountain Village met tower site, view upriver (southeast), D. Vaught photo

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Summary

The wind resource measured at the Mountain Village met tower site 0068 is very good with measured wind power class 5 (excellent). In addition to high average wind speeds and high wind power density, the site experiences very low turbulence and low extreme wind speed probability.

Met tower data synopsis

Data dates	November 5, 2009 to August 9, 2011 (21 months), status: operational
Wind power class	Low Class 5 (excellent)
Power density mean, 50 m	523 W/m^2
Wind speed mean, 50 m	7.62 m/s
Max. 10-min wind speed average	26.5 m/s
Maximum 2-sec. wind gust	31.8 m/s (Feb. 2011)
Weibull distribution parameters	k = 2.12, c = 8.65 m/s
Wind shear power law exponent	0.180 (moderate)
Roughness class	2.28 (few trees)
IEC 61400-1, 3rd ed. classification	Class III-c
Turbulence intensity, mean	0.072 (at 15 m/s)
Calm wind frequency (at 46 m)	16% (< 4 m/s)

Community Description

Mountain Village has a population of 813 people (2010 census) and is located on north bank of the Yukon River, approximately 20 miles west of St. Mary's and 470 miles northwest of Anchorage. It is at the foot of the 500 ft elevation Azachorok Mountain, the first mountain encountered by those traveling up the Yukon. The climate is continental with maritime influences. Temperatures range from -44 to 80 °F. Annual precipitation averages 16 inches, with snowfall of 44 inches. High winds and low visibility are common during winter. The Lower Yukon is ice-free from mid-June to October.

Mountain Village was a summer fish camp until the opening of a general store in 1908. This prompted residents of Liberty Landing and Johnny's Place to immigrate. A Covenant Church missionary school was also built in that same year. A post office was established in 1923, followed by a salmon saltery in 1956 and a cannery in 1964. The city government was incorporated in 1967. Mountain Village became a regional education center in 1976 when it was selected as headquarters for the Lower Yukon School District.

A federally-recognized tribe is located in the community -- the Asa'carsarmiut Tribal Council. Mountain Village is a Yup'ik Eskimo community with traditional subsistence practices. Commercial fishing and fish processing provide income. The sale and importation of alcohol is banned in the village.

According to Census 2010, there were 211 housing units in the community and 184 were occupied. The Mountain Village population is 91.9 percent American Indian or Alaska Native, 4.2 percent white, 0.7 percent Asian, and 3.2 percent of the residents have multi-racial backgrounds. Additionally, 0.4 percent of the population is of Hispanic descent.

Water is derived from a well and is treated. Mountain Village operates a piped water and sewer system that serves 200 households and facilities. A landfill is available. Electricity is provided by AVEC. There is one school in the community, attended by 242 students. Local hospitals or health clinics include George Waskey Memorial Clinic in Mountain Village. Emergency service is provided by a health aide.

A summer road links Mountain Village to Pitka's Point, Andreafsky, and St. Mary's. Mountain Village is accessible by riverboat or barge. A state-owned 3,500' long by 75' wide gravel airstrip is available, and floatplanes land on the Yukon River. In the winter passengers, cargo, and mail are flown in by plane. Snowmachines and skiffs are used for local transportation.

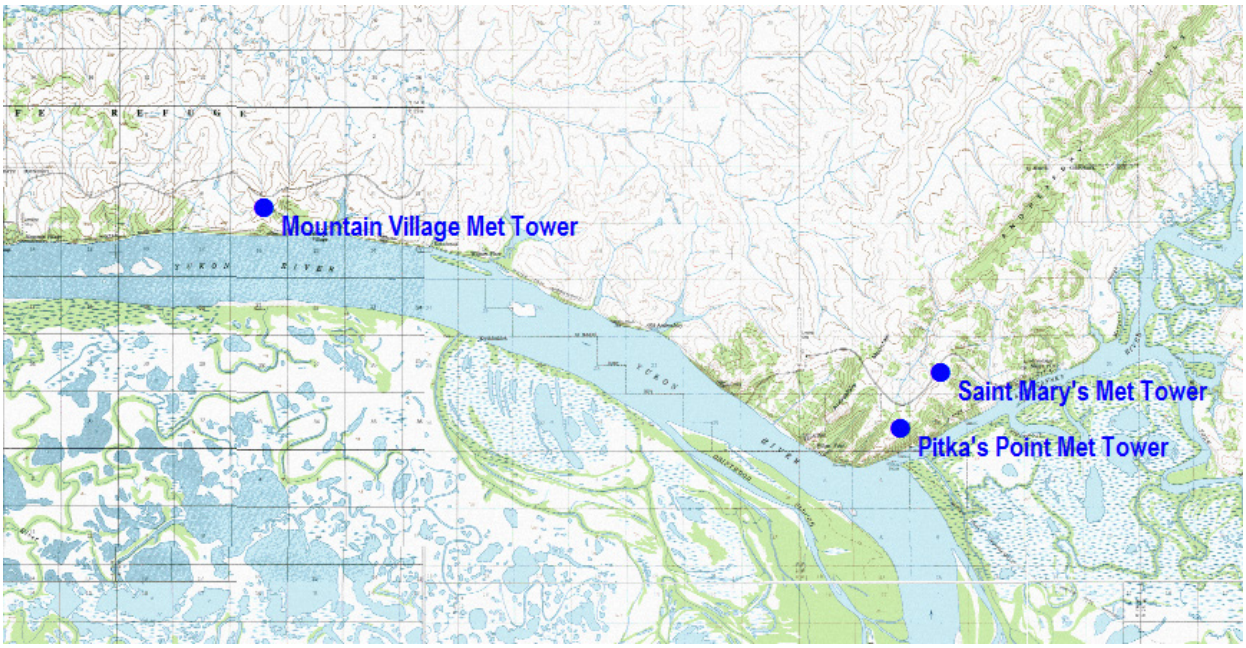
Test Site Location

The met tower is installed on an a broad, flat ridge on Mountain Village Native Corporation land east of the Mountain Village Airport and near the road that connects Mountain Village to the villages of Saint Mary's and Pitka's Point to the east. The site is large enough to accommodate several or more large turbines. Although the site is not at present near electrical distribution lines, near-term plans call for construction of an intertie adjacent to the road between Mountain Village and Saint Mary's, which would make wind development on the site more advantageous.

Site information

Site number	0068
Latitude/longitude	N 62° 05' 37.66" W 163° 35' 24.68", WGS 84
Site elevation	44 meters (144 ft)
Datalogger type	NRG Symphonie, 10 minute time step
Tower type	NRG 50-meter XHD tall tower, 254 mm diameter
Anchor type	Plate and /or duckbill

Topographic maps



Google Earth image

Tower sensor information

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40 anemometer	50.3 m (50 m A)	0.760	0.36	000° T
2	NRG #40 anemometer	50.5 m (50 m B)	0.757	0.41	135° T
3	NRG #40 anemometer	40.8 m (40 m)	0.761	0.33	000° T
13	NRG #40 anemometer	41.1 m (41 m)	0.758	0.33	135° T

14	NRG #40 anemometer	31.8 m (31 m)	0.758	0.34	000° T
15	NRG #40 anemometer	32.0 m (32 m)	0.761	0.33	135° T
7	NRG #200P wind vane	46.1 m	0.351	270	090° T
8	NRG #200P wind vane	40.0 m	0.351	270	090° T
9	NRG #110S Temp C	3 m	0.138	-86.3	N
10	RH-5 relative humidity	2 m	0.098	0	N
12	iPack batter voltmeter	n/a	0.021	0	n/a

Data Quality Control

Data quality is generally good with data recovery of all six anemometers greater than 90 percent and data recovery of the two wind vanes less but also greater than 90 percent. Data loss is limited to winter months only and is attributable to icing events, which are characterized by non-variant output of the anemometer at the minimum offset value (essentially zero) and by non-variant output of the direction vane at the last operable direction. Rime icing conditions have been observed at the nearby Saint Mary's and Pitka's Point met towers, but it is not known if icing conditions observed in the data are due to rime ice or freezing rain. Given the site elevation and known rime icing experience in Saint Mary's, caution would err toward the former.

