Egegik, Alaska Wind Resource Assessment Report

Egegik met tower, photo by Douglas Vaught

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Douglas Vaught, P.E.
V3 Energy, LLC
www.v3energy.com

V3 ENERGY LLC
Anchorage, Alaska 907.350.5047

Summary

The wind resource measured at the Egegik met tower site is outstanding with a mean annual wind speed of 7.43 m/s and a wind power density of 516 W/m^2 at 34 meters above ground level. In all respects the Egegik wind resource is highly suitable for wind power development. This wind resource assessment report was prepared by V3 Energy, LLC under contract to Lake and Peninsula Borough.

Met tower data synopsis

Data dates	8/20/2014 to 9/03/2016 (24.5 months)
Wind speed mean, 34 m, annual	7.43 m/s (16.6 mph)
Wind power density mean, 34 m	516 W/m^2
Wind power class	Class 5 (excellent)
Max. 10-min wind speed	32.6 m/s
Maximum 2-sec. wind gust	41.1 m/s (91.9 mph), December 2015
Weibull distribution parameters	k = 1.92, c = 8.34 m/s
Wind shear power law exponent	0.216 (moderate shear)
Surface roughness	0.28 meters (agricultural land with tall hedgerows)
IEC 61400-1, 3rd ed. classification	Class III-C
Turbulence intensity, mean (at 34 m)	0.104 (at 15 m/s)
Calm wind frequency (at 34 m)	19% (< 4 m/s)

Test Site Location and Selection Process

A 34 meter NRG Systems, Inc. tubular-type meteorological (met) tower was installed in Egegik in an open area of Becharof Corporation land on a hill approximately 2,200 ft. due east of the Egegik city office. Egegik is located on the south bank of the Egegik River on the Alaska Peninsula, 100 miles southeast of Dillingham and 326 air miles southwest of Anchorage. Egegik is incorporated as a 2nd class city in the Lake and Peninsula Borough with 85 permanent residents, but its population increases significantly during early and mid-summer when the local salmon processing plant is operational. Egegik falls within the southwest climate zone, characterized by persistently overcast skies, high winds, and frequent cyclonic storms.[1]

The test site was chosen after a decision was made not to lower and re-use an existing NRG Systems 30 meter, 4-inch diameter met tower located immediately across the street (due east) of the city office. This met tower had been in place for an unknown number of years and was in acceptable condition for re-use on site, but could not be moved because corrosion of the galvanized coating caused the slip-fit tower sections to fuse. It is not known who installed this tower, when, or the subsequent fate of any data collected from it.

Following abandonment of the old met tower location, focus was directed to the highest point of land in the community, excluding the location of the GCI cellular communications tower 2,300 ft. south of the subsequently-chosen met tower site. The met tower site is on Becharof Corporation land and their

[1] Community data obtained from State of Alaska DCCED Community and Regional Affairs website

approval was obtained for temporary installation of a met tower for the two-year life of the wind study. The site is a commanding location with excellent exposure and visibility in all directions. Heavy brush exists north and east of the site, which presents some concern for wind turbine operations.

After approval of the chosen site by Alaska Energy Authority (AEA), they forwarded a suggestion to instead consider a site at the intersection of the airport road and the GCI tower access road to better locate the met tower with existing power infrastructure. This site was inspected during a pre-installation visit and was deemed undesirable for met tower installation due to heavy brush and an undesirable slope for a met tower. Additionally, landowner permission and an FAA obstruction determination had already been obtained for the chosen location. But, given the strong wind resource measured in Egegik, this alternate site could be suitable wind turbines.

Southwest Alaska and Egegik, Google Maps image

Met Tower Information

The met tower was installed in late August 2014 with highly appreciated labor and material assistance from City of Egegik.

Met tower details

Site number	5500
Latitude/longitude	N 58° 12’ 31.50”, W 157° 21’ 49.00”
Time offset	-9 hours from UTC (Yukon/Alaska time zone)
Site elevation	45 meters (148 ft.)
Datalogger type	NRG SymphoniePLUS3, 10 minute time step
Tower type	Guyed tubular, 15 cm (6 in.) diameter, 34 meter (112 ft.) height

Tower sensor information

Channel	Sensor type	Designation	SN[2]	Height	Multiplier	Offset	Orientation
1	NRG #40C anem.	34 m A	222521	33.8 m	0.744	0.40	320 T[3]
2	NRG #40C anem.	34 m B	222522	34.0 m	0.758	0.34	185 T
3	NRG #40C anem.	20 m	222523	20.4 m	0.752	0.38	320 T
7	NRG #200P vane	Direction		33.1 m	0.351	000	000 T
9	NRG #110S Temp C	Temp		2.5 m	0.136	-86.38	030 T

