# Kivalina Wind Resource Report

Kivalina aerial photo by Doug Vaught, July 2011

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Douglas Vaught, P.E.
dvaught@v3energy.com
V3 Energy, LLC
Eagle River, Alaska

## Purpose

The Kivalina wind resource report is a component of a larger feasibility study to install wind turbines in either Kivalina or at the Red Dog Port facility located 27 km (17 miles) to the southeast. The feasibility study includes an analysis of a potential electrical intertie connecting Kivalina to Red Dog Port. A follow-on version of this wind resource report will include a comparison of wind data being collected at Red Dog Port.

## Summary

The wind resource measured at the Kivalina met tower site is good with measured wind power class 4 (description: good) if considering power density and wind power class 3 (description: fair) if considering only mean wind speed. Given the cold temperatures in Kivalina, higher wind density results in a higher power density than at standard temperature and pressure. In other respects, Kivalina's wind characteristics are ideal with exceptionally low turbulence and low wind shear. Kivalina experiences very cold winter temperatures, which will increase energy production of both variable pitch and stall-regulated wind turbines, but the low elevation of the site keeps it free of problematic rime icing problems that have been noted elsewhere in northern Alaska.

The Kivalina wind resource study was funded by the Alaska Energy Authority and managed by WHPacific for the Alaska Village Electric Cooperative (AVEC). WHPacific contracted V3 Energy, LLC to write this wind resource report. AVEC and WHPacific points of contact, respectively, are Brent Petrie, Key Accounts Manager (bpetrie@avec.org), and Katherine Keith, Distributed Energy Specialist (kkeith@whpacific.com).

## Met tower data synopsis

| | |
|---|---|
| Data dates | May 9, 2011 to May 18, 2012 (12.3 months); status: operational |
| Wind power class | Class 3 to Class 4 |
| Wind power density mean, 30 m | 325 W/m$^2$ |
| Wind speed mean, 30 m | 5.87 m/s |
| Max. 10-min wind speed average | 26.7 m/s |
| Maximum 2-sec. wind gust | 33.6 m/s (November, 2011) |
| Weibull distribution parameters | k = 1.66, c = 6.56 m/s |
| Wind shear power law exponent | 0.194 (moderate) (see report for notes) |
| Roughness class | 2.11 (few trees) (see report for notes) |
| IEC 61400-1, 3$^{rd}$ ed. classification | Class III-C |
| Turbulence intensity, mean | 0.075 (at 15 m/s) |
| Calm wind frequency (at 33 m) | 34% (< 4 m/s) |

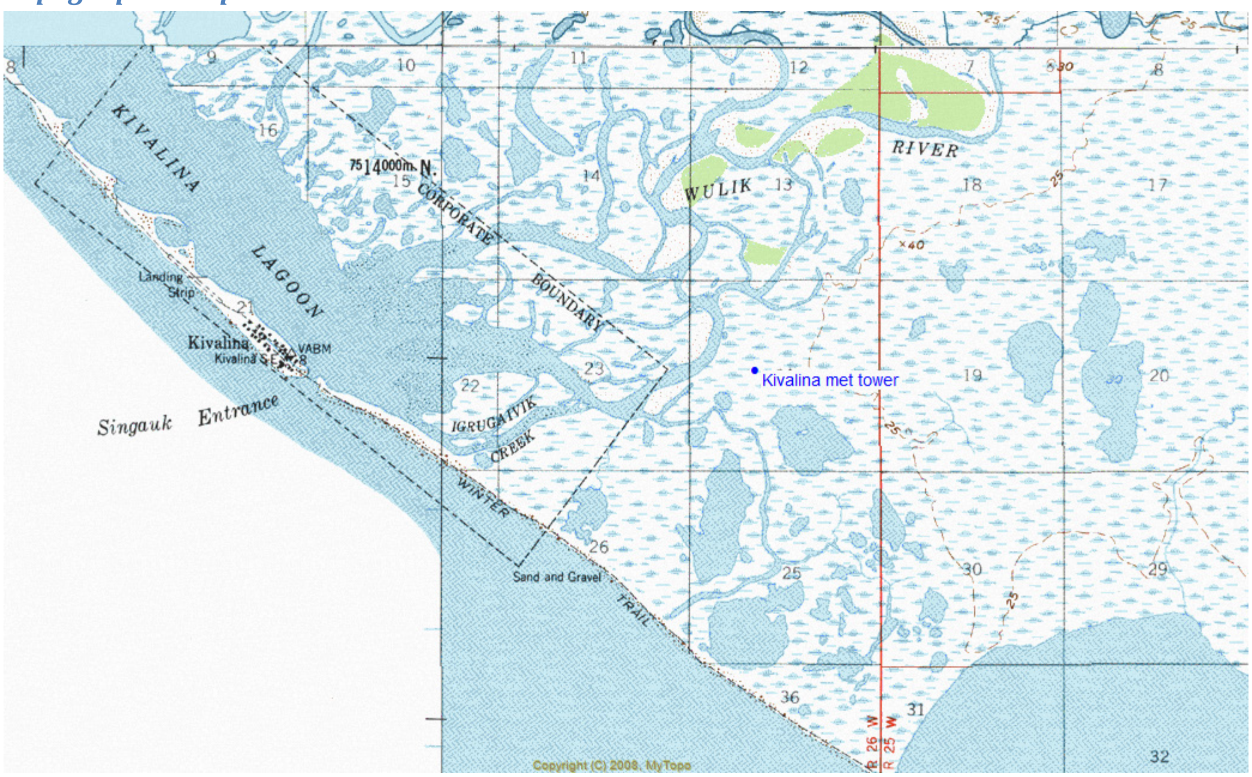
## Test Site Location

Wind measurement instrumentation was installed on a six-inch diameter 30 meter NRG tubular Tall Tower (met tower) approximately three kilometers (two miles) east of the village of Kivalina and approximately 1.5 km (1 mile) from the Chukchi Sea coast. The tower is located on open tundra in the general vicinity of the new Kivalina town site should the village be relocated due to continuing erosion and flooding risk at the existing village location, which is on an exposed coastal barrier island. The met tower was installed on May 6, 2011 by Echelon Energy Corp. of San Jose, California.