Data recovery summary table

Label	Units	Height	Possible Records	Valid Records	Recovery Rate (%)
Speed 50 m A	m/s	50.3 m	92,472	85,955	93.0
Speed 50 m B	m/s	50.5 m	92,472	86,241	93.3
Speed 40 m	m/s	40.8 m	92,472	87,252	94.4
Speed 41 m	m/s	41.1 m	92,472	87,349	94.5
Speed 31 m	m/s	31.8 m	92,472	87,168	94.3
Speed 32 m	m/s	32 m	92,472	86,449	93.5
Direction 46 m	°	46 m	92,472	83,646	90.5
Direction 40 m	°	40 m	92,472	85,157	92.1
Temperature	°C		92,472	92,376	99.9
RH-5 Humidity %RH	%RH		92,472	87,632	94.8
Voltmeter	volts		92,472	92,382	99.9

Anemometer data recovery

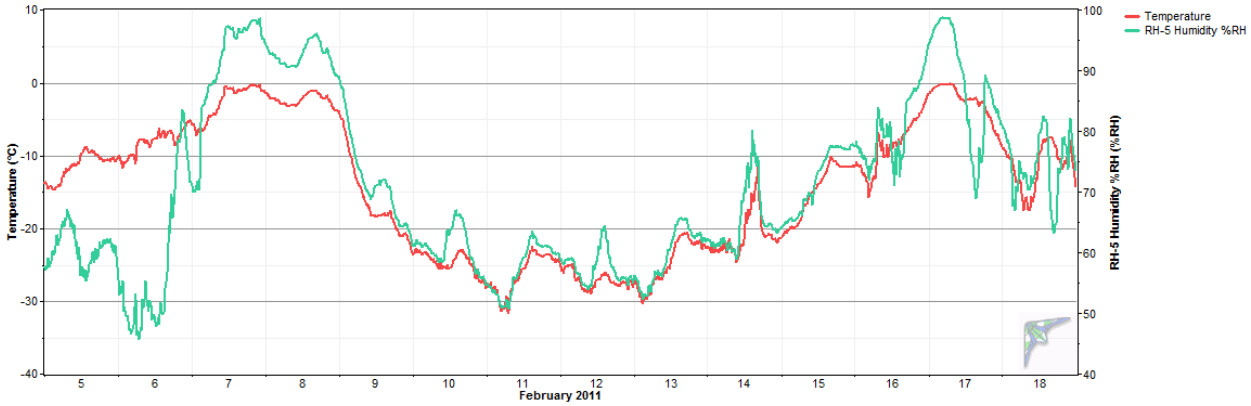
			50 m A anem.		50 m B	40 m	41 m	31 m	32 m
Year	Month	Possible Records	Valid Records	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)
2009	Nov	3,744	3,660	97.8	97.8	97.8	97.8	97.8	94.3
2009	Dec	4,464	4,113	92.1	92.1	92.1	92.1	92.1	92.1
2010	Jan	4,464	4,038	90.5	90.2	98.5	91.9	95.1	93.3
2010	Feb	4,032	3,111	77.2	75.7	77.2	77.2	77.2	77.2
2010	Mar	4,464	3,516	78.8	78.5	87.9	92.5	86.3	85.3
2010	Apr	4,320	4,320	100.0	100.0	100.0	100.0	100.0	100.0

2010	May	4,464	4,464	100.0	99.8	99.2	99.2	100.0	99.5
2010	Jun	4,320	4,320	100.0	100.0	100.0	100.0	100.0	100.0
2010	Jul	4,464	4,464	100.0	100.0	100.0	100.0	100.0	100.0
2010	Aug	4,464	4,464	100.0	100.0	100.0	100.0	100.0	100.0
2010	Sep	4,320	4,320	100.0	100.0	100.0	100.0	100.0	100.0
2010	Oct	4,464	3,829	85.8	83.5	91.9	91.9	91.9	86.0
2010	Nov	4,320	4,037	93.5	92.3	89.1	91.8	88.3	90.2
2010	Dec	4,464	4,132	92.6	91.8	94.9	96.0	96.5	90.9
2011	Jan	4,464	3,791	84.9	92.4	92.6	91.2	92.5	92.1
2011	Feb	4,032	2,211	54.8	60.5	55.6	57.8	57.4	57.7
2011	Mar	4,464	4,464	100.0	100.0	100.0	100.0	100.0	100.0
2011	Apr	4,320	4,320	100.0	100.0	100.0	100.0	100.0	100.0
2011	May	4,464	4,421	99.0	99.0	99.0	99.0	99.0	99.0
2011	Jun	4,320	4,320	100.0	100.0	100.0	100.0	100.0	100.0
2011	Jul	4,464	4,464	100.0	100.0	100.0	100.0	100.0	100.0
2011	Aug	1,176	1,176	100.0	100.0	100.0	100.0	100.0	100.0
		92,472	85,955	93.0	93.3	94.4	94.5	94.3	93.5

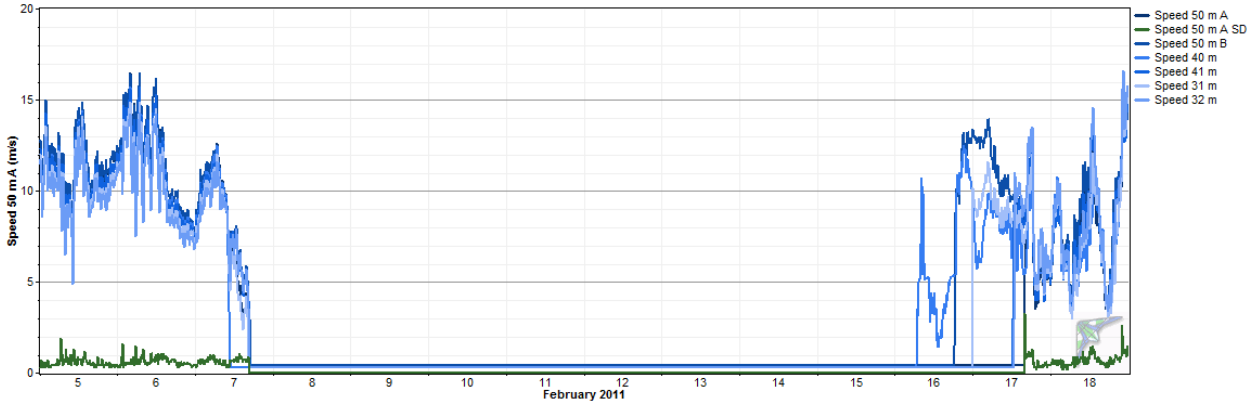
Icing Event

Data indicating an apparent icing event in February 2011 is shown below. In the days preceding the event, characterized by loss of anemometer function, the temperature had been -15° C, warming to 0° C. Relatively humidity had been moderate but increased to 100 percent coinciding with the temperature warm-up to the freezing point. At this time, on February 7, all six anemometers ceased functioning. The moderate temperature and high humidity conditions continued for two days which were followed by a rapid decrease of temperature to -32° C on February 11. Anemometers remained inoperative and presumably encased in ice until February 16 and 17 when the temperature again warmed to 0° C and humidity rose to 100 percent, indicating another precipitation event. High winds and warming temperatures were sufficient to break loose the anemometers and they resumed normal function.

