Wind Monitoring Update for Tuktoyaktuk, Winter 2009

Prepared for

AURORA RESEARCH INSTITUTE
AURORA COLLEGE

by

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Summary

In September 2007 the Aurora Research Institute moved a wind monitoring station from a site by a shooting range south of the hamlet to a new location closer to the community and power line. The wind data from the new ARI wind monitoring site in Tuktoyaktuk was analysed and correlated with the airport's automated station wind measurements. The 10-year average wind speed at the new ARI site is estimated to be 5.35 m/s at 37 m AGL. A computer wind flow model that is calibrated to the ARI wind monitoring station at Site WM #2 (the new wind monitoring site) estimates the wind speed at the proposed wind development site are from 5.3 to 5.4 m/s at 37 metres above ground.

Acronyms

AGL – Above ground level

ARI – the Aurora Research Institute

MACA – Municipal and Community Affairs, government of NWT.

MCP – Measure-Correlate-Predict, a method for projecting short-term wind measurements to long-term using nearby long-term weather stations such as those at the airport.

WM – wind monitoring site, refers to the site where the wind energy measurements are made.

Introduction and Site Description

Tuktoyaktuk (see Figure 1) is a prime candidate for a wind-diesel energy development in the near future. The community is ideally suited for such a project as it is accessible by winter road, and has industrial equipment and personnel available to locally install and maintain a wind park. The community also has potential to act as a regional hub for development of wind-diesel systems in outlying communities of the NWT and the Yukon.

In May 2006 an ARI wind monitoring station was installed at the far south end of the community, near a shooting range south of the community's sewage lagoon (ARI WM #1 – Figure 2). In a previous report by Pinard (2007) the long-term mean wind speed at this site was estimated at 5.05 m/s at 30 m AGL.

