

# Atqasuk Wind Resource Report

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Date of Report: August 26, 2010*



Atqasuk met tower; D. Vaught photo

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## Summary

The wind resource measured to date in Atqasuk appears to be promising for wind power development, but winter data recovery was very poor. Wind power class 3 (fair) is calculated but that with only one year of data characterized by poor winter data recovery, that classification may well be in error. With respect to other criteria, the Atqasuk site experiences very low turbulence conditions and apparent low extreme wind probability.

To improve confidence of measurement of the wind resource in Atqasuk, especially during the winter months, a met tower equipped with heated sensors (at least one anemometer and one wind vane) is strongly suggested.

### *Met tower data synopsis*

|   |  |
|---|--|
| Data dates                                      | June 22, 2009 to July 16, 2010 (13 months)                                   |
| Wind power class                                | Class 3 (fair)   |
| Power density mean, 30 m                        | 305 W/m <sup>2</sup> (QC'd data); 266 W/m <sup>2</sup> (with synthetic data) |
| Wind speed mean, 30 m                           | 6.48 m/s (QC'd data); 6.07 m/s (with synthetic data)                         |
| Max. 10-min wind speed average                  | 19.6 m/s   |
| Maximum wind gust                               | 23.1 m/s (Feb 2010)  |
| Weibull distribution                            | k = 2.23, c = 7.15 m/s   |
| Wind shear power law exponent                   | 0.119 (moderate)   |
| Roughness class                                 | 0.73 (lawn grass)  |
| IEC 61400-1, 3 <sup>rd</sup> ed. classification | Class III-c (lowest defined and most common)                                 |
| Turbulence intensity, mean                      | 0.075 (at 15 m/s)  |
| Calm wind frequency                             | 19% (<3.5 m/s)   |

### *Community profile*

|                              |  |
|------------------------------|--|
| Current Population:          | 201 (2009 DCCED Certified Population)                      |
| Incorporation Type:          | 2nd Class City   |
| Borough Located In:          | North Slope Borough  |
| Taxes:                       | Sales: None, Property: 18.5 mills (Borough), Special: None |
| Coastal Management District: | North Slope Borough  |

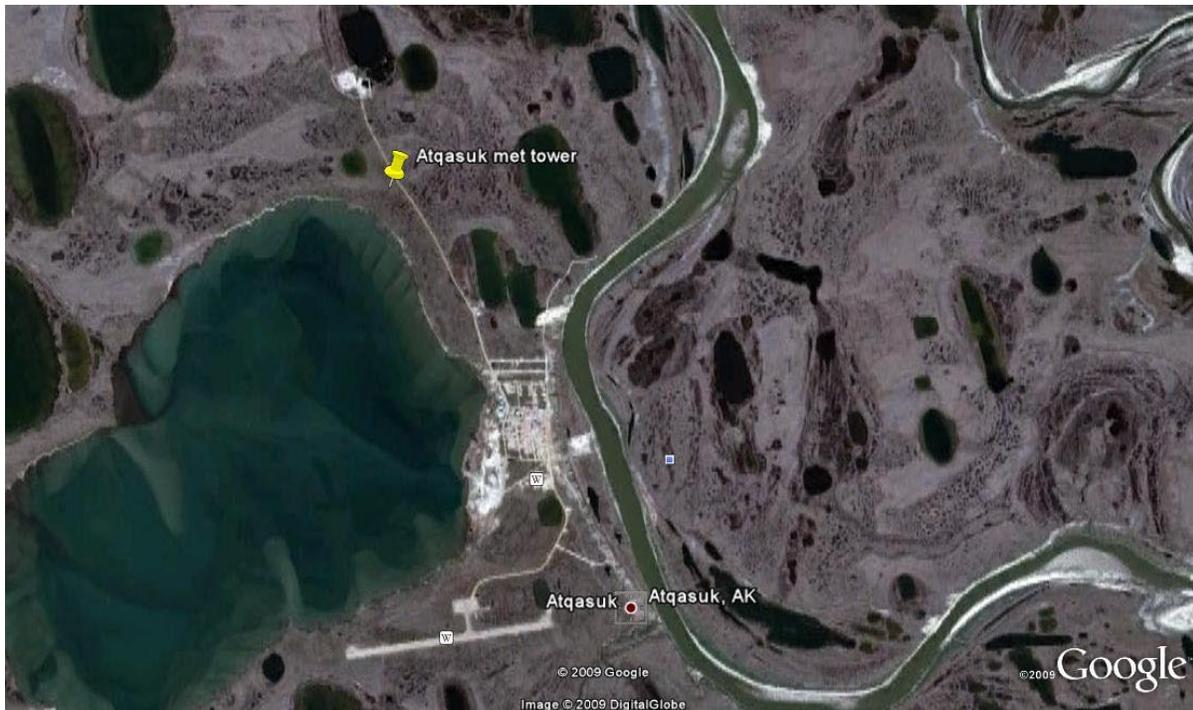
## Test Site Location

The met tower was installed approximately 1,500 meters (4,800 ft) northwest of the village of Atqasuk, near a large lagoon and just south of the village landfill. This site is well exposed to winter winds with no upwind obstructions.

### Site Information

|                    |   |
|--------------------|---|
| Site number        | 0223  |
| Latitude/longitude | N 70° 29.810' W 157° 26.826', WGS 84                      |
| Site elevation     | 23 meters (74 ft)   |
| Datalogger type    | NRG Symphonie, 10 minute time step                        |
| Tower type         | NRG 34-meter tall tower, 152 mm diameter, erected to 30 m |
| Anchor type        | 1.5 m screw-in  |

### Google Earth image



### Tower Sensor Information

| Channel | Sensor type            | Height   | Multiplier | Offset  | Orientation |
|---------|------------------------|----------|------------|---------|-------------|
| 1       | NRG #40 anemometer     | 30 m (A) | 0.754      | 0.40    | 181° T      |
| 2       | NRG #40 anemometer     | 30 m (B) | 0.758      | 0.35    | 271° T      |
| 3       | NRG #40 anemometer     | 20 m     | 0.753      | 0.41    | 272° T      |
| 7       | NRG #200P wind vane    | 29 m     | 0.351      | 357     | 357° T      |
| 9       | NRG #110S Temp C       | 3 m      | 0.136      | -86.383 | N           |
| 10      | RH-5 relative humidity | 2 m      | 0.098      | 0       | S           |
| 12      | Voltmeter              | 2 m      | 0.021      | 0       | n/a         |

## Photographs



Soft rice ice on guy wire; D. Vaught photo



Icing buildup on datalogger box; D. Vaught photo



Top of met tower; D. Vaught photo



Robert Akpik in Atqasuk; D. Vaught photo

## Data Quality

Data recovery in Atqasuk was marginal with 63 to 73 percent data return from the anemometers and wind vane. The missing data represents the windier winter months when data recovery was extremely poor. This poor data recovery was due to soft rime ice (hoarfrost), beginning in October and lasting to early May (note a very similar data loss pattern was documented in Wainwright). Photographs taken in early February indicated heavy hoarfrost icing conditions which likely prevailed during the entire winter and were largely responsible for the poor data return. Note also that data loss from the relative humidity sensor is due to voltage drawdown of the iPack battery during the dark months of winter. Full operability of this sensor returned in early April when the PV panels recharged the iPack battery sufficiently to power it.