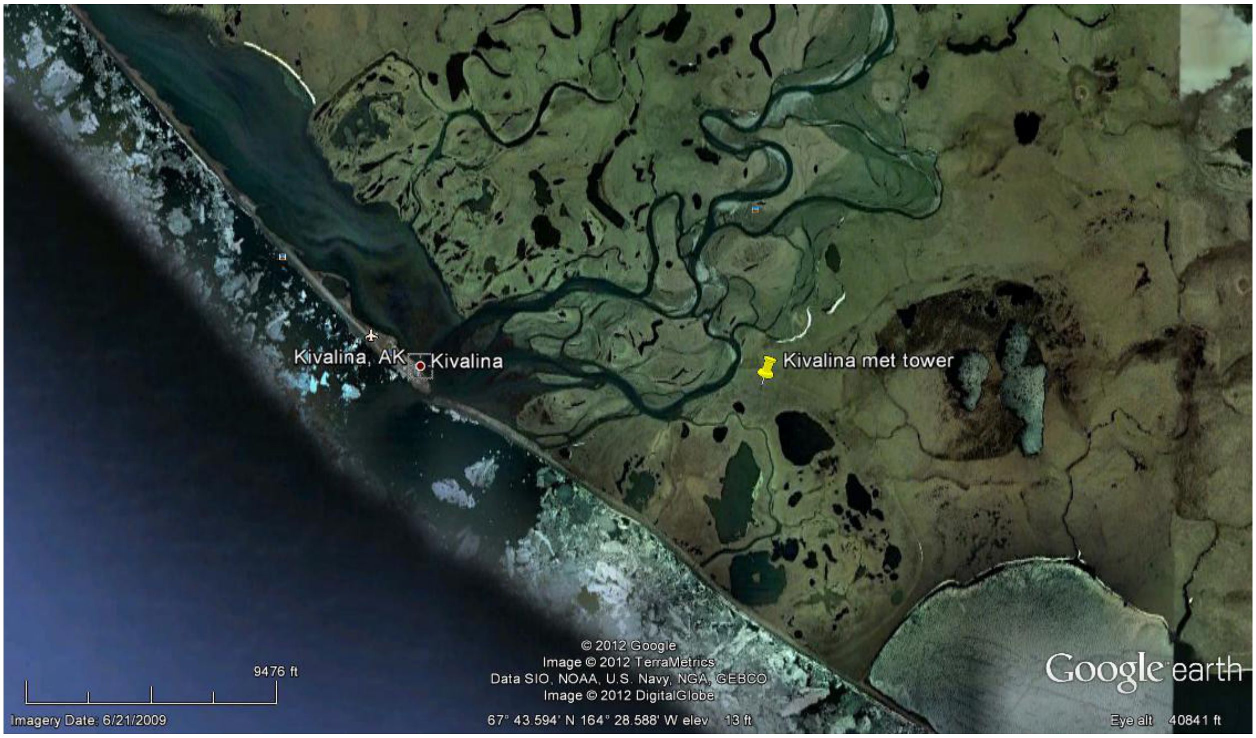
### Site information

| | |
|---|---|
| Site number | 9750 |
| Latitude/longitude | N 67° 43' 29.64" W 164° 26' 25.38", NAD 83 |
| Site elevation | 3 meters (10 ft) |
| Datalogger type | NRG Symphonie, 10 minute time step |
| Tower type | NRG Tall Tower, 30 meters, six-inch diameter |

### *Topographic map*



## Google Earth image




## Tower sensor information

| Channel | Sensor type | Height | Multiplier | Offset | Orientation |
|---|---|---|---|---|---|
| 1 | NRG #40 anemometer | 30 m A | 0.765 | 0.35 | north |
| 2 | NRG #40 anemometer | 30 m B | 0.765 | 0.35 | south |
| 3 | NRG #40 anemometer | 20 m | 0.765 | 0.35 | north |
| 7 | NRG #200P wind vane | 29 m | 0.351 | 351 | 351° T |
| 9 | NRG #110S Temp C | 3 m | 0.138 | -86.3 | north |

## Tower sensors photo (view to the southwest)

## Data Quality Control

Data quality is generally very good for the 30 meter level anemometers, excellent for the wind vane and temperature sensor, and very poor for the 20 meter level anemometer. An installation error with the 20 meter anemometer resulted in it being located directly in line with the north-facing third-level guy wire, resulting in fouling of the sensor in the wire after the tower settled in the tundra a bit and the guy wires slackened. In the data analysis, a filter was used to remove 20 meter anemometer data significantly divergent from 30 meter A anemometer data, but that is not a precise tool and it is not possible to definitively determine all times that the 20 m anemometer was fouled. Recovered 20 m level anemometer data is not usable by itself for wind speed or other data, but it is usable, with qualification, for calculation of the wind shear coefficient.

Data loss due to icing conditions was very infrequent in Kivalina compared to coastal sites in western Alaska. This may be due to the extremely cold winter of 2011/2012 and the otherwise normal extensive sea ice offshore of Kivalina and resulting low moisture content in the air. Icing conditions in the anemometer data are characterized by output of the anemometer at the minimum offset value of 0.4 m/s, standard deviation of zero, and temperatures less than 1 degree Centigrade. For wind direction data, icing is characterized by non-variant output at the last operable wind direction (standard deviation of zero) and temperature less than 1 degree Centigrade.

In addition to icing, 30 meter level anemometer data was filtered for tower shadow using an algorithm that identifies wind from a 30 degree sector opposite the anemometer and filters that data. With frequent northerly winds, the south-facing 30 m B anemometer was filtered more frequently than the north-facing 30 m A anemometer.

### *Data recovery summary table*

| Sensor | Units | Height | Possible Records | Valid Records | Recovery Rate (%) |
|---|---|---|---|---|---|
| Speed 30 m A | m/s | 30 m | 54,018 | 51,676 | 95.7 |
| Speed 30 m B | m/s | 30 m | 54,018 | 47,240 | 87.5 |
| Speed 20 m | m/s | 20 m | 54,018 | 15,965 | 29.6 |
| Direction 29 m | ° | 29 m | 54,018 | 53,408 | 98.9 |
| Temperature | °C | | 54,018 | 53,868 | 99.7 |

### *Anemometer and wind vane data recovery*

| Year | Month | 30 m A Recovery Rate (%) | 30 m B Recovery Rate (%) | 20 m Recovery Rate (%) | Vane Recovery Rate (%) | Temp Recovery Rate (%) |
|---|---|---|---|---|---|---|
| 2011 | May | 88.6 | 92.2 | 43.7 | 95.5 | 100.0 |
| 2011 | Jun | 93.9 | 88.5 | 9.7 | 100.0 | 100.0 |
| 2011 | Jul | 93.7 | 95.5 | 5.7 | 100.0 | 100.0 |
| 2011 | Aug | 94.5 | 96.2 | 15.3 | 100.0 | 100.0 |
| 2011 | Sep | 96.2 | 81.4 | 25.8 | 100.0 | 100.0 |
| 2011 | Oct | 99.3 | 90.5 | 25.0 | 98.3 | 100.0 |

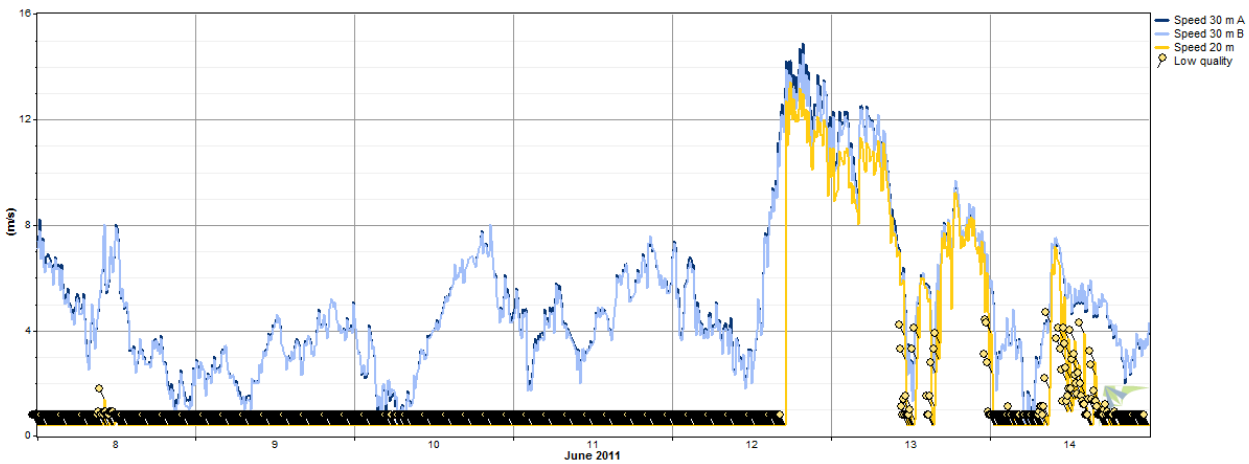
| Year | Month | 30 m A Recovery Rate (%) | 30 m B Recovery Rate (%) | 20 m Recovery Rate (%) | Vane Recovery Rate (%) | Temp Recovery Rate (%) |
|---|---|---|---|---|---|---|
| 2011 | Nov | 99.4 | 85.5 | 18.5 | 100.0 | 100.0 |
| 2011 | Dec | 90.8 | 80.5 | 57.2 | 91.4 | 96.8 |
| 2012 | Jan | 98.0 | 87.2 | 54.7 | 100.0 | 100.0 |
| 2012 | Feb | 97.8 | 84.3 | 44.0 | 100.0 | 100.0 |
| 2012 | Mar | 99.3 | 74.8 | 27.0 | 100.0 | 100.0 |
| 2012 | Apr | 94.7 | 93.0 | 26.0 | 100.0 | 100.0 |
| 2012 | May | 96.0 | 89.1 | 39.8 | 99.8 | 99.8 |
| All Data | | 95.7 | 87.5 | 29.6 | 98.9 | 99.7 |

### *Data flag statistics*

| Anemometer | Possible Records | Icing % | Low quality % | Tower shading % |
|---|---|---|---|---|
| Speed 30 m A | 54,018 | 0.4% | 0.0% | 3.6% |
| Speed 30 m B | 54,018 | 0.4% | 0.0% | 11.4% |
| Speed 20 m | 54,018 | 24.4% | 68.6% | 0.0% |

Note: low quality and icing flags of 20 m anemometer often overlap.