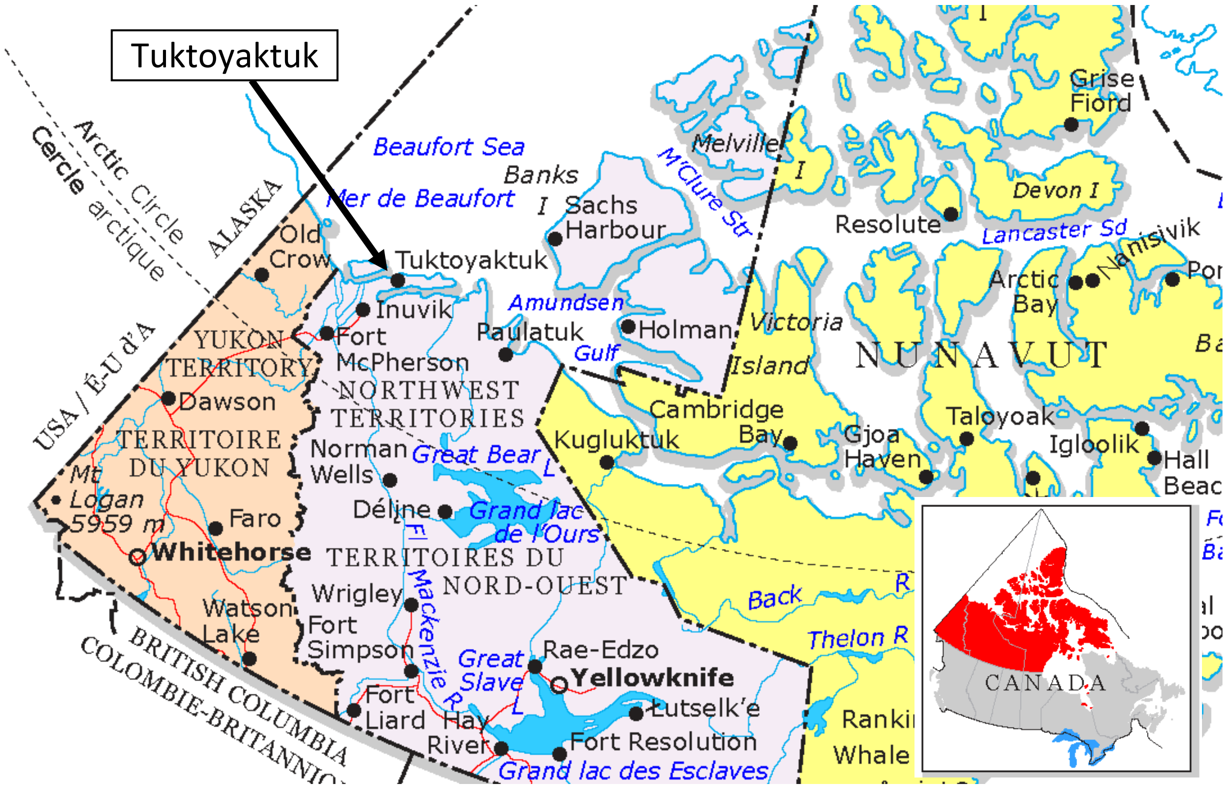

Figure 1: The location of Tuktoyaktuk in relation to the rest of Canada.

Projected to 37 m AGL (the hub height of the proposed wind turbine towers for Tuktoyaktuk) the long-term average wind speed at the WM #1 site is 5.29 m/s. This wind speed estimate at this site was based on a long-term mean over a six-year period from 2001 to 2006.

The community expressed interest in the possibility of a wind development and suggested a better site near the community for a wind project with possibly higher wind speeds; the wind monitoring equipment was moved to this site in September 2007 (ARI WM #2 – Figure 2).

The current wind monitoring site (WM #2) only has room for up to two wind turbines. A larger site exists about 900 m further north of WM #2 (Figures 2, 3 and 4) and is presently being considered as the site for a future wind development. This last site ("Proposed Wind Park" in Figure 2) is about 150 m from existing power and has an area that is about 100 by 400 m located on a shallow ridge that is about 4 to 5 m above sea level. This last site has room for seven wind turbines or more.

Following the previous reports (Pinard 2007 and Maissan 2008) the purpose of this report is to provide an update of the latest wind monitoring results from the ARI site WM #2. These are compared to the long-term measurements made by Environment Canada's weather stations at the airport and to those of site WM #1.

