Saint Mary's Area Wind Power Report

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Pitka's Point met tower

Saint Mary's met tower

Mountain Village met tower

Aerial view of Village of Saint Mary's

Photos top and bottom right: Doug Vaught; photo bottom left: Dave Johnson

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Summary Information

Saint Mary's, Alaska is the largest village on the lower Yukon River and a high priority wind power project site for Alaska Village Electric Cooperative (AVEC). In addition to the existing electrical intertie between Saint Mary's and Pitka's Point, current plans calls for continuation of an existing intertie west from the Saint Mary's Airport to Mountain Village and possible future construction of an intertie east from Saint Mary's to Pilot Station.

Project Recommendations

Wind data collected for more than one year at the Pitka's Point met tower site, from October 2007 to February 2009, indicates a Class 6 (outstanding) wind resource. Wind data collected since October 2008 at the Saint Mary's met tower site indicates a Class 4 (good) wind resource. In November, 2009, a met tower installed near Mountain Village has measured an excellent wind resource to date, possibly Class 5.

The wind resource at the Pitka's Point, Saint Mary's and Mountain Village sites clearly are noteworthy for wind power development, but wintertime icing may present a challenge. Although analysis of met tower data cannot easily distinguish between icing events that are due to freezing rain and those due to rime icing, there is strong evidence that rime icing occurs, an example the collapse of the Pitka's Point and Saint Mary's met towers in February 2009. Interestingly though, there appears to have been fewer and less severe rime ice events at the Saint Mary's met tower during winter 2009/2010 compared to winter 2008/2009. Additionally, the Mountain Village met tower data indicates relatively few icing events during winter 2009/2010.

The original purpose of selecting three met tower sites in the Saint Mary's area was to identify the optimum location for wind turbines based on proximity to power lines, geotechnical considerations, land ownership and access, physical space for a turbine layout, and wind resource considerations such as wind power class, turbine capacity factor, possible availability loss, extreme wind probability and turbulence. With these factors in mind, all three sites – Pitka's Point, Saint Mary's and Mountain Village – present pros and cons for wind power development.

Pitka's Point clearly has the superior wind resource of the three sites, with approximately seven percentage points turbine capacity factor advantage over Saint Mary's and an estimated four percentage points capacity factor advantage over Mountain Village. This equates to an extra 61 MWh/year of additional power production vs. Saint Mary's and 35 MWh/yr vs. Mountain Village (per 100 kW of wind turbine capacity). However, this assumes one hundred percent turbine availability. This is not possible even in with perfect operating conditions, but at the Pitka's Point site, turbine availability likely will be negatively impacted by wintertime rime icing. Because rime ice has the potential to cause turbine availability loss and given the known risk of rime icing at the Pitka's Point site, active anti-icing and/or de-icing measures will likely be necessary to mitigate the risk of excessive turbine downtime during winter. This expense and effort, however, may well be worthwhile with increased power production at this high wind energy site.

The Saint Mary's site may be most advantageous from a project development perspective. It has more physical space for multi-turbine layout than the Pitka's Point site, land use site control for wind turbine construction has already been secured, and it is nearer existing power lines than the Pitka's Point site. Although it has the lowest wind resource of the three sites monitored, it still measures as a very respectable Class 4 wind resource and would yield approximately 30 percent turbine capacity factor. Rime icing, though less severe than at the Pitka's Point site, still may be sufficiently problematic to warrant use of turbine anti-icing and de-icing features to maintain continuous wintertime turbine availability.

Monitoring of the Mountain Village site has not yet reached the one year point, but to date it shows excellent potential for wind power development. In a concurrent comparison with the Saint Mary's met tower, Mountain Village experiences approximately three higher wind speed monthly averages. The site experienced very little icing during winter 2009/2010, turbulence intensity is extremely low, and the site has plenty of physical space for turbine layout. Disadvantages of the site, however, are its relative remoteness from Mountain Village, lack of nearby power transmission infrastructure at present, and lack of winter maintenance of the road link between Saint Mary's and Mountain Village. If the intertie is built, the infrastructure problem is solved as the power line will be near the site, but winter maintenance of the road, at least from the Mountain Village airport to the wind site, will be a new and necessary operational requirement.

Considering the pros and cons of each site, which are discussed in this report, a possible wind power development approach might be to install turbines at all three sites. Advantages of this approach include reducing the instantaneous power surge effects of gusting winds by displacing the turbine sufficiently that they will receive somewhat different winds at each site. This is especially true if turbines are located in both Pitka's Point or Saint Mary's *and* Mountain Village. Another advantage is that although turbines installed at Pitka's Point would produce more energy than at the other sites, they likely will suffer more severe icing problems. This trade-off of power production versus icing would be less at the other two sites: Saint Mary's and Mountain Village site turbines would generate less energy annually but probably also experience higher availability in winter. Because the energy production/icing loss trade-off is not at present well understood with respect to predicting a decrease in turbine availability, installing turbines at all three sites potentially optimizes energy recovery overall and at a minimum spreads the risk of lower than expected power recovery due to icing problems.

Pitka's Point and Saint Mary's Summary

In comparing the Pitka's Point and Saint Mary's met tower sites, the Pitka's Point site appears to experience slightly more frequent icing conditions than the Saint Mary's site. On the other hand, the Pitka's Point data clearly demonstrates a superior wind resource for wind power development. This can be seen in the table below. Comparing the standard anemometers mounted at 38 meters on both towers, one sees a 12.2 percent decrease in wind speed and a very significant 31.9 percent decrease in wind power density (WPD) from Pitka's Point to Saint Mary's.

It is possible that given the complexity of terrain, high frequency of northeasterly winds, and location of the Saint Mary's met tower north of and away from the bluff edge compared to the bluff proximity of the Pitka's Point met tower, the wind resource at the Saint Mary's met tower site might be better closer to the river. However, it seems unlikely that it would be sufficient to match the clearly superior wind resource measured at the Pitka's Point met tower during the five month data overlap period.

Year	Month	Pitka's 38 m speed mean	St. M's 38 m speed mean	Decrease of Wind Speed from Pitka's Point to St. Mary's		Pitka's 38 m WPD mean	St. M's 38 m WPD mean	Decrease of Wind Power Density from Pitka's Point to Saint Mary's	
		(m/s)	(m/s)	(m/s)	(%)	(W/m^2)	(W/m^2)	(W/m^2)	(%)
2008	Sep	6.37	5.66	0.71	-11.1%	225.9	160.4	65.6	-29.0%
2008	Oct	6.75	5.98	0.76	-11.3%	411.8	285.2	126.6	-30.7%
2008	Nov	6.05	5.86	0.19	-3.1%	275.9	242.9	33.0	-11.9%
2008	Dec	9.43	8.05	1.38	-14.6%	875.7	520.6	355.1	-40.5%
2009	Jan	10.40	8.22	2.17	-20.9%	1299.8	684.3	615.5	-47.4%
data average		7.80	6.76	1.04	-12.2%	617.8	378.7	239.1	-31.9%

Saint Mary's and Mountain Village Summary

In comparing the Saint Mary's and Mountain Village met tower sites, both sites during winter 2009/2010 appeared to experience similar icing loss. Also, both sites have experience similar wind speeds with a slight advantage recorded to date to Mountain Village as seen in the table below. Comparing the 40 meter anemometers, one sees a 2.9 percent decrease in wind speed and a 15.6 percent decrease in wind power density (WPD) from Mountain Village to Saint Mary's.

Year	Month	Mtn V. 40 m speed mean	St. M's 40 m speed mean*	Decrease of Wind Speed from Mtn Village to St Mary's		Mtn V. 40 m WPD mean	St. M's 40 m WPD mean	Decrease of WPD from Mtn Village to Saint Mary's	
		(m/s)	(m/s)	(m/s)	(%)	(W/m^2)	(W/m^2)	(W/m^2)	(%)
2009	Nov	7.32	7.31	0.01	-0.1%	524.3	410.5	113.8	-21.7%
2009	Dec	9.25	8.16	1.09	-11.7%	894.1	569.6	324.4	-36.3%
2010	Jan	8.56	9.08	-0.52	6.1%	600.6	720.7	-120.1	20.0%
2010	Feb	7.66	7.43	0.22	-2.9%	562.2	414.1	148.1	-26.3%
2010	Mar	8.02	7.92	0.10	-1.2%	478.9	470.7	8.2	-1.7%
2010	Apr	7.07	6.94	0.13	-1.8%	445.4	402.2	43.1	-9.7%
2010	May	5.93	5.60	0.33	-5.6%	220.4	195.9	24.5	-11.1%
2010	Jun	7.31	7.02	0.29	-3.9%	380.4	322.8	57.6	-15.1%
data average		7.64	7.43	0.21	-2.7%	513.3	438.3	75.0	-14.6%

*data adjusted to 40 m from 38 m anemometer

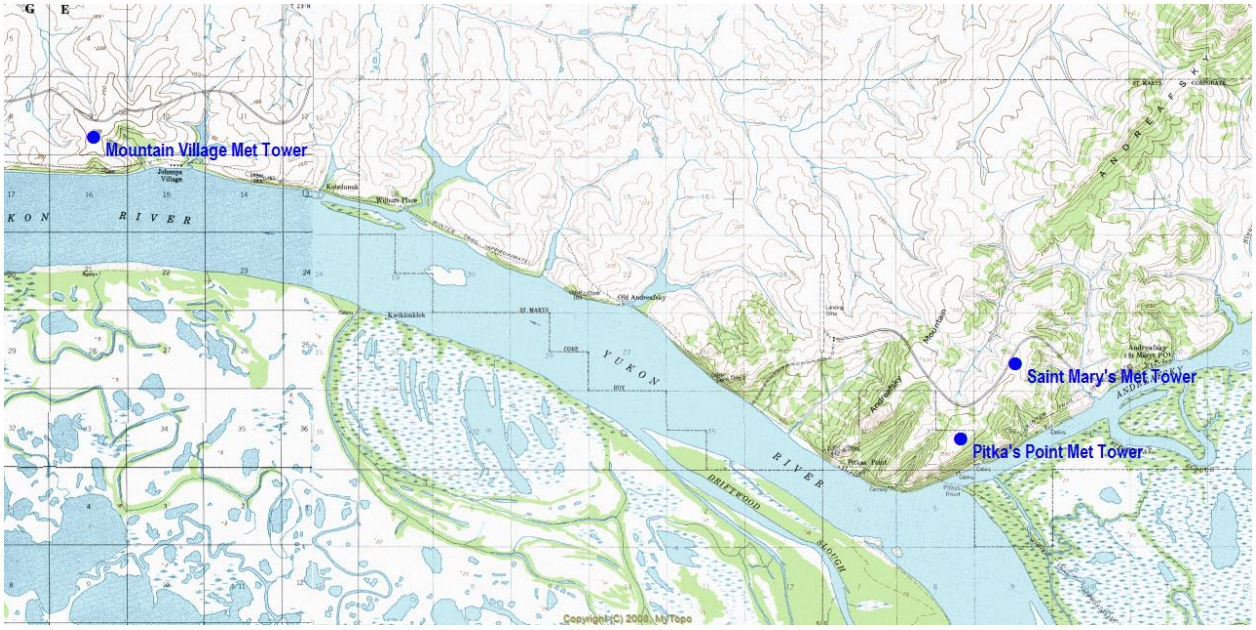
Site Information

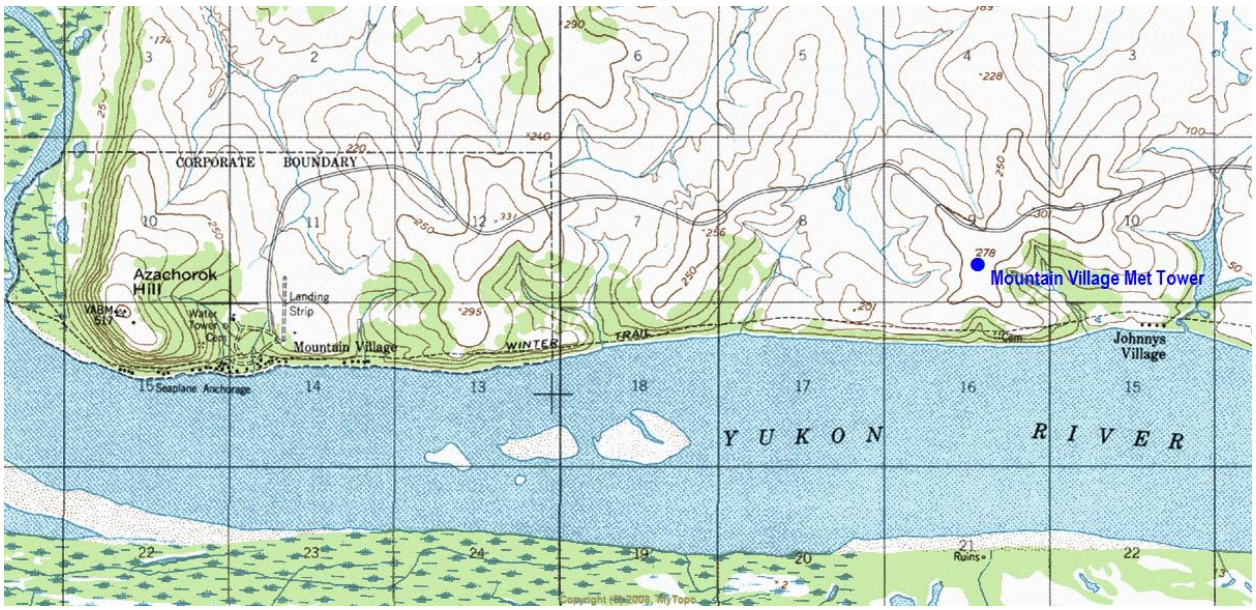
	Pitka's Point	Saint Mary's	Mountain Village
Site number	0066	0026	0068
Site Description	Near a construction borrow pit near the bluff overlooking Pitka's Point and the Yukon River	On a plateau near the Airport Road about 1.5 km northeast of the Pitka's Point met tower	On a plateau near the Yukon River approximately 5 km east of the Mountain Village airport
Latitude/longitude	N 62° 02.252' W 163° 14.82' (WGS 84)	N 62° 02.951' W 163° 13.54' (WGS 84)	N 62° 05.513' W 163° 35.38' (WGS 84)
Site elevation	177 meters	139 meters	85 meters
Datalogger & modem type	NRG Symphonie, Iridium iPack	NRG Symphonie, Iridium iPack	NRG SymphoniePlus, Iridium iPack
Tower type	NRG 40-meter SHD tall tower, 202 mm (8 in.)	NRG 40-meter SHD tall tower, 202 mm (8 in.)	NRG 50-meter XHD tall tower, 254 mm (10 in.)