### *Fouled 20 meter anemometer*




## Wind Speed

Anemometer data obtained from the met tower, from the perspectives of both mean wind speed and mean wind power density, indicate a good wind resource. Mean wind speeds are greater at higher elevations on the met tower as one would expect. Note that the cold mean annual air temperature in Kivalina contributed to a higher wind power density than otherwise expected for the mean wind speeds.

### *Anemometer data summary*

| Variable | Speed 30 m A | Speed 30 m B |
|---|---|---|
| Measurement height (m) | 30 | 30 |
| Mean wind speed (m/s) | 5.87 | 5.52 |
| Median wind speed (m/s) | 5.20 | 5.00 |
| Max 10-min avg wind speed (m/s) | 26.7 | 26.7 |
| Max gust wind speed (m/s) | 33.2 | 33.6 |
| Weibull k | 1.66 | 1.62 |
| Weibull c (m/s) | 6.56 | 6.15 |
| Mean power density ($W/m^2$) | 325 | 274 |
| Mean energy content ($kWh/m^2/yr$) | 2,845 | 2,398 |
| Energy pattern factor | 2.41 | 2.47 |
| Frequency of calms (%) | 34.4 | 37.3 |

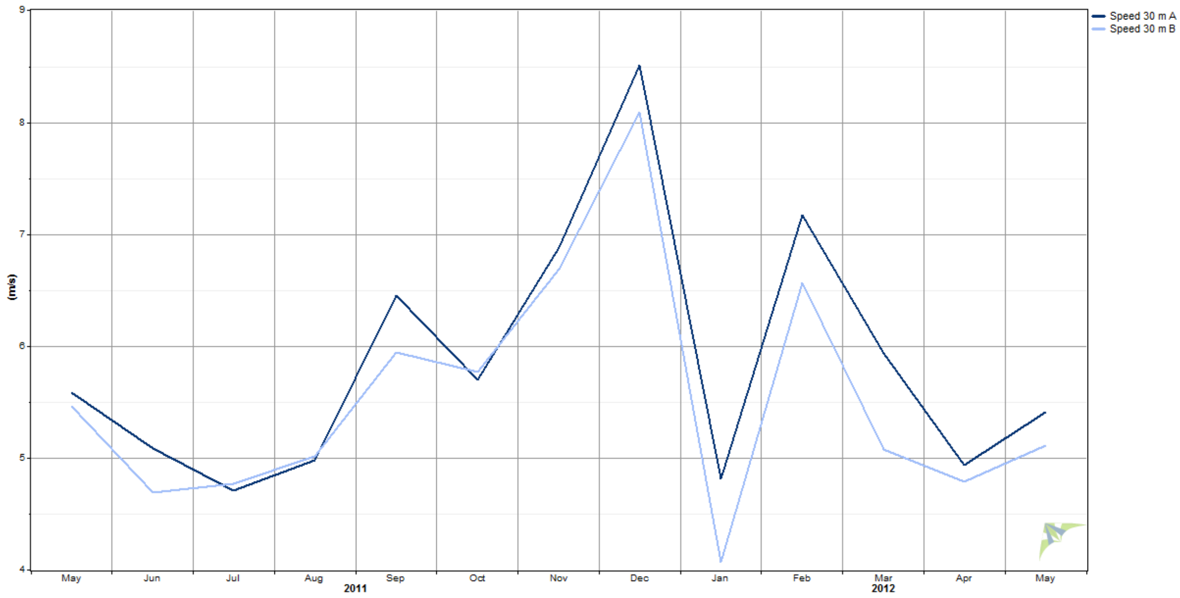
## Time Series

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 typical village load profile where winter months have a high electric and heat demand and summer months a lesser demand. The a diurnal profile indicates remarkably stable wind speeds throughout the day with a minor "valley" of wind speeds during the morning hours and a minor "peak" of wind speeds during late afternoon.

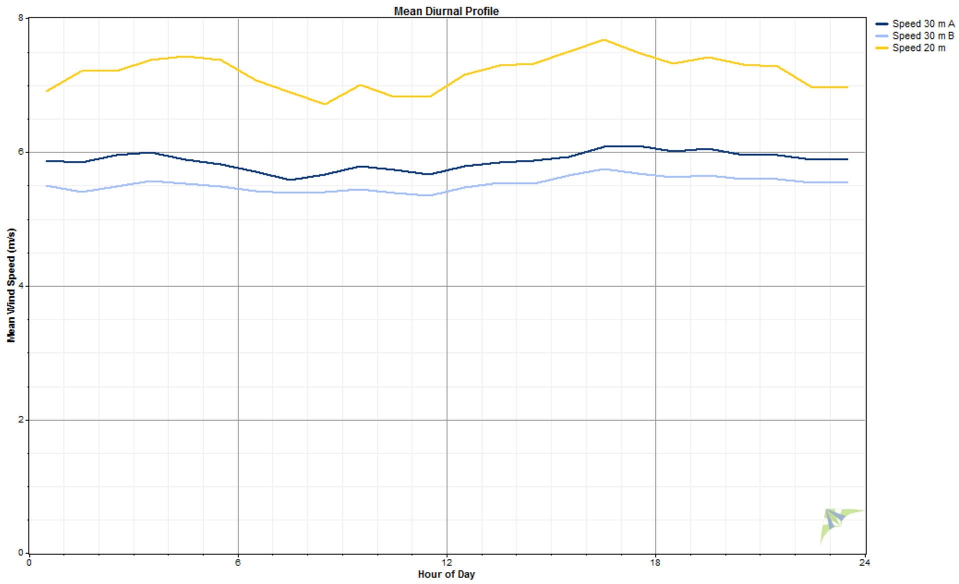
### *30 m A anemometer data summary*

| Year | Month | Mean (m/s) | Max 10-min (m/s) | Max Gust (m/s) | Std. Dev. (m/s) | Weibull k (-) | Weibull c (m/s) |
|---|---|---|---|---|---|---|---|
| 2011 | May | 5.58 | 14.0 | 17.2 | 2.83 | 2.04 | 6.29 |
| 2011 | Jun | 5.09 | 14.9 | 18.3 | 2.70 | 1.95 | 5.73 |
| 2011 | Jul | 4.71 | 13.8 | 17.9 | 2.53 | 1.92 | 5.29 |
| 2011 | Aug | 4.98 | 12.5 | 15.6 | 2.35 | 2.19 | 5.60 |
| 2011 | Sep | 6.45 | 17.8 | 22.9 | 3.14 | 2.15 | 7.28 |
| 2011 | Oct | 5.69 | 18.5 | 22.9 | 3.08 | 1.92 | 6.42 |
| 2011 | Nov | 6.88 | 26.7 | 33.2 | 4.08 | 3.55 | 10.12 |
| 2011 | Dec | 8.51 | 21.2 | 25.6 | 4.19 | 2.14 | 9.60 |
| 2012 | Jan | 4.81 | 24.7 | 27.1 | 4.24 | 1.17 | 5.08 |
| 2012 | Feb | 7.17 | 21.2 | 24.8 | 4.43 | 1.64 | 8.00 |
| 2012 | Mar | 5.94 | 16.7 | 19.5 | 3.47 | 1.71 | 6.63 |
| 2012 | Apr | 4.94 | 17.6 | 22.9 | 3.87 | 1.21 | 5.24 |
| 2012 | May | 5.41 | 13.5 | 16.1 | 2.60 | 2.19 | 6.10 |
| All Data | | 5.87 | 26.7 | 33.2 | 3.63 | 1.66 | 6.56 |
| Mean of monthly means | | 5.88 | | | | | |