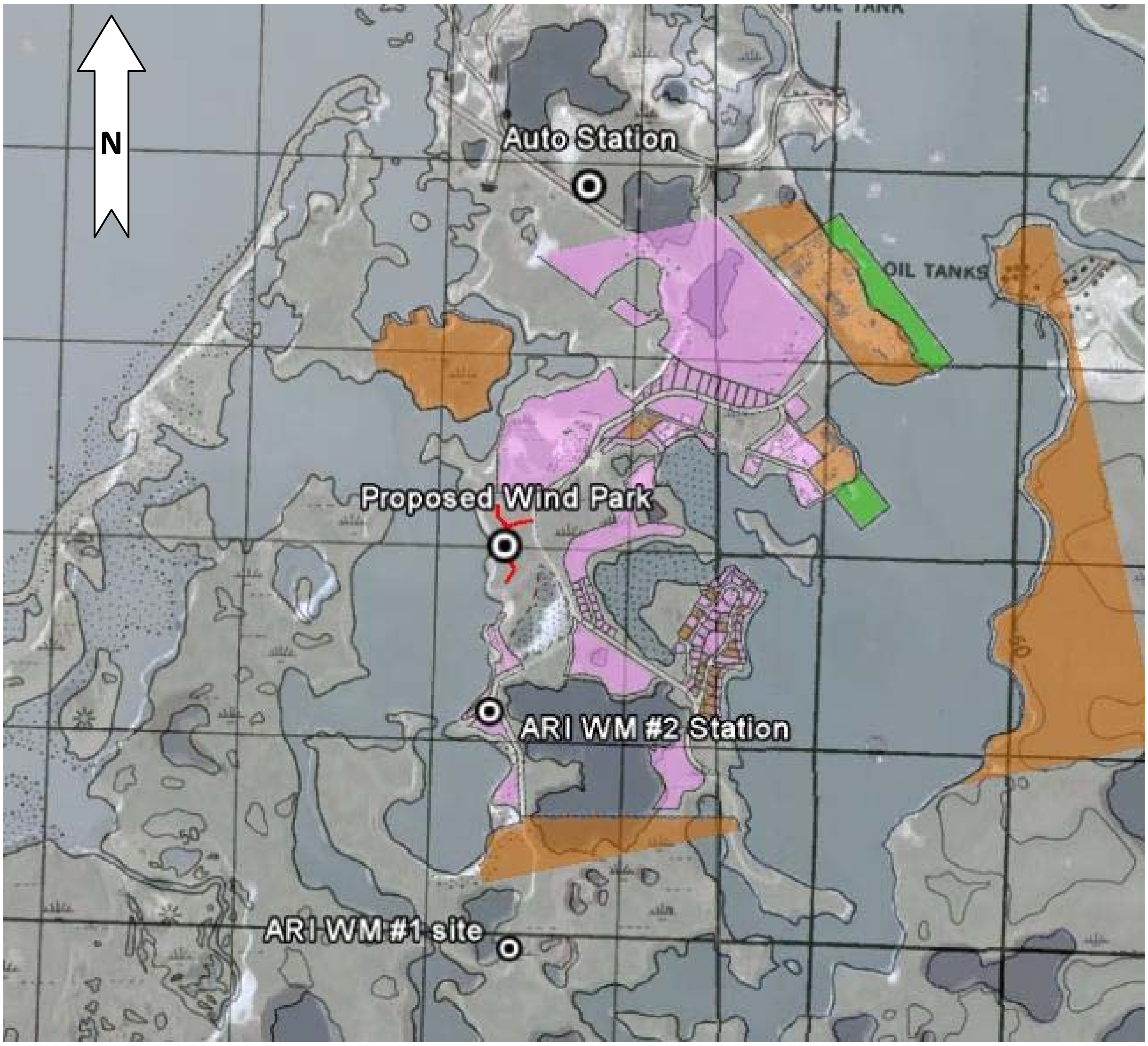

Figure 2: Map of area south of Tuktoyaktuk where wind monitoring sites are located and where a wind park is proposed. For reference purposes the map is a satellite image (Google Earth) overlaid with an NTS map and a legal plan from MACA.

Figure 3: Aerial view of land just south of Tuktoyaktuk, the locations of Site WM #2 and the proposed wind farm area.

Figure 4: Panoramic view of the area around the wind monitoring station at site WM #2. The lower part of the wind monitoring tower is visible in the foreground. The view is looking to the north with the new proposed wind park site shown.

The Wind Collecting Stations

The wind monitoring station currently at WM #2 is a 30 m tower set up with 4 wind speed sensors (anemometers). The sensors are located at 10-, 20- and 30 m above ground level (AGL, see Figure 5) on the tower. Three anemometer booms (1.1 m long) point to the southwest and a fourth sensor is on a vertical tube putting the sensor 30 cm above the tower top. A wind vane is also installed at the tower top on a boom pointing south and a temperature sensor is at the bottom of the tower. All four speed sensors are calibrated. The ARI station at WM #2 has been collecting data since September 29, 2007 and the data used for this study were obtained between Sept 29, 2007 and December 1, 2008.

At the airport there are apparently two stations that measure the wind speed at 10 m AGL. The weather data for both stations are stored on Environment Canada's website. One of the stations is an "auto" station (automatic data collection, see Figure 2, "Auto Station") and has monitored weather conditions 24 hours a day since 1994. The data from the auto station are recorded at the top of the hour and stored directly to a data logger. The airport "A" station ("A" meaning that is operated and data collected by the airport staff) is typically monitored during office hours and its data is recorded at the top of each hour by local staff. The A station has collected data since 1970. It is possible that the measurements come from the same station, which is the only one found by the author at the Tuktoyaktuk airport (see Figure 6).