Apparent icing event, Feb. 2011, temp. and RH



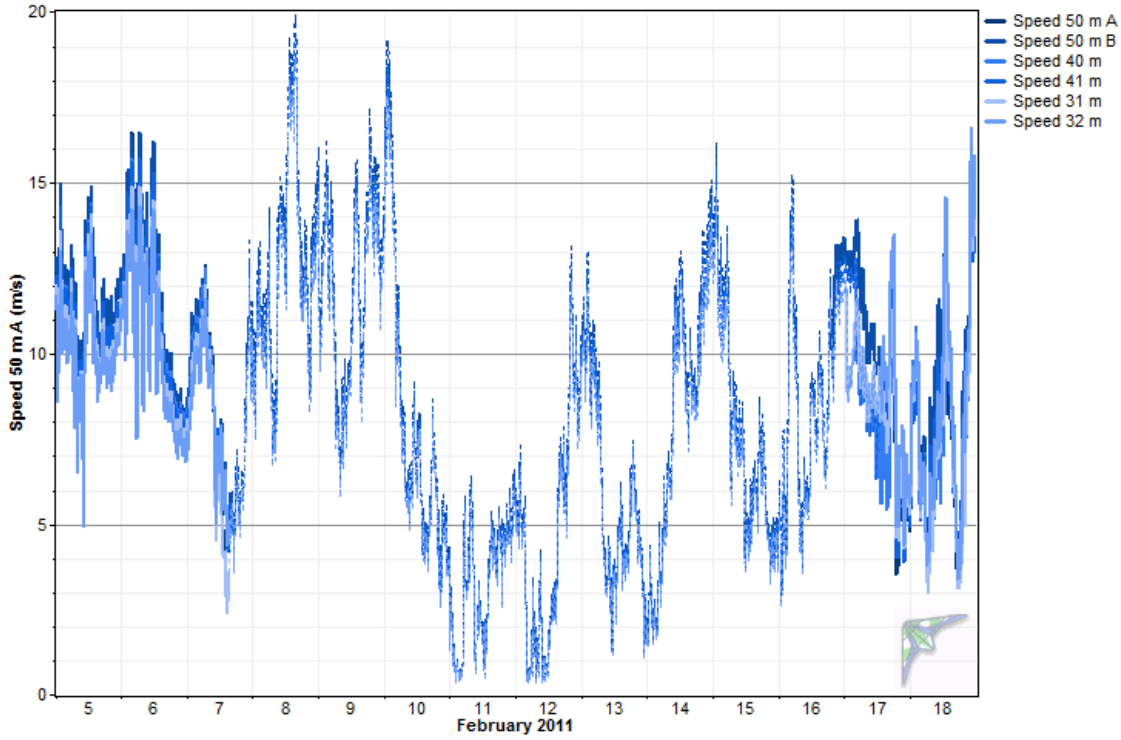
Apparent icing event, Feb. 2011, anemometers



Data Gap-fill

Although the overall loss of anemometer data due to icing was less than 90 percent, this includes the summer months which of course do not experience icing conditions. Wintertime icing loss was much higher, with data recovery of the anemometers as low as the 50 percent range in February 2011. Ice event data is removed from the file to avoid biasing the mean wind speed low (zero wind speed when the wind is likely blowing), but that can create the opposite situation, where the data set bias is high (no recorded wind speed during the ice periods, leaving just higher wind speeds in the data set). To overcome these errors, a data gap-fill algorithm contained in Windographer software was employed to synthesize missing data and create a statistically truer representation of the Mountain Village wind resource than the file without data gap-fill. Note: dotted lines below are synthesized data.

Gap-fill of Feb. 2011 icing event



Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate an excellent wind resource. Mean wind speeds are greater at higher elevations on the met tower, as one would expect. Note that cold temperatures contributed to a higher wind power density than otherwise might have been expected for the mean wind speeds. Also note, as discussed in the previous section, that anemometer summary information is the table below is *post* gap-fill. None gap-filled mean wind speeds and power densities are slightly higher than below.

Anemometer data summary

Variable	Speed 50 m A	Speed 50 m B	Speed 41 m	Speed 40 m	Speed 32 m	Speed 31 m
Measurement height (m)	50.3	50.5	41.1	40.8	32.0	31.8
Mean wind speed (m/s)	7.57	7.67	7.32	7.31	7.06	7.02
MMM wind speed (m/s)	7.52	7.63	7.28	7.26	7.02	6.97
Max 10-min wind speed (m/s)	26.6	26.5	26.0	26.0	25.4	25.2
Max gust wind speed (m/s)	31.5	31.8	31.8	32.7	31.5	31.4
Weibull k	2.13	2.12	2.09	2.12	2.10	2.12
Weibull c (m/s)	8.54	8.65	8.25	8.24	7.96	7.91
Mean power density (W/m²)	510	534	472	462	421	409
MMM power density (W/m²)	500	523	463	452	413	401
Mean energy content (kWh/m²/yr)	4,469	4,674	4,133	4,047	3,686	3,585
MMM energy content (kWh/m²/yr)	4,379	4,580	4,054	3,958	3,615	3,513
Energy pattern factor	1.79	1.80	1.84	1.81	1.83	1.81
Frequency of calms (< 4 m/s)	17.3	16.8	18.9	18.5	19.8	20.2
1-hr autocorrelation coefficient	0.926	0.929	0.926	0.924	0.922	0.921
Diurnal pattern strength	0.020	0.020	0.022	0.020	0.025	0.021
Hour of peak wind speed	22	22	21	21	19	20

Time Series

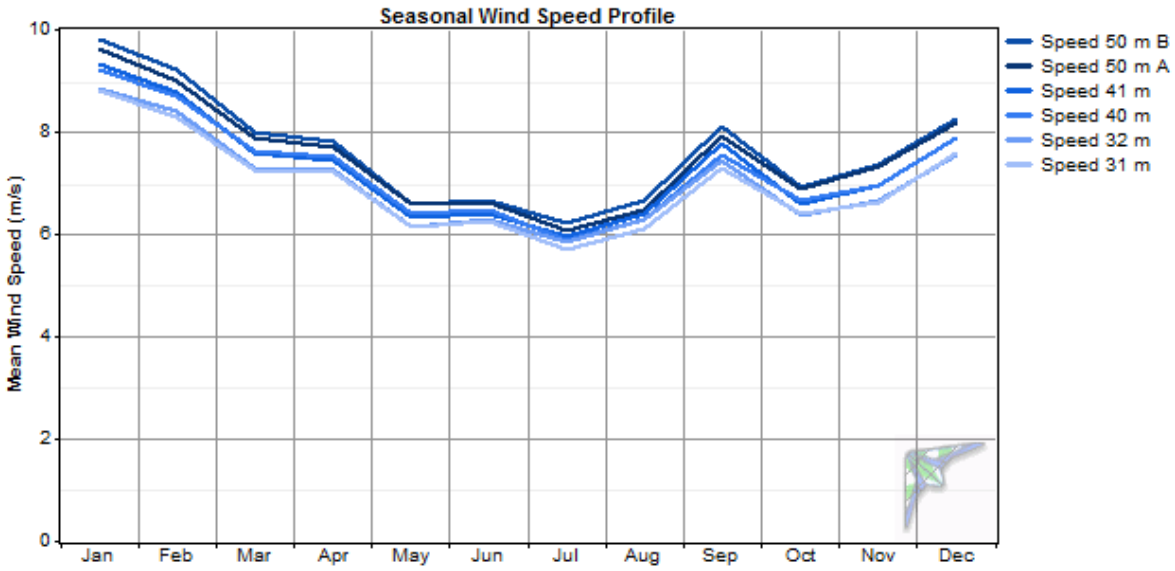
Time series calculations indicate high mean wind speeds during the winter months with more moderate mean wind speeds during summer months. This correlates well with the village load profile where winter months have a high electric and heat demand and summer months a lesser demand.

50 m B anemometer data summary

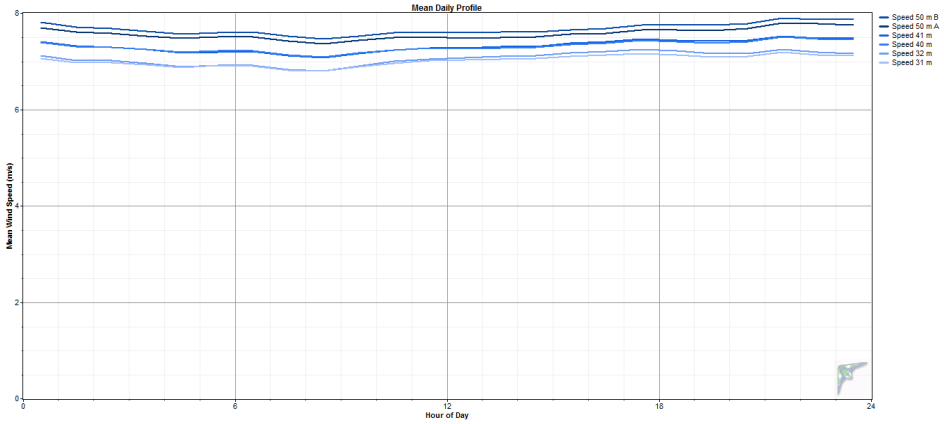
Year	Month	Mean (m/s)	Max (m/s)	Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
2009	Nov	7.67	24.8	31.1	3.71	2.16	8.66
2009	Dec	9.40	25.1	28.4	4.50	2.18	10.59
2010	Jan	8.91	19.7	23.5	3.49	2.76	9.97
2010	Feb	8.92	20.6	23.1	3.84	2.49	10.05
2010	Mar	8.02	16.2	19.0	3.06	2.83	8.95
2010	Apr	7.34	22.2	27.3	3.91	1.94	8.26
2010	May	6.05	15.6	17.8	2.87	2.22	6.83
2010	Jun	7.40	20.0	26.5	3.26	2.41	8.34
2010	Jul	5.48	13.9	17.4	2.36	2.47	6.16