### *Wind speed time series graph*




### *Diurnal profile*

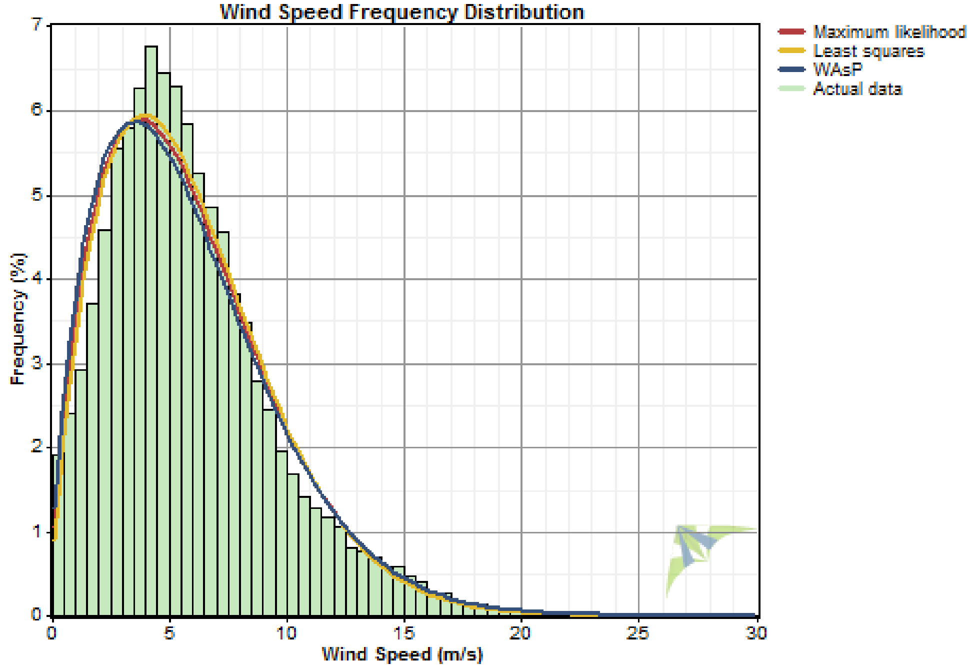



Note: disregard the Speed 20 m curve due to problems with data recovery

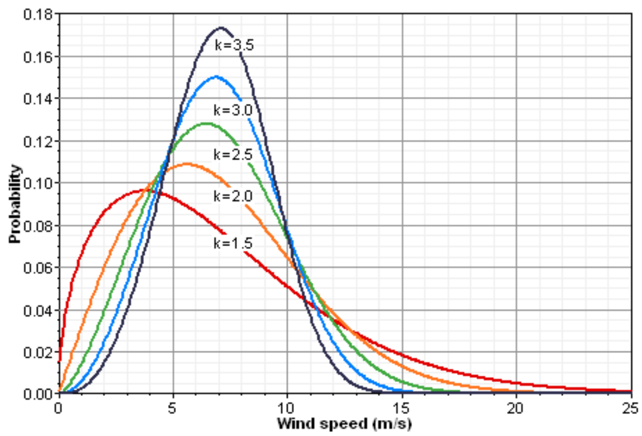
## Wind Speed Distribution

The probability distribution function (PDF), or histogram, of Kivalina wind speed data indicates a shape curve somewhat dominated by lower wind speeds, as opposed to a "normal" shape curve, known as the Rayleigh distribution (Weibull k = 2.0), which is defined as the standard wind distribution for wind power analysis. As one can see in the PDF of 30 meter A anemometer, the most frequently occurring wind speeds are between 4 and 6 m/s with very few wind events exceeding 25 m/s (the cutout speed of most wind turbines; see following wind speed statistical table).

### *Wind speed distribution of 30 m A anemometer*




### *Weibull k shape curve table*




### *Weibull comparison table*

| Algorithm | Weibull k (-) | Weibull c (m/s) | Mean (m/s) | Proportion Above 5.872 m/s | Power Density (W/m2) | R Squared (-) |
|---|---|---|---|---|---|---|
| Maximum likelihood | 1.660 | 6.560 | 5.864 | 0.435 | 291.8 | 0.977 |
| Least squares | 1.704 | 6.586 | 5.875 | 0.439 | 283.8 | 0.980 |
| WAsP | 1.603 | 6.496 | 5.823 | 0.427 | 299.2 | 0.970 |
| Actual data | (51,676 time steps) | | 5.872 | 0.427 | 299.2 | |

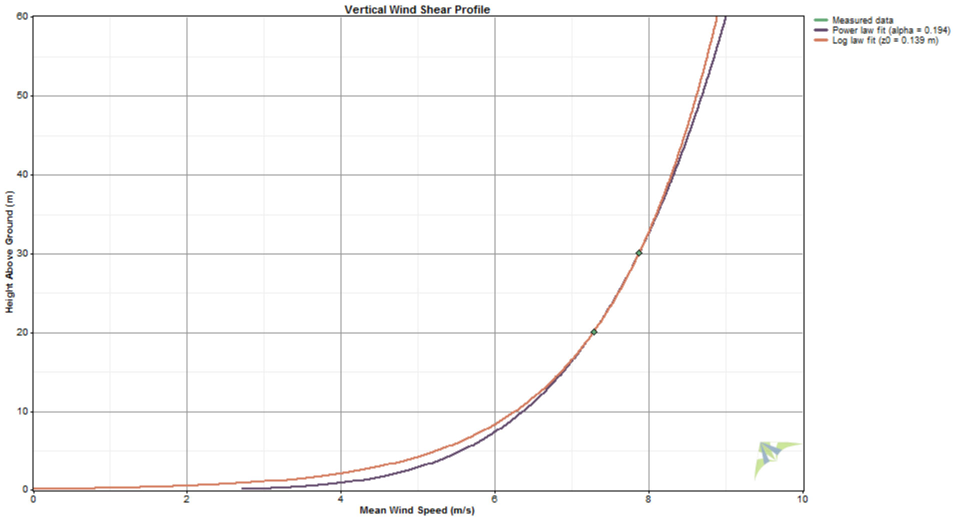
### *Occurrence by wind speed bin*

| Bin Endpoints (m/s) | | Occurrences | | Bin Endpoints (m/s) | | Occurrences | |
|---|---|---|---|---|---|---|---|
| Lower | Upper | No. | Percent | Lower | Upper | No. | Percent |
| 0 | 1 | 2,224 | 4.5% | 14 | 15 | 604 | 1.2% |
| 1 | 2 | 3,420 | 6.9% | 15 | 16 | 443 | 0.9% |
| 2 | 3 | 5,226 | 10.5% | 16 | 17 | 287 | 0.6% |
| 3 | 4 | 6,219 | 12.5% | 17 | 18 | 180 | 0.4% |
| 4 | 5 | 6,821 | 13.7% | 18 | 19 | 122 | 0.2% |
| 5 | 6 | 6,261 | 12.6% | 19 | 20 | 78 | 0.2% |
| 6 | 7 | 5,213 | 10.5% | 20 | 21 | 37 | 0.1% |
| 7 | 8 | 4,327 | 8.7% | 21 | 22 | 18 | 0.0% |
| 8 | 9 | 3,236 | 6.5% | 22 | 23 | 13 | 0.0% |
| 9 | 10 | 2,271 | 4.6% | 23 | 24 | 17 | 0.0% |
| 10 | 11 | 1,610 | 3.2% | 24 | 25 | 22 | 0.0% |
| 11 | 12 | 1,270 | 2.5% | 25 | 26 | 25 | 0.1% |
| 12 | 13 | 962 | 1.9% | 26 | 27 | 13 | 0.0% |
| 13 | 14 | 757 | 1.5% | all | | 49,817 | 100.0% |