*Data recovery summary table*

| Label             | Units | Height | Possible Records | Valid Records | Recovery Rate (%) |
|-------------------|-------|--------|------------------|---------------|-------------------|
| Speed 30 A        | m/s   | 30 m   | 56,088           | 39,791        | 70.9              |
| Speed 30 B        | m/s   | 30 m   | 56,088           | 40,649        | 72.5              |
| Speed 20          | m/s   | 20 m   | 56,088           | 40,924        | 73.0              |
| Direction 29      | °     | 29 m   | 56,088           | 35,258        | 62.9              |
| Temperature       | °C    |        | 56,088           | 55,907        | 99.7              |
| RH-5 Humidity %RH | %RH   |        | 56,088           | 35,572        | 63.4              |
| iPack Voltmeter   | volts |        | 56,088           | 55,944        | 99.7              |

*Anemometer data recovery*

| Year     | Month | 30 m A           |               |                   | 30 m B        |                   | 20 m          |                   |
|----------|-------|------------------|---------------|-------------------|---------------|-------------------|---------------|-------------------|
|          |       | Possible Records | Valid Records | Recovery Rate (%) | Valid Records | Recovery Rate (%) | Valid Records | Recovery Rate (%) |
| 2009     | Jun   | 1,296            | 1,296         | 100.0             | 1,296         | 100.0             | 1,296         | 100.0             |
| 2009     | Jul   | 4,464            | 4,464         | 100.0             | 4,464         | 100.0             | 4,464         | 100.0             |
| 2009     | Aug   | 4,464            | 4,464         | 100.0             | 4,464         | 100.0             | 4,464         | 100.0             |
| 2009     | Sep   | 4,320            | 4,320         | 100.0             | 4,320         | 100.0             | 4,320         | 100.0             |
| 2009     | Oct   | 4,464            | 3,386         | 75.9              | 3,214         | 72.0              | 3,510         | 78.6              |
| 2009     | Nov   | 4,320            | 1,147         | 26.6              | 1,274         | 29.5              | 1,225         | 28.4              |
| 2009     | Dec   | 4,464            | 89            | 2.0               | 164           | 3.7               | 340           | 7.6               |
| 2010     | Jan   | 4,464            | 1,190         | 26.7              | 1,190         | 26.7              | 1,190         | 26.7              |
| 2010     | Feb   | 4,032            | 1,960         | 48.6              | 1,830         | 45.4              | 2,528         | 62.7              |
| 2010     | Mar   | 4,464            | 3,124         | 70.0              | 3,719         | 83.3              | 2,737         | 61.3              |
| 2010     | Apr   | 4,320            | 3,750         | 86.8              | 4,195         | 97.1              | 4,188         | 96.9              |
| 2010     | May   | 4,464            | 4,071         | 91.2              | 4,073         | 91.2              | 4,132         | 92.6              |
| 2010     | Jun   | 4,320            | 4,320         | 100.0             | 4,236         | 98.1              | 4,320         | 100.0             |
| 2010     | Jul   | 2,232            | 2,210         | 99.0              | 2,210         | 99.0              | 2,210         | 99.0              |
| All data |       | 56,088           | 39,791        | 70.9              | 40,649        | 72.5              | 40,924        | 73.0              |

**Wind Speed**

Wind data collected from the met tower, from the perspective of both mean wind speed and mean power density, indicates a moderate wind resource, but loss of such a significant percentage of winter data reduces the certainty of this assessment. Because it is problematic analyzing wind data with significant concentrated data loss, synthetic data was inserted in the data gaps to create a more realistic wind speed data profile. To be sure, long segments of synthetic data introduce uncertainty to the data set, in this significantly, but missing data is uncertain as well. To overcome this uncertainty, improved data collection with heated sensors would be necessary and advisable for Atqasuk.

*Anemometer summary*

| Variable                                     | Original data set |               |             | Synthesized data set |               |             |
|--|-------------------|---------------|-------------|----------------------|---------------|-------------|
|  | Speed<br>30 A     | Speed<br>30 B | Speed<br>20 | Speed<br>30 A        | Speed<br>30 B | Speed<br>20 |
| Measurement height (m)                       | 30                | 30            | 20          | 30                   | 30            | 20          |
| Mean wind speed (m/s)                        | 6.48              | 6.21          | 5.95        | 6.07                 | 6.07          | 5.77        |
| Max wind speed (m/s) (10-min avg)            | 19.5              | 19.6          | 18.6        | 19.5                 | 19.6          | 18.6        |
| Max wind speed (m/s) (gust)                  | 23.0              | 23.1          | 22.6        |                      |               |             |
| Weibull k                                    | 2.23              | 2.17          | 2.18        | 2.15                 | 2.14          | 2.11        |
| Weibull c (m/s)                              | 7.15              | 7.06          | 6.80        | 6.89                 | 6.88          | 6.55        |
| Mean power density (W/m <sup>2</sup> )       | 305               | 290           | 256         | 266                  | 267           | 233         |
| Mean energy content (kWh/m <sup>2</sup> /yr) | 2,674             | 2,543         | 2,239       | 2,333                | 2,338         | 2,038       |
| Energy pattern factor                        | 1.71              | 1.75          | 1.75        | 1.76                 | 1.77          | 1.79        |
| Frequency of calms (%)                       | 18.0              | 19.5          | 21.2        | 20.5                 | 20.8          | 23.4        |
| 1-hr autocorrelation coefficient             | 0.943             | 0.946         | 0.947       | 0.940                | 0.940         | 0.941       |
| Diurnal pattern strength                     | 0.063             | 0.060         | 0.068       | 0.062                | 0.061         | 0.068       |
| Hour of peak wind speed                      | 18                | 18            | 18          | 18                   | 18            | 17          |