2010	Aug	6.16	19.9	25.0	3.37	1.91	6.94
2010	Sep	8.13	19.6	23.1	3.63	2.39	9.16
2010	Oct	6.91	19.7	25.0	3.57	2.03	7.80
2010	Nov	7.08	17.5	20.5	2.69	2.82	7.93
2010	Dec	7.15	17.0	20.8	3.01	2.52	8.01
2011	Jan	10.70	21.9	25.8	4.19	2.74	11.96
2011	Feb	9.51	26.2	31.8	4.86	2.04	10.72
2011	Mar	7.99	23.6	27.3	3.78	2.15	8.96
2011	Apr	8.28	26.5	30.7	4.06	2.11	9.33
2011	May	7.14	16.9	19.7	2.94	2.62	8.03
2011	Jun	5.91	18.2	21.6	2.97	2.08	6.67
2011	Jul	6.97	19.1	25.0	3.53	2.08	7.88
2011	Aug	8.59	18.4	22.4	3.28	2.81	9.64
All data		7.67	26.5	31.8	3.77	2.12	8.65

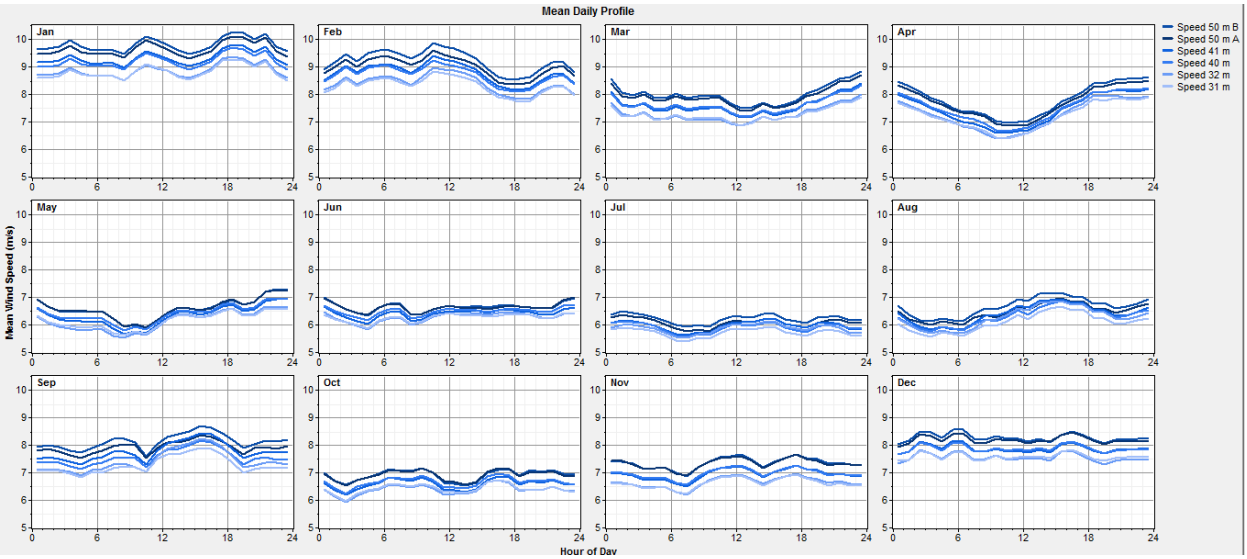
Annualized time series graph



Annual daily wind profile



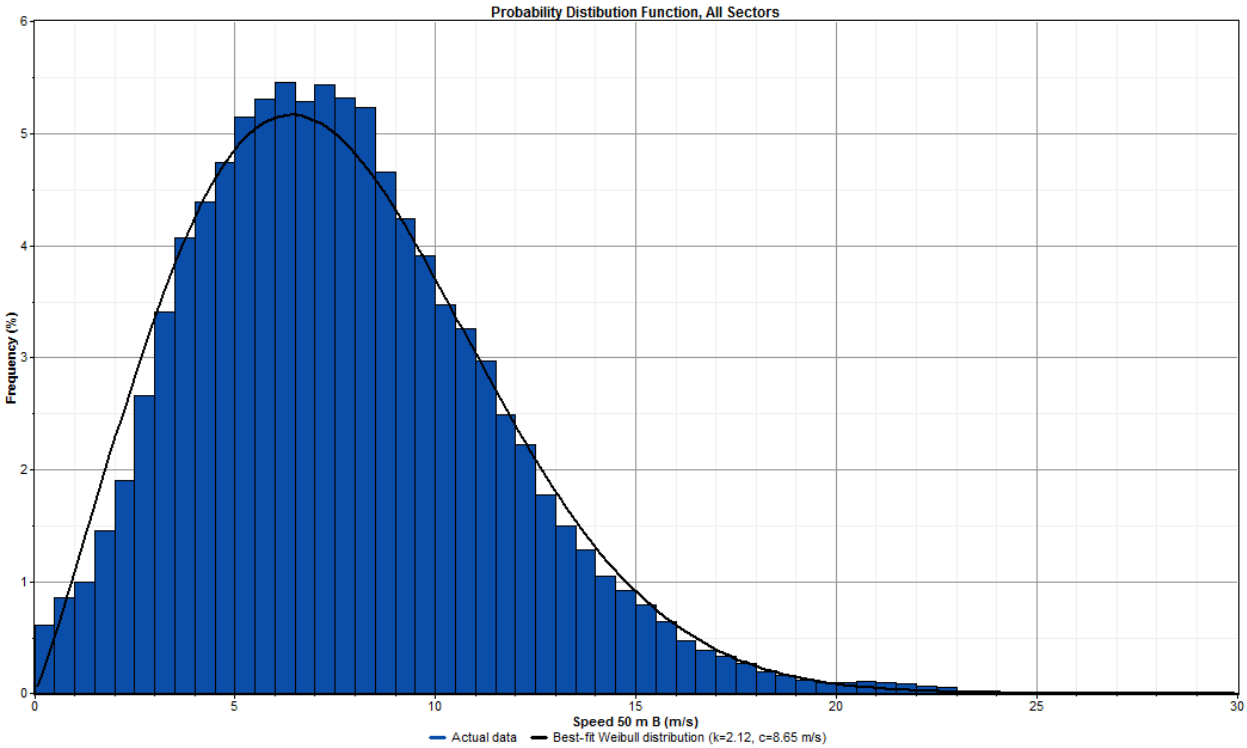
Monthly daily wind profile



Probability Distribution Function

The probability distribution function (PDF), or histogram, of wind speed indicates a near-normal shape curve, defined as the Raleigh distribution (k=2.0), defined as standard for wind power sites. As one can see in the PDF, the most frequently occurring wind speeds are between 5 and 8 m/s with very few wind events exceeding 25 m/s, the cutout speed of most wind turbines.