Meteorological Tower Data Synopses

	Pitka's Point	Saint Mary's	Mountain Village
Data start date	October 26, 2007	August 15, 2008	November 5, 2009
Data end date	February 13, 2009	June 30, 2010 (in progress)	June 30, 2010 (in progress)
Wind power class	Class 6 – Outstanding	Class 4 – Good	Class 5 – Excellent (note: 7.7 mo. data)
Wind speed annual average (38 meters)	7.72 m/s	6.84 m/s	7.68 m/s (40 m anem., to date)
Maximum wind gust	36.3 m/s (Jan. 2008)	30.6 m/s (Jan. 2009)	32.7 m/s (Nov. 2009)
Maximum ten minute average wind speed	29.5 m/s	24.0 m/s	25.6 m/s
Wind power density at 50 meters	662 W/m^2 (extrapolated)	382 W/m^2 (extrapolated)	581 W/m^2 (measured, to date)
Wind power density (38 meters)	572 W/m^2 (measured)	360 W/m^2 (measured)	518 W/m^2 (measured, to date, 40 meters)
IEC 61400-1 3rd edition extreme wind class	Class III (may be Class II)	Class III	Insufficient data at present to calculate
Weibull distribution parameters	k = 1.95, c = 8.70 m/s	k = 2.16, c = 7.49 m/s	k = 2.27, c = 8.95 m/s (to date)
Surface roughness	0.106 m (few trees)	0.095 m (few trees)	0.137 m (few trees)
Power law exponent	0.178 (moderate wind shear)	0.183 (moderate wind shear)	0.175 (moderate wind shear)
Frequency of calms (>4 m/s)	20%	20% (to date)	13% (to date)
Mean TI, at 15 m/s	0.076 (IEC cat. C)	0.105 (IEC cat. C)	0.068 (IEC cat. C)

Test Site Location Maps




CORPORATE BOUNDARY
Azachorok Hill
Mountain Village
Mountain Village Met Tower
Johnnys Village
WINTER TRAIL
Y U K O N R I V E R

Saint Mary's met tower
St Marys
Saint Marys, AK
St Mary's
Pitka's Point met tower
Pitkas Point
2651 m
Image © 2010 DigitalGlobe
© 2010 Google
© 2010 Europa Technologies
Google

Mountain Village met tower
Mountain Village
3.73 km
Image © 2010 DigitalGlobe
Image © 2010 TerraMetrics
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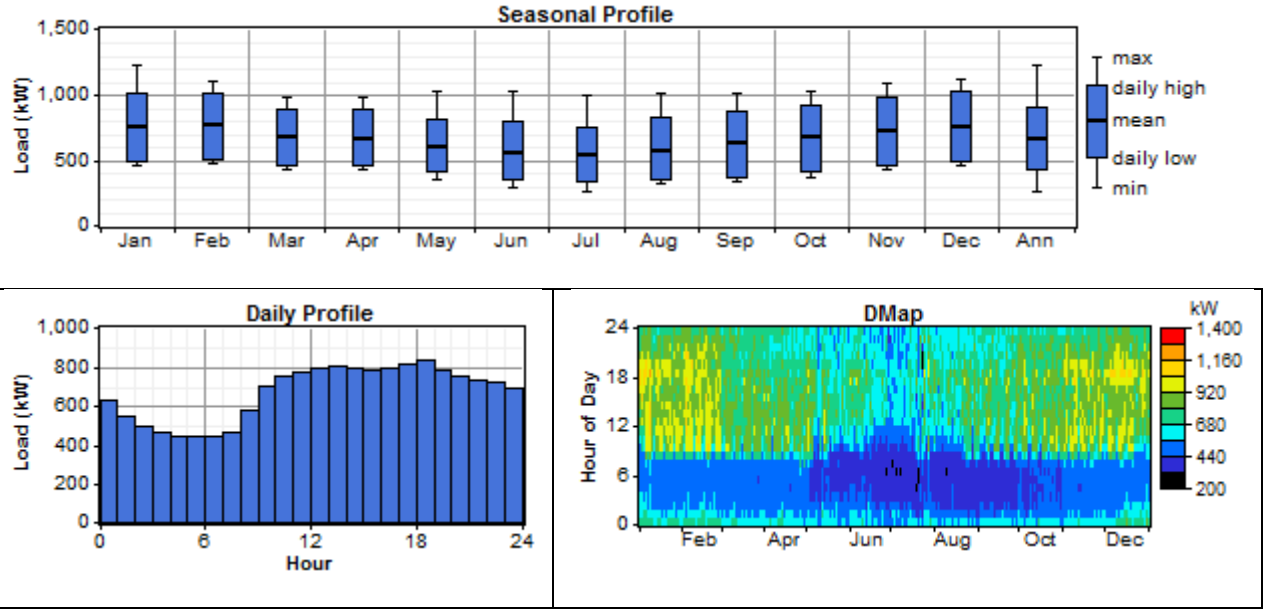
Intertie and Wind Farm Proposal

AVEC has proposed construction of an intertie to electrically connect Saint Mary's and Pitka's Point (these two village are already intertied with a three phase connection) to the village of Mountain Village, located thirty kilometers (19 miles) west of Saint Mary's on the Yukon River. Concurrent with an intertie project, AVEC proposes to install wind turbines to augment the diesel generators and to offset the use of fossil fuel for power generation.

Village Load

A combined Saint Mary's and Mountain Village hourly load profile was synthesized using the Alaska village load calculator Excel spreadsheet developed by Alaska Energy Authority several years ago. The results were adjusted slightly to match actual village average and peak loads of Saint Mary's and Mountain Village (separately) documented by AVEC in their 2009 annual power generation report. The result is a virtual Saint Mary's -Mountain Village community with a 669 kW average load, 1,226 kW peak load and average daily power usage of 16.0 MWh/day. HOMER software was used to create a combined Saint Mary's -Mountain Village simulation model. Seasonal, daily and DMap profiles of the Saint Mary's-Mountain Village virtual load are shown below.



Turbine Output

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 blades) and practical limitations of generator weight and rated output. For these reasons and others, a wind turbine in a lower power class wind regime may

still produce sufficient energy to warrant installation of turbines while a turbine in a higher power class wind regime may not generate as much energy as one might expect.

A simplistic consideration of possible turbine output at the Pitka's Point, Saint Mary's and Mountain Village wind sites 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 if necessary. Note that the analyses are 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 (100 kW, 21 meter rotor diameter, stall control, synchronous generator), the Aeronautica 29-225 (225 kW, 29 meter rotor diameter, stall control, asynchronous generator) and the Vestas V27 (225 kW, 27 meter rotor diameter, pitch control, asynchronous generator). These turbines were selected for analysis for several reasons, including present wide use in Alaska village wind power applications, ready availability, and appropriate rated capacity for the intertied village electrical load.

Note that the met tower in Mountain Village was installed in November 2009 and hence less than one year of data has been collected. The Mountain Village airport is not equipped with an Automated Weather Observing System (AWOS) to provide reference wind data, so an average ratio of collected monthly Mountain Village data compared to equivalent Saint Mary's data was calculated and applied to Saint Mary's data of the missing months to create probable monthly average wind speeds in Mountain Village (for the missing months). The HOMER software can use monthly data with other parameters such as the Weibull k (shape value) and autocorrelation factor to generate a synthetic full year wind data set.

Turbines, Pitka's Point Site

Saint Mary's to Mountain Village intertied, Pitka's Point site									
Turbine	No.	Hub ht. (m)	Penetration (%)	CF (%)	Wind prod. MWh/yr	Displ. fuel (gal)	Excess elec. MWh/yr	Excess elec. (%)	Storage needed?
NW100/21	4	37	22.9	37.1	1,340	88,413	6	0.1	possibly
	6	37	34.3	37.1	2,010	126,984	94	1.6	yes
	8	37	45.7	37.1	2,680	157,169	308	5.0	yes
Aero 29-225	2	40	24.5	36.4	1,434	93,757	18	0.3	possibly
	3	40	36.7	36.4	2,151	132,249	154	2.6	yes
	4	40	49.0	36.4	2,868	160,159	478	7.5	yes
Vestas V-27	2	40	25.1	37.3	1,472	95,979	23	0.4	possibly
	3	40	37.7	37.3	2,208	134,656	178	2.9	yes
	4	40	50.2	37.3	2,944	160,979	527	8.3	yes

Turbines, Saint Mary's Site

Saint Mary's to Mountain Village intertied, Saint Mary's site									
Turbine	No.	Hub ht. (m)	Penetration (%)	CF (%)	Wind prod. MWh/yr	Displ. fuel (gal)	Excess elec. MWh/yr	Excess elec. (%)	Storage needed?
NW100/21	4	37	18.6	30.2	1,091	72,143	1	0.0	possibly
	6	37	28.0	30.2	1,634	105,212	45	0.7	possibly
	8	37	37.3	30.2	2,183	133,519	165	2.7	yes
Aero 29-225	2	40	19.5	28.9	1,140	75,053	6	0.1	possibly
	3	40	29.2	28.9	1,711	108,122	77	1.3	yes
	4	40	38.9	28.9	2,281	134,048	260	4.2	yes
Vestas V-27	2	40	20.0	29.7	1,172	76,852	9	0.1	possibly
	3	40	30.0	29.7	1,757	110,291	90	1.5	yes
	4	40	40.0	29.7	2,343	135,899	294	4.8	yes

Turbines, Mountain Village Site

Saint Mary's to Mountain Village intertied, Mountain Village site									
Turbine	No.	Hub ht. (m)	Penetration (%)	CF (%)	Wind prod. MWh/yr	Displ. fuel (gal)	Excess elec. MWh/yr	Excess elec. (%)	Storage needed?
NW100/21	4	37	20.7	33.6	1,213	80,079	3	0.0	possibly
	6	37	31.1	33.6	1,819	116,032	64	1.1	possibly
	8	37	41.4	33.6	2,426	145,794	225	3.7	yes
Aero 29-225	2	40	21.9	32.5	1,280	83,968	10	0.2	possibly
	3	40	32.8	32.5	1,921	119,921	108	1.8	yes
	4	40	43.7	32.5	2,561	147,011	346	4.2	yes
Vestas V-27	2	40	22.4	33.4	1,315	85,952	15	0.3	possibly
	3	40	33.7	33.4	1,972	122,169	127	2.1	yes
	4	40	44.9	33.4	2,630	148,757	390	6.2	yes

Notes:

1. Wind resource based on specific site met tower data, assume turbines at **that location**
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 and/or energy storage might be necessary to avoid curtailment control of turbines
6. Availability loss due to icing not considered; turbines at this site may require active de-icing capability to maintain wintertime availability
7. Penetration refers to average annual load supplied by wind turbines
8. Wind data is not adjusted against long-term average
9. Mountain Village met tower data incomplete; St Mary's data used as substitute for missing months

Data Quality Control and Icing Loss

Data was filtered to remove presumed icing events that yield false zero wind speed data and non-variant wind direction data. Data that met the following criteria were filtered: wind speed < 1 m/s (or non-variant direction), standard deviation = 0, temperature < 3 °C and high relative humidity if that data is available. Note that for all three met towers, icing data is removed from the data set and hence not counted in summary data calculations such as average wind speed, wind power density, etc. Synthetic data to fill the removed data was not employed.

It was thought that at Pitka's Point, installation of a heated anemometer and wind vane would result in better data recovery than from the standard non-heated sensors, but that did not prove entirely true. As one can see below in the Data Recovery Table, Pitka's Point, data recovery for the heated (IceFree) anemometer is no better than the other anemometers, although data recovery from the heated wind vane is somewhat better than from the standard vane. It is not clear why data recovery from the heated sensors was so poor. One possible explanation is excessive voltage drop from the power line tie-in to the sensors on the met tower.

Quality Control

Data Recovery Table, Pitka's Point

		anemometers				vanes	
Year	Month	38 m Recovery Rate (%)	28 m IceFree Recovery Rate (%)	29 m Recovery Rate (%)	21 m Recovery Rate (%)	38 m Recovery Rate (%)	29 m IceFree Recovery Rate (%)
2007	Oct	87.9	77.9	87.9	87.9	80.4	27.0
2007	Nov	52.2	100.0	55.2	54.7	43.6	100.0
2007	Dec	73.3	76.5	83.4	83.4	74.4	75.9
2008	Jan	24.4	24.4	31.9	37.9	54.1	69.6
2008	Feb	75.6	76.6	78.7	76.2	65.1	86.4
2008	Mar	89.5	80.7	90.5	94.1	77.3	88.5
2008	Apr	37.8	78.4	55.3	41.1	65.9	75.8
2008	May	97.7	100.0	96.4	96.3	96.1	97.9
2008	Jun	100.0	100.0	100.0	100.0	100.0	100.0
2008	Jul	100.0	100.0	100.0	100.0	100.0	100.0
2008	Aug	100.0	100.0	100.0	100.0	100.0	100.0
2008	Sep	100.0	100.0	100.0	100.0	96.6	100.0
2008	Oct	96.3	92.3	98.8	96.9	92.4	98.8
2008	Nov	62.3	27.6	59.9	56.7	54.3	81.5
2008	Dec	62.2	33.8	64.6	61.0	44.4	70.9
2009	Jan	52.6	39.6	53.7	56.2	42.3	51.5
All data		75.7	75.5	78.5	77.6	74.2	82.7

Data Recovery Table, Saint Mary's

		anemometers			vanes	
Year	Month	38 m Recovery Rate (%)	29 m Recovery Rate (%)	18 m Recovery Rate (%)	38 m Recovery Rate (%)	29 m Recovery Rate (%)
2008	Aug	100.0	100.0	100.0	100.0	100.0
2008	Sep	100.0	100.0	100.0	96.4	96.3
2008	Oct	100.0	100.0	94.6	95.9	96.1
2008	Nov	61.6	65.0	65.1	55.2	58.9
2008	Dec	86.7	83.7	82.7	70.6	73.6
2009	Jan	52.1	53.3	51.7	47.3	47.3
2009	Feb	37.8	56.3	39.1	40.0	40.0
2009	Mar	0.0	0.0	0.0	0.0	0.0
2009	Apr	46.2	0.0	47.2	45.2	45.2
2009	May	97.7	0.0	97.7	96.4	96.4
2009	Jun	100.0	0.0	100.0	100.0	100.0
2009	Jul	100.0	0.0	100.0	100.0	100.0
2009	Aug	100.0	0.0	100.0	100.0	100.0
2009	Sep	99.7	0.0	99.0	100.0	100.0
2009	Oct	92.4	0.0	92.4	90.4	90.4
2009	Nov	95.8	74.4	93.6	93.3	93.3
2009	Dec	93.4	93.7	93.2	87.1	87.1
2010	Jan	98.3	98.3	98.3	95.3	96.4
2010	Feb	79.5	78.3	78.1	93.5	94.4
2010	Mar	100.0	100.0	84.5	100.0	100.0
2010	Apr	96.9	99.8	99.8	94.0	94.0
2010	May	100.0	100.0	100.0	95.9	95.9
2010	Jun	100.0	100.0	100.0	100.0	100.0
All data		84.1	55.6	83.2	82.2	82.6

Data Recovery Table, Mountain Village

		anemometers					
Year	Month	50 m A Recovery Rate (%)	50 m B Recovery Rate (%)	41 m Recovery Rate (%)	40 m Recovery Rate (%)	32 m Recovery Rate (%)	31 m Recovery Rate (%)
2009	Nov	97.8	97.8	97.8	97.8	94.2	97.8
2009	Dec	91.6	91.6	91.6	91.6	91.6	91.6
2010	Jan	87.8	87.3	89.0	95.7	90.6	92.4
2010	Feb	85.5	83.3	77.5	86.7	86.9	85.6
2010	Mar	78.7	78.5	90.9	87.8	85.3	86.3
2010	Apr	100.0	100.0	100.0	100.0	100.0	100.0

2010	May	100.0	100.0	99.2	99.2	100.0	100.0
2010	Jun	100.0	100.0	100.0	100.0	100.0	100.0
all data		92.6	92.2	93.3	94.8	93.6	94.2

Icing Loss

In comparing Pitka's Point to Saint Mary's, one can see in the Icing Loss Comparison Table, Pitka's Point and Saint Mary's, which is focused only on the complete common data months of September 2008 to January 2009, that data recovery is six to ten percent better at the Saint Mary's met tower. This indicates fewer icing events and/or less severe icing than at the Pitka's Point met tower. Note again, however, that Pitka's Point recorded significantly higher wind speeds during this comparison period, indicating a tradeoff between stronger winds and an increased icing risk.

In the following table of icing loss comparison between Saint Mary's and Mountain Village, one can see comparable icing data loss during winter 2009/2010, but this data loss was very minimal and stands in sharp contrast to the previous winter when the Saint Mary's met tower experienced considerable icing loss, culminating in loss of the met tower in February 2009 due to icing.

Because there is no simultaneous data from all three met towers addressed in this study, it is not possible to directly compare wind resource and icing of all three sites. But, one can conclude that rime icing does occur, the Pitka's Point site appears to experience worse icing than the Saint Mary's and Mountain Village sites, but the number and severity of icing events apparently differ considerably from one winter to the next. The Saint Mary's and Mountain Village met towers will remain in place at least through winter 2010/2011, so an excellent opportunity exists to determine if the coming winter more resembles winter 2008/2009 or winter 2009/2010.