Figure 5: Looking up at the ARI wind monitoring station set up at site WM #2. The anemometer booms are pointing to the southwest.

Figure 6: View looking south from the airport terminal to what is believed to be the auto and the "A" weather stations operated by Environment Canada.

Wind Direction Analysis

Over an eight-year period the auto station has measured almost an equal distribution of wind energy coming from the west-north-westerly direction and the easterly direction (Figure 7). The wind data from the current ARI wind monitoring station (site WM #2) also confirms that the prevailing wind directions in the Tuktoyaktuk area are west-north-westerly but with more wind energy for the east.

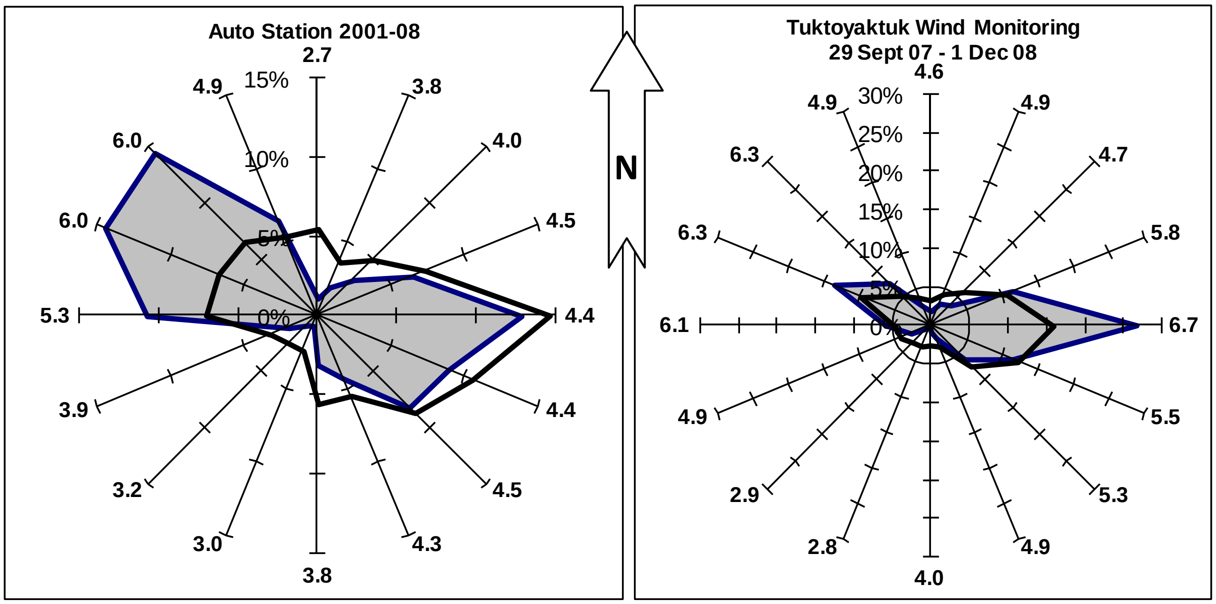

Figure 7: Wind energy rose depicting where the two main wind energy directions are according to the wind monitoring stations at the airport (auto station) and site WM #2. The shaded rose is the relative wind energy by direction, and the outlined rose is the wind frequency of occurrence by direction. The mean wind speed by direction sector is indicated at the end of each axis. The outlined area represents the frequency of winds and the shaded area represents the energy in the wind by direction. North is up and west is to the right.

Wind Speed Analysis

Defining the Long-term Mean in Tuktoyaktuk

At the airport the A station and the auto station were compared to each other for the period 2001-06 (see Figure 8). During this period the auto station had an annual mean wind speed of 4.25 m/s and the A station was 4.07 m/s (both measured at 10 m AGL); the auto station's mean wind speed was about 4% above the A station during this period. The difference is most likely due to the A station data being only collected during office hours and the auto station recording automatically 24 hours a day.