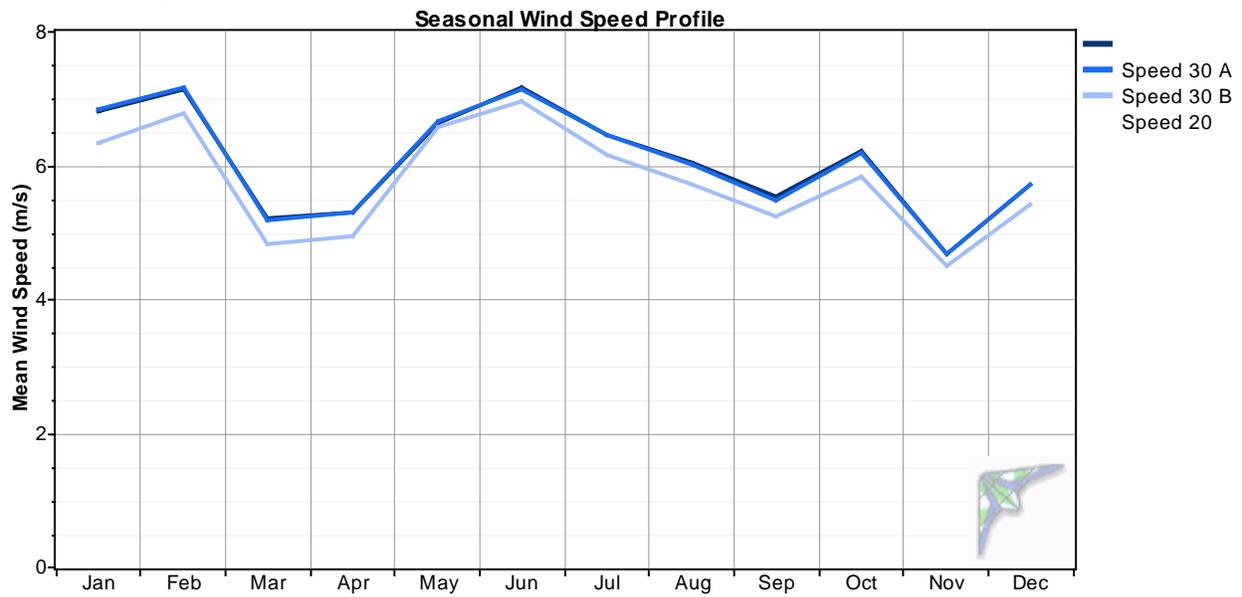
**Time Series**

Time series calculations indicated moderate wind speed averages throughout the year with lower winds measured in late winter and autumn. Poor data return, however, may have affected this analysis.

*30m A data summary*

| Year       | Month | Original data |                         |                   | Synthesis data |                         |                   |
|------------|-------|---------------|-------------------------|-------------------|----------------|-------------------------|-------------------|
|            |       | Mean<br>(m/s) | Max 10-<br>min<br>(m/s) | Max gust<br>(m/s) | Mean<br>(m/s)  | Max 10-<br>min<br>(m/s) | Max gust<br>(m/s) |
| 2009       | Jun   | 7.75          | 12.6                    | 15.1              | 7.75           | 12.6                    | 15.1              |
| 2009       | Jul   | 6.21          | 13.5                    | 16.2              | 6.21           | 13.5                    | 16.2              |
| 2009       | Aug   | 6.05          | 14.7                    | 18.5              | 6.05           | 14.7                    | 18.5              |
| 2009       | Sep   | 5.54          | 16.2                    | 20.7              | 5.54           | 16.2                    | 20.7              |
| 2009       | Oct   | 6.51          | 17.9                    | 21.5              | 6.21           | 17.9                    | 21.5              |
| 2009       | Nov   | 5.79          | 13.0                    | 17.0              | 4.67           | 13.0                    | 17.0              |
| 2009       | Dec   | 8.07          | 11.0                    | 15.5              | 5.72           | 16.5                    | 15.5              |
| 2010       | Jan   | 6.65          | 13.1                    | 15.9              | 6.81           | 16.2                    | 15.9              |
| 2010       | Feb   | 7.47          | 19.5                    | 23.0              | 7.16           | 19.5                    | 23.0              |
| 2010       | Mar   | 5.84          | 12.7                    | 15.1              | 5.23           | 12.7                    | 15.1              |
| 2010       | Apr   | 5.57          | 14.7                    | 17.0              | 5.30           | 14.7                    | 17.0              |
| 2010       | May   | 6.74          | 14.9                    | 17.0              | 6.64           | 14.9                    | 17.0              |
| 2010       | Jun   | 6.98          | 14.7                    | 17.7              | 6.98           | 14.7                    | 17.7              |
| 2010       | Jul   | 6.94          | 14.4                    | 17.0              | 6.96           | 14.4                    | 17.0              |
| MMM annual |       | 6.48          | 19.5                    | 23.0              | 6.07           | 19.5                    | 23.0              |

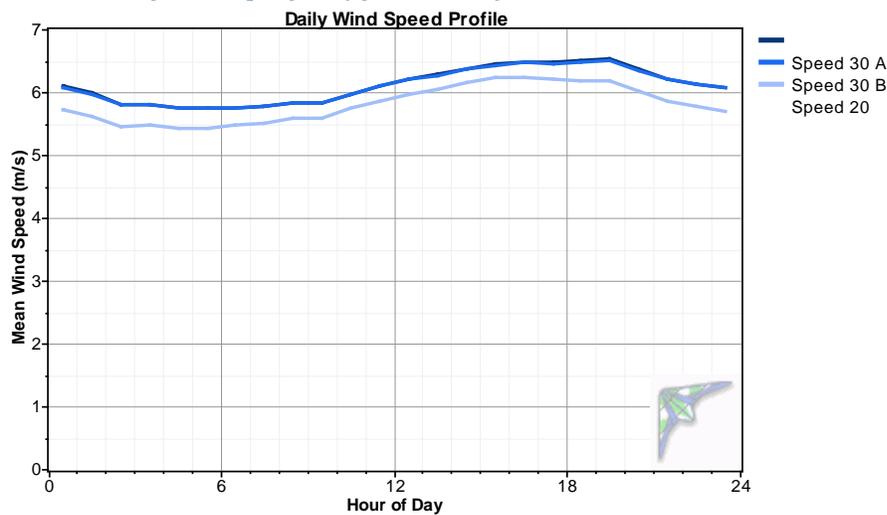
*Time series graph (synth. data)*



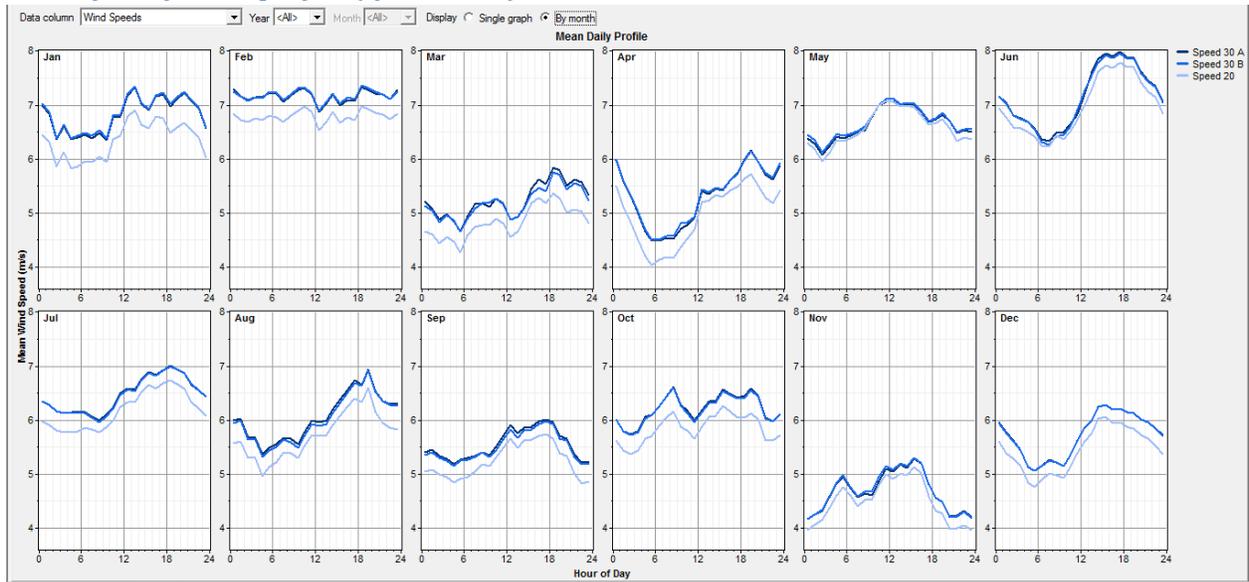
**Daily Wind Profile**

The daily wind profile indicates relatively high variation (for a cold climate location) of wind speeds throughout the day, with lowest wind speeds during the morning hours and highest wind speeds during late afternoon and early evening hours. This perspective changes somewhat when considering monthly views of daily profiles as considerably more variation is observed.