Met tower installation; use of bulldozer to lift the tower

Tower sensor photographs

North side, up tower

East side, up tower

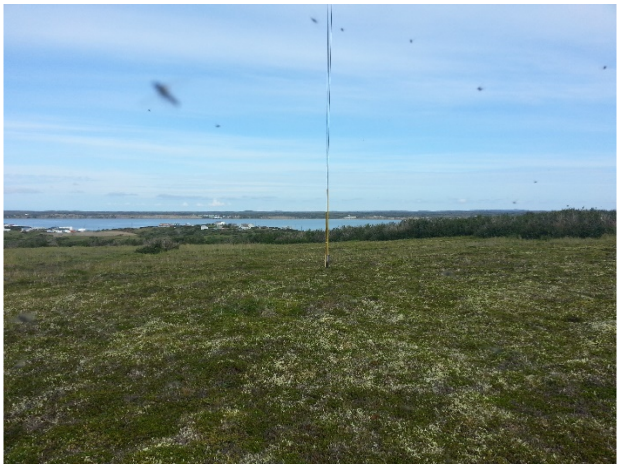
South side, up tower

West side, up tower

[2] Anemometer serial number

[3] Degrees true, or relative to Earth's geographic North Pole

Met tower site photographs



Site view to north

Site view to northeast

Site view to east

Site view to southeast

Site view to south

Site view to southwest

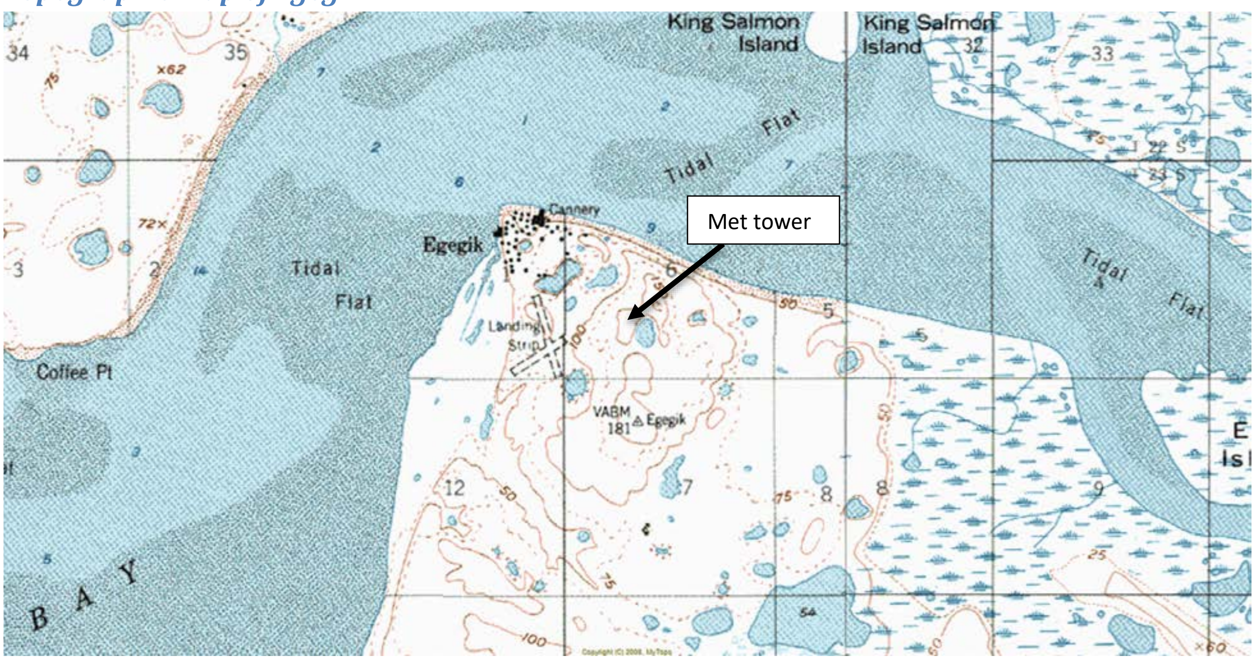

Site view to west


Site view to northwest

Egegik, view north, Google Earth image

Egegik, view south-southeast, Google Earth image

Topographic map of Egegik



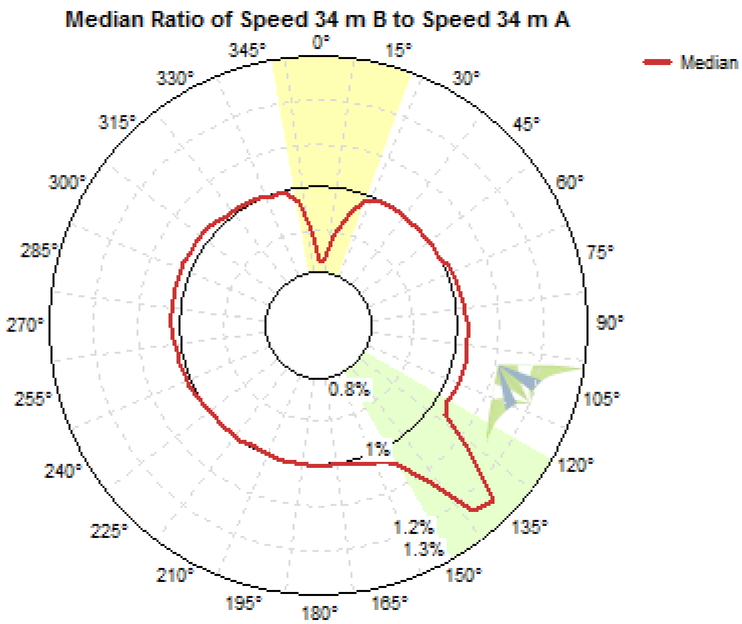
Data Quality Control

Data was filtered to remove presumed icing events that yield false zero wind speed data and non-variant wind direction data. Data that met criteria listed below were automatically filtered. In addition, data was manually filtered for obvious icing that the automatic filter didn't identify, and invalid or low quality data for situations such as logger initialization and other situations.

- Anemometer icing – data filtered if temperature < 1°C, speed SD = 0, and speed changes < 0.25 m/s for minimum 2 hours
- Vane icing – data filtered if temperature < 1°C and vane SD = 0 for minimum of 2 hours
- Tower shading of 34 meter A and B paired anemometers – data filtered when winds from ± 15° of behind tower; refer to graphic below

In general, icing conditions were infrequent indicating minimal concern for wind turbine energy production loss due to ice. With frequent southeasterly winds, tower shadow affected anemometer 34 m A (channel 1, oriented to 320° T) much more often than anemometer 34 m B (channel 2, oriented to 185° T), hence the significantly lower recovery rate of anemometer 34 m A.

Tower shading plot



Sensor data recovery table

Data Column	Possible Records	Valid Records	Recovery Rate	Icing	Invalid	Tower shading
Speed 34 m A	107,322	83,265	77.6%	1,927	197	21,793
Speed 34 m B	107,322	97,663	91.0%	1,632	198	7,880
Speed 20 m	107,322	105,077	97.9%	1,906	195	0
Direction 34 m	107,322	103,168	96.1%	3,804	206	0
Temperature	107,322	106,983	99.7%	0	195	0

Sensor data recovery rate by month (includes tower shading for 34 m A & B)

Year	Month	34 m A	34 m B	20 m	Vane	Temp
2014	Aug	82.5	83.6	88.7	88.1	88.7
2014	Sep	86.3	87.3	100.0	100.0	100.0
2014	Oct	91.1	75.1	100.0	100.0	100.0

Year	Month	34 m A	34 m B	20 m	Vane	Temp
2014	Nov	74.7	92.5	99.7	86.5	100.0
2014	Dec	75.1	96.8	95.2	86.5	100.0
2015	Jan	72.4	72.5	78.7	69.9	100.0
2015	Feb	76.5	87.7	96.4	94.9	100.0
2015	Mar	75.7	84.9	92.6	92.3	100.0
2015	Apr	80.6	87.7	100.0	100.0	100.0
2015	May	38.7	96.7	100.0	100.0	100.0
2015	Jun	80.7	96.7	100.0	100.0	100.0
2015	Jul	76.0	98.1	100.0	100.0	100.0
2015	Aug	89.1	89.7	100.0	100.0	100.0
2015	Sep	89.3	86.5	100.0	100.0	100.0
2015	Oct	83.9	88.5	100.0	100.0	100.0
2015	Nov	85.0	94.3	100.0	96.8	100.0
2015	Dec	77.6	91.7	98.5	93.4	100.0
2016	Jan	77.8	92.8	96.8	96.8	96.8
2016	Feb	80.9	95.7	97.3	97.4	100.0
2016	Mar	84.3	85.9	98.4	96.1	100.0
2016	Apr	61.2	97.5	100.0	100.0	100.0
2016	May	67.0	98.0	100.0	100.0	100.0
2016	Jun	83.3	97.5	100.0	100.0	100.0
2016	Jul	88.0	98.2	100.0	100.0	100.0
2016	Aug	68.4	94.3	100.0	100.0	100.0
2016	Sep	43.6	98.8	100.0	100.0	100.0
All Data		77.6	91.0	97.9	96.1	99.7

Data Synthesis

Filtering removes compromised sensor readings from the data set. This is desirable for icing in that it eliminates the negative speed bias of false "zero" data. Filtering for tower shadow is more nuanced in that filtered results bias both paired anemometers, but it's not obvious in which direction for either. One solution is to remove filtered data and fill the missing gaps with synthesized data using a gap-filling subroutine[4] contained in Windographer Pro software. Gap-filling, or data synthesis, yields more a more representative and realistic data set. This is especially true for tower shadow-filtered data in that the flagged data from one paired anemometer can be reconstructed with data from the other anemometer of the pair. The result is a true representation of wind speeds from both paired anemometers. Gap-filling icing-flagged data is more complex in that often all anemometers and/or wind vanes freeze simultaneously and hence Windographer software must use the Markov transition to create a probable result for the flagged period. For short icing periods, the inherent uncertainty of this approach is low; for long periods, it is higher.

[4] First-order Markov transition matrix; described in Windographer Help

Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a moderate wind resource. Note that cold temperatures contributed to a higher wind power density than standard conditions would yield for the measured mean wind speeds. This is reflected in the CRMC (cubed root mean cubed) wind speed, which reflects a calculation of a steady wind speed, at the measured mean air density, that would yield the measured mean wind power density. In other words, given the cool climate in Egegik, the winds punch above their weight.