The auto station recorded the most recent 5-year (2004-08) mean wind speed of 4.43 m/s at 10m AGL, a ten-year (1999-2008) mean wind speed of 4.27, and a 13-year mean (the extent of the auto measurement period) of 4.28 m/s. The standard deviation of the mean annual wind speed about the 10-year mean is 0.29 m/s. A time series of the annual mean speeds for the last 13 years is shown (Figure 8). Although it appears to show a trend of increasing wind speed there are other longer term variables such as those due to ocean water temperature oscillations like the Arctic Decadal Oscillation (see Bond, 2009) that may be at play.

According to the report Canadian Climate Normals (AES, 1982) the mean wind speed for the Tuktoyaktuk airport station was 4.8 m/s at 10m AGL for a 6-year period between 1970 and 1980. On verifying some of the wind data from Environment Canada's Website it was found however, that in several of those years wind data was not recorded during some of the winter months when wind speeds are usually reduced. Because of its 24-hour availability the auto station wind data is used in this study for the comparative analysis with the 30-m data from the wind energy monitoring station (WM#2).

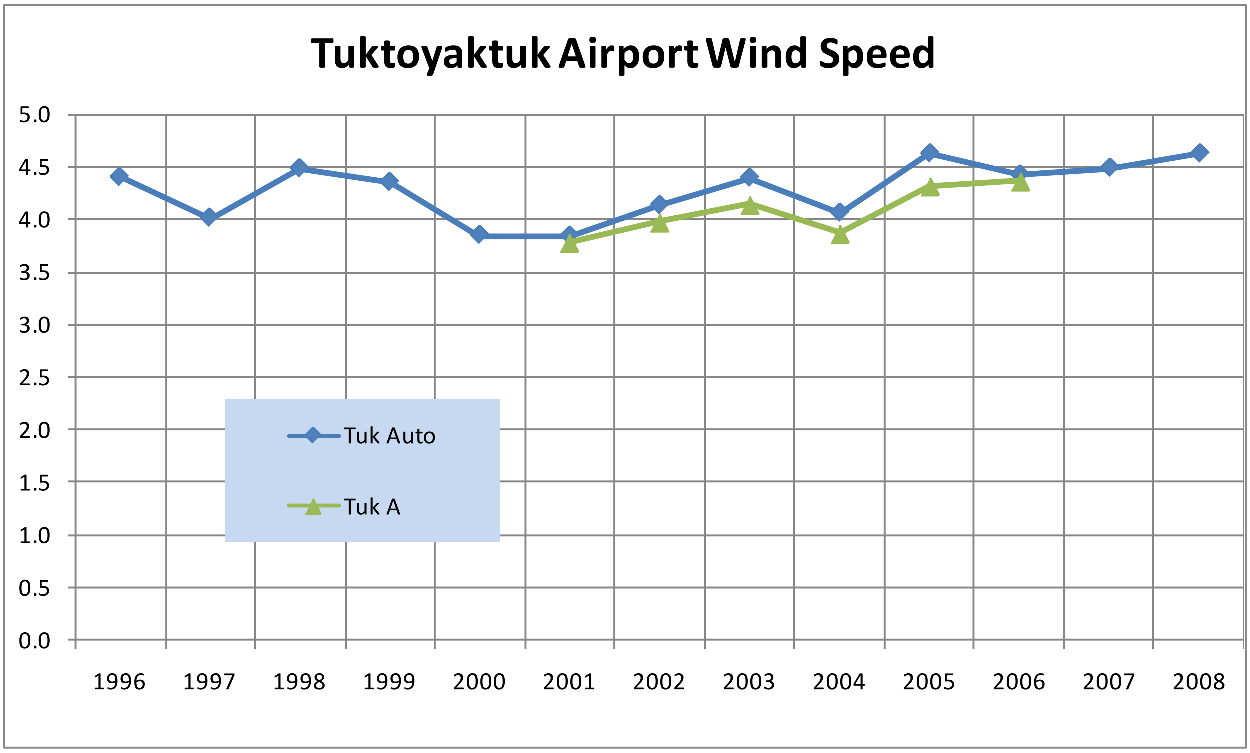

Figure 8: Time series graph comparing annual mean wind speed at the airport auto station and A station.