Icing Data Loss Comparison Table, Pitka's Point and Saint Mary's

		anemometers						vanes	
		Pitka's Pt 38 m	St Mary's 38 m	Pitka's Pt 29 m	St Mary's 29 m	Pitka's Pt 21 m	St Mary's 18 m	Pitka's Pt 38 m	St Mary's 38 m
Year	Month	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)	Recovery Rate (%)
2008	Sep	100.0	100.0	100.0	100.0	100.0	100.0	96.6	96.4
2008	Oct	96.3	100.0	98.8	100.0	96.9	94.6	92.4	95.9
2008	Nov	62.3	61.6	59.9	65.0	56.7	65.1	54.3	55.2
2008	Dec	62.2	86.7	64.6	83.7	61.0	82.7	44.4	70.6
2009	Jan	52.6	52.1	53.7	53.3	56.2	51.7	42.3	47.3
data average		74.7	80.1	75.4	80.4	74.2	78.8	66.0	73.1

Icing Data Loss Comparison Table, Saint Mary's and Mountain Village

		Saint Mary's anemometers			Mountain Village anemometers		
Year	Month	38 m Recovery Rate (%)	29 m Recovery Rate (%)	18 m Recovery Rate (%)	50 m A Recovery Rate (%)	41 m Recovery Rate (%)	32 m Recovery Rate (%)
2009	Nov	95.8	74.4	93.6	97.8	97.8	94.2
2009	Dec	93.4	93.7	93.2	91.6	91.6	91.6
2010	Jan	98.3	98.3	98.3	87.8	89.0	90.6
2010	Feb	79.5	78.3	78.1	85.5	77.5	86.9
2010	Mar	100.0	100.0	84.5	78.7	90.9	85.3
2010	Apr	96.9	99.8	99.8	100.0	100.0	100.0
2010	May	100.0	100.0	100.0	100.0	99.2	100.0
2010	Jun	100.0	100.0	100.0	100.0	100.0	100.0
		95.5	93.1	93.4	92.7	93.3	93.6

Documentation of Icing Events

Rime icing is more problematic for wind turbine operations than freezing rain (clear ice) given its tenacity and longevity in certain climatic conditions. For this reasons, wind power in the Saint Mary's area should be developed with consideration to the possible need for anti-icing and de-icing measures. These measures may include redundant control sensors, heated rotor blades, and/or leading edge blade heaters. This may be a particular concern at the Pitka's Point wind site. Although ideally one would factor availability loss due to icing into turbine performance

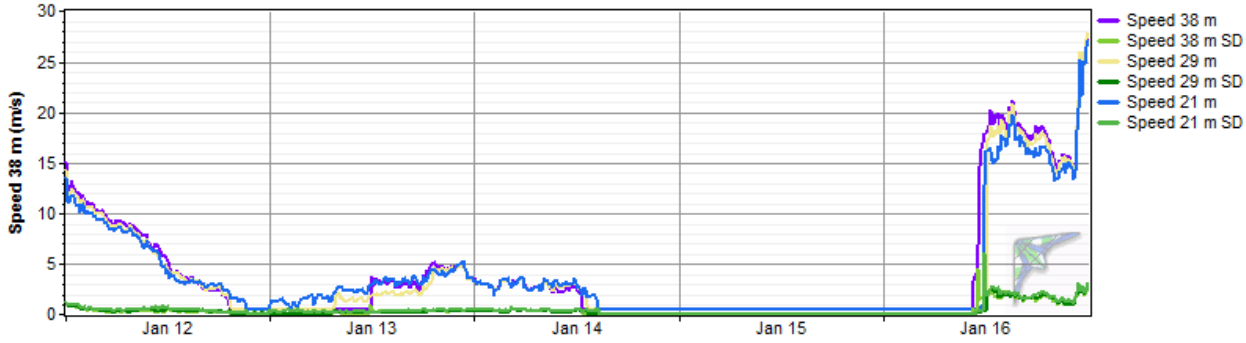
Following is documentation of rime icing conditions encountered in the met tower data and observed by AVEC personnel. Note also that rime icing during a winter storm led to collapse of the Pitka's Point and Saint Mary's met towers in February 2009.

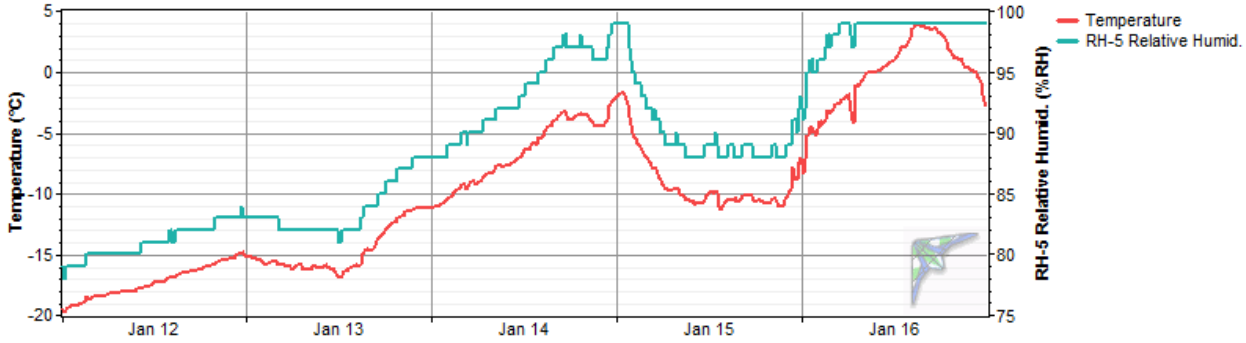
An icing event leading to data recovery loss from the sensors is indicated in the January 15, 2009 photographs below, which clearly indicate the presence of icing conditions. This icing event is also shown in the data graphs of January 15 below. Note that temperature is below freezing, relative humidity is high, wind speed standard deviation equals zero, and the wind speeds are stopped at their offset values of 0.4 m/s. Note that both met towers collapsed on February 13, 2009 from ice loading, providing graphic evidence of the problematic icing environment at the sites.

Pitka's Point Icing Event Photographs, 1/15/2009

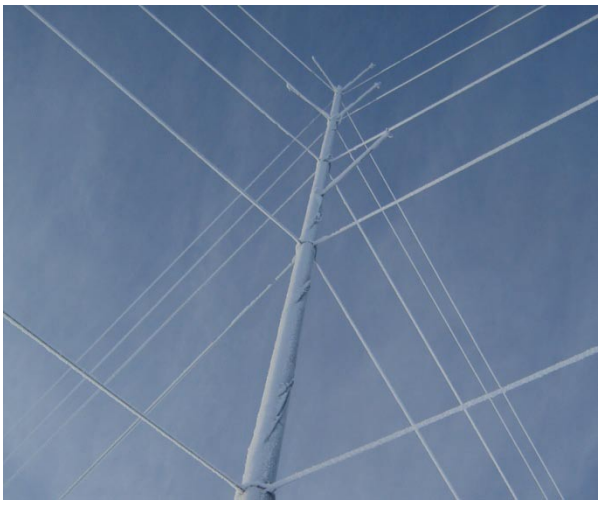
Brian Fouts photos

Pitka's Point Icing Event Data, 1/14 to16/2009



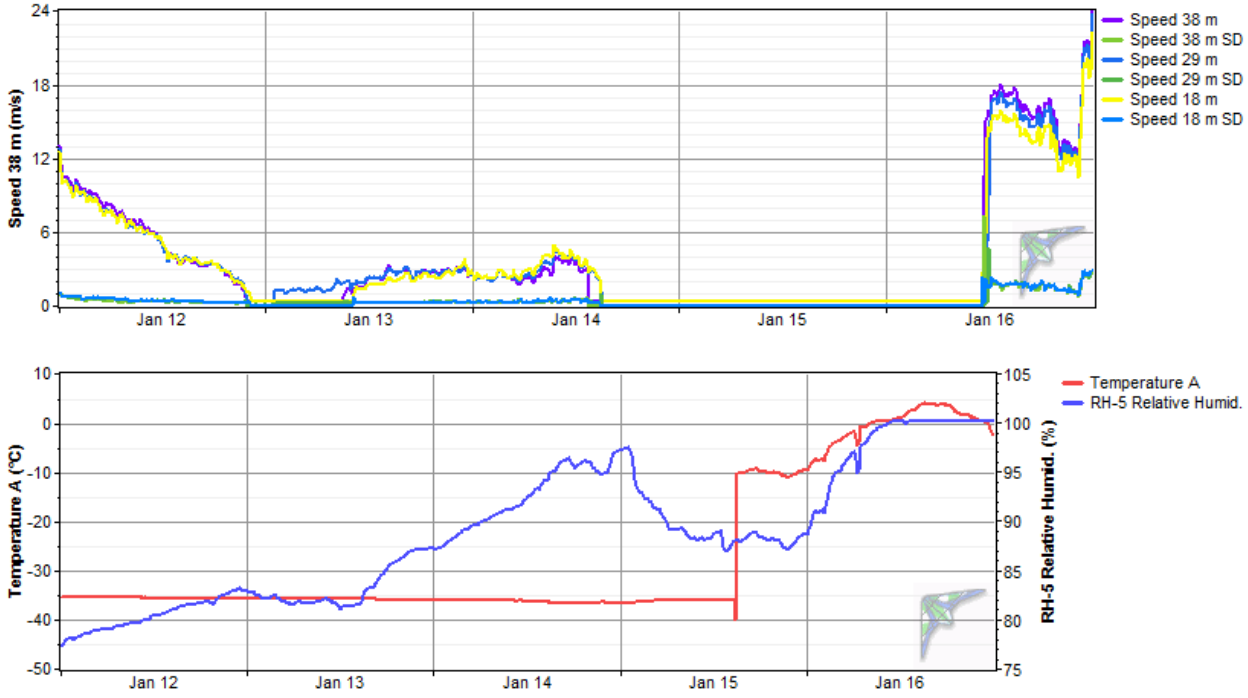


Saint Mary's Icing Event Photographs, 1/15/2009



Brian Fouts photos

Saint Mary's Icing Event Data, 1/14 to16/2009

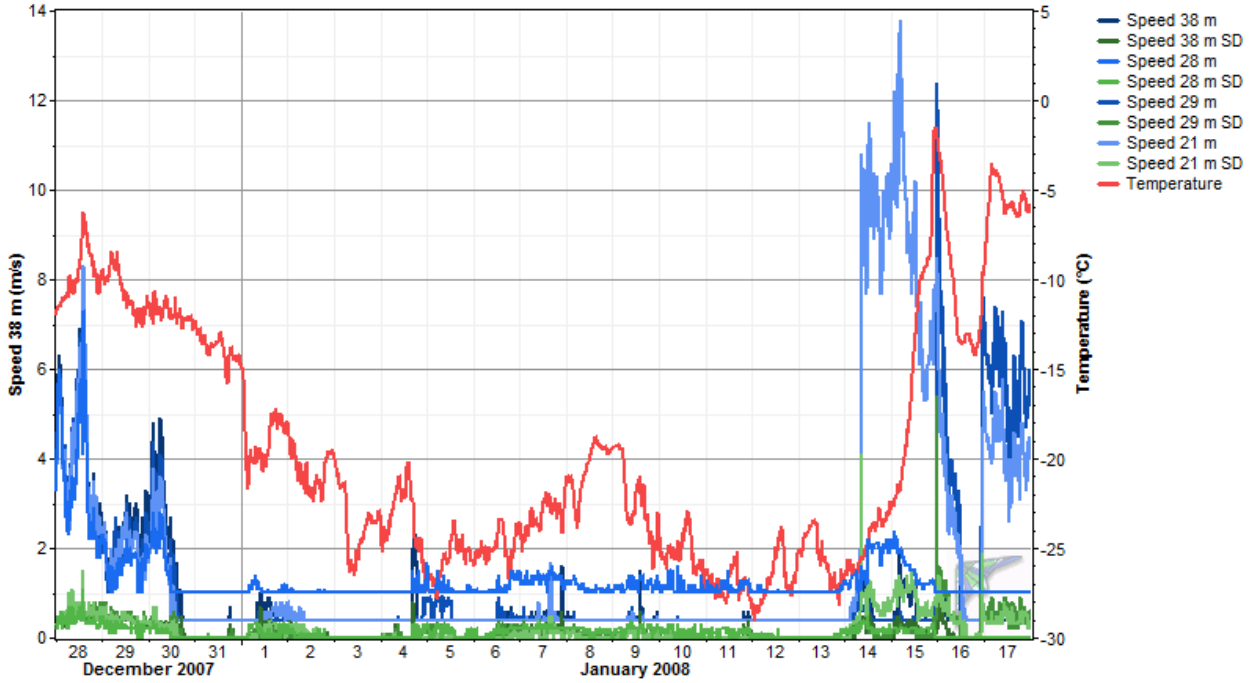


Note: Saint Mary's temperature sensor malfunctioned, repaired midday Jan. 15

Note, however, that the January 15, 2009 icing event was relatively minor in that the ice layer accumulated on the met towers was relatively thin and the anemometers were frozen and out of service for only forty hours or so. Other icing events, although not documented with photographs, have been more significant. For instance, from December 30, 2007 to January 14, 2008, an icing event occurred at the Pitka's Point met tower sufficient to render all four anemometers, including the heated IceFree anemo-

meter, inoperative. The humidity sensor was not installed on the met tower at that time, so relative humidity data cannot be reviewed, but clearly this had been an icing event.

Pitka's Point Icing Event Data, 12/30/2007 to 1/14/2008



Pitka's Point Met Tower

Met Tower Sensor Information, Pitka's Point

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40C anemometer	38 m	0.765	0.35	NNE
2	NRG IceFree III anemo-meter	28 m	0.572	1.0	WNW
3	NRG #40C anemometer	29 m	0.765	0.35	NNE
4	NRG #40C anemometer	21 m	0.765	0.35	NNE
7	NRG #200P wind vane	38 m	0.351	260	080° T
8	NRG IceFree III wind vane	29 m	0.351	350	350° T
9	iPack Voltmeter		0.021	0	
10	NRG #110S Temp C	2 m	0.136	-86.383	N/A
12	RH-5 relative humidity	2 m	0.097	0	

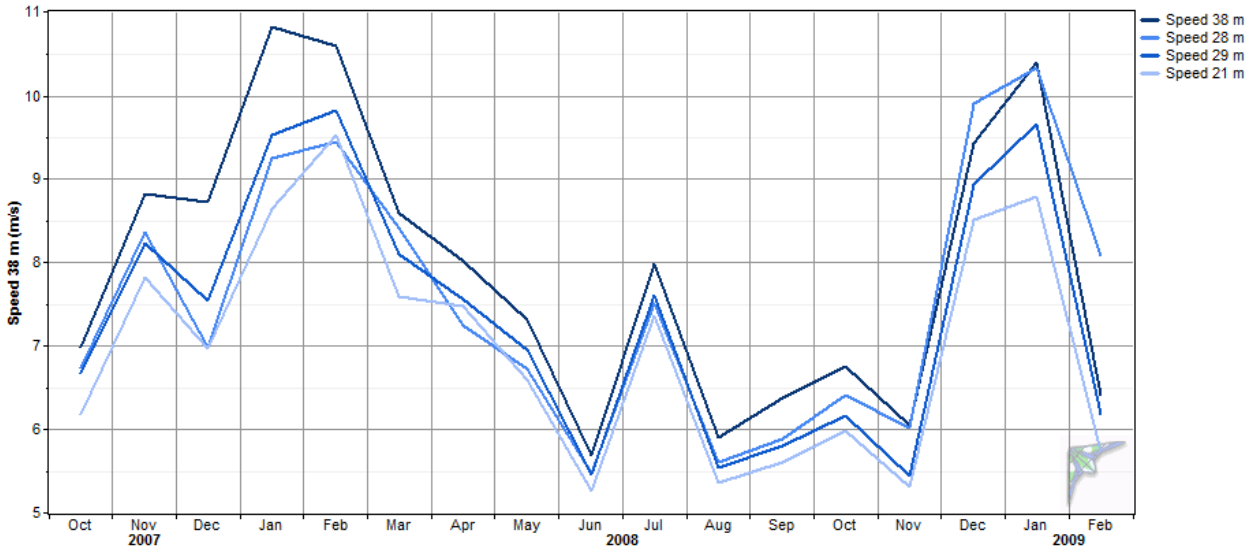
Measured Wind Speeds

Measured wind speeds at the Pitka's Point met tower are quite high, with an annual average exceeding 7.7 m/s at the top of the tower.