*Annual daily wind profile (synth. data)*

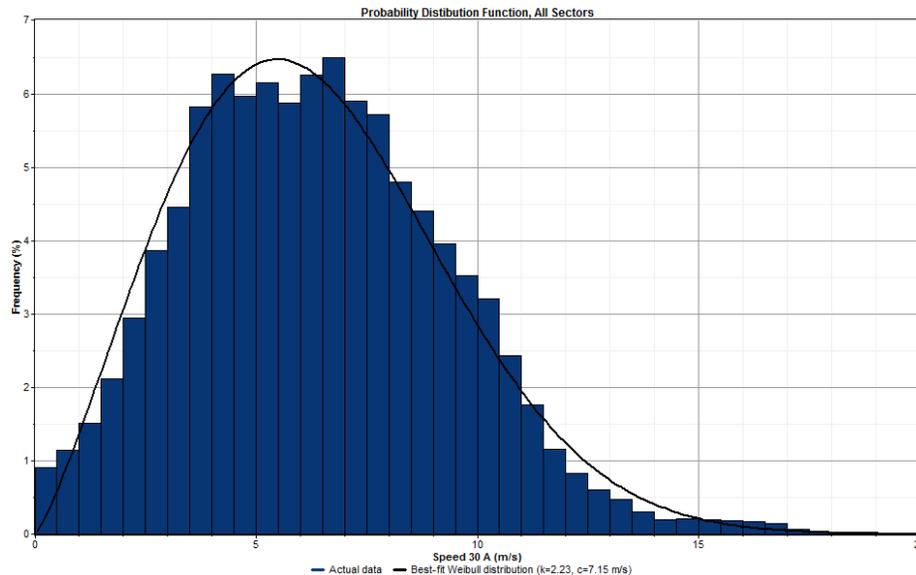


### Monthly daily wind profile (synth. data)



### Probability Distribution Function

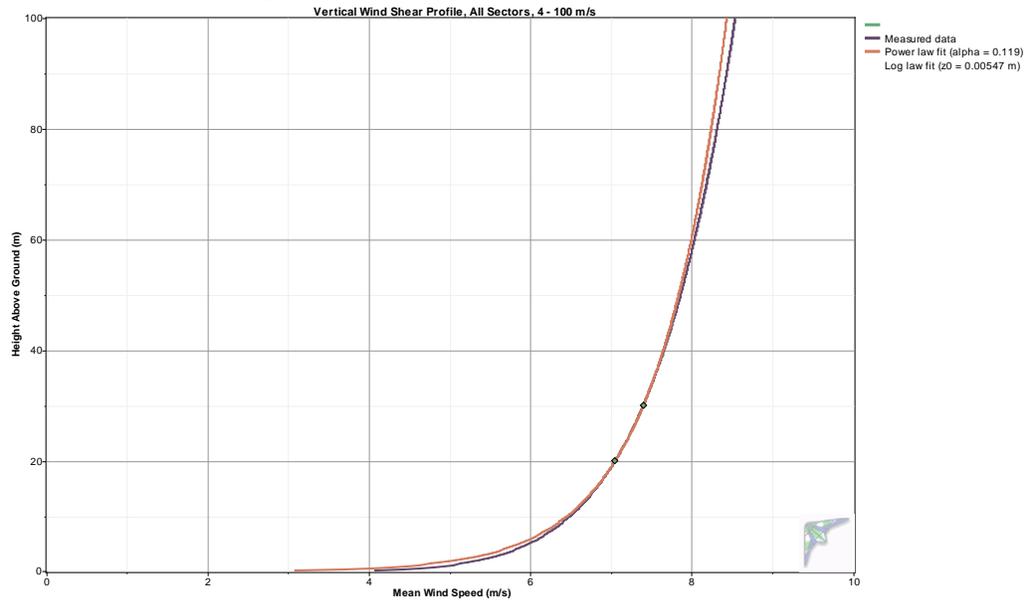
The probability distribution function (or histogram) of wind speed indicates a near-normal shape curve of wind speeds (defined as the Raleigh distribution,  $k=2.0$ ).



### Wind Shear and Roughness

A wind shear power law exponent of 0.119 indicates moderately low wind shear at the site; hence turbine construction at a low hub height is possibly a desirable option. Related to wind shear, a calculated surface roughness of 0.0078 meters (indicating the height above ground level where wind velocity would be zero) indicates relatively smooth terrain (roughness description: lawn grass) surrounding the met tower, especially toward the prevailing wind direction of northeast.

**Vertical wind shear profile, wind speed > 4 m/s**



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

| Direction Sector  | Time Steps | Sector Wind (%) | Mean Wind Speed (m/s) |          | Best-Fit Power Law Exp | Best-Fit Surface Roughness (m) |
|-------------------|------------|-----------------|-----------------------|----------|------------------------|--------------------------------|
|                   |            |                 | Speed 30 B            | Speed 20 |                        |                                |
| 348.75° - 11.25°  | 1,310      | 5.0%            | 6.34                  | 6.08     | 0.101                  | 0.0012                         |
| 11.25° - 33.75°   | 3,067      | 11.6%           | 6.98                  | 6.70     | 0.101                  | 0.0013                         |
| 33.75° - 56.25°   | 7,948      | 30.2%           | 7.69                  | 7.47     | 0.073                  | 0.0000                         |
| 56.25° - 78.75°   | 5,030      | 19.1%           | 8.35                  | 8.07     | 0.085                  | 0.0002                         |
| 78.75° - 101.25°  | 1,457      | 5.5%            | 6.99                  | 6.38     | 0.223                  | 0.2741                         |
| 101.25° - 123.75° | 507        | 1.9%            | 5.95                  | 5.47     | 0.206                  | 0.1915                         |
| 123.75° - 146.25° | 318        | 1.2%            | 6.36                  | 5.72     | 0.259                  | 0.5125                         |
| 146.25° - 168.75° | 549        | 2.1%            | 6.94                  | 6.29     | 0.241                  | 0.3866                         |
| 168.75° - 191.25° | 536        | 2.0%            | 7.17                  | 6.61     | 0.198                  | 0.1574                         |
| 191.25° - 213.75° | 1,017      | 3.9%            | 7.06                  | 6.68     | 0.137                  | 0.0166                         |
| 213.75° - 236.25° | 1,287      | 4.9%            | 6.72                  | 6.27     | 0.172                  | 0.0735                         |
| 236.25° - 258.75° | 1,237      | 4.7%            | 8.00                  | 7.59     | 0.133                  | 0.0131                         |
| 258.75° - 281.25° | 736        | 2.8%            | 6.80                  | 6.41     | 0.145                  | 0.0243                         |
| 281.25° - 303.75° | 425        | 1.6%            | 6.39                  | 6.11     | 0.113                  | 0.0035                         |
| 303.75° - 326.25° | 367        | 1.4%            | 5.81                  | 5.56     | 0.107                  | 0.0021                         |
| 326.25° - 348.75° | 551        | 2.1%            | 5.45                  | 5.27     | 0.085                  | 0.0002                         |