A table following that below presents the same data but with anemometer icing and tower shadow data removed from the data set and then synthesized with Windographer software's gap-filling subroutine. The advantage of gap-filling is that a more representative data set is achieved, especially with inclusion of data from the opposing anemometer (with paired anemometers) when data is filtered for tower shadow (gap-filling synthesizes tower shadow data by referencing the paired anemometer where data is not flagged).

Anemometer data summary (gap-filled)

Variable	Speed 34 m A	Speed 34 m B	Speed 20 m
Measurement height (m)	33.8	34.0	20.4
Mean wind speed (m/s)	7.36	7.41	6.60
MoMM[5] wind speed (m/s)	7.38	7.43	6.61
Max 10 min avg. wind speed (m/s)	32.6	32.6	30.0
Max gust wind speed (m/s)	41.1	38.7	40.8
CRMC wind speed (m/s)	9.24	9.32	8.27
Weibull k	1.94	1.92	1.97
Weibull c (m/s)	8.29	8.34	7.44
Mean power density (W/m²)	498	511	357
MoMM power density (W/m²)	503	516	361
Mean energy content (kWh/m²/yr)	4,359	4,475	3,129
MoMM energy content (kWh/m²/yr)	4,403	4,519	3,159
Energy pattern factor	1.98	1.99	1.97
Frequency of calms (<4 m/s) (%)	19.8	19.9	24.3

Time Series

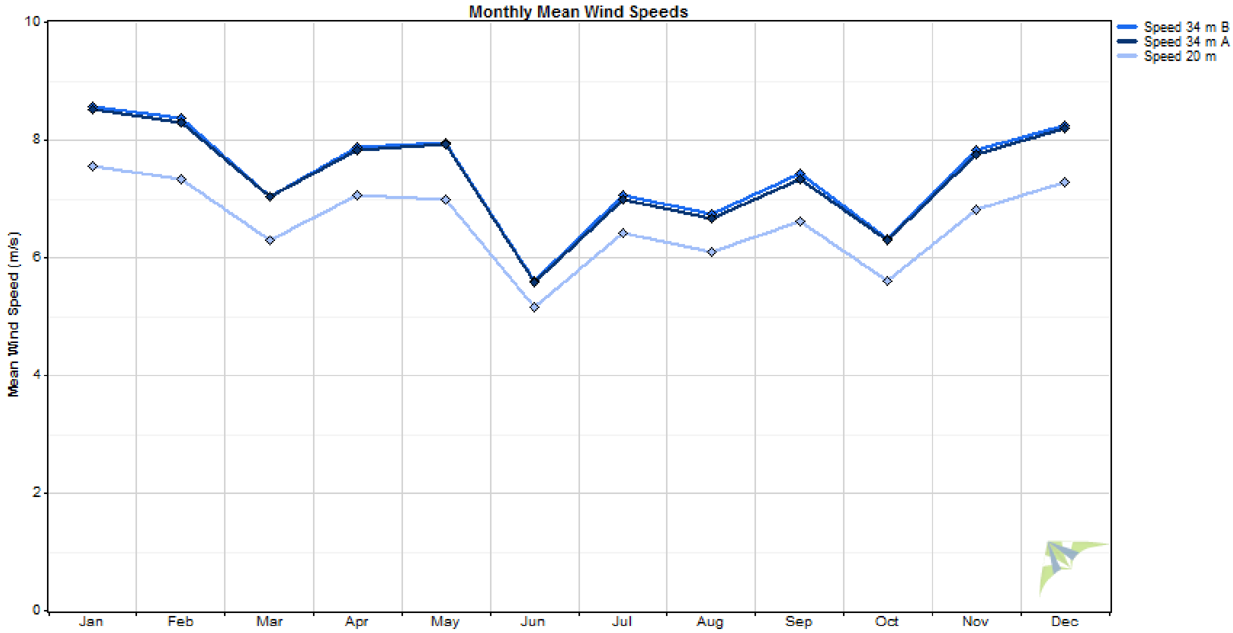
Time series calculations indicate higher wind speeds during the winter months compared to summer month, but this difference is not highly pronounced. The daily wind profile (annual basis) indicates higher wind speeds during the day with peak winds occurring between 3 and 4:00 p.m.

[5] MoMM: mean of monthly means, or annual

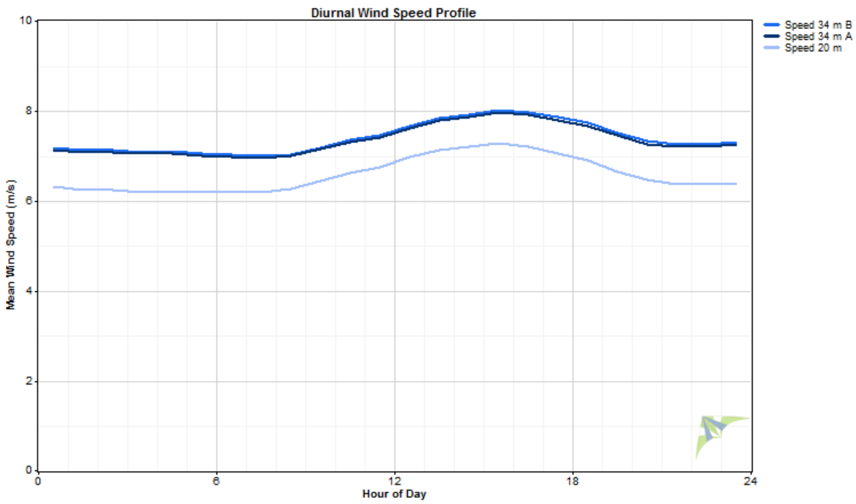
34 m B anemometer data summary

Year	Month	Raw Mean (m/s)	Filtered Mean (m/s)	Gap-filled Mean (m/s)	Max 10-min Avg (m/s)	Max Gust (m/s)	Std. Dev. (m/s)	Weibull k (-)	Weibull c (m/s)
2014	Aug	6.68	6.79	6.71	14.4	19.0	2.72	2.62	7.53
2014	Sep	7.40	7.52	7.51	22.4	28.0	4.00	1.92	8.44
2014	Oct	6.14	6.26	6.38	15.9	19.9	3.02	2.19	7.17
2014	Nov	7.04	7.24	7.08	22.0	28.0	3.89	1.87	7.96
2014	Dec	7.77	7.94	7.88	28.0	34.6	4.78	1.74	8.88
2015	Jan	6.34	7.82	7.89	18.7	25.7	3.26	2.55	8.87
2015	Feb	7.87	7.98	8.15	23.9	31.8	3.81	2.26	9.20
2015	Mar	7.04	7.69	7.61	19.2	24.6	3.49	2.31	8.58
2015	Apr	7.65	7.87	7.74	20.2	25.7	3.90	2.09	8.74
2015	May	8.98	9.17	8.99	23.4	29.2	4.92	1.87	10.10
2015	Jun	5.79	5.87	5.81	19.6	24.6	3.17	1.90	6.54
2015	Jul	6.89	6.99	6.90	22.6	28.0	3.93	1.81	7.75
2015	Aug	7.13	7.34	7.19	16.7	20.7	3.25	2.35	8.12
2015	Sep	7.49	7.59	7.58	21.7	28.0	3.90	2.02	8.54
2015	Oct	6.19	6.16	6.29	16.0	19.9	3.22	1.91	7.00
2015	Nov	8.60	8.64	8.62	21.9	28.0	3.85	2.38	9.72
2015	Dec	8.48	8.89	8.62	32.6	41.1	5.57	1.58	9.60
2016	Jan	9.15	9.29	9.17	26.7	34.6	4.28	2.25	10.34
2016	Feb	8.41	8.64	8.58	20.4	26.8	3.79	2.40	9.66
2016	Mar	6.43	6.42	6.53	19.5	23.6	4.22	1.47	7.16
2016	Apr	8.02	8.13	8.04	22.9	28.0	4.16	2.02	9.07
2016	May	6.93	7.00	6.94	18.9	24.6	3.63	2.00	7.83
2016	Jun	5.43	5.49	5.44	20.1	25.7	3.49	1.62	6.08
2016	Jul	7.24	7.27	7.25	16.8	19.9	3.35	2.30	8.17
2016	Aug	6.31	6.41	6.34	15.9	19.9	2.98	2.24	7.15
2016	Sep	5.05	5.09	5.05	10.6	14.2	2.35	2.31	5.71
All Data		7.26	7.47	7.41	32.6	41.1	3.98	1.92	8.34
Annual		7.27	7.48	7.43					