Wind Speed Sensor Summary, Pitka's Point (Oct 2007 to Feb 2009)

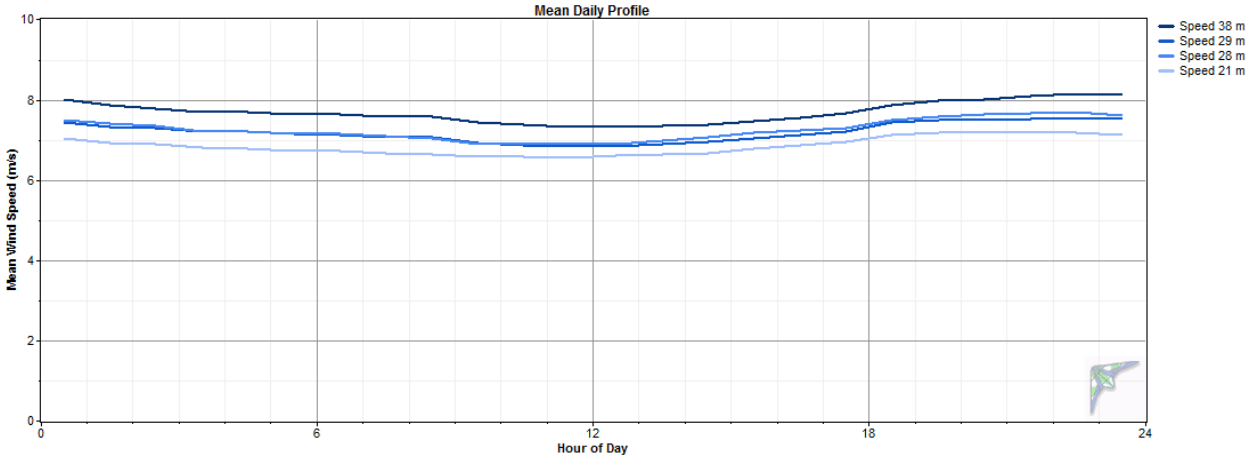
Variable	Speed 38 m	Speed 29 m	Speed 28 m IceFree	Speed 21 m
Height above ground (m)	38	29	28	21
Mean wind speed (m/s)	7.72	7.21	7.24	6.88
MMM wind speed (m/s)	7.81	7.27	7.36	6.94
Max 10-min avg wind speed (m/s)	29.5	29.2	28.2	28.4
Max gust wind speed (m/s)	35.9	36.3	35.1	36.3
Weibull k	1.96	1.88	2.07	1.91
Weibull c (m/s)	8.70	8.12	8.16	7.74
Mean power density (W/m²)	579	491	450	420
MMM power density (W/m²)	587	493	474	419
Mean energy content (kWh/m²/yr)	5,069	4,299	3,941	3,676
MMM energy content (kWh/m²/yr)	5,145	4,320	4,156	3,672
Energy pattern factor	1.95	2.02	1.84	2.00
Frequency of calms (%)	20.1	22.7	19.6	24.3
Data recovery rate (%)	75.2	78.1	75.1	77.2
1-hr autocorrelation coefficient	0.946	0.947	0.944	0.946
Diurnal pattern strength	0.046	0.045	0.050	0.044
Hour of peak wind speed	24	23	23	22

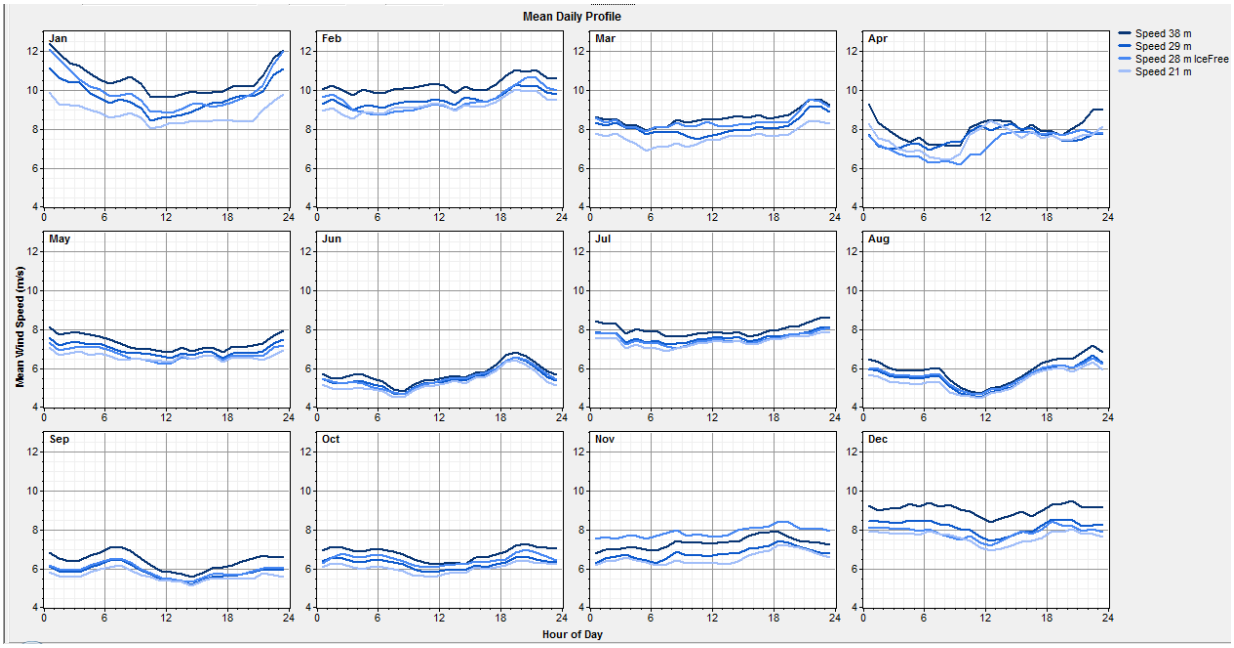
Seasonal Wind Profile, Pitka's Point



Daily Wind Profile, Pitka's Point

The daily wind profile indicates that the lowest wind speeds of the day occur midday from about 10 a.m. to 2 p.m. and the highest wind speeds of the day occur during the evening hours of 8 p.m. to midnight. The daily variation of wind speed is remarkably minimal on an annual basis but more pronounced on a monthly basis (second graph).

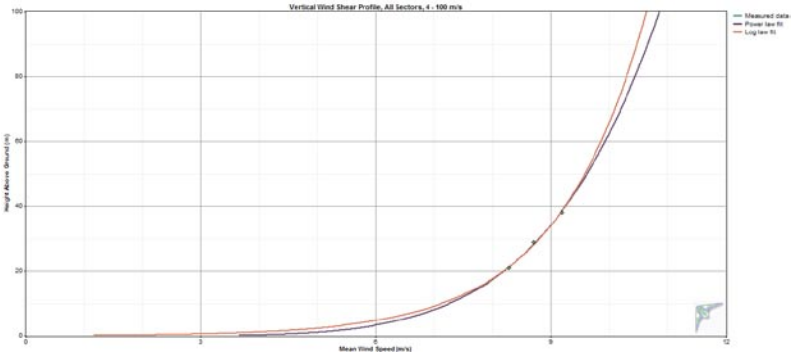




Wind Shear

At the Pitka's Point met tower, the power law exponent was calculated at 0.175 with wind speeds filtered to include only those greater than 4 m/s, the cut-in speed for most turbines. This indicates moderate wind shear at the Pitka's Point met tower site. Considering the high wind class of the site, a lower turbine hub height is likely a preferred option.

Wind Shear Profile, Pitka's Point



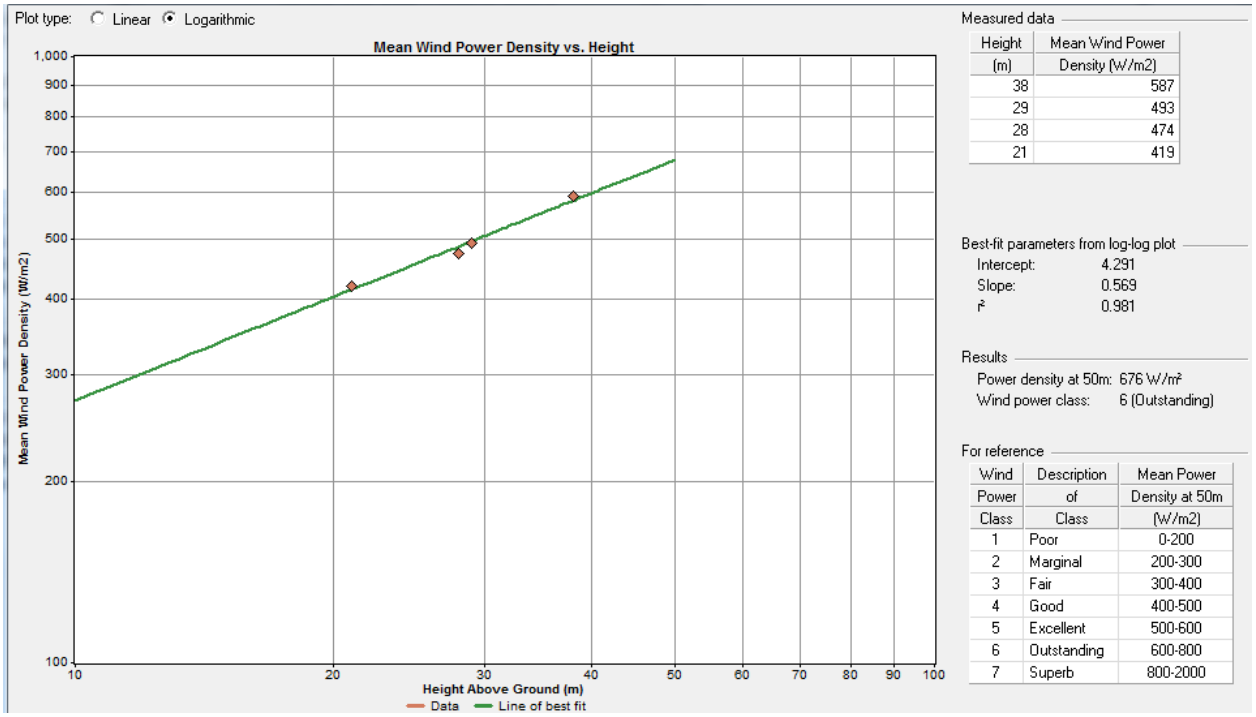
Wind Power Density

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 analy-

sis software uses the power law exponent derived from the two (or more) measurement heights to extrapolate up or down.

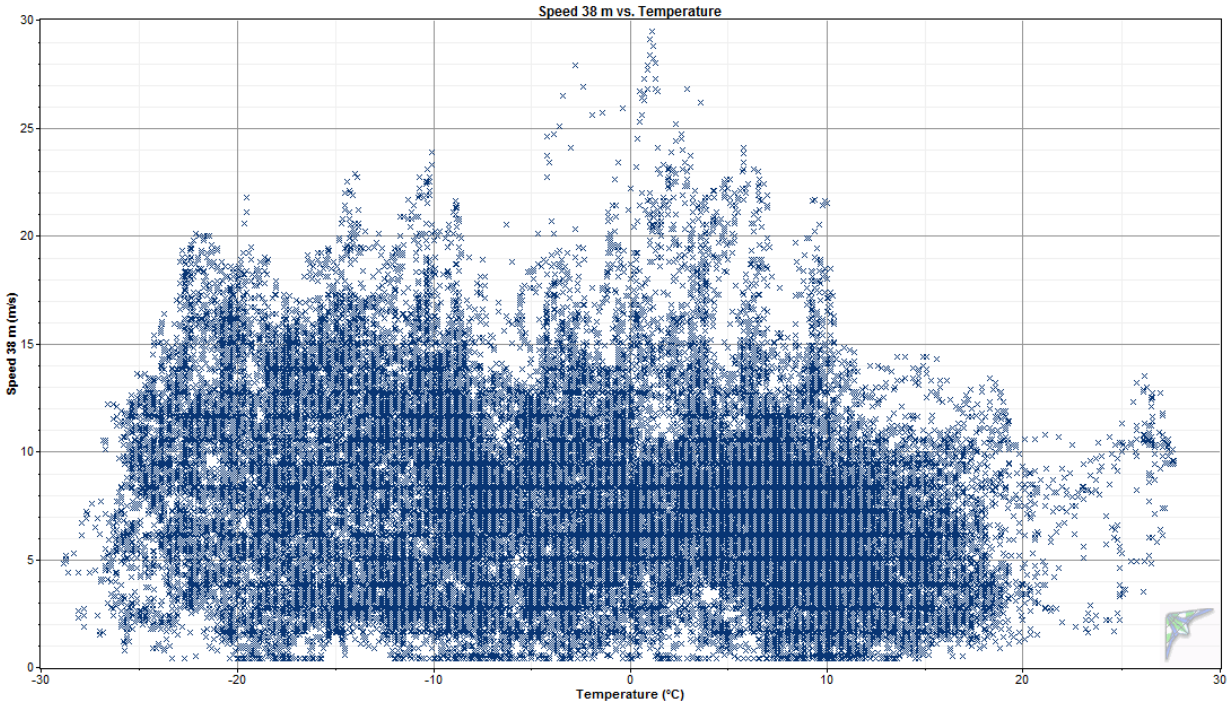
As can be seen in the figure below, power density and hence potential turbine power production increases substantially with turbine hub height at the Pitka's Point site. Note that the measured power densities in the figure below differ from those reported in the data summary table of this report. The figure below uses all collected data (October 2007 to February 2009) while in the summary table these data are presented as annual averages.



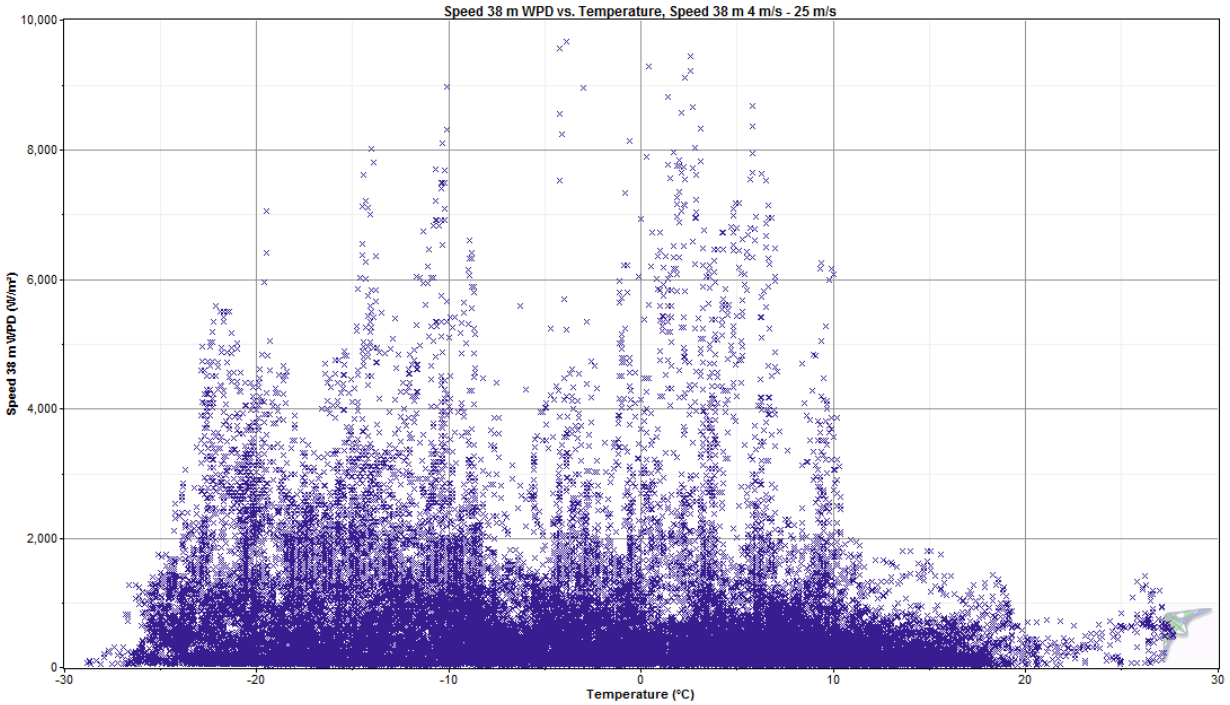
Temperature Scatterplots

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 the entire temperature range of the Pitka's Point site, even as low as (near) -30° C. A turbine selected for the Pitka's Point site should be capable of operation down to at least -30° C but a -40° C temperature rating is preferable as an arctic standard.