## Extreme Winds

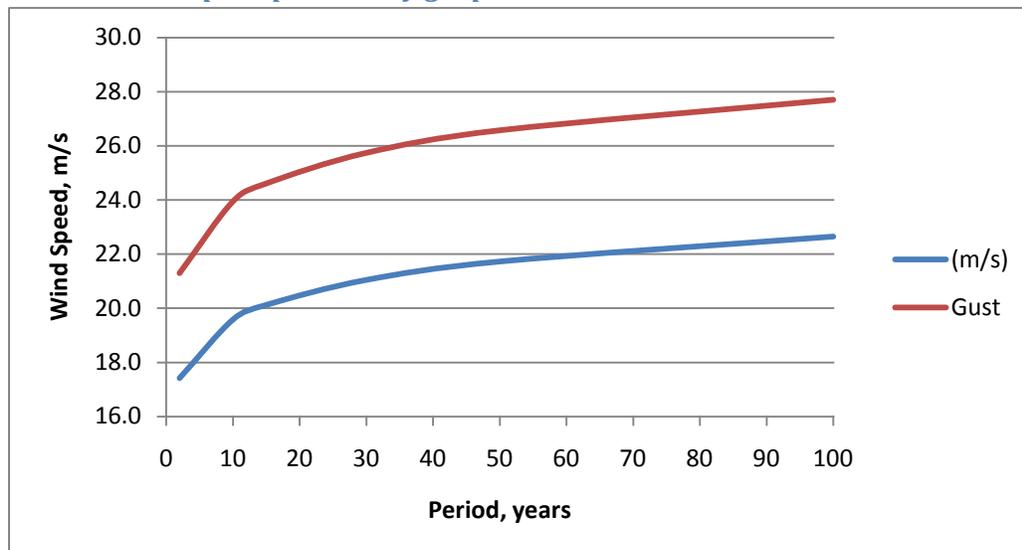
Although thirteen months of data is minimal for calculation of extreme wind probability, use of a modified Gumbel distribution analysis, based on monthly maximum winds vice annual maximum winds, yields reasonably good results. Extreme wind analysis indicates a very low probability of extreme wind events, but one should be cautioned that the poor winter anemometer data return significantly reduces the confidence of this calculation. Even so, general aspects of Atqasuk, including distance from the coast, far northerly location and lack of exposure to Gulf of Alaska storm winds increases the likelihood that extreme wind events are uncommon and not highly energetic.

Industry standard reference of extreme wind is the 50 year, 10-minute average probable wind speed, referred to as  $V_{ref}$ . For Wainwright, this calculates to 21.7 m/s, well below the 37.5 m/s threshold of International Electrotechnical Commission (IEC) 61400-1, 3<sup>rd</sup> edition criteria for a Class III site. Note that Class III extreme wind classification is the lowest defined and all wind turbines are designed for this wind regime.

### Extreme wind speed probability table (original data)

| Period (years)       | $V_{ref}$<br>(m/s) | Gust<br>(m/s) | IEC 61400-1, 3rd ed.<br>Class | $V_{ref}$ , m/s        |
|----------------------|--------------------|---------------|-------------------------------|------------------------|
| 2                    | 17.4               | 21.3          | I                             | 50.0                   |
| 10                   | 19.6               | 24.0          | II                            | 42.5                   |
| 15                   | 20.1               | 24.6          | III                           | 37.5                   |
| 30                   | 21.0               | 25.8          | S                             | designer-<br>specified |
| 50                   | 21.7               | 26.6          |                               |                        |
| 100                  | 22.7               | 27.7          |                               |                        |
| average gust factor: | 1.22               |               |                               |                        |

### Extreme wind speed probability graph



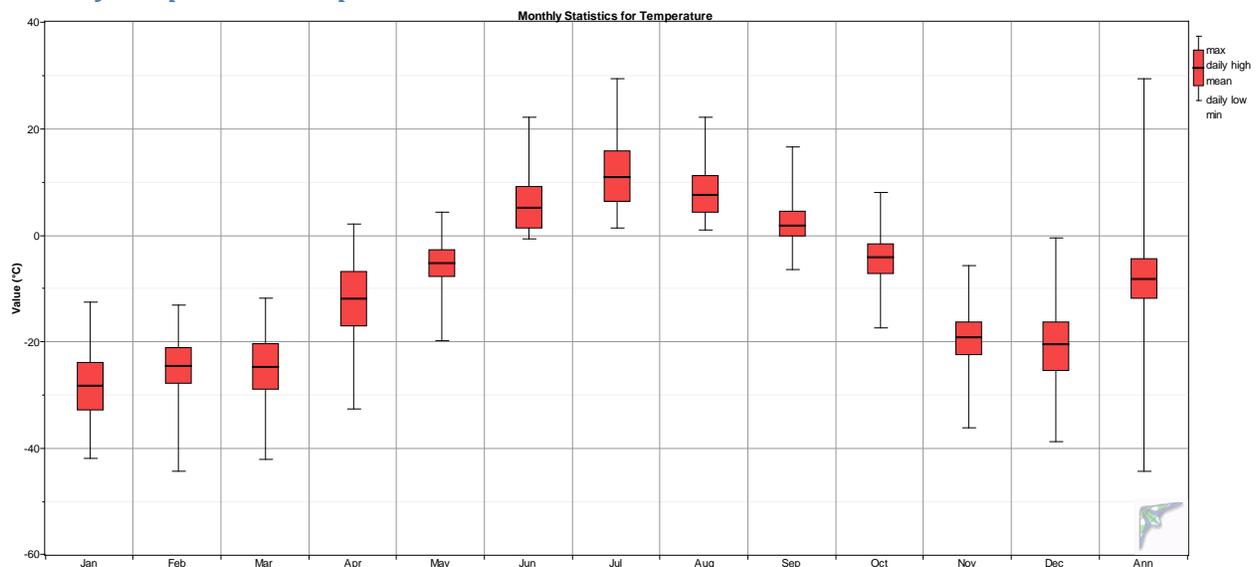
## Temperature and density

Atqasuk experiences relatively warm summers (compared to the coast) and extremely cold winters with multiple recordings of sub negative 40 degree temperatures. The result is high air density; calculated air density exceeds standard air density for a 23 meter elevation (1.222 Kg/m<sup>3</sup>) by nine percent. This is advantageous in wind power operations as most wind turbines produce more power at low temperatures (high air density) than at standard temperature and density.