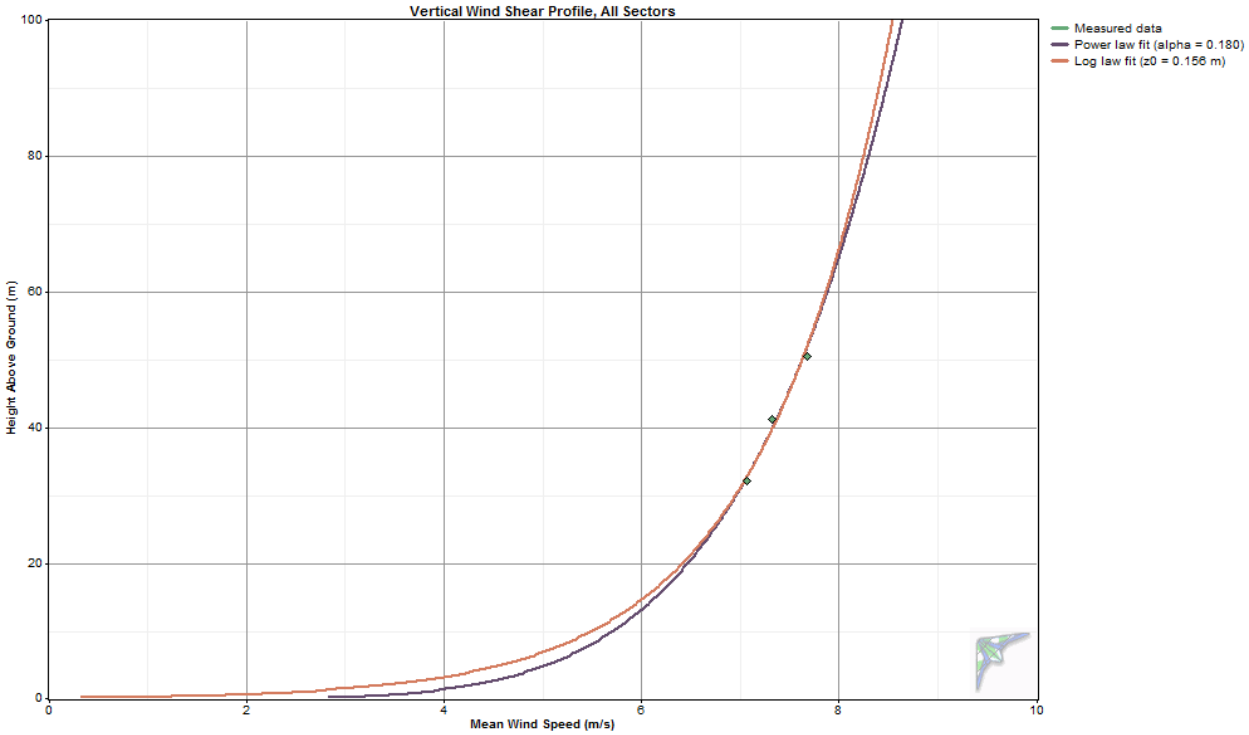
PDF of 50 m B anemometer



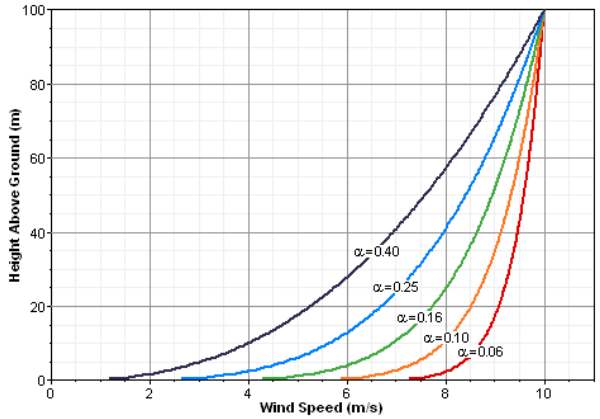
Wind Shear and Roughness

A wind shear power law exponent (α) of 0.180 indicates moderate wind shear at the site. Related to wind shear, a calculated surface roughness of 0.114 meters (indicating the height above ground level where wind velocity would be zero) indicates moderately uneven terrain (roughness description: few trees) surrounding the met tower. This indicates that it would be beneficial to construct turbines at higher hub heights in order to maximum power production.

Vertical wind shear profile



Comparative wind shear profiles



Wind shear by direction sector, wind speed > 4 m/s

Direction Sector	Time Steps	Wind Sector (%)	Mean Wind Speed Speed 50 m A (m/s)	Speed 40 m (m/s)	Speed 31 m (m/s)	Power Law Exp (α)	Surface Roughness (m)
345° - 15°	8,938	13.0%	7.91	7.64	7.37	0.148	0.0465
15° - 45°	10,312	15.0%	8.66	8.22	7.81	0.215	0.3811
45° - 75°	7,928	11.6%	8.68	8.18	7.83	0.214	0.3741
75° - 105°	8,142	11.9%	9.98	9.63	9.28	0.153	0.0578
105° - 135°	5,781	8.4%	9.47	9.18	8.75	0.167	0.0970
135° - 165°	5,163	7.5%	9.21	8.98	8.48	0.172	0.1137
165° - 195°	6,024	8.8%	9.55	9.20	8.73	0.189	0.1950
195° - 225°	3,088	4.5%	7.53	7.37	7.08	0.130	0.0179
225° - 255°	2,924	4.3%	7.13	7.16	6.96	0.052	0.0000
255° - 285°	1,946	2.8%	7.45	7.46	7.19	0.076	0.0001
285° - 315°	2,927	4.3%	7.09	6.86	6.61	0.146	0.0407
315° - 345°	5,425	7.9%	7.49	7.25	7.00	0.143	0.0352

Extreme Winds

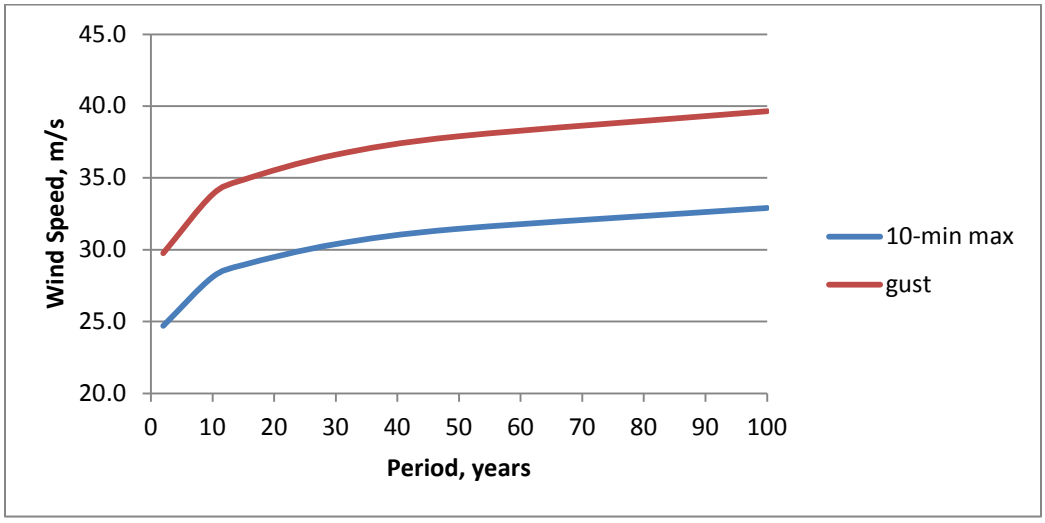
A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Mountain Village met tower site. Extreme wind analysis indicates a highly desirable situation in Mountain Village: relatively high mean wind speeds combined with low extreme wind speed probabilities.

Industry standard reference of extreme wind is the 50 year 10-minute average probable wind speed, referred to as V_{ref}. For Mountain Village, this calculates to 31.5 m/s (at 50 meters), below the threshold of International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria for a Class III site. Note that Class III extreme wind classification is the lowest defined. All wind turbines are designed for a Class III wind regime.