Wind Speed vs. Temperature, Pitka's Point, 38 m anem.



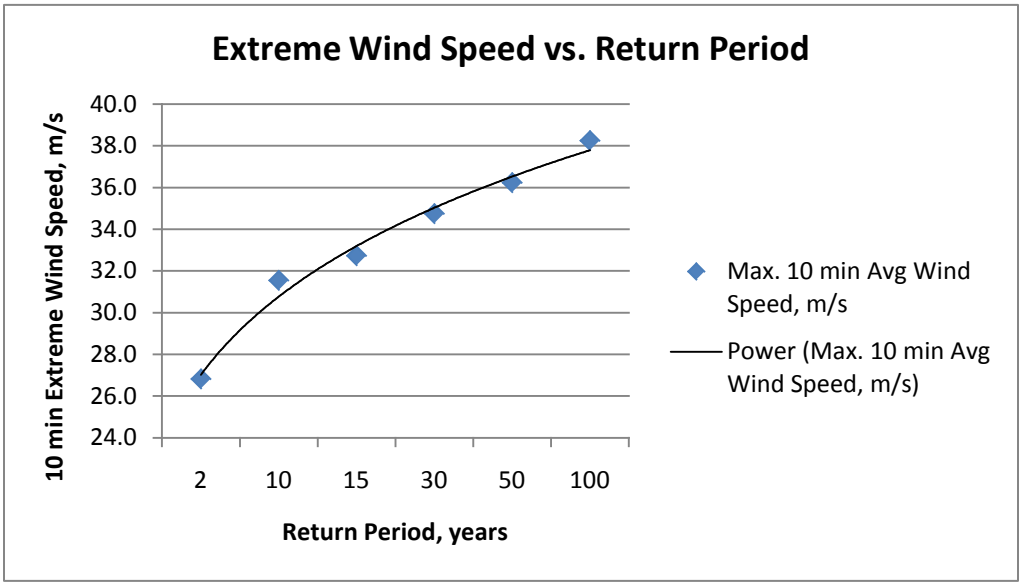
Wind Power Density vs. Temperature, Pitka's Point, 38 m anem.



Extreme Wind Analysis

Using a modified Gumbel distribution, the probability of winds exceeded a certain value within a defined period of time is predicted. 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 Pitka's Point met tower site, maximum predicted 50 year wind speed (ten minute average) at 38 meters is 36.2 m/s and the maximum predicted 50 year wind gust (two second) at 38 meters elevation is 44.0 m/s. This (just barely) qualifies the site as IEC Class III, the lowest and most common extreme wind designation class.

RETURN PERIOD SPEED		Average Gust Factor:	1.22	IEC 50-year extreme wind	
Pitka's Point	**RETURN YR**	**10 min average, m/s**	**2 sec gust, m/s**	Class	V_{ref} (10 min), (m/s)
38 meter	**2**	**26.8**	**32.6**	I	50.0
	10	**31.5**	**38.3**	II	42.5
	15	**32.7**	**39.8**	III	37.5
	30	**34.7**	**42.2**	S	mfr specified
	50	**36.2**	**44.0**		
	100	**38.3**	**46.5**		



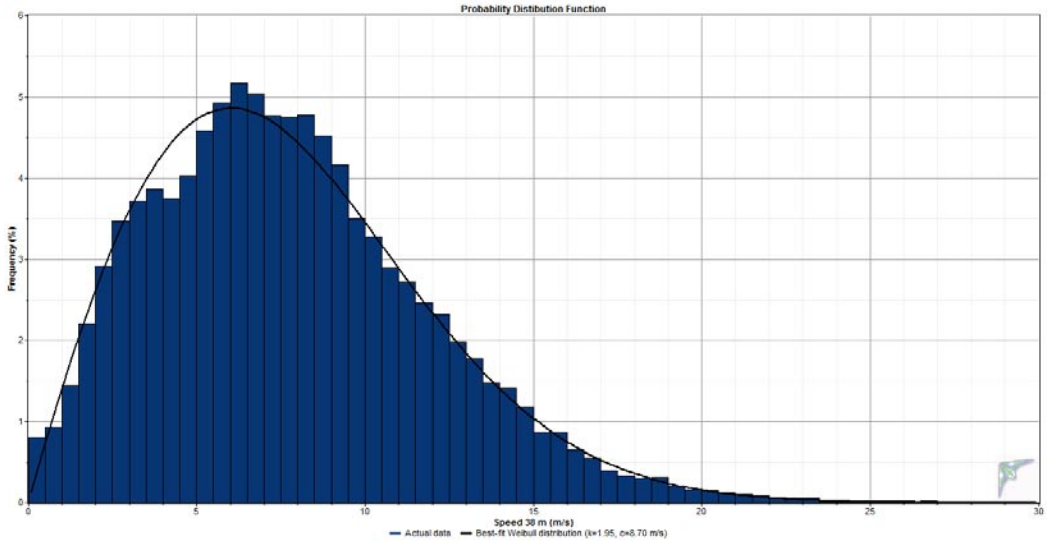
Probability Distribution Function

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

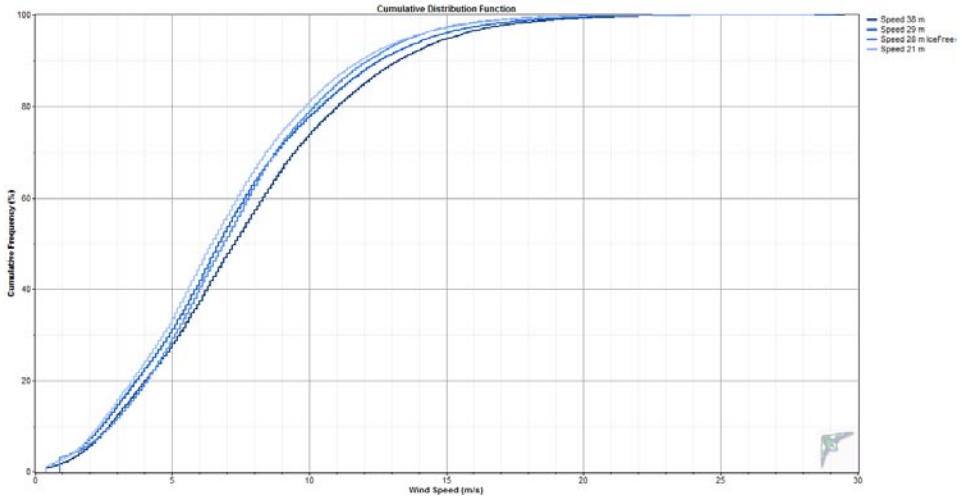
at hub height reaches 4 m/s, known as the "cut-in" wind speed. The black line in the graph is a best fit Weibull distribution. At the 38 meter level, Weibull parameters are k = 1.95 and c = 8.67 m/s ("k" is the shape factor and "c" is the scale factor) for the data period. This shape factor is indicative of a normal (Raleigh) 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 22 percent of the winds at 38 meters are less than 4 m/s, the standard cut-in speed of most turbines and almost 100 percent of the winds are less than 25 m/s, the standard high wind cut-out speed for most turbines (speeds refer to 10-min averages).

PDF Curve, Pitka's Point, 38 m



CDF Curve, Pitka's Point, 38 m

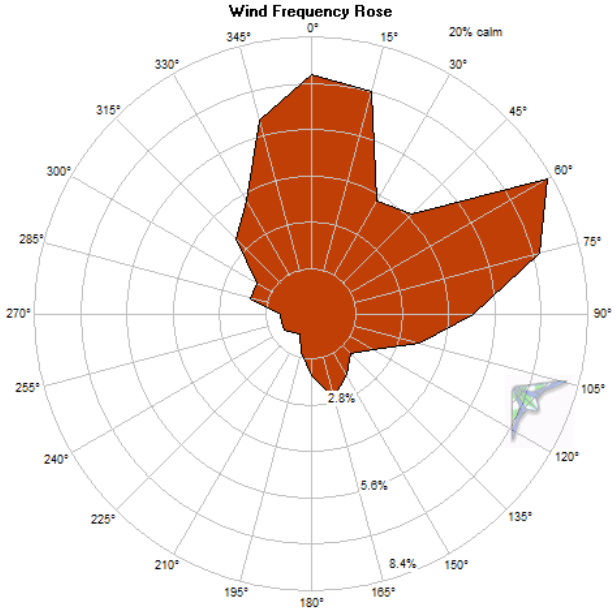


Wind Roses

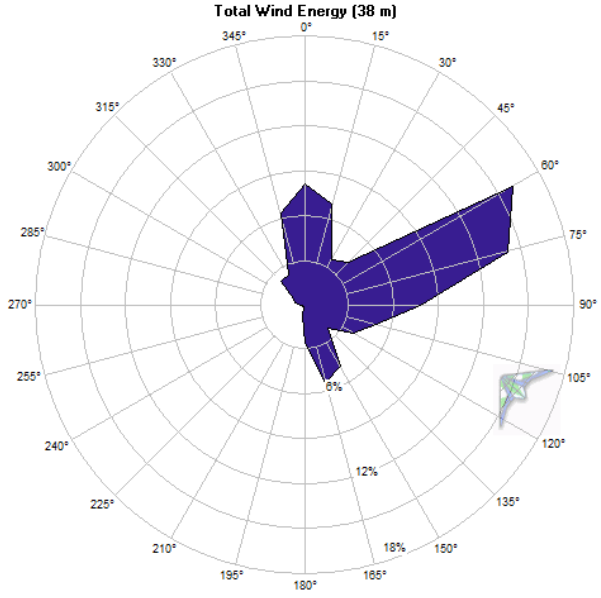
Pitka's Point winds are bi-directional with the wind frequency rose indicating a nearly equal component of north and east-northeast winds, with slightly more frequent ENE winds. For power producing winds, one can then see that ENE winds dominate.

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, Pitka's Point experiences twenty percent annual calm conditions (see wind frequency rose below).

Wind Frequency Rose



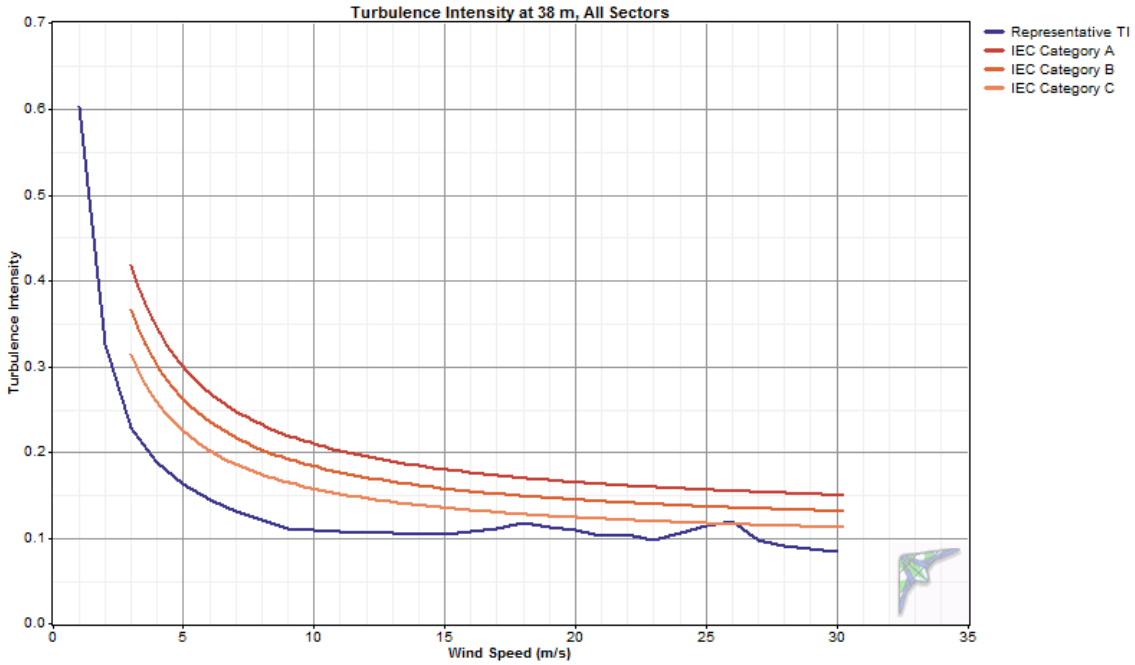
Total Value (power density) Rose



Turbulence Intensity

The turbulence intensity (TI) is acceptable with a mean turbulence intensity of 0.076 and a representative turbulence intensity of 0.105 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. These data are shown in the turbulence intensity graph below. As seen, representative TI (90th percentile of the turbulence intensity values, assuming a normal distribution) at 15 m/s is well under IEC Category C criteria at the Pitka's Point met tower site.

IEC 3rd Edition Turbulence Intensity Graph, Pitka's Point, 38 m Anemometer

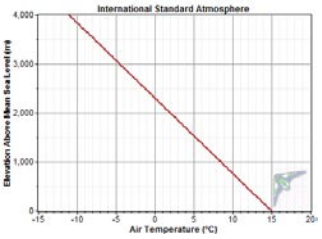


Air Temperature and Density

Over the reporting period, the Pitka's Point met tower had an average temperature of -2.8° C. The minimum recorded temperature during the measurement period was –28.8° C and the maximum temperature was 27.7° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations.