Monthly time series (annual), mean wind speeds (gap-filled data set)



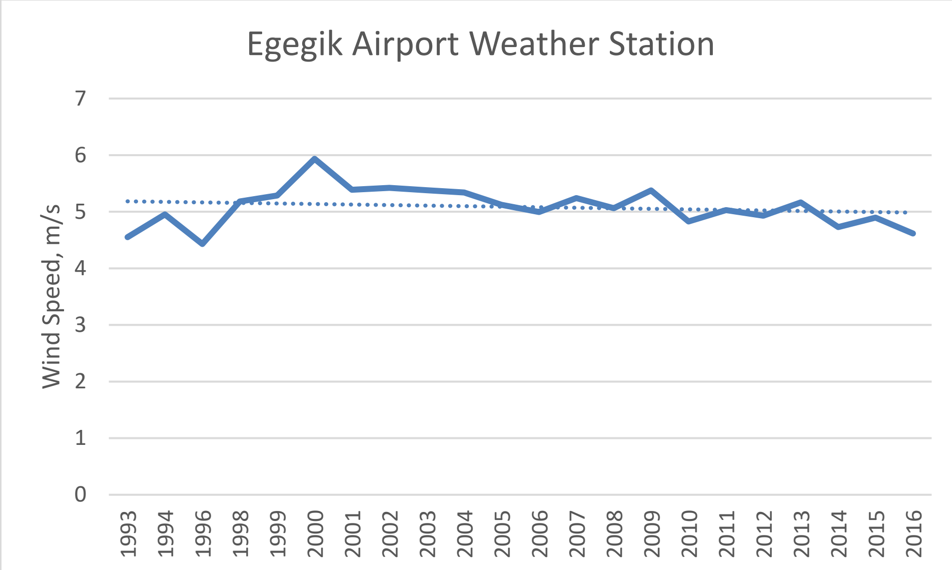
Daily wind profile (gap-filled data set)



Long-term Wind Speed Average

Comparing the 24 months of measured wind speed data at the Egegik met tower is possible by reference to the nearby Egegik Airport automated weather station. Data for this station was obtained for the time period of June 1993 through Dec. 31, 2016. For this 27.5 year time period, the AWOS station recorded an average wind speed of 5.09 m/s (at a 10 meter measurement height). In 2015, which comprises the only full calendar year of the Egegik met tower operating time period, the AWOS station wind speed average was 4.89 m/s, which is 4% less than the long-term average. Note also a very slight declining trend in wind speed over the 27.5 year period, although this data trend is mostly driven by high wind speed variability from 1993 to 2000. Since 2000, winds at the Egegik Airport have been fairly constant.

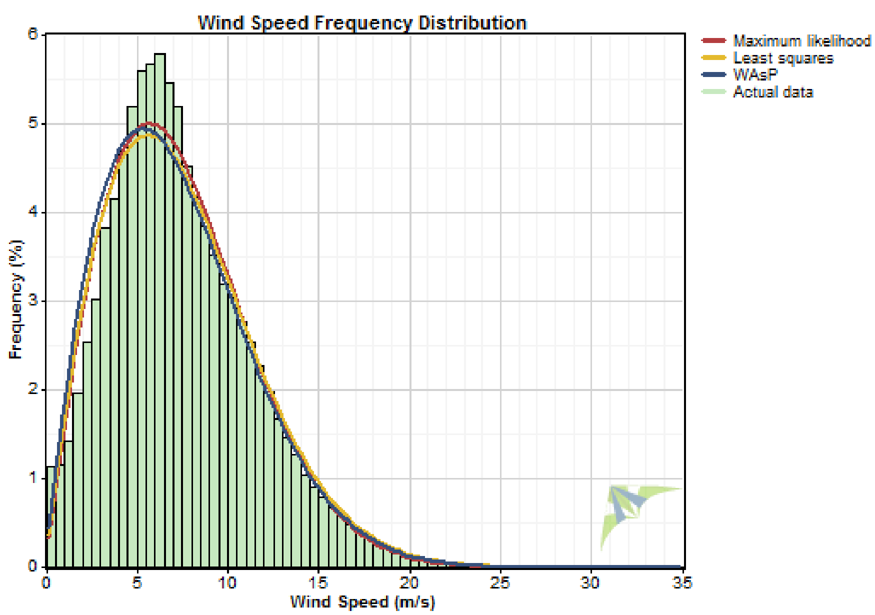
Egegik Airport wind speed



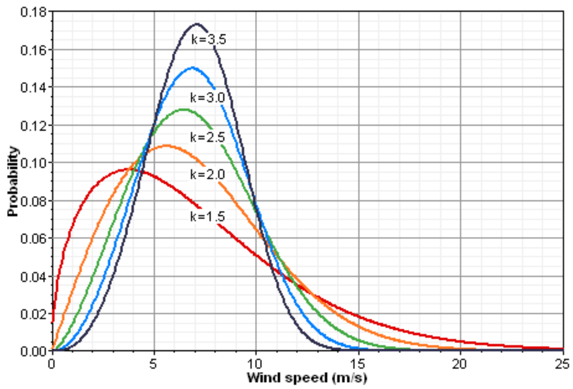
Probability Distribution Function

The probability distribution function (PDF), or histogram, of the Egegik met tower site wind speed indicates a shape curve dominated by moderate wind speeds and is mostly reflective of 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 seen below in the wind speed distribution of the 34 meter B anemometer, the most frequently-occurring wind speeds are between 4 and 8 m/s with few wind events exceeding 20 m/s, the cutout speed of most wind turbines. Also, note the accompanying cumulation distribution with respect to the infrequency of very high wind speeds in Egegik.