Extreme wind probability table, 50 m B data

Period (years)	V_{ref} (m/s)	Gust (m/s)	IEC 61400-1, 3rd ed. Class	V_{ref}, m/s
2	24.7	29.8	I	50.0
10	28.1	33.8	II	42.5
15	28.9	34.9	III	37.5
30	30.4	36.6	S	designer-specified
50	31.5	37.9		
100	32.9	39.6		
average gust factor:	1.20			

Extreme wind graph



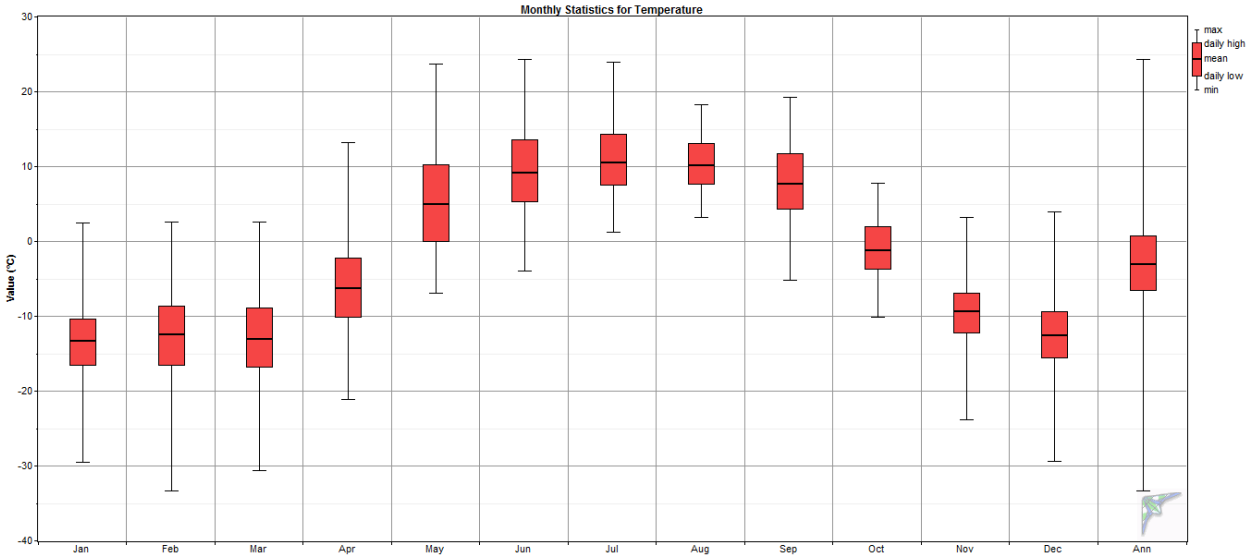
Temperature, Density, and Relative Humidity

Mountain Village experiences cool summers and cold winters with resulting higher than standard air density. Calculated air density during the met tower test period exceeds the 1.220 kg/m^3 standard air density for a 44 meter elevation by 6.3 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.

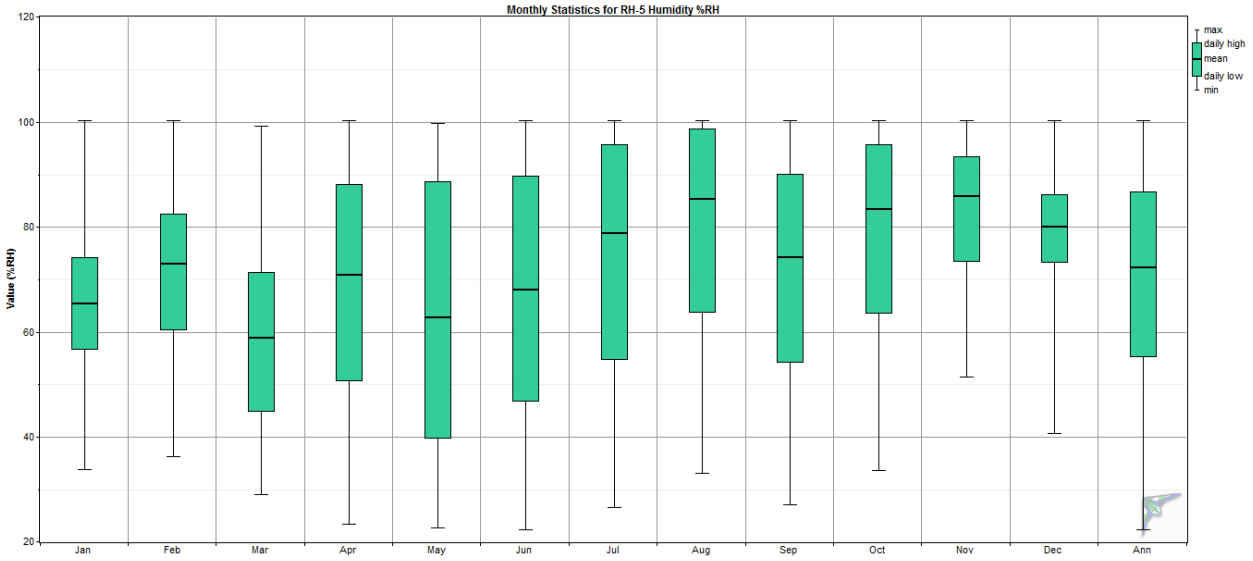
Temperature and density table

	Temperature			Air Density			RH
Month	Mean (°C)	Min (°C)	Max (°C)	Mean (kg/m³)	Min (kg/m³)	Max (kg/m³)	Mean (%)
Jan	-13.3	-29.5	2.5	1.352	1.274	1.441	65.5
Feb	-12.3	-33.3	2.6	1.348	1.273	1.464	73.1
Mar	-13.0	-30.6	2.6	1.350	1.273	1.447	59.0
Apr	-6.2	-21.1	13.2	1.316	1.226	1.393	71.0
May	5.0	-6.9	23.7	1.263	1.183	1.319	62.9
Jun	9.2	-3.9	24.3	1.244	1.180	1.304	68.2
Jul	10.6	1.2	24.0	1.237	1.181	1.280	78.9
Aug	10.2	3.2	18.3	1.239	1.205	1.270	85.4
Sep	7.7	-5.2	19.2	1.250	1.201	1.310	74.2
Oct	-1.1	-10.1	7.8	1.290	1.250	1.335	83.5
Nov	-9.3	-23.8	3.2	1.330	1.220	1.408	85.9
Dec	-12.5	-29.4	4.0	1.348	1.220	1.440	80.3
MMM	-2.0	-33.3	24.3	1.297	1.180	1.464	73.9