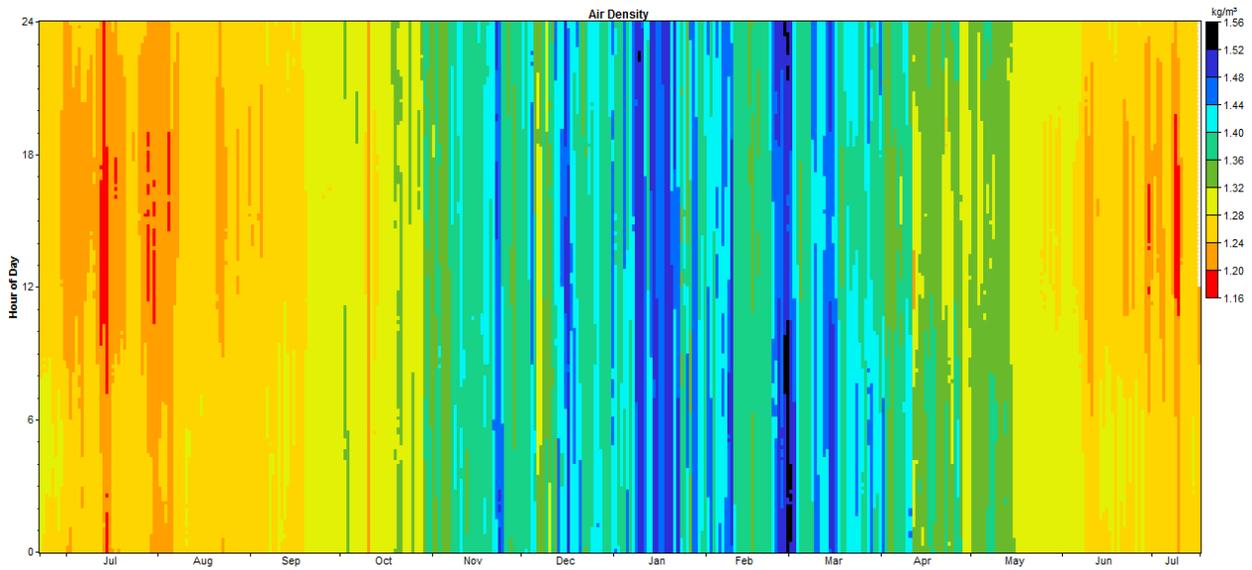
### Temperature and density table

| Month  | Temperature |          |          | Air Density               |                          |                          |
|--------|-------------|----------|----------|---------------------------|--------------------------|--------------------------|
|        | Mean (°C)   | Min (°C) | Max (°C) | Mean (kg/m <sup>3</sup> ) | Min (kg/m <sup>3</sup> ) | Max (kg/m <sup>3</sup> ) |
| Jan    | -28.1       | -41.9    | -12.6    | 1.438                     | 1.351                    | 1.522                    |
| Feb    | -24.5       | -44.4    | -13.1    | 1.417                     | 1.353                    | 1.538                    |
| Mar    | -24.7       | -42.2    | -11.8    | 1.417                     | 1.347                    | 1.524                    |
| Apr    | -11.9       | -32.7    | 2.0      | 1.347                     | 1.222                    | 1.464                    |
| May    | -5.1        | -19.8    | 4.3      | 1.313                     | 1.268                    | 1.389                    |
| Jun    | 5.3         | -0.7     | 22.1     | 1.264                     | 1.192                    | 1.292                    |
| Jul    | 11.0        | 1.3      | 29.4     | 1.239                     | 1.163                    | 1.282                    |
| Aug    | 7.6         | 1.0      | 22.1     | 1.254                     | 1.192                    | 1.284                    |
| Sep    | 2.0         | -6.5     | 16.6     | 1.279                     | 1.215                    | 1.320                    |
| Oct    | -4.1        | -17.5    | 8.1      | 1.305                     | 1.222                    | 1.377                    |
| Nov    | -19.1       | -36.3    | -5.7     | 1.386                     | 1.316                    | 1.486                    |
| Dec    | -20.5       | -38.8    | -0.6     | 1.394                     | 1.291                    | 1.502                    |
| Annual | -9.3        | -44.4    | 29.4     | 1.338                     | 1.163                    | 1.538                    |