PDF of 34 m B anemometer (gap-filled)



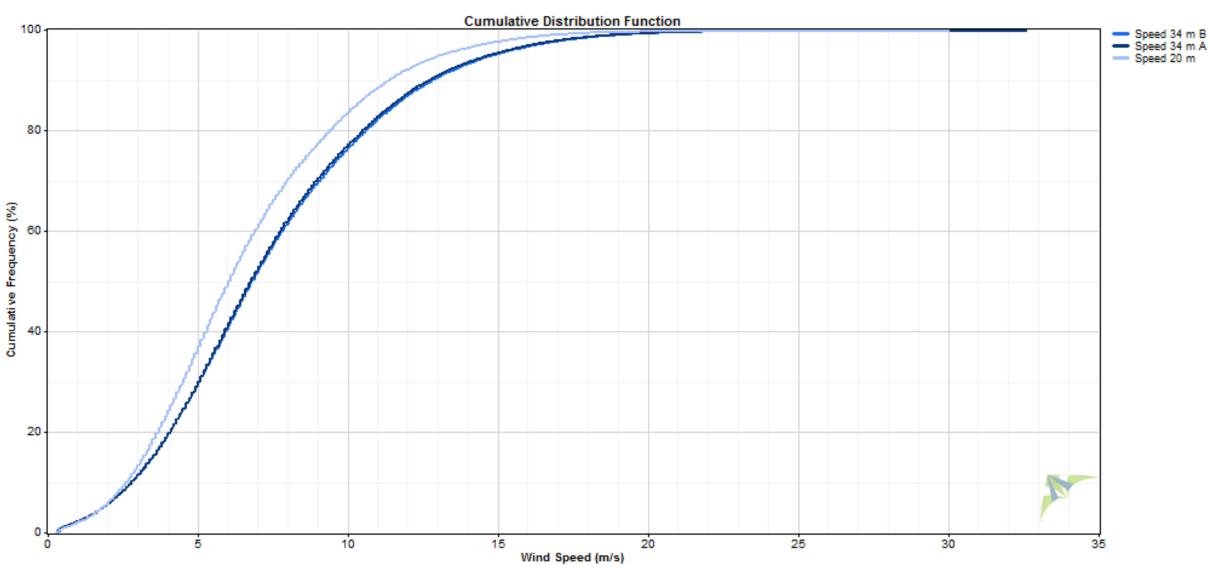
Weibull k shape curve table



Weibull values table, 34m B anemometer

Algorithm	Weibull k	Weibull c (m/s)	Mean (m/s)	Proportion Above 7.41 m/s	Power Density (W/m2)	R Squared[6]
Maximum likelihood	1.92	8.34	7.39	0.451	493.1	0.981
Least squares	1.87	8.42	7.47	0.455	524.1	0.976
WAsP	1.83	8.19	7.28	0.435	495.5	0.971
Actual data			7.41	0.435	495.5	

Cumulative distribution



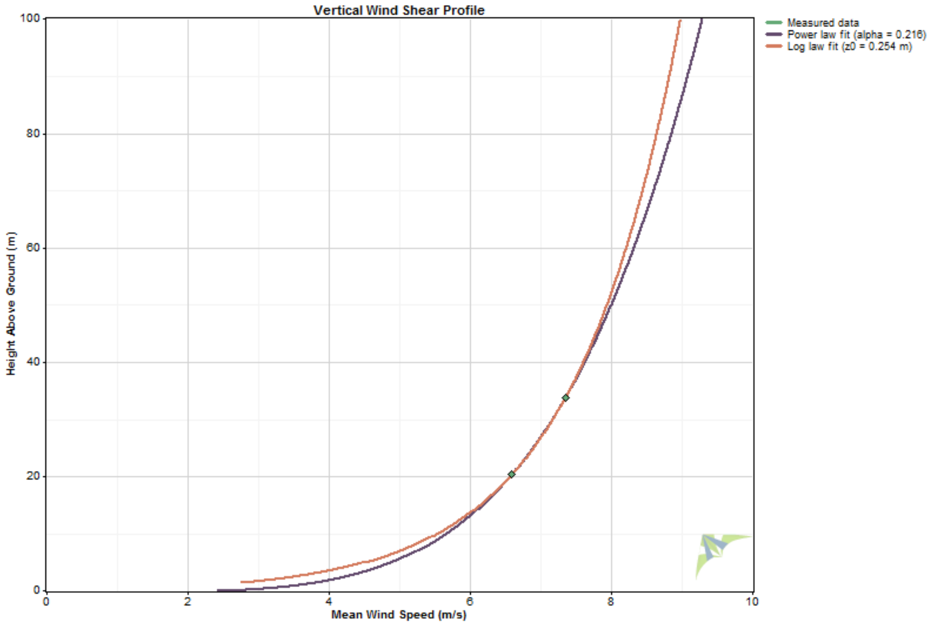
Wind Shear and Roughness

Wind shear at the Egegik met tower site was calculated with the 34 m A and 20 m anemometers, both of which were oriented toward 320° T. The calculated power law exponent of 0.216 indicates a moderate

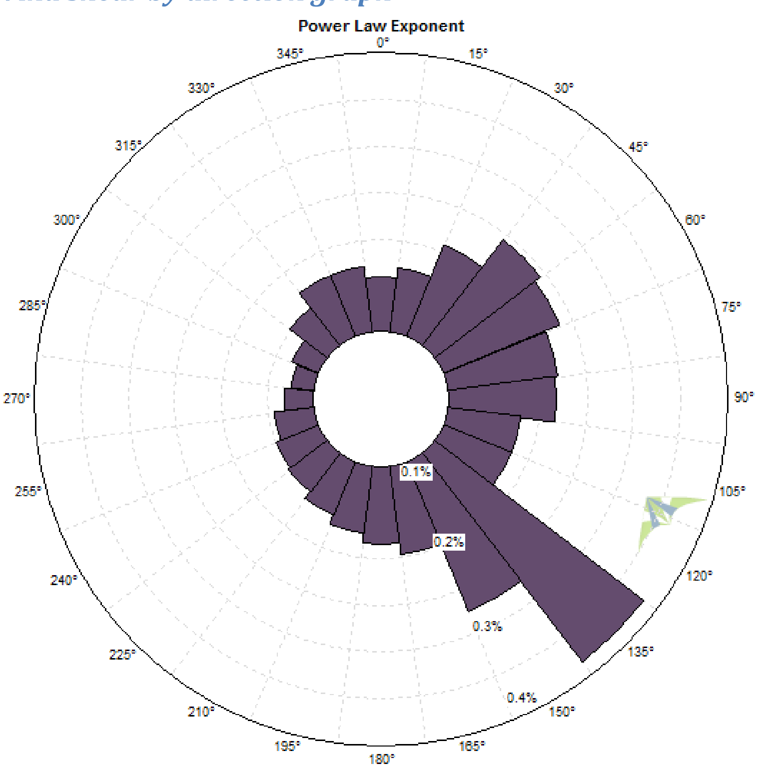
[6] Relatedness or correlation of Weibull approximation algorithm with actual data

wind shear at the site. Calculated surface roughness at the site is 0.29 m (the height above ground where wind speed would be zero) for a roughness class of 2.88 (description: agricultural land). Note the high shear with southeasterly winds, undoubtedly due to upwind brush. Mitigation should be considered if wind turbines are located at or near this site, such as removal of the brush.

Vertical wind shear profile



Wind shear by direction graph



Extreme Winds

International Electrotechnical Commission (IEC) 61400-1, 3rd edition extreme wind probability classification is one criteria – with turbulence the other – that describes a site with respect to suitability for wind turbine models. Extreme wind is described by the 50 year V_{ref}, or reference velocity in a 50 year return period; in other words, V_{ref} is the wind speed (10-minute average) predicted to occur once every 50 years.