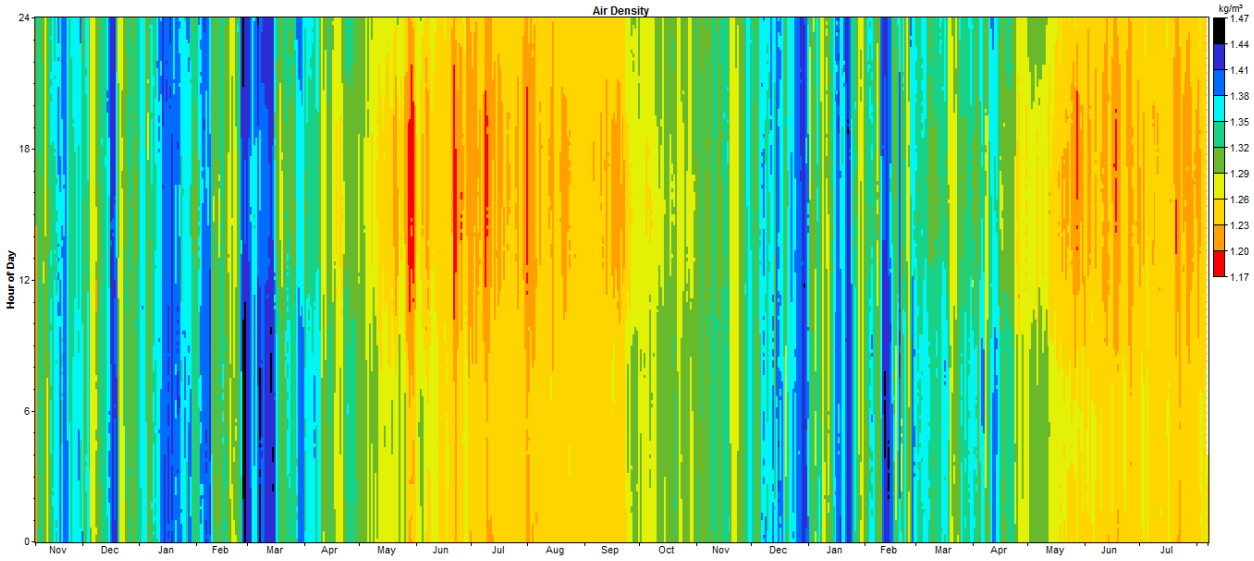
Temperature boxplot



Relative humidity boxplot



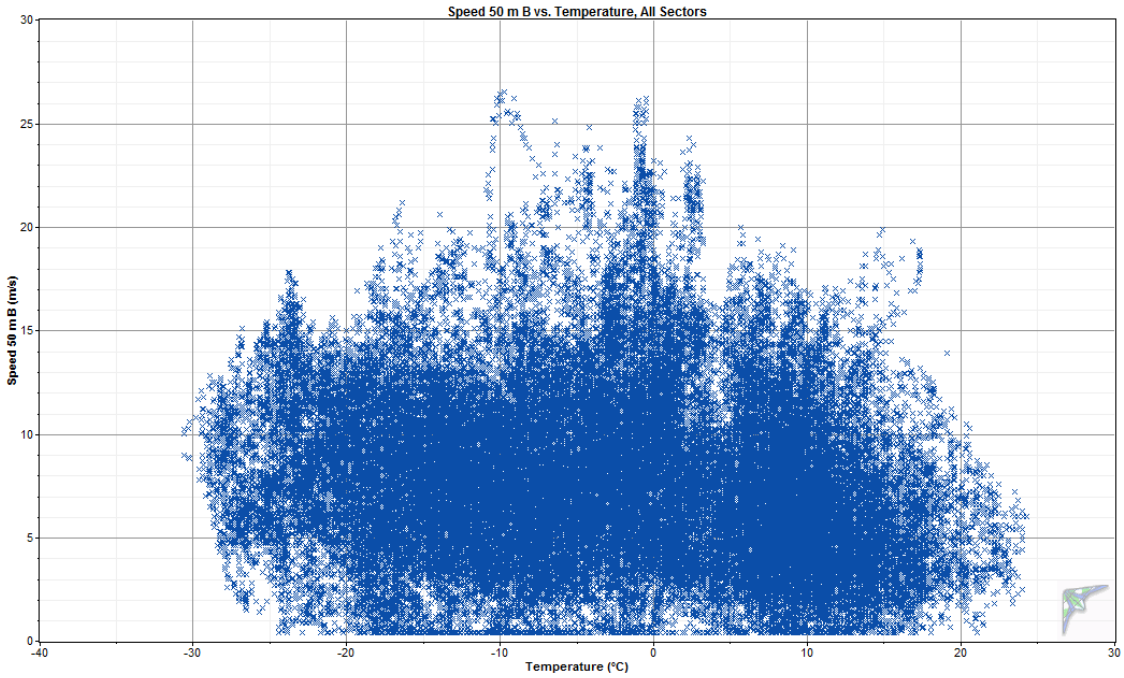
Air density DMap



Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind at the Mountain Village met tower site coincides with cold temperatures, as one would expect. However, during the met tower test periods, temperatures did not fall below -40°C, which is the minimum operating temperature for arctic-capable wind turbines, and fell below -30°C on just a few occasions. Colder temperatures may occur during particular severe winters, but it is likely that temperatures colder than -40°C are extremely rare at the site. Hence, restrictions of wind turbine operations due to extreme cold should not be expected.

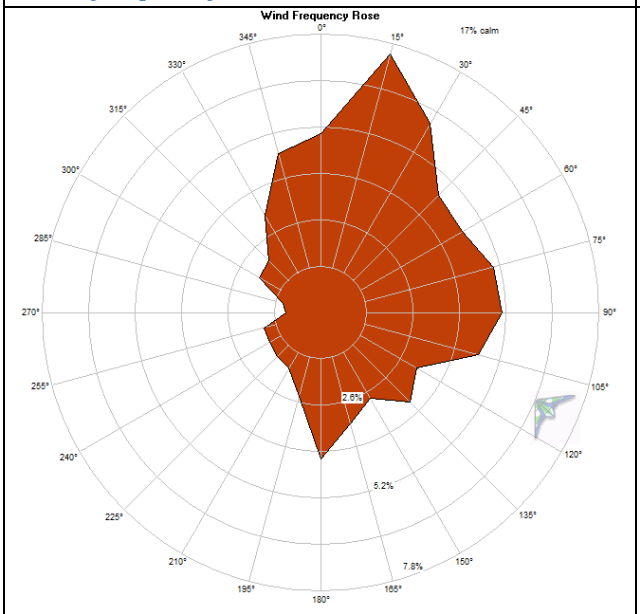
Wind speed/temperature



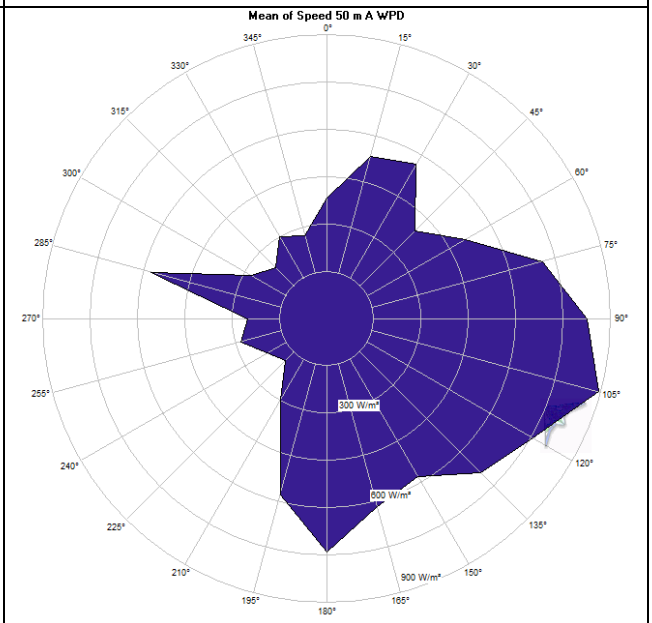
Wind Direction

Wind frequency rose data indicates that winds at the Mountain Village met tower site are not especially directional, although northerly and easterly winds predominate overall. The mean value rose indicates that easterly and southerly winds, when they do occur, are of high energy and hence likely storm winds. The wind energy rose indicates that for wind turbine operations the majority of power-producing winds are from the north-northeast, east, southeast and south. Calm frequency (percent of time that winds at the 50 meter level are less than 4 m/s) was 17 percent during the met tower test period.