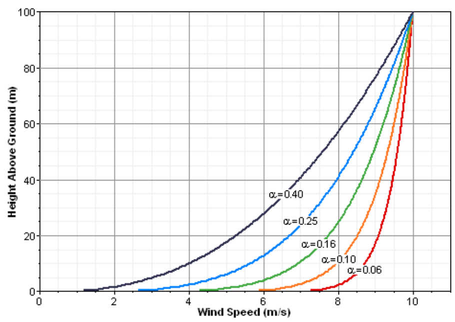
## Wind Shear and Roughness

A wind shear power law exponent (α) of 0.194 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 rough terrain (roughness description: few trees) surrounding the met tower. This data is comprised however by very poor data recovery from the 20 meter level anemometer, which was installed such that it was often fouled in the third level north-facing guy wire. The power law exponent is calculated only with time step data with valid anemometer data from the selected sensors (the 30 m A anemometer and the 20 meter anemometer); in this case only 28 percent of the time steps qualified. This is a statistically sufficient amount of data except that filtering of the 20 meter data to remove the time steps where the anemometer was fouled is not precise and some data that should have been filtered was undoubtedly retained. Although the power law exponent and roughness length are generally reasonable, one might expect both values to be lower considering the flat, featureless, and typically snow-covered terrain surrounding the met tower.

### *Vertical wind shear profile*




### *Comparative wind shear profiles*



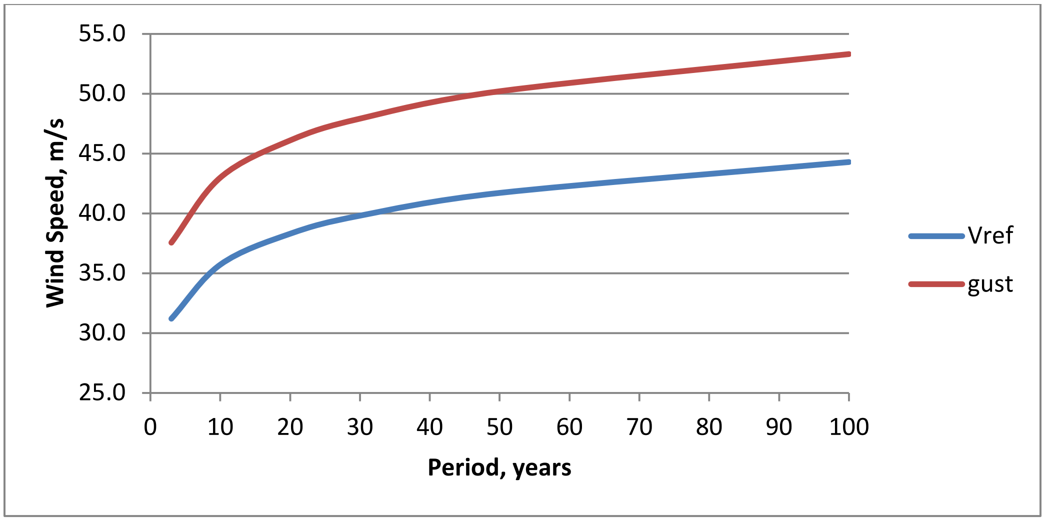

## Extreme Winds

A modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, was used to predict extreme winds at the Kivalina met tower site. Industry standard reference of extreme wind is the 50 year probable (50 year return period) ten-minute average wind speed, referred to as $V_{ref}$. For Kivalina, this calculates to 35.8 m/s (at 30 meters), which qualifies as an International Electrotechnical Commission (IEC) 61400-1, 3rd edition criteria Class III site, the lowest defined. All wind turbines are designed for IEC 61400-1 Class III conditions.

### *Extreme wind probability table, 30 m A data*

| Period (years) | $V_{ref}$ (m/s) | Gust (m/s) | IEC 61400-1, 3rd ed. Class | $V_{ref}$, m/s |
|---|---|---|---|---|
| 3 | 26.8 | 32.8 | I | 50.0 |
| 10 | 30.7 | 37.5 | II | 42.5 |
| 20 | 32.9 | 40.2 | III | 37.5 |
| 30 | 34.2 | 41.8 | S | designer-specified |
| 50 | 35.8 | 43.8 | | |
| 100 | 38.0 | 46.5 | | |

### *Extreme wind graph*



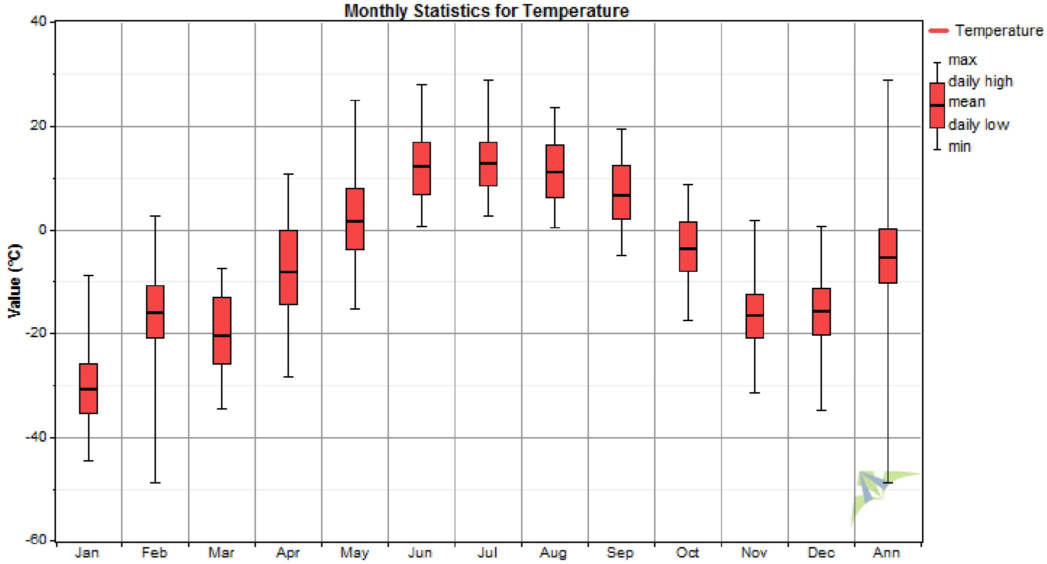

## Temperature and Density

Kivalina experiences cool summers and very cold winters with resulting higher than standard air density. Calculated annual mean air density during the met tower test period exceeds by 7.8 percent the 1.225 kg/m$^3$ standard air density at a 3 meter elevation. This is advantageous in wind power operations as wind turbines typically produce more power at low temperatures/high air density than at standard temperature and density.