### Monthly temperature boxplot



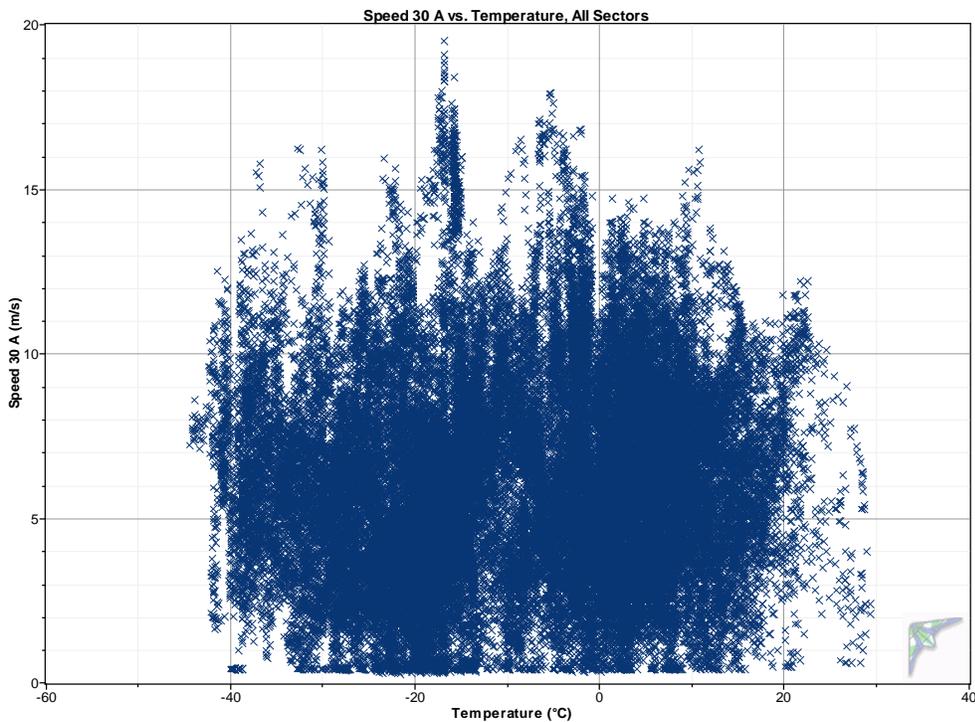
### Air density DMap



### Wind Speed Scatterplot

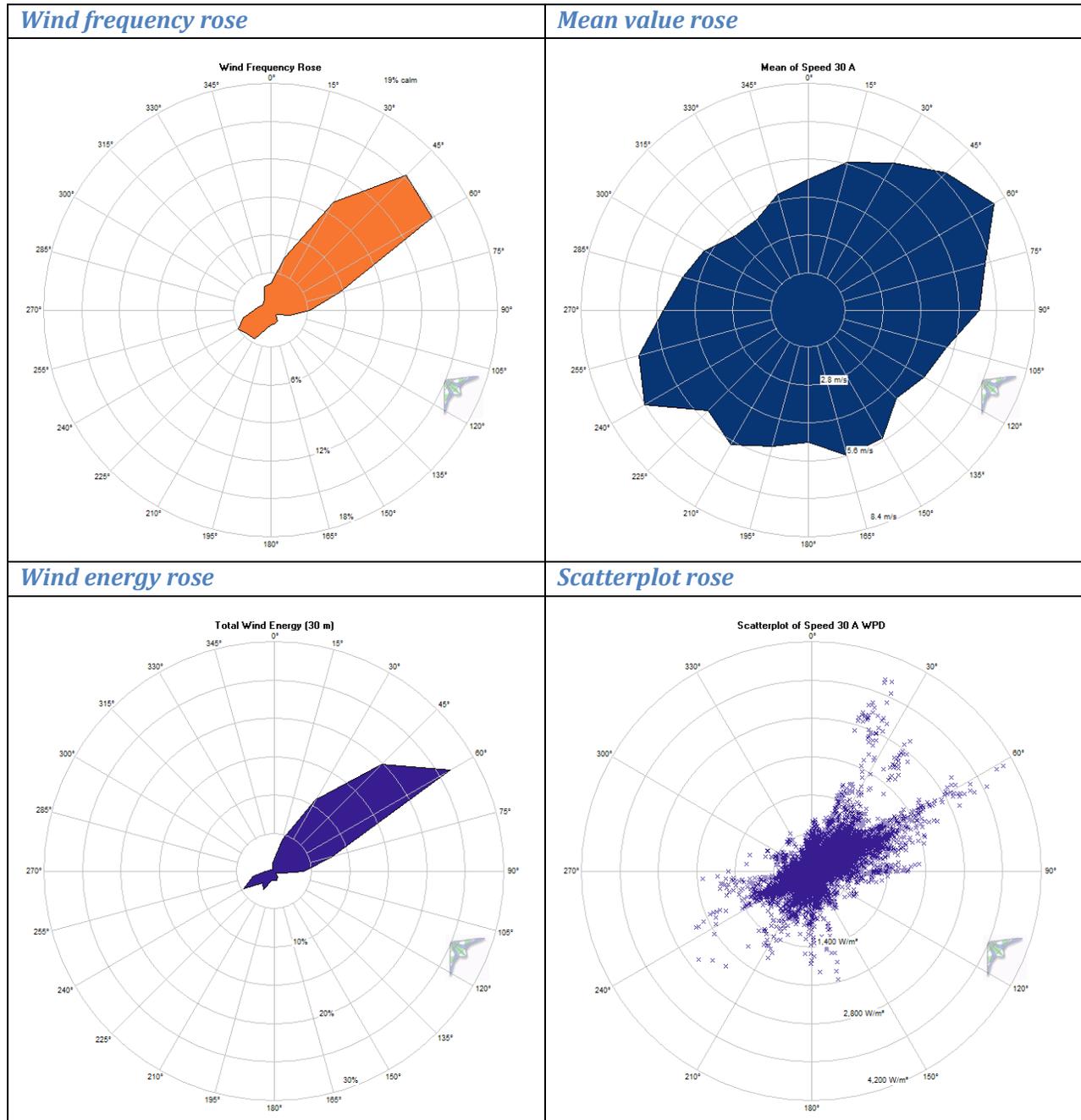
The wind speed versus temperature scatterplot below indicates that a substantial percentage of wind in Atqasuk coincides with very cold temperatures, as one would expect given its high arctic location. During the met tower test period, temperatures fell below  $-40^{\circ}\text{C}$  on many occasions.

### Wind speed versus temperature scatterplot (synth. data)

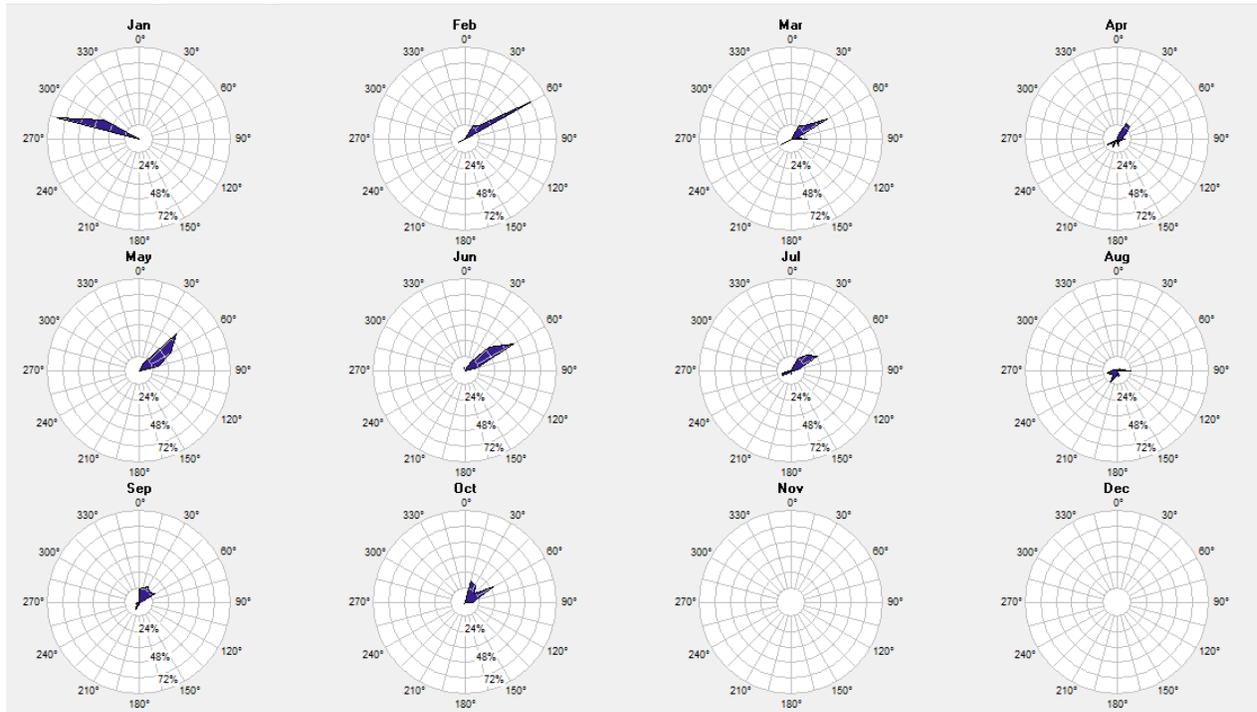


## Wind Direction

Wind frequency rose data indicates highly directional winds from the northeast. Power density rose data (representing the power in the wind) indicates power winds are also strongly directional, from the northeast. Calm frequency (percent of time that winds at 30 meter level are less than 3.5 m/s) was 19 percent during the met tower test period. Note however that the wind vane had extremely poor data return during the winter months, so winter wind roses below should be evaluated with caution.