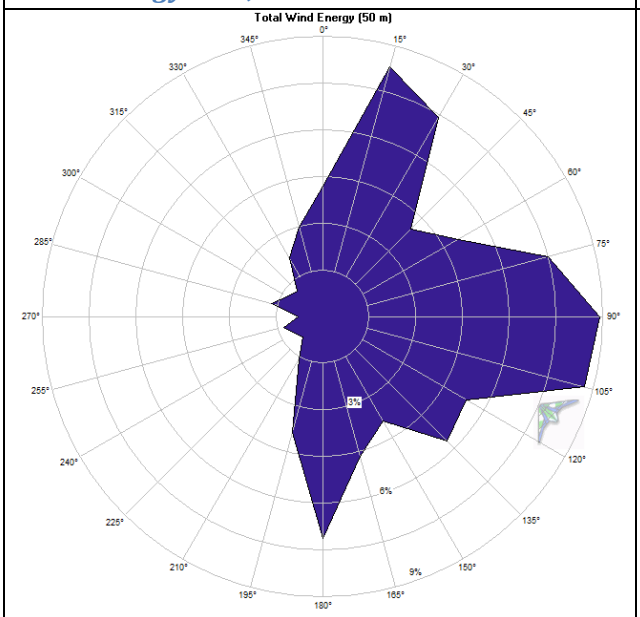
Wind frequency rose, 46 m



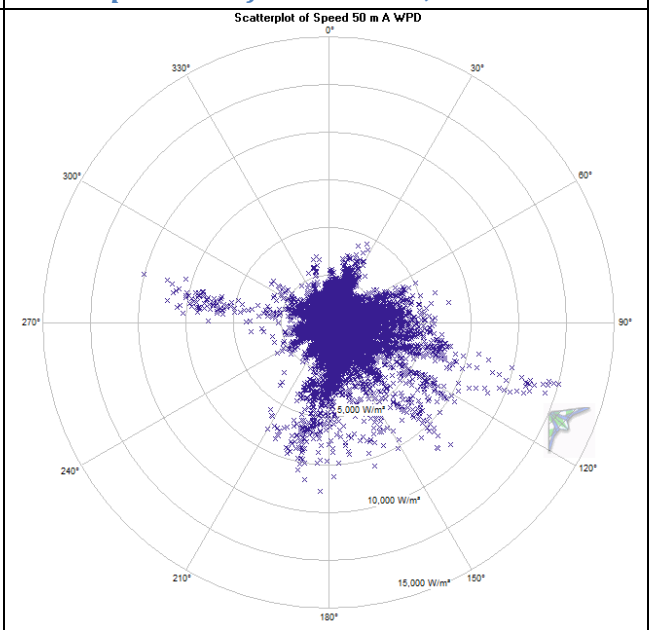
Mean value rose, 46 m



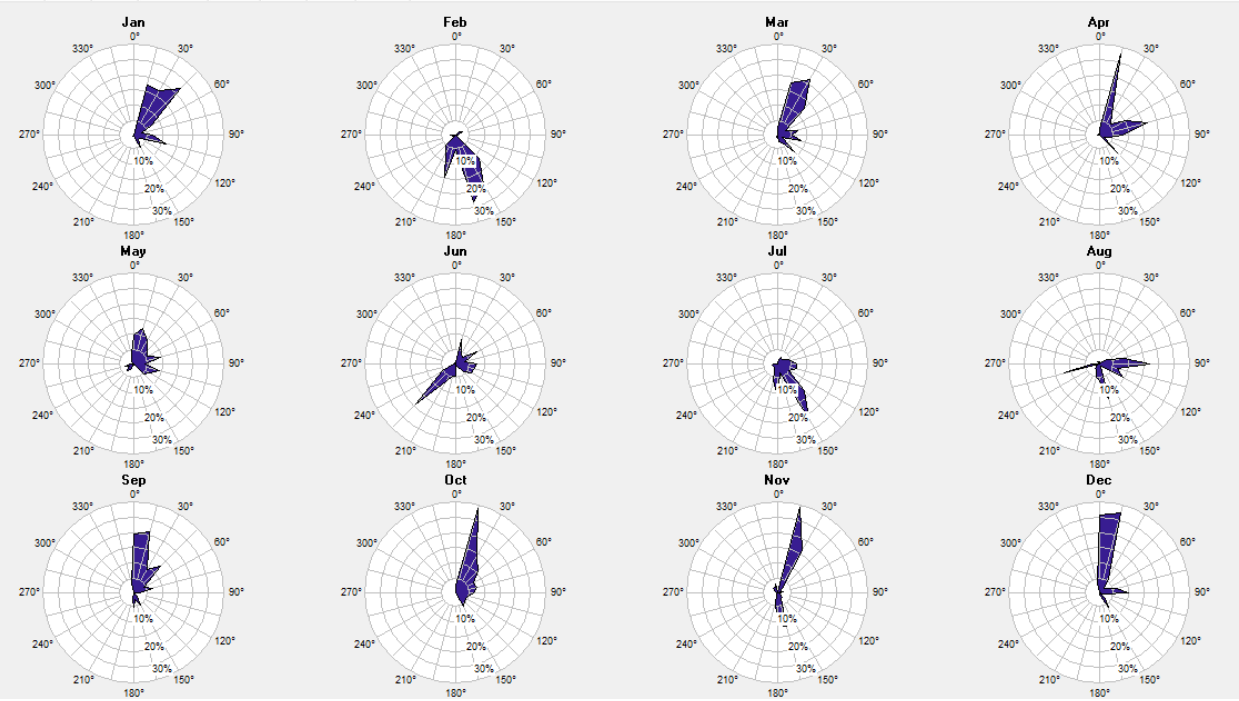
Wind energy rose, 46 m



Scatterplot rose of 50 m A WPD, 46 m vane



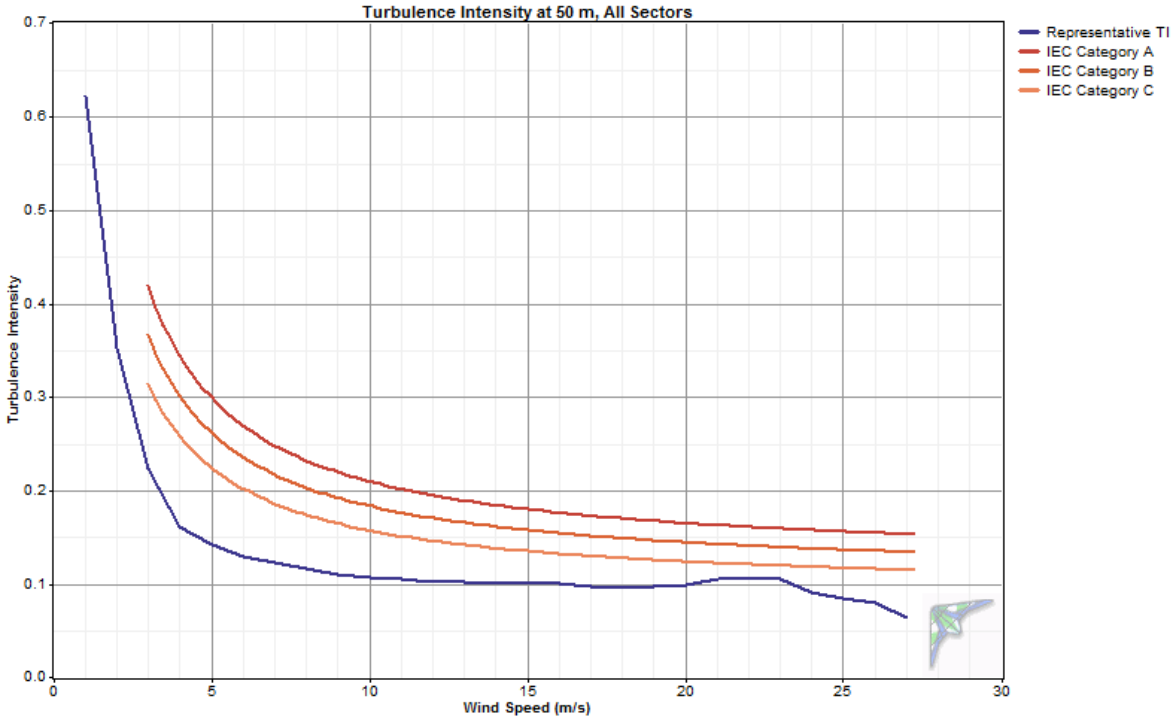
Wind density roses by month



Turbulence

Turbulence intensity at the Mountain Village met tower test site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined.

Turbulence intensity, 50 m B, all direction sectors



Turbulence table, 50 m B data

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	1,574	0.407	0.168	0.622	1.538
2	1.5	2.5	2,857	0.206	0.114	0.352	1.500
3	2.5	3.5	5,181	0.136	0.069	0.224	1.030
4	3.5	4.5	7,323	0.102	0.046	0.161	0.564
5	4.5	5.5	8,530	0.090	0.041	0.142	0.440
6	5.5	6.5	9,431	0.082	0.037	0.129	0.452
7	6.5	7.5	9,298	0.078	0.035	0.122	0.439
8	7.5	8.5	9,095	0.074	0.033	0.116	0.346
9	8.5	9.5	7,675	0.071	0.030	0.109	0.447
10	9.5	10.5	6,270	0.071	0.028	0.106	0.242
11	10.5	11.5	5,236	0.069	0.028	0.105	0.245
12	11.5	12.5	4,026	0.069	0.026	0.103	0.203
13	12.5	13.5	2,761	0.070	0.025	0.102	0.167
14	13.5	14.5	2,001	0.070	0.024	0.100	0.163
15	14.5	15.5	1,490	0.072	0.024	0.102	0.171
16	15.5	16.5	979	0.074	0.020	0.100	0.150
17	16.5	17.5	646	0.073	0.019	0.098	0.149
18	17.5	18.5	416	0.071	0.019	0.095	0.125
19	18.5	19.5	251	0.073	0.019	0.097	0.145
20	19.5	20.5	168	0.076	0.017	0.098	0.138
21	20.5	21.5	192	0.081	0.020	0.106	0.189
22	21.5	22.5	137	0.082	0.018	0.106	0.145
23	22.5	23.5	71	0.080	0.020	0.106	0.150
24	23.5	24.5	34	0.074	0.013	0.091	0.113
25	24.5	25.5	20	0.072	0.010	0.084	0.097
26	25.5	26.5	20	0.067	0.009	0.079	0.086
27	26.5	27.5	1	0.064	0	0.064	0.064