IEC 61400-1 extreme wind classification

IEC 61400-1, 3rd ed.	
Class	V_{ref}, m/s
I	50
II	42.5
III	37.5
S	designer-specified

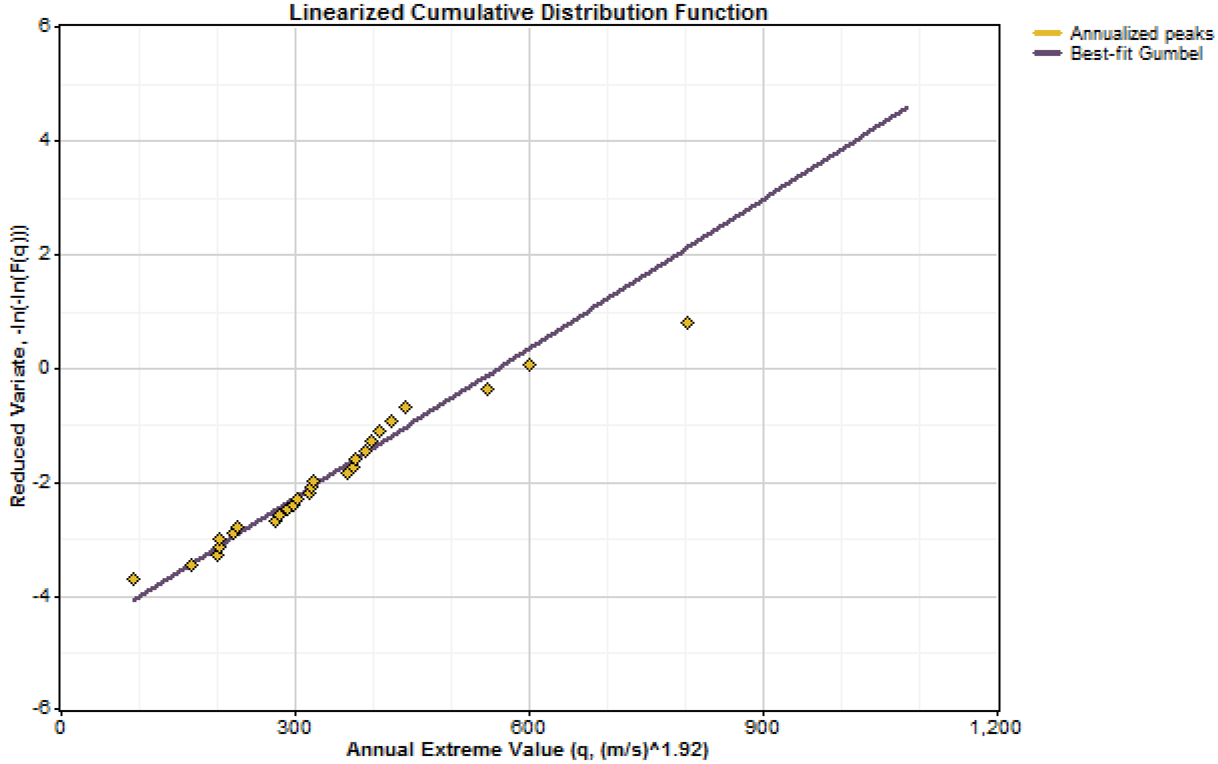
Periodic Maxima

One method to estimate V_{ref} is a Gumbel distribution analysis modified for monthly maximum winds versus annual maximum winds, which are typically used for this calculation. Thirty-four months of wind data in the 50 meter met tower data set are acceptable for this analysis, although, as noted previously, the latter months of that data set were compromised by sensor failure and all sensors were compromised by icing during the winter months.

For this analysis, the 34 meter level B anemometer is referenced because it recorded the highest wind speeds of the three anemometers on the tower. With filtered, gap-filled, and preconditioned[7] (by the Weibull k value as an exponent) data, the predicted V_{ref} by this method is 36.6 m/s. This result meets IEC 3rd edition Class III criteria, the lowest-defined category of extreme wind probability. Note, however, the presumed substantial loss of higher speed winter anemometer data due to icing. Given the comparison of measured and filtered mean wind speed to the AWS Truepower model, it is possible that V_{ref} may be higher than calculated.

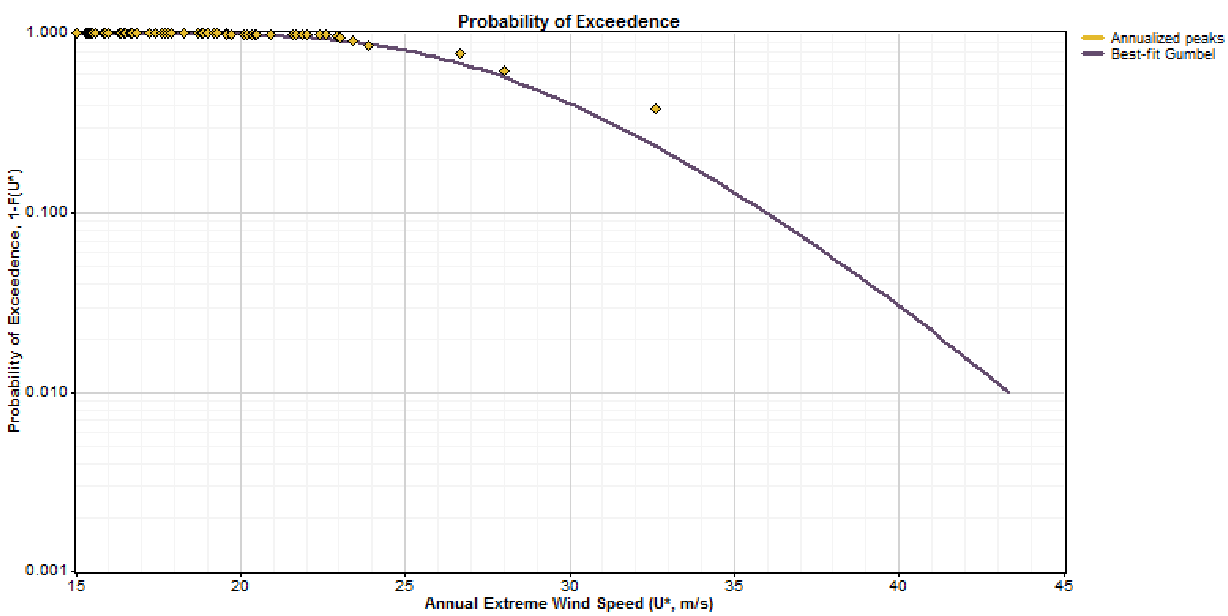
[7] Preconditioning improves the accuracy of 50-year extreme wind speed estimates; Windographer Help (references 1996 (Harris) and 2009 (Langreder et al.) studies).

Periodic maxima cumulative distribution, 34 m B anemometer



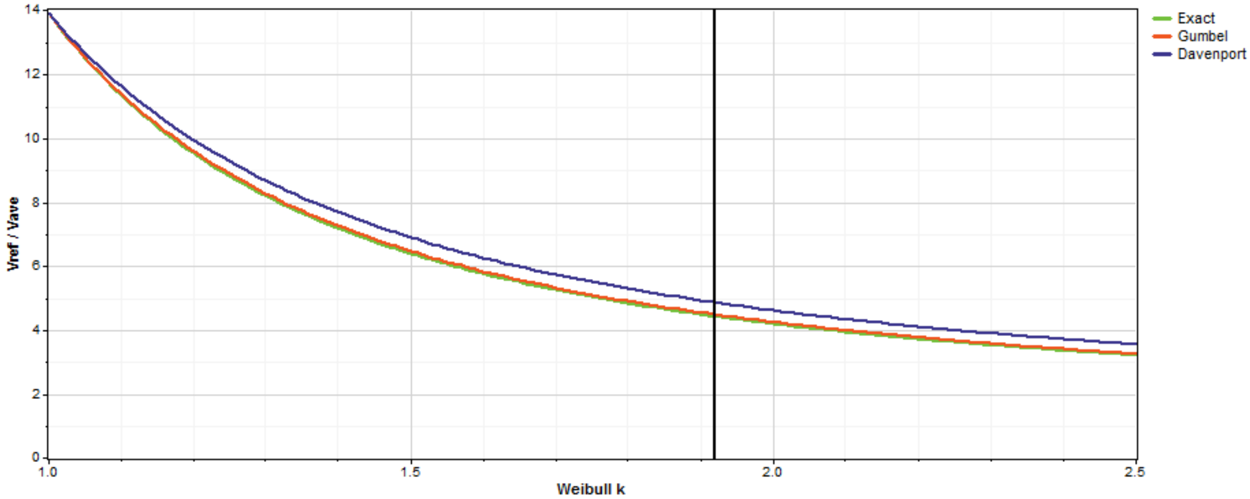
A second technique, Method of Independent Storms, yields a V_{ref} estimate of 41.2 m/s, higher than that predicted by the periodic maxima method but still within the classification constraint to classify as IEC 61400-1 Class II extreme wind.