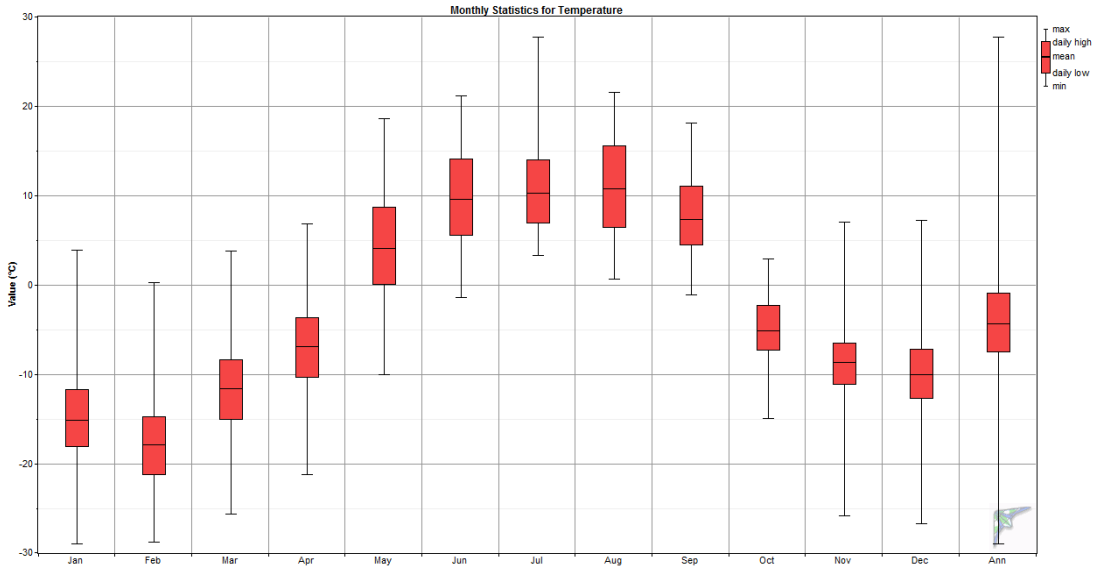
Consequent to the cool temperatures, the average air density of 1.285 kg/m^3 is nearly seven percent higher than the standard air density of 1.204 kg/m^3 (13.8° C and 99.2 kPa standard temperature and pressure at 177 m elevation), indicating that the Pitka's Point met tower site has denser air than the standard air density used to calculate turbine power curves (note that all turbine power curves are calculated at a sea level standard of 15.0° 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	-15.1	-29.0	3.9	1.321	1.204	1.416
Feb	-18.0	-28.8	0.2	1.355	1.264	1.414
Mar	-11.7	-25.7	3.8	1.323	1.248	1.397
Apr	-7.0	-21.3	6.8	1.299	1.235	1.372
May	4.1	-10.1	18.6	1.247	1.185	1.314
Jun	9.5	-1.4	21.2	1.223	1.174	1.272
Jul	10.3	3.3	27.7	1.220	1.149	1.250
Aug	10.7	0.6	21.6	1.218	1.173	1.263



Sep	7.3	-1.1	18.1	1.233	1.187	1.270
Oct	-5.2	-15.0	2.9	1.287	1.204	1.339
Nov	-8.7	-25.9	7.0	1.308	1.234	1.398
Dec	-10.1	-26.8	7.2	1.305	1.204	1.403
Annual	-2.8	-28.8	27.7	1.285	1.149	1.416

Annual Temperature Boxplot, Pitka's Point



Saint Mary's Met Tower

Met Tower Sensor Information, Saint Mary's

Channel	Sensor type	Height	Multiplier	Offset	Orientation
1	NRG #40C anemometer	38 m	0.765	0.35	N
2	NRG #40C anemometer	28.5 m	0.765	0.35	N
3	NRG #40C anemometer	18 m	0.765	0.35	N
7	NRG #200P wind vane	38 m	0.351	265	085° T
8	NRG #200P wind vane	29 m	0.351	285	105° T
9	iPack Voltmeter		0.021	0	
11	NRG #110S Temp C	2 m	0.136	-86.383	N/A
12	RH-5 relative humidity	2 m	0.098	0	

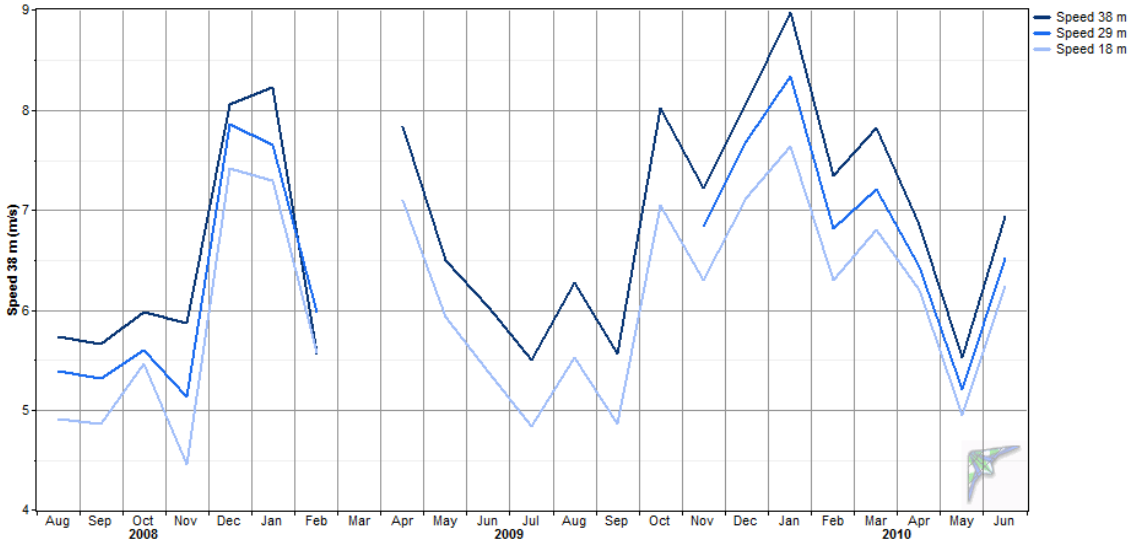
Measured Wind Speeds

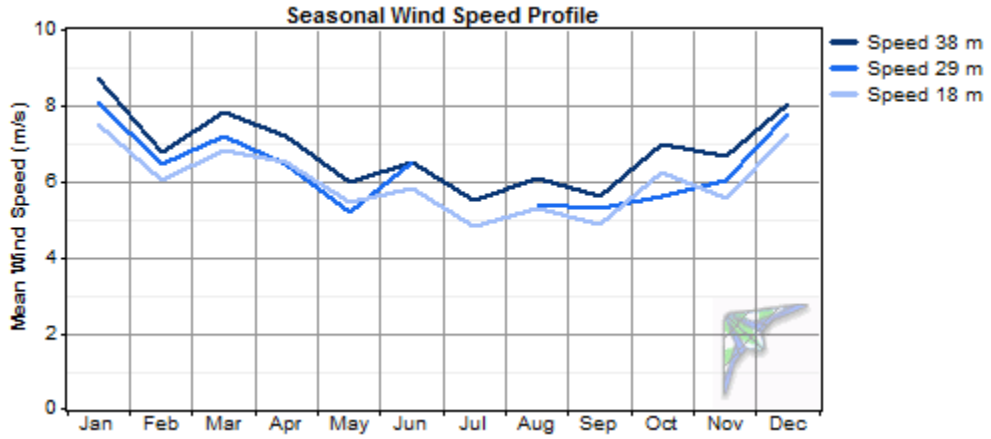
Measured wind speeds at the Saint Mary's met tower are moderately high, with an annual average exceeding of 6.8 m/s at the top of the tower.

Wind Speed Sensor Summary, Saint Mary's (Aug 2008 to June 2010)

Variable	Speed 38 m	Speed 29 m	Speed 18 m
Measurement height (m)	38	28.5	18
Mean wind speed (m/s)	6.80	6.56	5.99
MMM wind speed (m/s)	6.83	6.37	6.02
Max 10-min avg wind speed (m/s)	24.0	23.8	22.3
Max gust wind speed (m/s)	29.8	29.8	30.6
Weibull k	2.21	2.16	2.15
Weibull c (m/s)	7.66	7.40	6.76
Mean power density (W/m²)	353	327	248
MMM power density (W/m²)	359	299	251
Mean energy content (kWh/m²/yr)	3,092	2,867	2,169
MMM energy content (kWh/m²/yr)	3,142	2,621	2,199
Energy pattern factor	1.742	1.776	1.791
Frequency of calms (%)	20.4	22.0	26.9
Data recovery rate (%)	84.1	55.6	83.2
1-hr autocorrelation coefficient	0.917	0.918	0.913
Diurnal pattern strength	0.040	0.034	0.051
Hour of peak wind speed	21	20	18

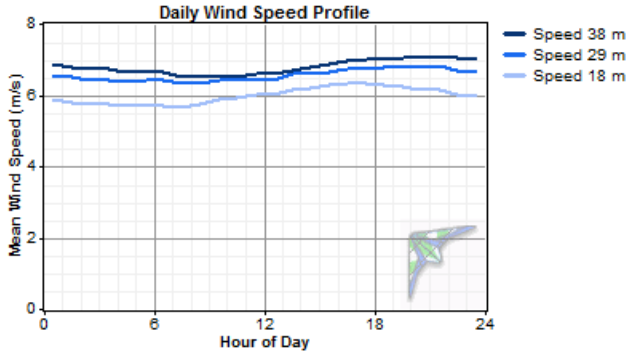
Monthly and Seasonal Wind Profiles, Saint Mary's





Daily Wind Profile, Saint Mary's

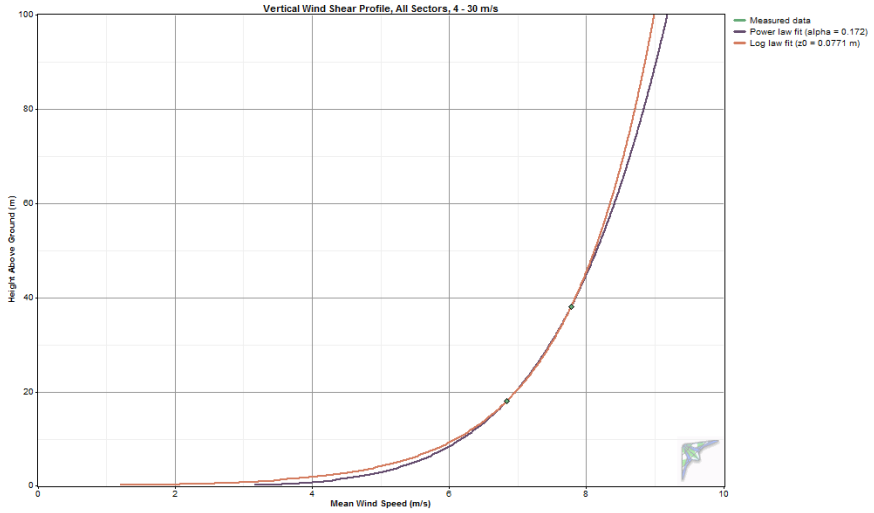
Similarly as measured by the Pitka's Point met tower, daily wind profile at the Saint Mary's met tower is rather flat but higher wind speeds do occur in the afternoon and early evening as one would expect.



Wind Shear

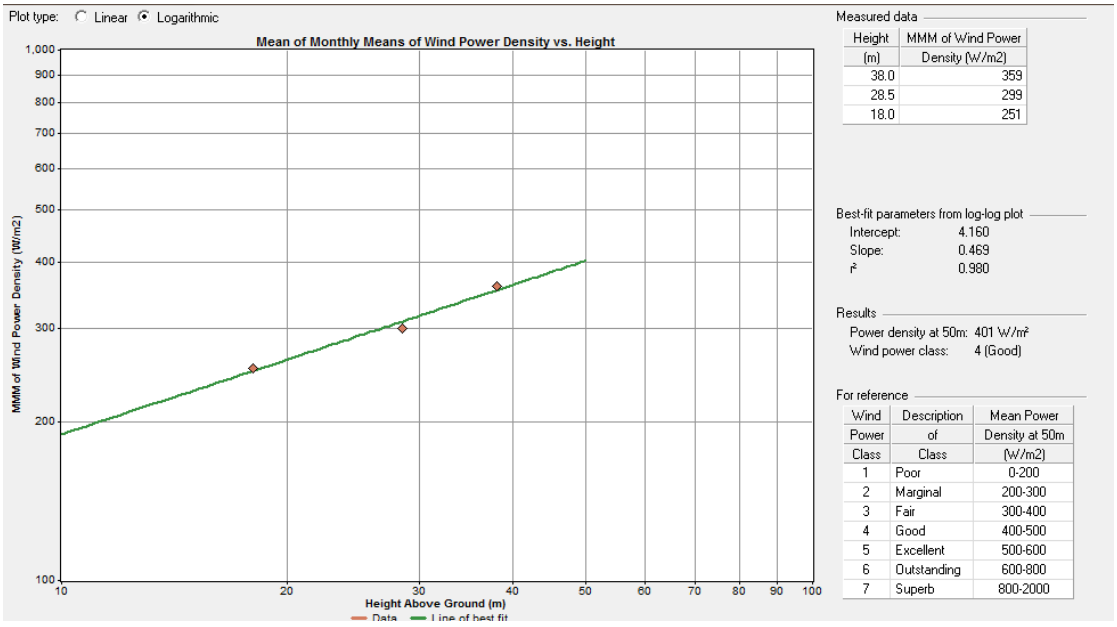
At the Saint Mary's met tower, the power law exponent was calculated at 0.175 with wind speeds filtered to include only those greater than 4 m/s, the cut-in speed for most turbines, indicating moderate wind shear at the Pitka's Point met tower site.

Wind Shear Profile, Saint Mary's



Wind Power Density

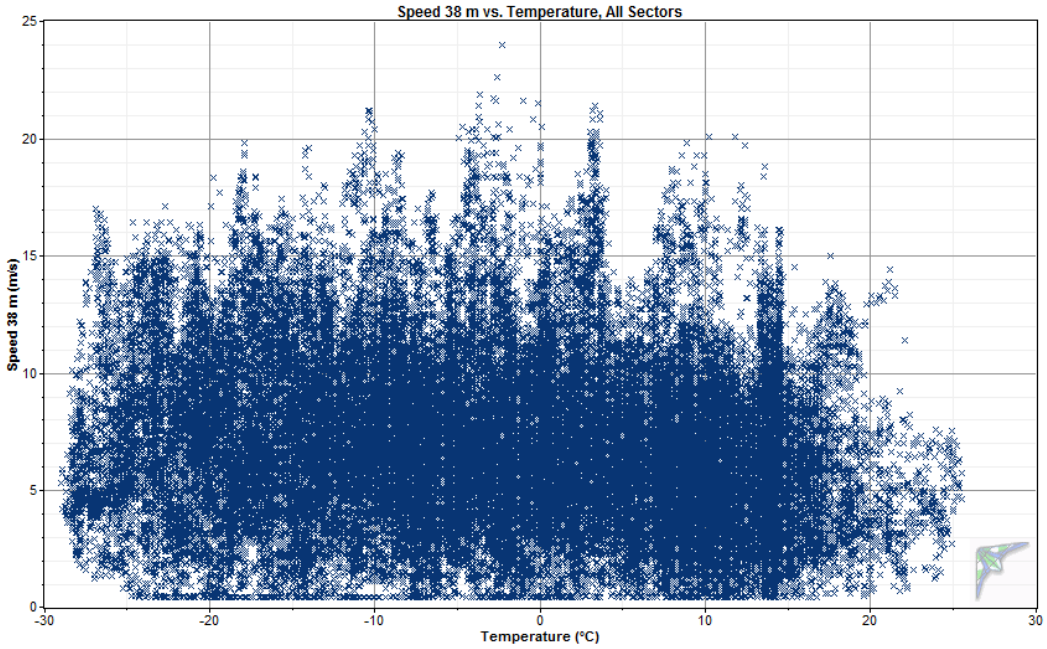
Power density and hence potential turbine power production increases substantially with turbine hub height at the Saint Mary's site. Note that the measured power densities in the figure below differ from those reported in the data summary table of this report. The figure below uses all collected data (August 2008 to June 2010) while in the summary table these data are presented as annual averages.



Scatterplot

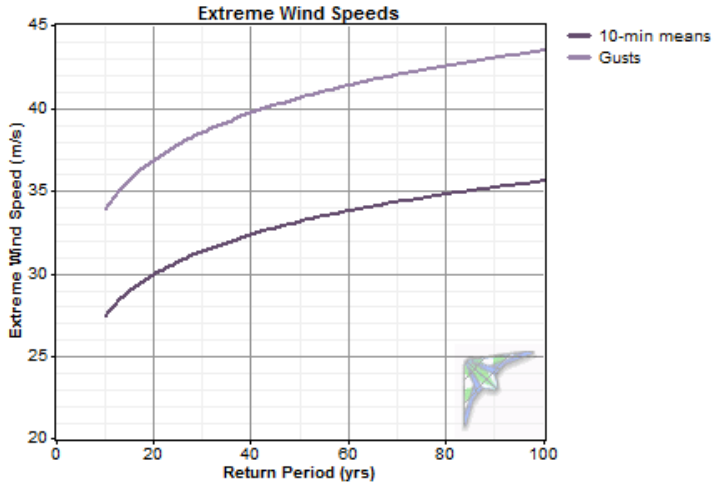
At the Saint Mary's site, power producing winds (greater than 4 m/s) are present through the entire temperature range of the site, even as low as (near) -30° C. A turbine selected for the Saint Mary's site should be capable of operation down to at least -30° C but a -40° C temperature rating is preferable as an arctic standard.

Wind Speed vs. Temperature, Saint Mary's, 38 m anem.