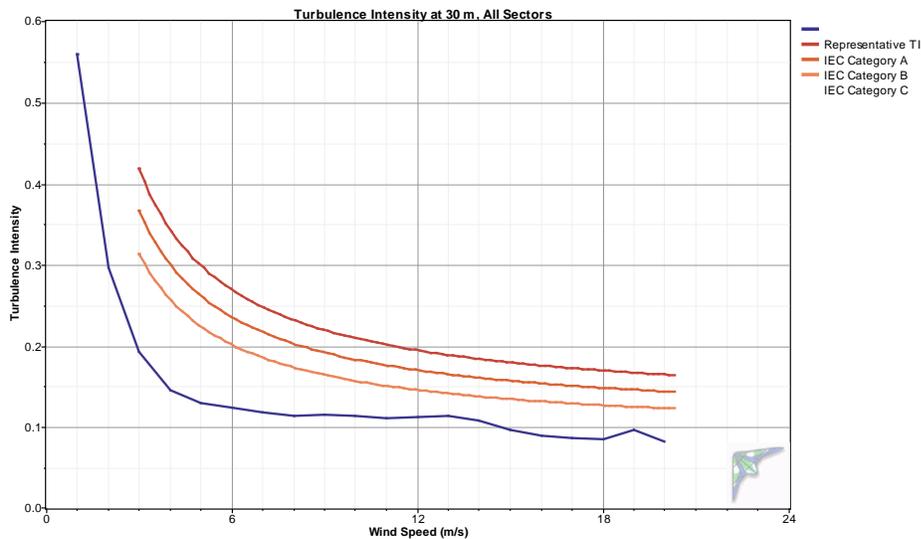
*Wind density roses by month*



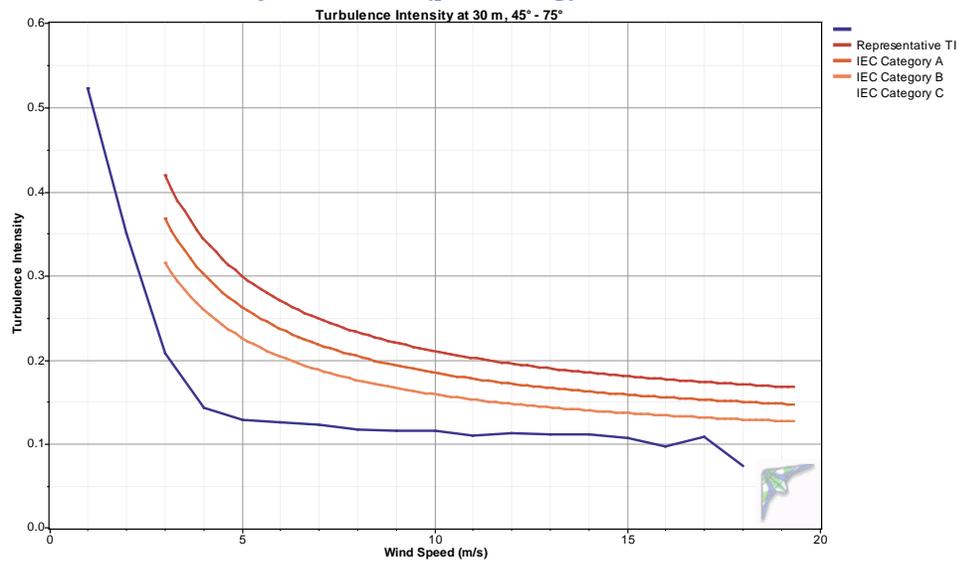
**Turbulence**

To date, the mean turbulence intensity of 0.075 at 15 m/s is within acceptable standards and classifies the site as IEC (International Electrotechnical Commission) 61400-1, 3<sup>rd</sup> edition (2005) turbulence category C (lowest).

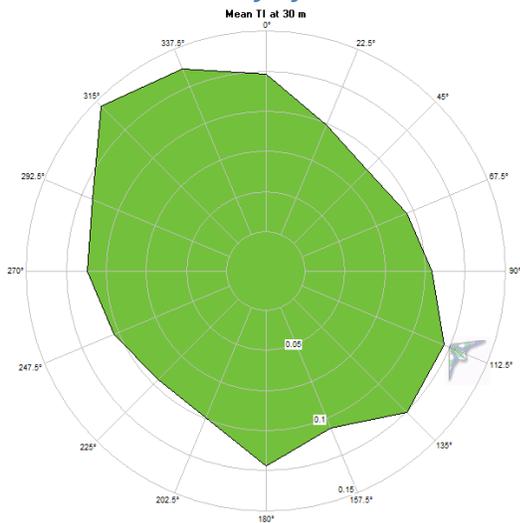
*Turbulence intensity, all wind sectors*



**Turbulence intensity, northeast (prevailing) wind sector**



**Turbulence intensity by direction**



**Turbulence table**

| Bin               | Bin Endpoints  |                | Records<br>in Bin | Mean TI | Std<br>Dev.<br>of TI | Representative<br>TI | Peak<br>TI |
|-------------------|----------------|----------------|-------------------|---------|----------------------|----------------------|------------|
| Midpoint<br>(m/s) | Lower<br>(m/s) | Upper<br>(m/s) |                   |         |                      |                      |            |
| 1                 | 0.5            | 1.5            | 1,057             | 0.362   | 0.154                | 0.559                | 0.857      |
| 2                 | 1.5            | 2.5            | 2,010             | 0.177   | 0.093                | 0.296                | 1.190      |
| 3                 | 2.5            | 3.5            | 3,306             | 0.118   | 0.059                | 0.193                | 0.594      |
| 4                 | 3.5            | 4.5            | 4,808             | 0.094   | 0.040                | 0.145                | 0.425      |
| 5                 | 4.5            | 5.5            | 4,819             | 0.084   | 0.035                | 0.129                | 0.667      |
| 6                 | 5.5            | 6.5            | 4,820             | 0.084   | 0.031                | 0.123                | 0.386      |
| 7                 | 6.5            | 7.5            | 4,924             | 0.082   | 0.028                | 0.117                | 0.288      |

|    |      |      |       |       |       |       |       |
|----|------|------|-------|-------|-------|-------|-------|
| 8  | 7.5  | 8.5  | 4,184 | 0.082 | 0.025 | 0.113 | 0.227 |
| 9  | 8.5  | 9.5  | 3,324 | 0.084 | 0.024 | 0.115 | 0.234 |
| 10 | 9.5  | 10.5 | 2,679 | 0.083 | 0.024 | 0.114 | 0.505 |
| 11 | 10.5 | 11.5 | 1,667 | 0.082 | 0.023 | 0.111 | 0.175 |
| 12 | 11.5 | 12.5 | 789   | 0.085 | 0.021 | 0.112 | 0.200 |
| 13 | 12.5 | 13.5 | 429   | 0.089 | 0.020 | 0.114 | 0.236 |
| 14 | 13.5 | 14.5 | 202   | 0.086 | 0.017 | 0.108 | 0.148 |
| 15 | 14.5 | 15.5 | 165   | 0.075 | 0.016 | 0.096 | 0.138 |
| 16 | 15.5 | 16.5 | 140   | 0.073 | 0.012 | 0.089 | 0.115 |
| 17 | 16.5 | 17.5 | 84    | 0.073 | 0.010 | 0.086 | 0.114 |
| 18 | 17.5 | 18.5 | 15    | 0.070 | 0.012 | 0.085 | 0.098 |
| 19 | 18.5 | 19.5 | 5     | 0.077 | 0.015 | 0.096 | 0.099 |
| 20 | 19.5 | 20.5 | 1     | 0.082 | 0.000 | 0.082 | 0.082 |

### Airport AWSS Data

Airport wind data has been requested of National Oceanic and Atmospheric Administration's Anchorage office but not yet received.