Method of Independent Storms



A third method, known as EWTS II (European Wind Turbine Standards II), ignores recorded peak wind speeds and calculates V_{ref} from the Weibull k factor. There are three variations of this method – Exact, Gumbel and Davenport – which yields a V_{ref} between 32.9 and 36.2 m/s for Egegik. These are in-line with the periodic maxima method and within IEC 3rd edition Class III extreme wind criteria.

EWTS II plot



Summary

The calculated V_{ref} wind speeds by the three methods described above all meet IEC 61400-1, 3rd edition criteria for Class III wind classification, which has a V_{ref} limit of 42.5 m/s. The practical importance is that turbines suitable for Egegik should be IEC 61400-1 Class II certified, or possibly Class III certified if referencing only the periodic maxima and EWTS methodology.

EWTS II table

Method	Vref (50 yr) (m/s)
Periodic Maxima	36.6
Method of Independent Storms	41.3
EWTS II (Exact)	32.9
EWTS II (Gumbel)	33.4
EWTS II (Davenport)	36.2

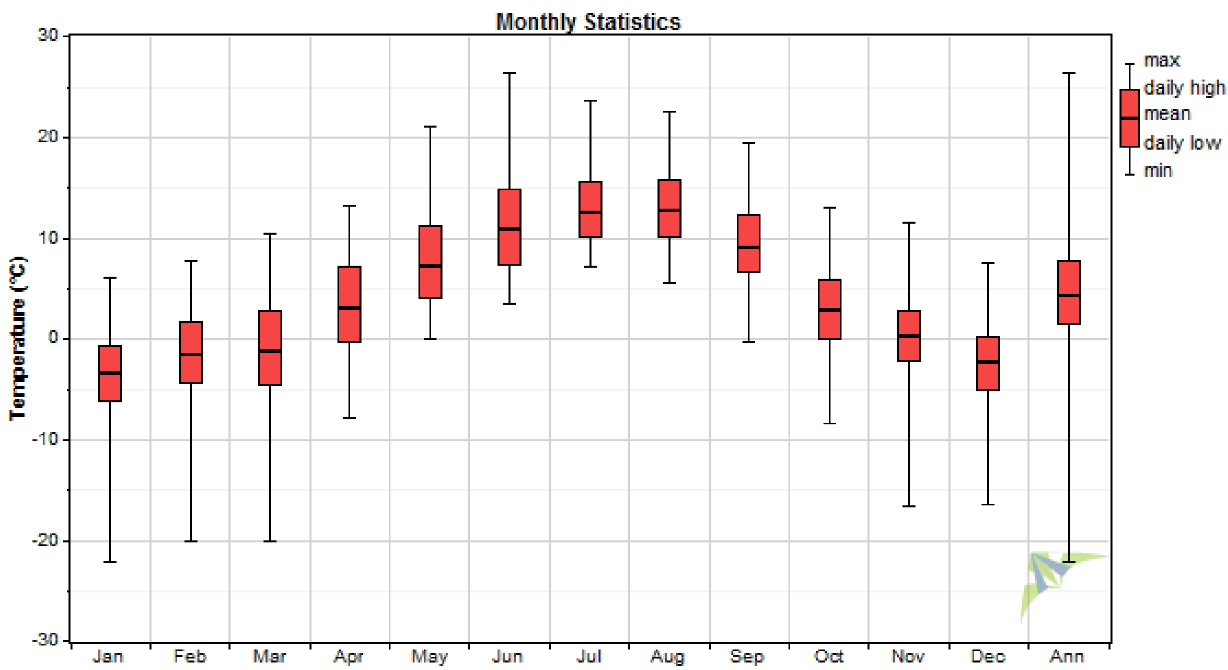
Temperature, Density, and Relative Humidity

Egegik experiences cool summers and relatively mild winters, by interior Alaska standards, 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 45 meter elevation by 3.6 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

Month	Mean (°C)	Min (°C)	Max (°C)	Mean (°F)	Min (°F)	Max (°F)	Mean (kg/m3)	Min (kg/m3)	Max (kg/m3)
Jan	-3.3	-22.1	6.1	26.1	-7.8	43.0	1.300	1.216	1.399
Feb	-1.4	-20.1	7.8	29.5	-4.2	46.0	1.292	1.248	1.388
Mar	-1.0	-20.1	10.6	30.2	-4.2	51.1	1.290	1.235	1.388
Apr	3.2	-7.7	13.3	37.8	18.1	55.9	1.270	1.223	1.323
May	7.4	0.1	21.1	45.3	32.2	70.0	1.250	1.188	1.284
Jun	11.0	3.5	26.4	51.8	38.3	79.5	1.233	1.165	1.268
Jul	12.8	7.2	23.7	55.0	45.0	74.7	1.225	1.177	1.251
Aug	12.8	5.5	22.6	55.0	41.9	72.7	1.225	1.182	1.259
Sep	9.3	-0.3	19.5	48.7	31.5	67.1	1.241	1.195	1.286
Oct	3.0	-8.4	13.1	37.4	16.9	55.6	1.271	1.224	1.326
Nov	0.5	-16.6	11.6	32.9	2.1	52.9	1.283	1.231	1.369
Dec	-2.0	-16.3	7.6	28.4	2.7	45.7	1.295	1.249	1.367
Annual	4.4	-22.1	26.4	39.8	-7.8	79.5	1.264	1.165	1.399