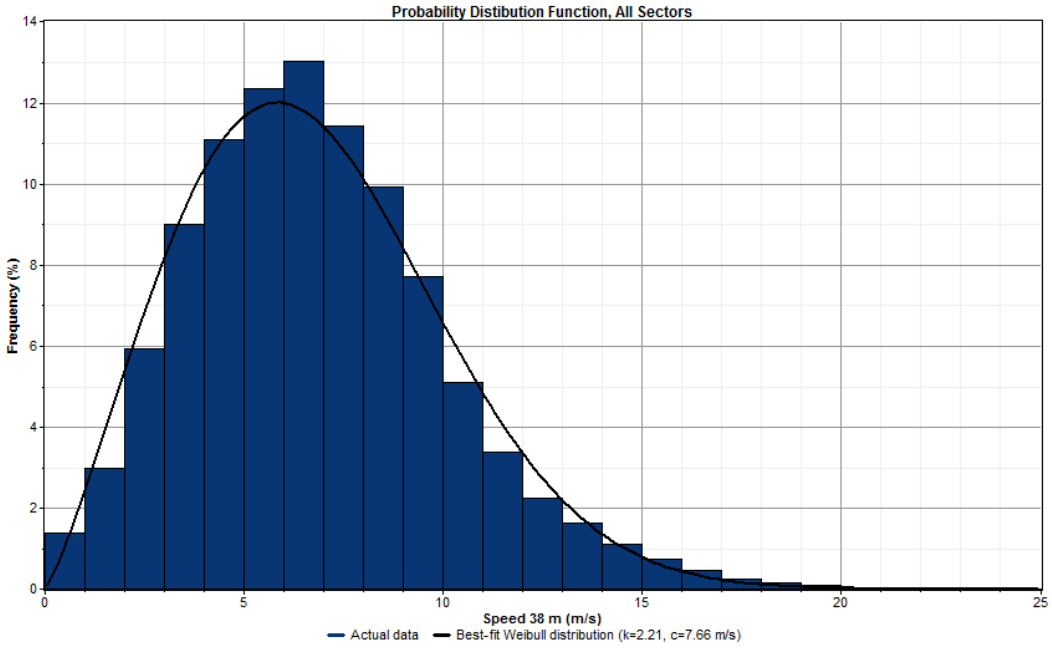
Extreme Wind Analysis

At the Saint Mary's met tower site, maximum predicted 50 year wind speed (ten minute average) at 38 meters is 33.1 m/s and the maximum predicted 50 year wind gust (two second) at 38 meters elevation is 40.6 m/s. This qualifies the site as IEC Class III, the lowest and most common extreme wind designation class.



Probability Distribution Function

At the 38 meter level at the Saint Mary's site, Weibull parameters are k = 2.21 and c = 7.66 m/s ("k" is the shape factor and "c" is the scale factor) for the data period. This shape factor is indicative of a near normal (Raleigh) wind distribution for wind power sites.

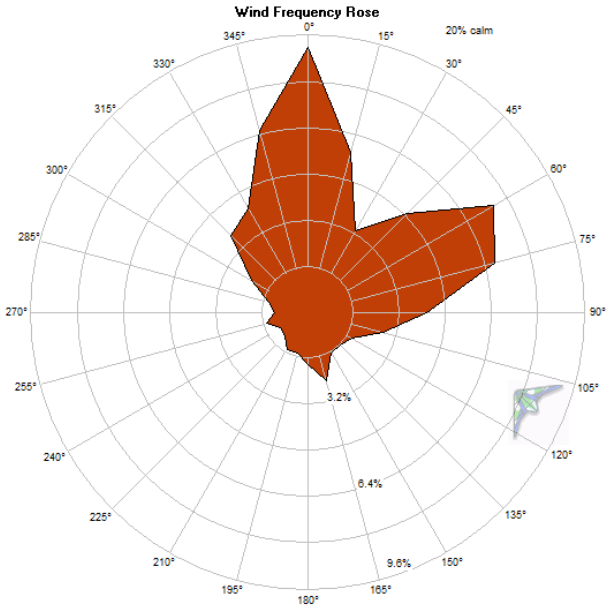


Wind Roses

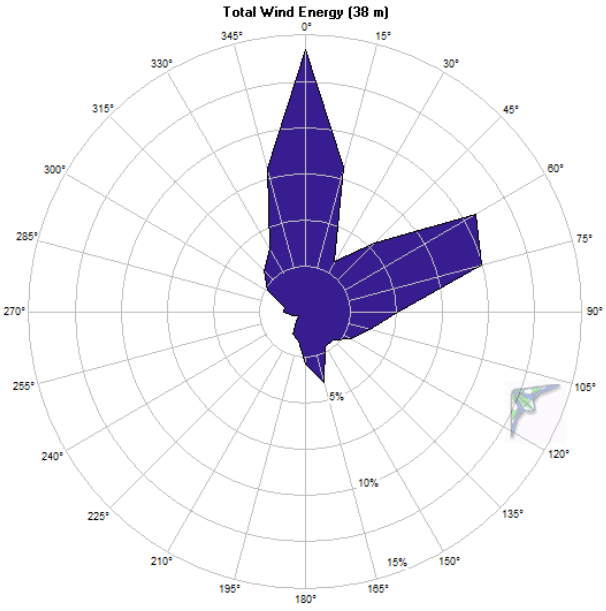
Saint Mary's winds are bi-directional with the wind frequency rose indicating a nearly equal component of north and east-northeast winds, with an edge towards more frequent ENE winds. Power density winds are also bi-directional north and ENE without the domination of ENE winds observed at the Pitka's Point site. This lesser extent of powerful ENE winds may be a reflection of the wind class difference be-

tween Pitka's Point and Saint Mary's. Note also that the Saint Mary's site experiences 20 percent calm wind conditions (winds less than 4 m/s).

Wind Frequency Rose



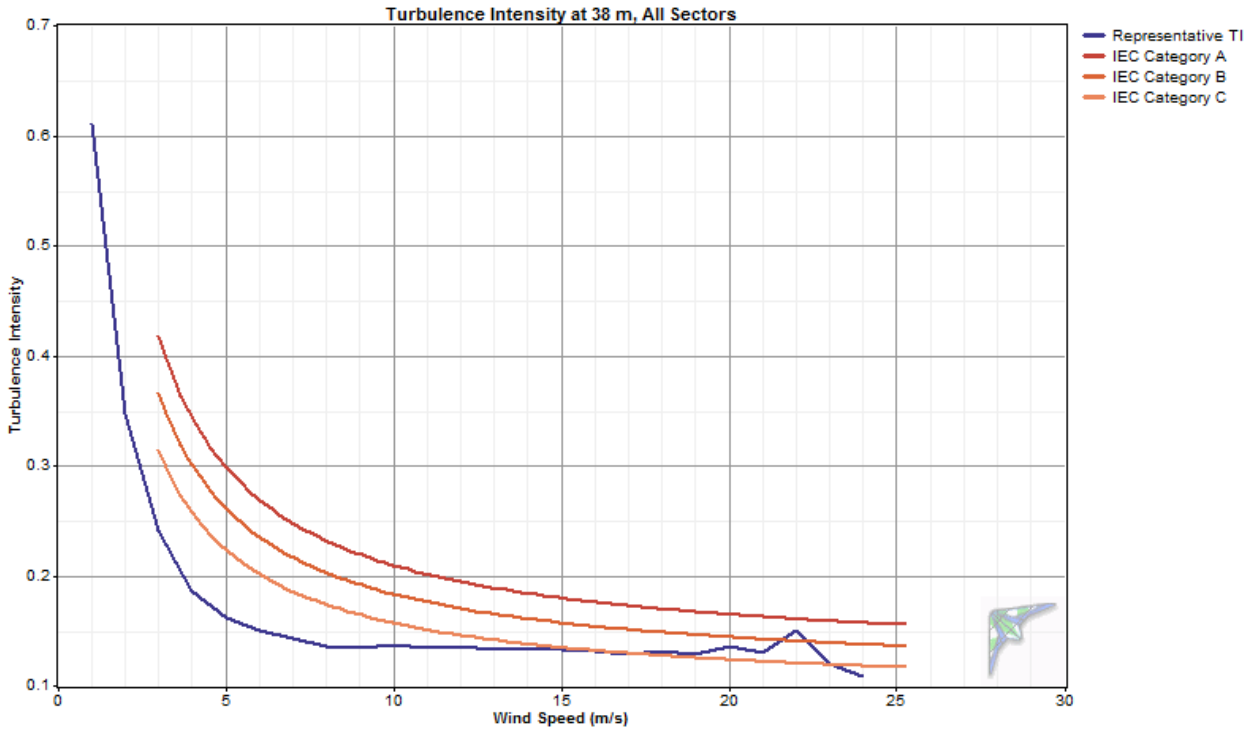
Total Value (power density) Rose



Turbulence Intensity

The turbulence intensity (TI) is acceptable with a mean turbulence intensity of 0.101 and a representative turbulence intensity of 0.132 at 15 m/s wind speed, indicating 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. These data are shown in the turbulence intensity graph below.

IEC 3rd Edition Turbulence Intensity Graph, Saint Mary's, 38 m Anemometer



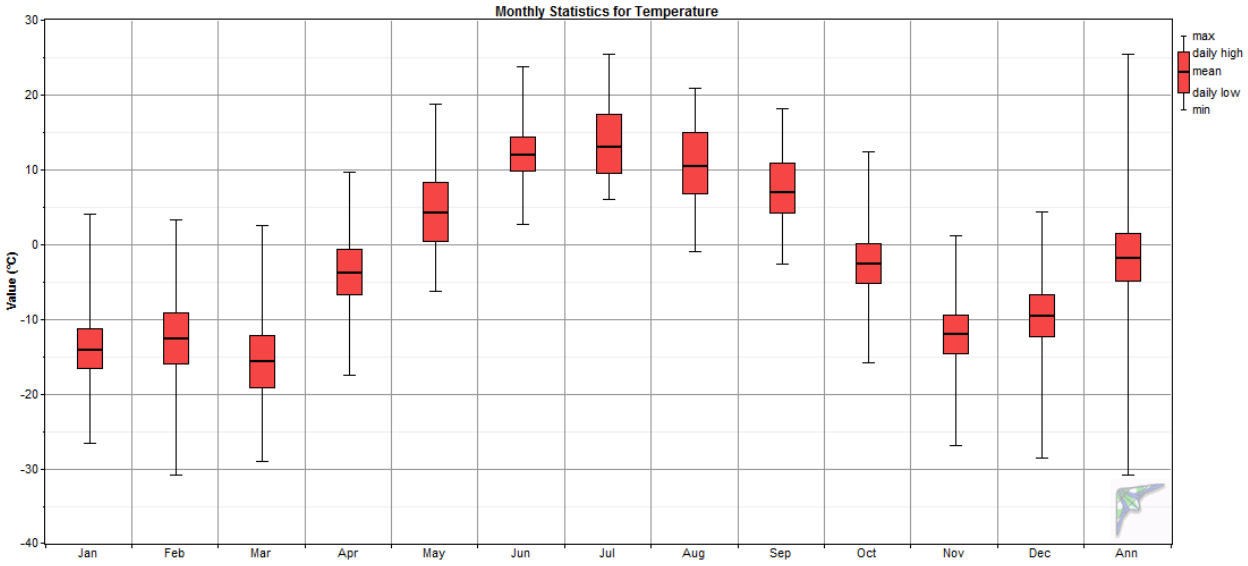
Air Temperature and Density

Over the reporting period, the Saint Mary's met tower recorded an average temperature of -1.8° C. The minimum recorded temperature during the measurement period was –30.9° C and the maximum temperature was 25.5° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations.

Consequent to the cool temperatures, the average air density of 1.271 kg/m^3 is five percent higher than the standard air density of 1.209 kg/m^3 (14.1° C and 99.6 kPa standard temperature and pressure at 139 m elevation), indicating that the Saint Mary's met tower site 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 15.0° C and 101.3 kPa pressure).

	Temperature			Air Density		
Month	Mean	Min	Max	Mean	Min	Max
	(°C)	(°C)	(°C)	(kg/m³)	(kg/m³)	(kg/m³)
Jan	-14.0	-26.7	4.0	1.309	1.209	1.409
Feb	-12.5	-30.9	3.2	1.329	1.209	1.433
Mar	-15.6	-29.0	2.5	1.279	1.209	1.422
Apr	-3.7	-17.5	9.7	1.268	1.209	1.358
May	4.3	-6.3	18.8	1.252	1.189	1.301
Jun	12.0	2.7	23.7	1.217	1.170	1.259
Jul	13.2	6.0	25.5	1.213	1.162	1.244
Aug	10.6	-1.0	20.9	1.224	1.181	1.276
Sep	7.1	-2.6	18.2	1.239	1.192	1.283
Oct	-2.5	-15.9	12.4	1.283	1.216	1.350
Nov	-11.9	-27.0	1.1	1.327	1.209	1.410
Dec	-9.5	-28.6	4.3	1.317	1.209	1.420
Annual	-1.8	-30.9	25.5	1.271	1.162	1.433

Annual Temperature Boxplot, Saint Mary's



Mountain Village Met Tower

Met Tower Sensor Information, Mountain Village

Channel	Sensor type and design.	Height	Multiplier	Offset	Orientation
1	NRG #40C, 50 m A	50.3 m	0.760	0.36	000° T
2	NRG #40C, 50 m B	50.5 m	0.757	0.41	135° T
3	NRG #40C, 40 m	40.8 m	0.761	0.33	000° T
13	NRG #40C, 41 m	41.1 m	0.758	0.33	135° T
14	NRG #40C, 31 m	31.8 m	0.758	0.34	000° T
15	NRG #40C, 32 m	32.0 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	40.1 m	0.351	270	090° T
9	NRG #110S Temp C	2 m	0.136	-86.383	000° T
10	RH-5 relative humidity	2 m	0.098	0	
12	iPack Voltmeter		0.021	0	

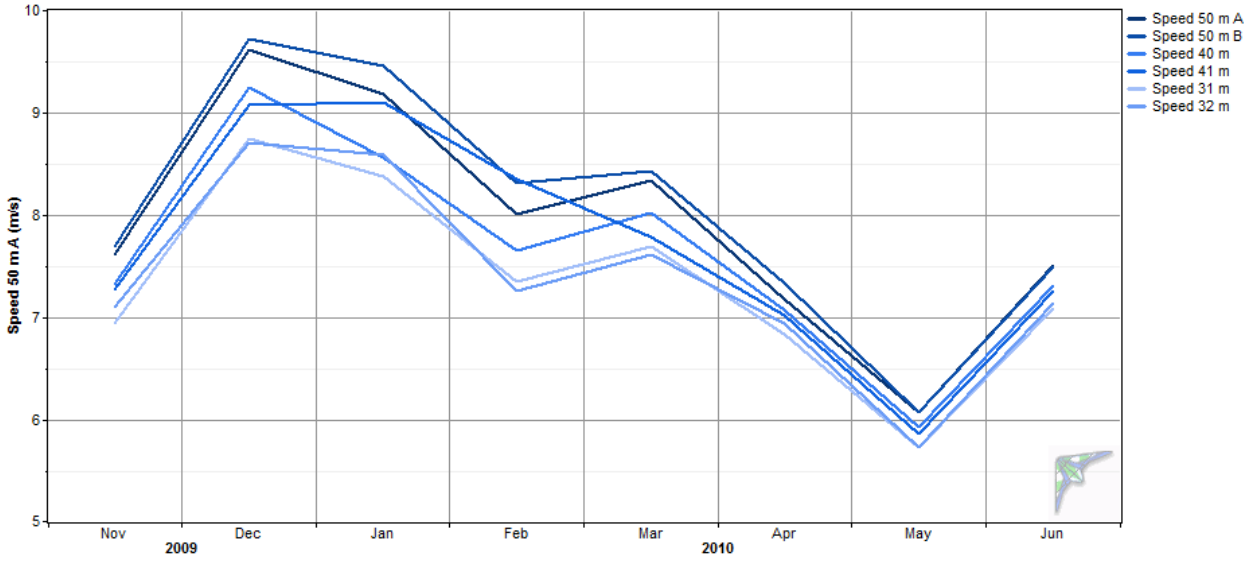
Measured Wind Speeds

Measured wind speeds at the Mountain Village met tower are reasonably high to date, with an average of 8.0 m/s at the top of the tower (50 meters). Note however that most of summer data has yet to be collected so annual average wind speed is likely to be less than 8.0 m/s.