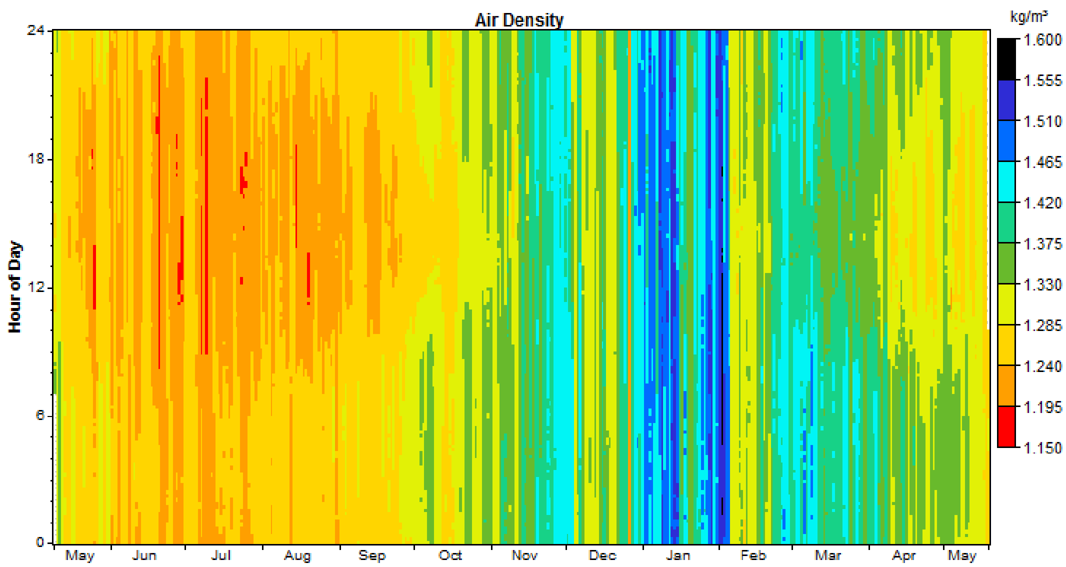
### *Temperature and density table*

| | Temperature | | | Density | | |
|---|---|---|---|---|---|---|
| Month | Mean (°C) | Min (°C) | Max (°C) | Mean (kg/m³) | Min (kg/m³) | Max (kg/m³) |
| Jan | -30.7 | -44.5 | -8.9 | 1.456 | 1.335 | 1.543 |
| Feb | -15.9 | -48.7 | 2.7 | 1.374 | 1.279 | 1.572 |
| Mar | -20.2 | -34.5 | -7.4 | 1.395 | 1.327 | 1.478 |
| Apr | -7.9 | -28.4 | 10.6 | 1.331 | 1.243 | 1.441 |
| May | 1.8 | -15.4 | 25.0 | 1.284 | 1.183 | 1.369 |
| Jun | 12.2 | 0.7 | 28.1 | 1.237 | 1.171 | 1.288 |
| Jul | 12.9 | 2.6 | 28.9 | 1.234 | 1.168 | 1.279 |
| Aug | 11.3 | 0.4 | 23.5 | 1.240 | 1.189 | 1.290 |
| Sep | 6.8 | -5.1 | 19.3 | 1.260 | 1.206 | 1.316 |
| Oct | -3.5 | -17.6 | 8.7 | 1.308 | 1.252 | 1.380 |
| Nov | -16.5 | -31.5 | 1.8 | 1.376 | 1.283 | 1.460 |
| Dec | -15.5 | -35.0 | 0.5 | 1.367 | 1.224 | 1.481 |
| Annual | -5.2 | -48.7 | 28.9 | 1.321 | 1.168 | 1.572 |

### *Annual temperature boxplot*



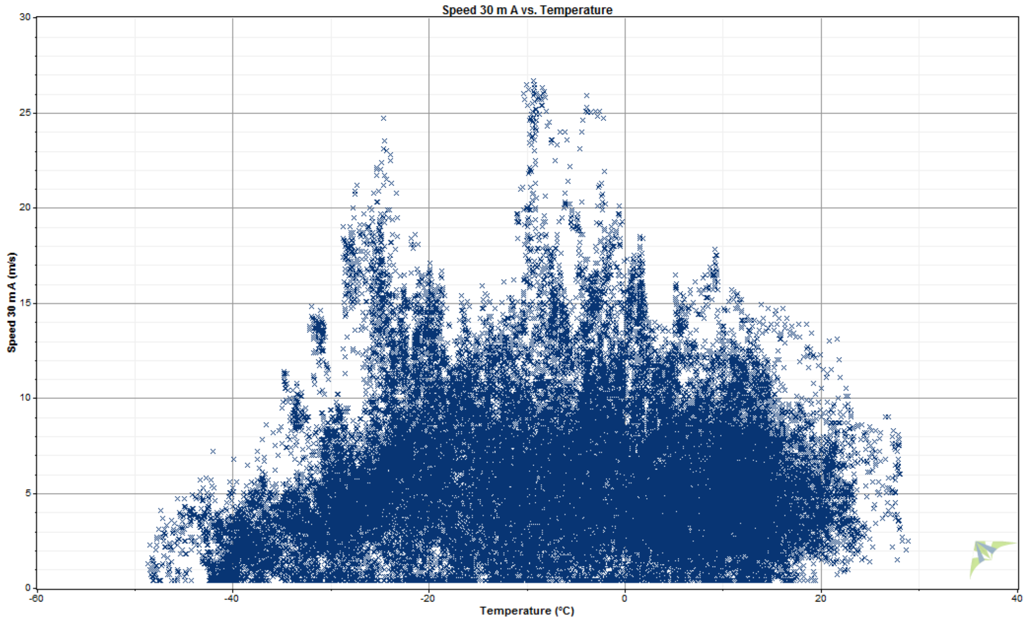

### *Air density DMap*




## Wind Speed Scatterplot

The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Kivalina coincides with cold temperatures as one would expect. During the met tower test period, temperatures fell below -40°C, the minimum operating temperature for arctic-capable wind turbines, on a number of occasions. Wind speeds during periods of extreme cold are generally low, however, and loss of wind turbine availability during these times would not be significant. Also note that periods of high winds (wind speeds greater than 20 m/s) are characterized by cold temperatures, between 0°C and -25°C.

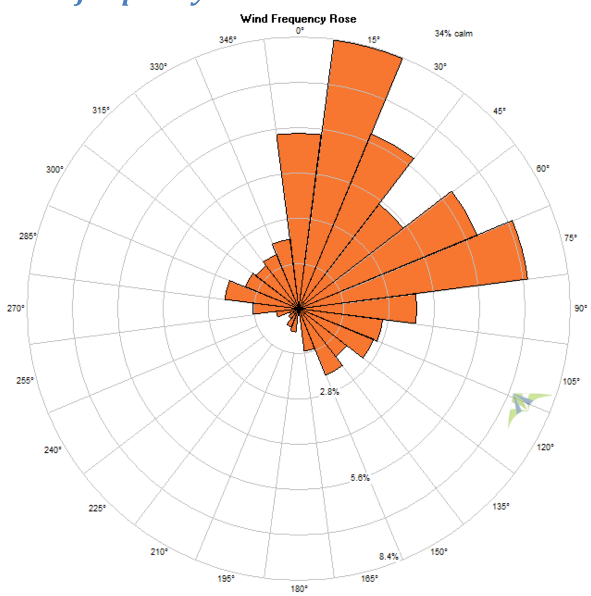
### *Wind speed/temperature*



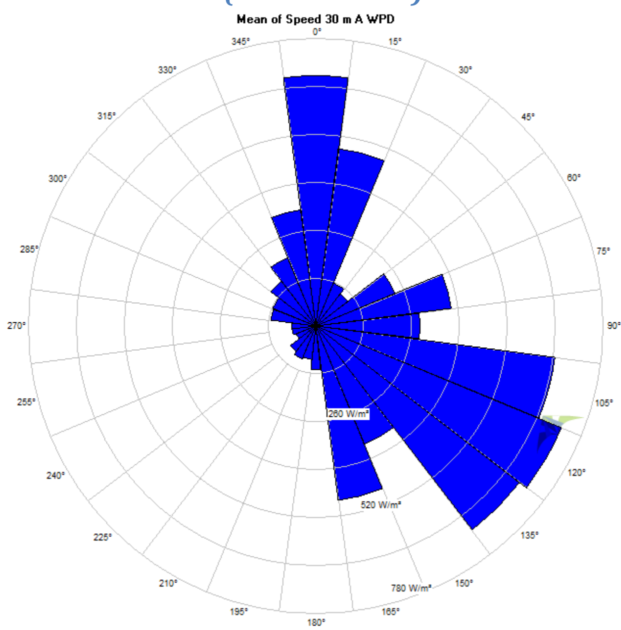

## Wind Direction

Wind frequency rose data indicates that winds at Kivalina are relatively directional, with north-northeasterly and east-northeasterly predominating. The mean value rose indicates that infrequent southeasterly winds, when they do occur, are of high energy and hence likely storm winds. The wind energy rose indicates that winds for wind turbine operations power-producing are northerly and southeasterly dominant. Calm frequency (percent of time that winds at the 30 meter level are less than 4 m/s) was 34 percent during the met tower test period.