Egegik temperature boxplot graph

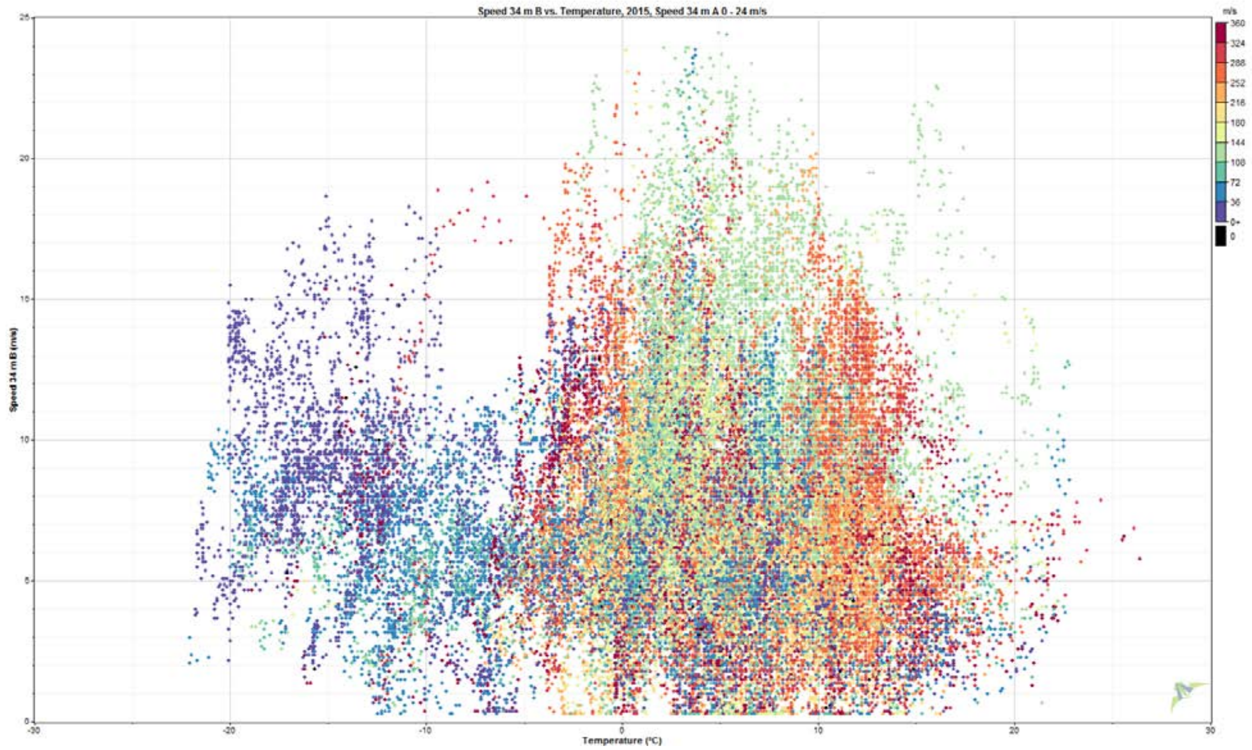


Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates relatively cool temperatures at the Egegik met tower site but on average temperatures are above freezing, as indicated in the preceding temperate and density table. During the met tower test period, temperatures were not often colder than -20° C (-4° F), the minimum operating temperature for most standard-environment wind turbines.

With this, wind turbines with an arctic option, designed for -40° C operations, may not be necessary in Egegik.

Wind speed/temperature (color code indicates wind direction)

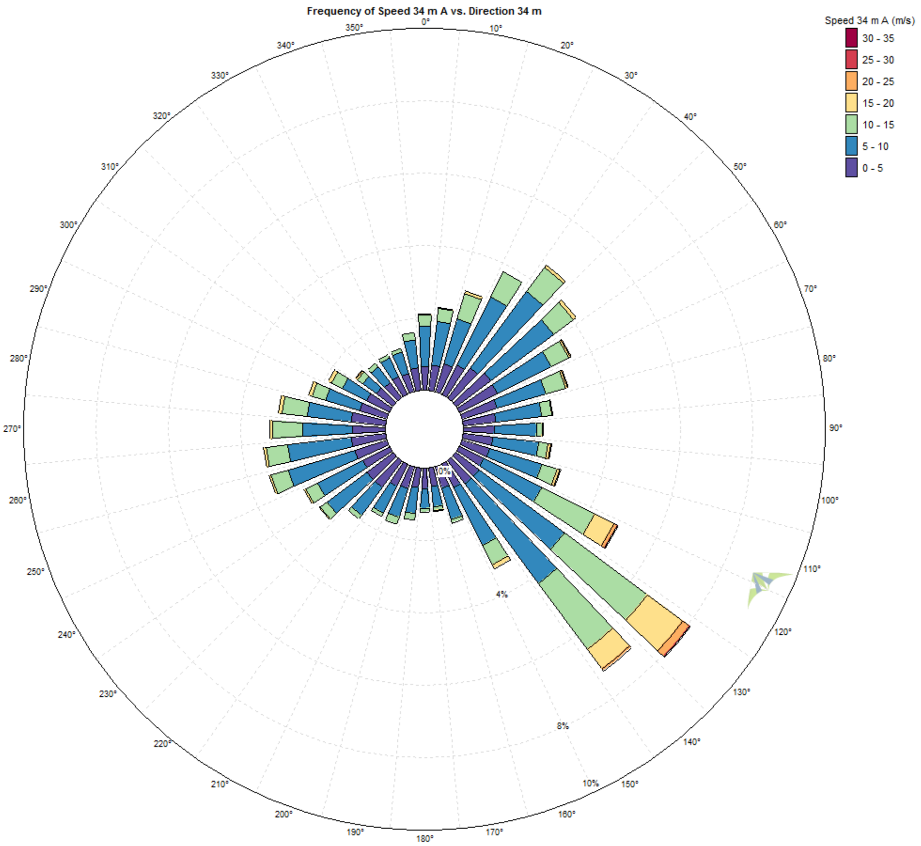


Wind Direction

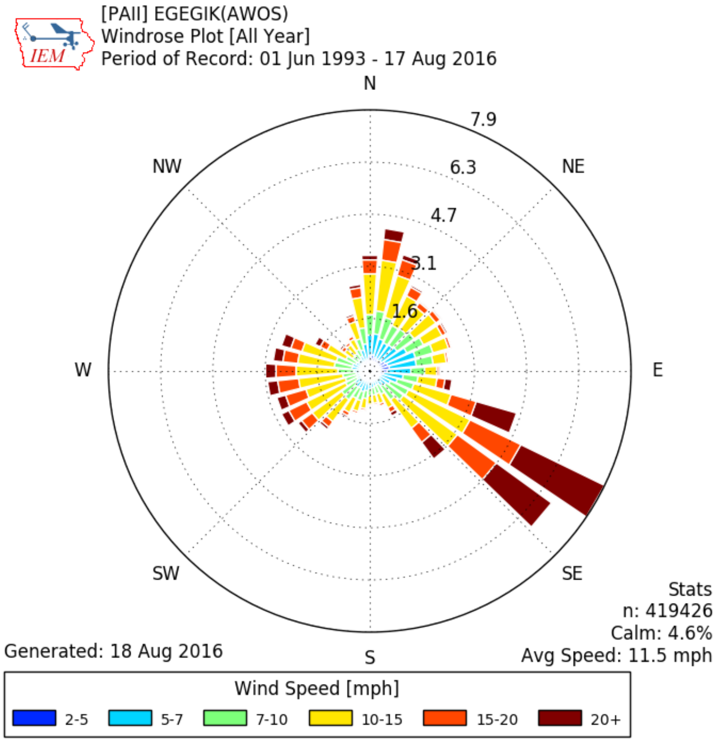
Wind frequency rose data indicates that winds at the Egegik met tower site are primarily southeasterly, with northeasterly and westerly winds frequent as well. The magnitude of the wind sector "pie" slices indicate that the strongest winds are very strongly southeasterly.

Note that the measured wind rose at the met tower site mostly correlates with that winds observed by the automated weather station at the nearby Egegik Airport. The primary difference is that the airport recorded more northerly winds that was measured at the met tower.

Wind frequency and energy rose



Egegik Airport wind rose



Turbulence

The turbulence intensity (TI) at the Egegik met tower site is low with a mean turbulence intensity of 0.075 and a representative turbulence intensity of 0.104 at 15 m/s wind speed at the 34 meter level, indicating smooth air for wind turbine operations. This equates to an International Electrotechnical Commission (IEC) 61400-1, 3rd Edition (2005) turbulence category C, which is the lowest defined category.

Turbulence Intensity table

Wind Speed Sensor	All Speed Bins				15 m/s Speed Bin			
	Mean TI	SD of TI	Representative TI	Peak TI	Mean TI	SD of TI	Representative TI	IEC 3 ed. Turb. Cat.
Speed 34 m B	0.130	0.090	0.250	1.46	0.104	0.018	0.127	C
Speed 34 m A	0.130	0.080	0.240	1.74	0.104	0.023	0.133	C
Speed 20 m	0.150	0.080	0.250	1.27	0.129	0.018	0.152	B

Turbulence intensity, all direction sectors