Wind Speed Sensor Summary, Mountain Village (November 2009 to June 2010)

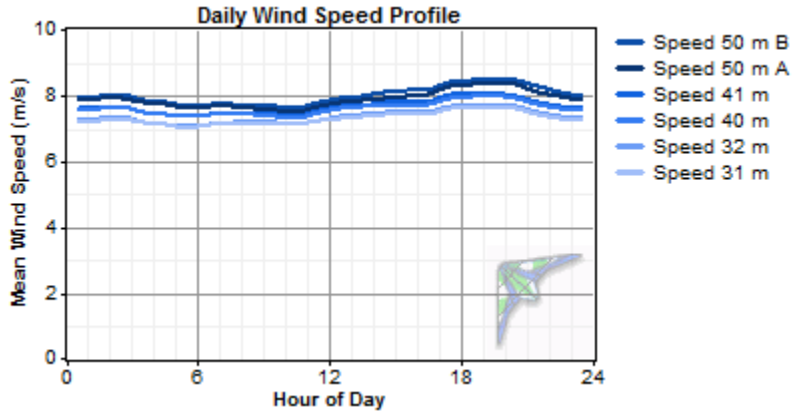
Variable	Speed 50 m B	Speed 50 m A	Speed 41 m	Speed 40 m	Speed 32 m	Speed 31 m
Measurement height (m)	50.5	50.3	41.1	40.8	32	31.8
Mean wind speed (m/s)	8.017	7.896	7.667	7.624	7.364	7.323
Max 10-min avg wind speed (m/s)	25.1	24.9	24.8	25.6	24.8	24.9
Max gust wind speed (m/s)	30.8	31.1				
Weibull k	2.231	2.245	2.21	2.221	2.213	2.228
Weibull c (m/s)	9.036	8.899	8.644	8.596	8.302	8.259
Mean power density (W/m²)	586	558	518	509	459	450
Mean energy content (kWh/m²/yr)	5,135	4,884	4,541	4,458	4,021	3,946
Energy pattern factor	1.722	1.714	1.74	1.739	1.74	1.737
Frequency of calms (%)	14.39	14.76	15.77	16.08	17.26	17.37
Data recovery rate (%)	92.21	92.56	93.27	94.83	93.56	94.16
1-hr autocorrelation coefficient	0.927	0.925	0.924	0.925	0.921	0.922
Diurnal pattern strength	0.045	0.041	0.036	0.032	0.035	0.033
Hour of peak wind speed	20	20	19	19	19	19

Monthly Wind Profile, Mountain Village



Daily Wind Profile

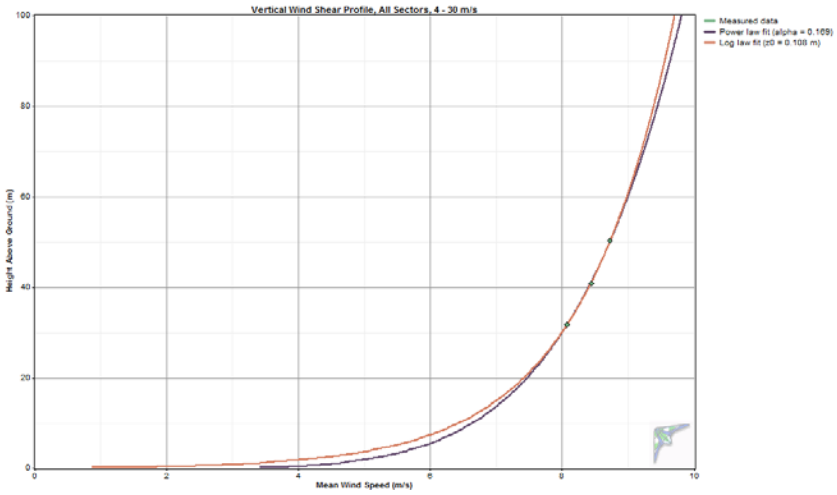
Similarly as measured at the Pitka's Point and Saint Mary's met towers, daily wind profile to date at the Mountain Village met tower is rather flat but higher wind speeds do occur in the afternoon and early evening as one would expect.



Wind Shear

At the Mountain Village met tower, the power law exponent is calculated date at 0.169 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 Mountain Village met tower site.

Wind Shear Profile, Mountain Village

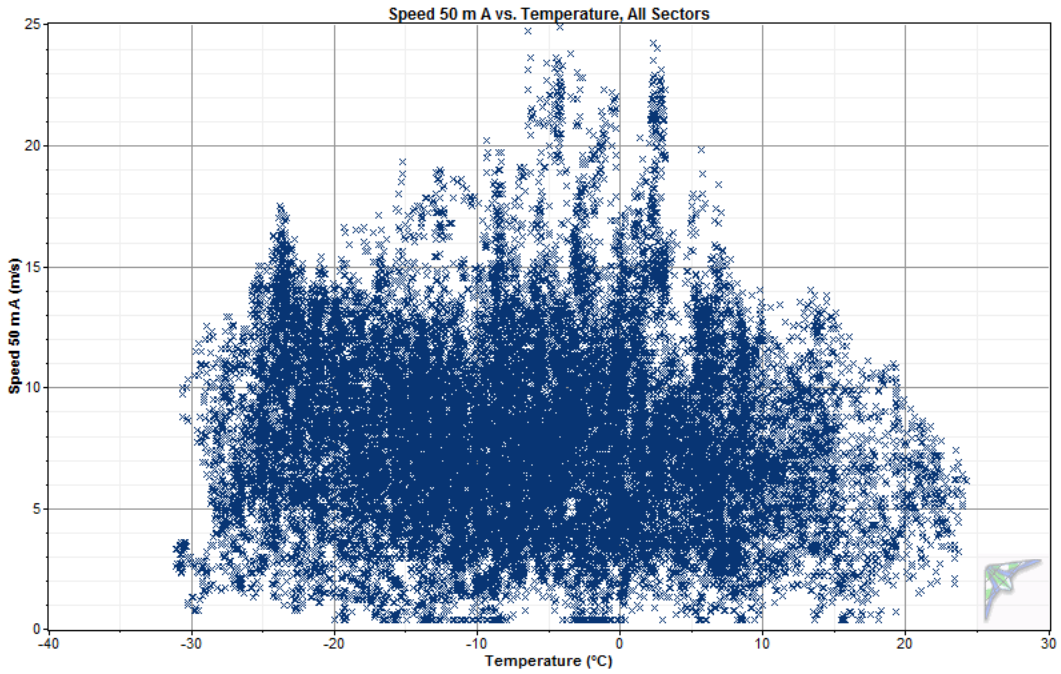


Wind Power Density

Power density as a function of height at the Mountain Village met tower site will be presented when additional data has been collected.

Scatterplot

At the Mountain Village site, power producing winds (greater than 4 m/s) are present through the entire temperature range of the site, even as low as (near) -30° C. A turbine selected for the Saint Mary's site should be capable of operation down to at least -30° C but a -40° C temperature rating is preferable as an arctic standard.

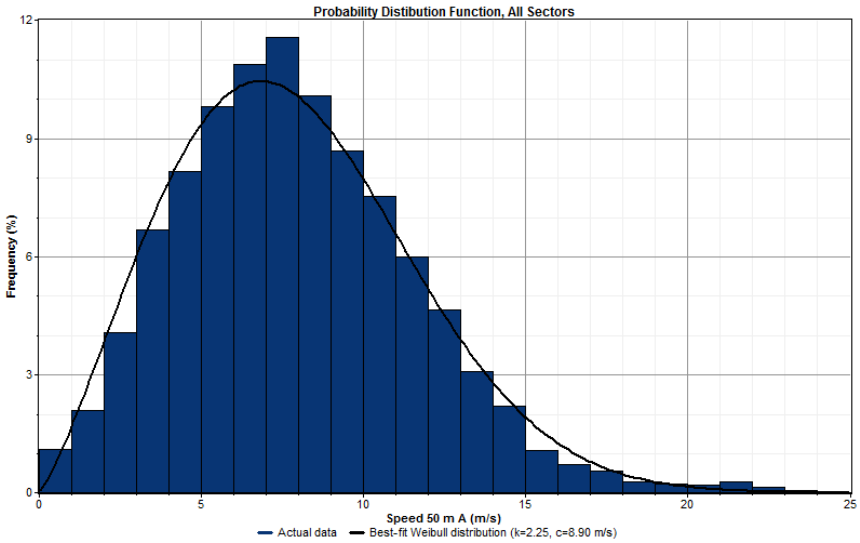


Extreme Wind Analysis

At present, insufficient data exists to calculate extreme wind probabilities for the Mountain Village met tower test site.

Probability Distribution Function

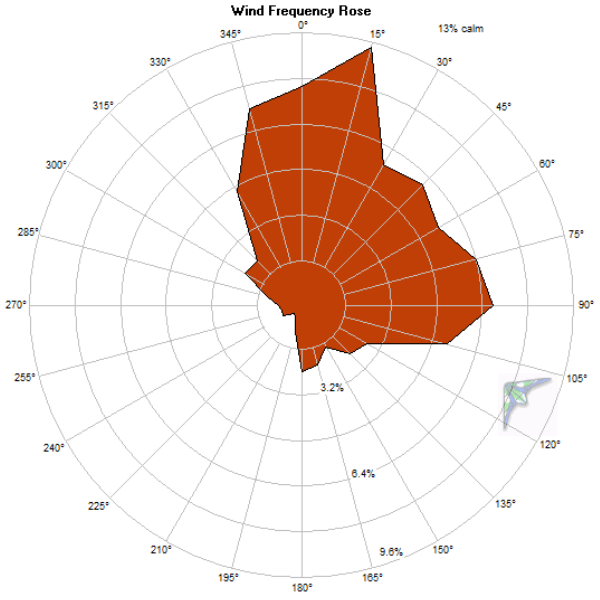
At the 50 meter level at the Mountain Village site to date, Weibull parameters are k = 2.25 and c = 8.90 m/s ("k" is the shape factor and "c" is the scale factor) for the data period. This shape factor is indicative of a near normal (Raleigh) wind distribution for wind power sites, although one weighted toward higher wind speeds. The shape factor will likely decrease toward 2.0 as additional summer data is included.



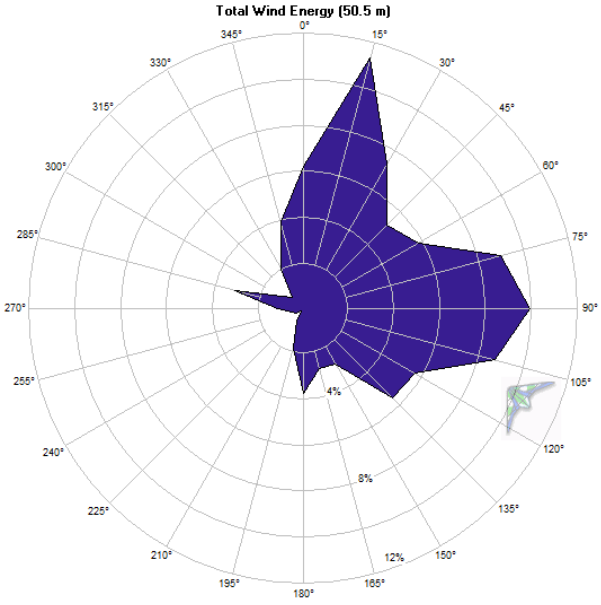
Wind Roses

To date, Mountain Village winds are dominated by north, northeast and east winds. Power density winds are more bi-directional with NNE and east winds. Note also that to date the Mountain Village site experiences 13 percent calm wind conditions (winds less than 4 m/s). This percentage will almost certainly increase with inclusion of additional summer data.

Wind Frequency Rose



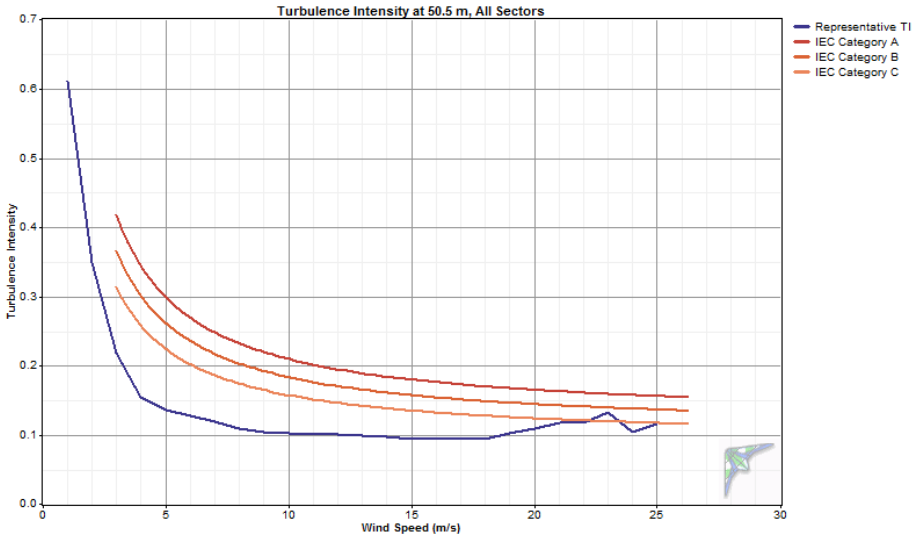
Total Value (power density) Rose



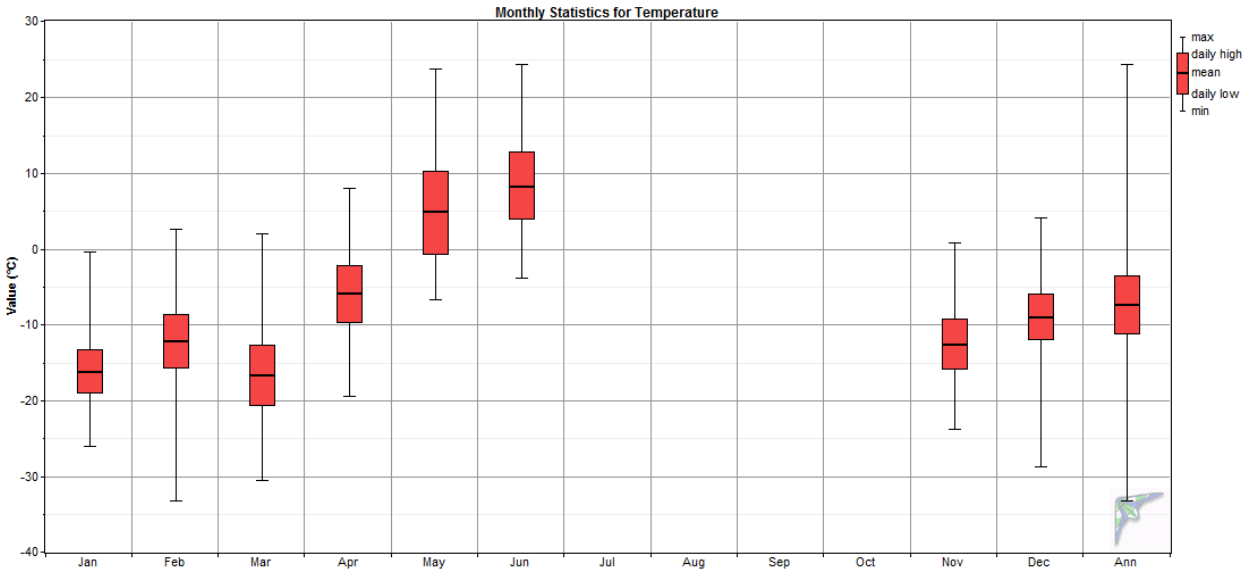
Turbulence Intensity

The Mountain Village site turbulence intensity (TI) is acceptable with a mean turbulence intensity of 0.068 and a representative turbulence intensity of 0.095 at 15 m/s wind speed, indicating very 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. These data are shown in the turbulence intensity graph below.

IEC 3rd Edition Turbulence Intensity Graph, Mountain Village, 50 m B anemometer



Air Temperature and Density

Over the reporting period, the Mountain Village met tower recorded an average temperature of -7.3° C. The minimum recorded temperature during the measurement period was –33.3° C and the maximum temperature was 24.3° C, indicating a wide variability of an ambient temperature operating environment important to wind turbine operations. Note, however, that the data period does not include most of the summer months, so average annual temperature will be higher, and likely equivalent to that recorded at the Pitka's Point and Saint Mary's met towers.

Annual Temperature Boxplot, Mountain Village