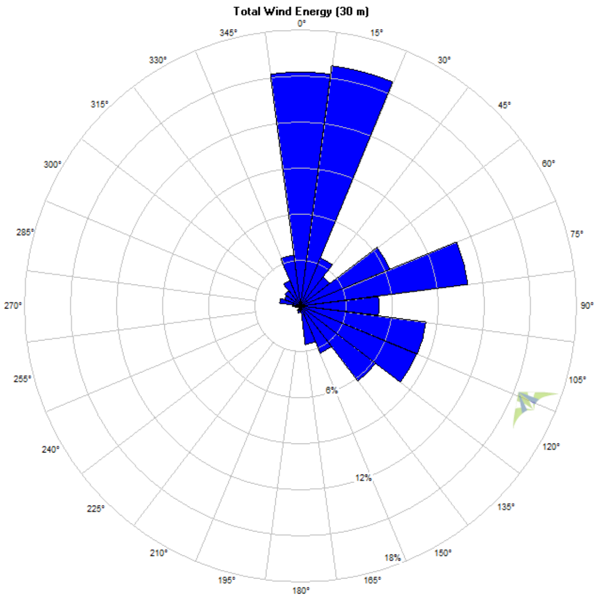
### *Wind frequency rose*



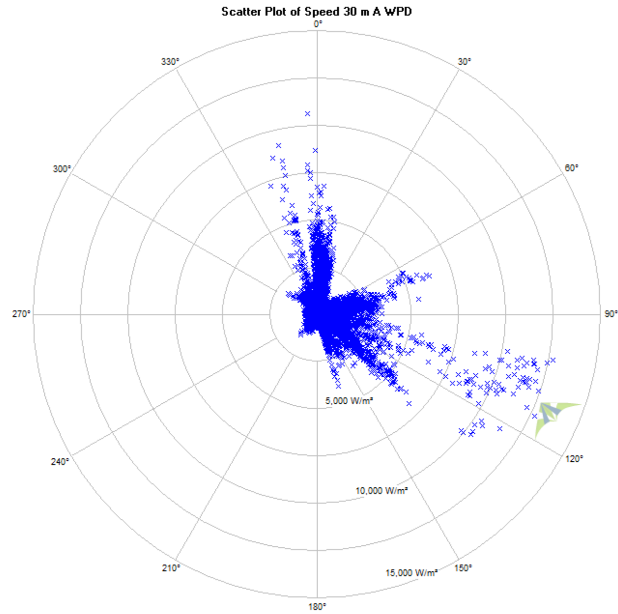

### *Mean value rose (30 m A anem.)*



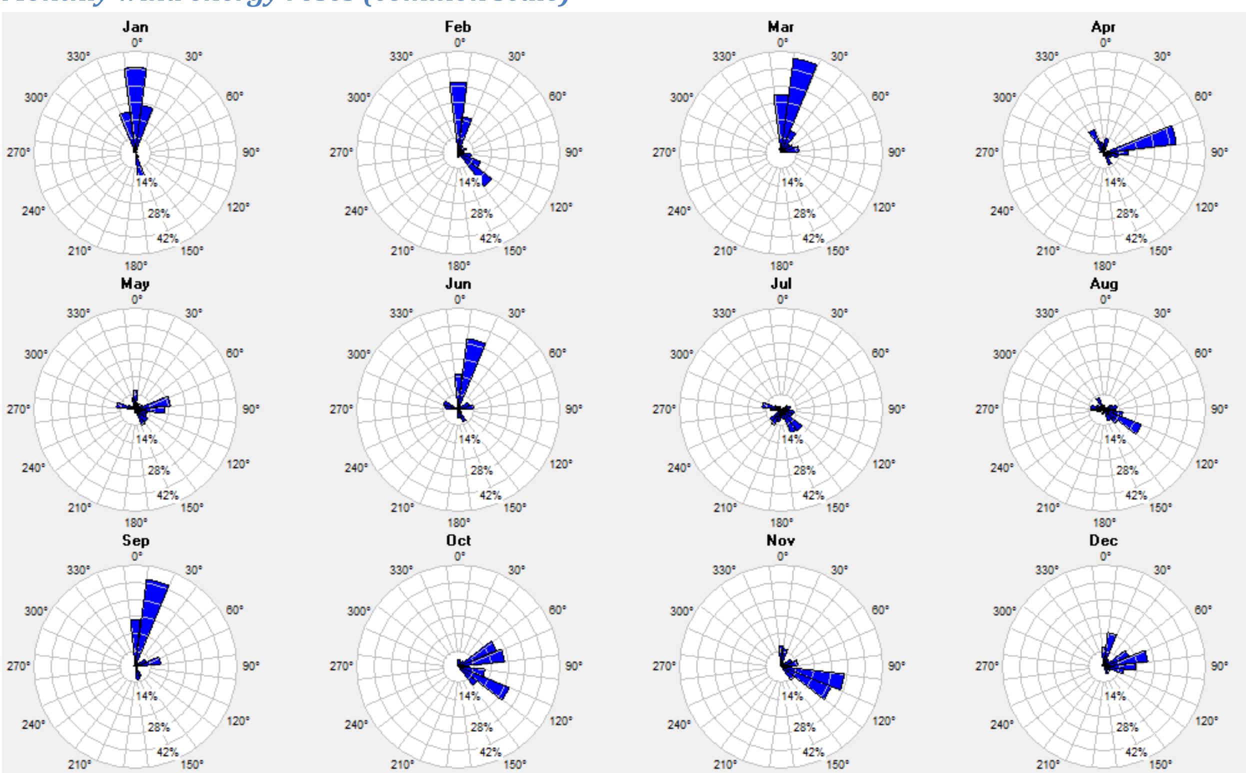
### *Wind energy rose (30 m A anem.)*




### *Scatterplot rose of 30m A wind power density*



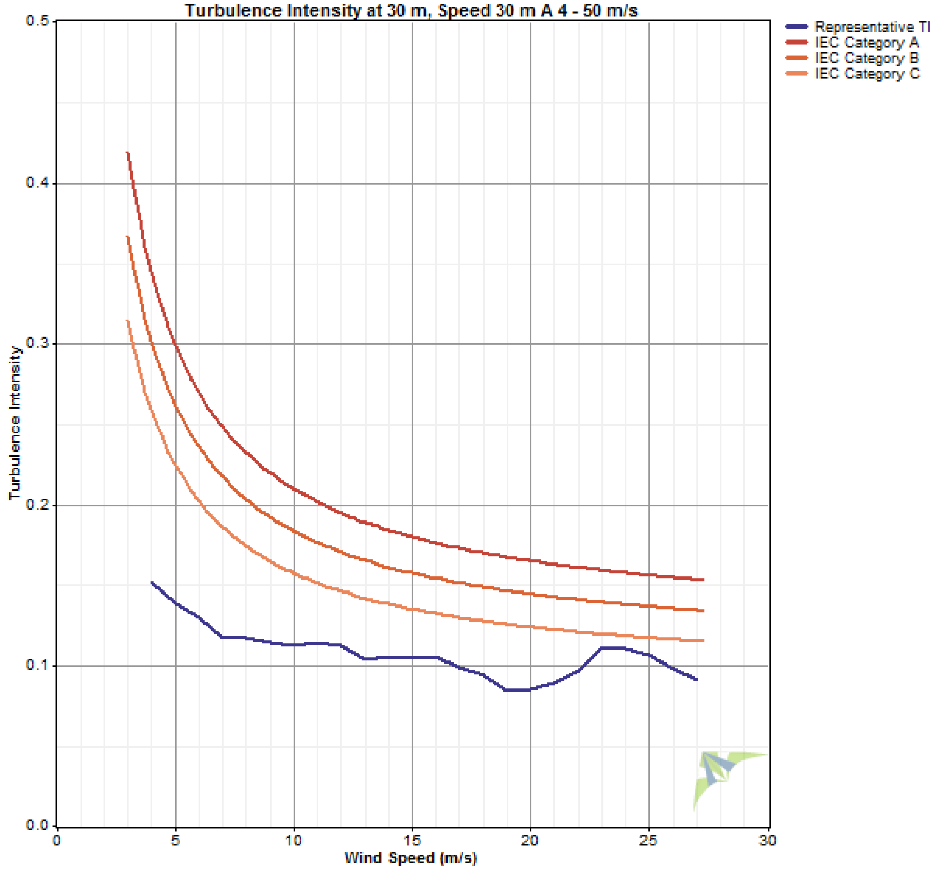

### *Monthly wind energy roses (common scale)*



## Turbulence

Turbulence intensity (TI) at the Kivalina met tower site is well within acceptable standards with an IEC 61400-1, 3rd edition (2005) classification of turbulence category C, which is the lowest defined. The mean TI at 15 m/s is 0.075 and the representative TI at 15 m/s is 0.105 (30 m A anemometer), both which can be considered very low and hence very desirable for wind turbine operations.

### *Turbulence intensity, 30 m A anemometer, all direction sectors*




### *Turbulence table, 30 m A data*

| Bin Endpoints Lower (m/s) | Bin Endpoints Upper (m/s) | Records in Bin | Mean TI | Standard Deviation of TI | Representative TI | Peak TI |
|---|---|---|---|---|---|---|
| 0.5 | 1.5 | 2,744 | 0.363 | 0.155 | 0.561 | 1.091 |
| 1.5 | 2.5 | 4,280 | 0.180 | 0.090 | 0.295 | 0.800 |
| 2.5 | 3.5 | 5,847 | 0.126 | 0.064 | 0.209 | 0.815 |
| 3.5 | 4.5 | 6,725 | 0.100 | 0.049 | 0.163 | 0.771 |
| 4.5 | 5.5 | 6,568 | 0.086 | 0.041 | 0.138 | 0.633 |
| 5.5 | 6.5 | 5,732 | 0.081 | 0.038 | 0.130 | 0.468 |
| 6.5 | 7.5 | 4,858 | 0.076 | 0.032 | 0.117 | 0.299 |
| 7.5 | 8.5 | 3,763 | 0.076 | 0.032 | 0.117 | 0.364 |
| 8.5 | 9.5 | 2,704 | 0.076 | 0.029 | 0.114 | 0.299 |

| Bin Endpoints Lower (m/s) | Upper (m/s) | Records in Bin | Mean TI | Standard Deviation of TI | Representative TI | Peak TI |
|---|---|---|---|---|---|---|
| 9.5 | 10.5 | 1,883 | 0.077 | 0.028 | 0.113 | 0.269 |
| 10.5 | 11.5 | 1,398 | 0.078 | 0.028 | 0.114 | 0.252 |
| 11.5 | 12.5 | 1,155 | 0.078 | 0.027 | 0.112 | 0.265 |
| 12.5 | 13.5 | 808 | 0.074 | 0.023 | 0.104 | 0.167 |
| 13.5 | 14.5 | 662 | 0.076 | 0.023 | 0.105 | 0.174 |
| 14.5 | 15.5 | 545 | 0.075 | 0.023 | 0.105 | 0.166 |
| 15.5 | 16.5 | 347 | 0.076 | 0.023 | 0.105 | 0.167 |
| 16.5 | 17.5 | 241 | 0.074 | 0.019 | 0.099 | 0.145 |
| 17.5 | 18.5 | 151 | 0.073 | 0.016 | 0.094 | 0.120 |
| 18.5 | 19.5 | 98 | 0.068 | 0.013 | 0.084 | 0.115 |
| 19.5 | 20.5 | 58 | 0.069 | 0.012 | 0.085 | 0.100 |
| 20.5 | 21.5 | 24 | 0.072 | 0.014 | 0.089 | 0.103 |
| 21.5 | 22.5 | 16 | 0.078 | 0.015 | 0.097 | 0.103 |
| 22.5 | 23.5 | 12 | 0.080 | 0.024 | 0.111 | 0.104 |
| 23.5 | 24.5 | 17 | 0.090 | 0.016 | 0.110 | 0.120 |
| 24.5 | 25.5 | 28 | 0.087 | 0.015 | 0.106 | 0.108 |
| 25.5 | 26.5 | 20 | 0.090 | 0.006 | 0.097 | 0.104 |
| 26.5 | 27.5 | 4 | 0.086 | 0.003 | 0.091 | 0.091 |

## Wind Turbine Performance

The selection of suitable wind turbines for a wind power project in Kivalina is beyond the scope of this report, but for initial planning purposes, predicted annual energy output and capacity factor for the 100 kW Northwind 100 B model (21 meter rotor, 37 meter hub height) is presented below.

Note that the Alaska Energy Authority considers 82 percent turbine availability (percent of time that the turbine is operational and available to produce power, irrespective of wind speed) as the default value for planning village power projects. Many wind turbines in rural Alaska operate with better than 82 percent availability, but for a number of reasons some operate with lower than 82 percent availability.

For this turbine performance analysis, adjustment of power output (from standard temperature and pressure conditions) of the NW100 turbine due to air density was not considered as Northern Power Systems has not published density-specific power curves for the turbine.

### *NW100B/21 at 37 m, 82% availability*

| Month | Hub Height Wind Speed (m/s) | Time At Zero Output (%) | Time At Rated Output (%) | Mean Net Power Output (kW) | Mean Net Energy Output (kWh/yr) | Net Capacity Factor (%) |
|---|---|---|---|---|---|---|
| Jan | 5.03 | 41.1 | 2.6 | 16.1 | 12,001 | 16.1 |
| Feb | 7.48 | 14.6 | 4.8 | 30.1 | 20,242 | 30.1 |
| Mar | 6.17 | 20.3 | 1.9 | 22.9 | 17,036 | 22.9 |

| Month | Hub Height Wind Speed (m/s) | Time At Zero Output (%) | Time At Rated Output (%) | Mean Net Power Output (kW) | Mean Net Energy Output (kWh/yr) | Net Capacity Factor (%) |
|---|---|---|---|---|---|---|
| Apr | 5.08 | 38.1 | 2.5 | 17.6 | 12,655 | 17.6 |
| May | 5.60 | 21.2 | 0.0 | 18.5 | 13,758 | 18.5 |
| Jun | 5.26 | 21.0 | 0.1 | 15.4 | 11,071 | 15.4 |
| Jul | 4.93 | 24.5 | 0.0 | 13.4 | 9,993 | 13.4 |
| Aug | 5.27 | 18.7 | 0.0 | 15.2 | 11,272 | 15.2 |
| Sep | 6.87 | 10.8 | 2.7 | 26.2 | 18,896 | 26.2 |
| Oct | 5.95 | 15.7 | 1.7 | 19.9 | 14,817 | 19.9 |
| Nov | 7.22 | 8.8 | 2.2 | 24.9 | 17,928 | 24.9 |
| Dec | 8.76 | 8.2 | 5.5 | 40.4 | 30,036 | 40.4 |
| Annual | 6.10 | 20.4 | 1.9 | 21.5 | 188,215 | 21.5 |