The long-term monthly wind speed as shown in Figure 9 (also found in Table 1) reveals faster winds during the summer months and particularly the month of May when it is estimated to be 4.51 m/s (measured at 10-m AGL). The winds diminish to a low during the winter when the slowest wind month is December with an estimated 3.74 m/s (10 m AGL).

Figure 9 also shows the corrected power ratio which increases to a maximum factor of 1.17 during the winter months of February to March but stays above 1 during the entire year. The corrected power ratio indicates that the effects of lower mean temperatures and the proximity to the ocean causes the air to be denser than the standard assumed air density used for calculating wind turbine power output. The denser air causes the turbines to produce more energy than is calculated at standard air temperature (+15°C) at sea level. More details of the wind speed and other information are shown below (Table 1).

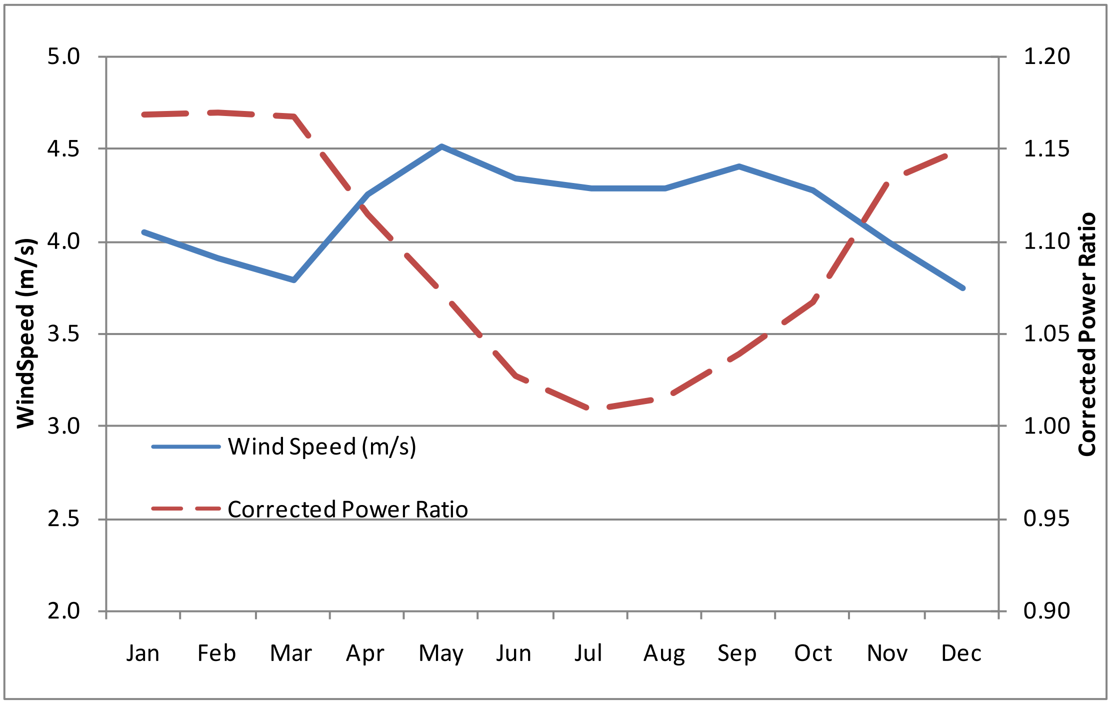

Figure 9: Long-term monthly means of the corrected power ratio and wind speed based on the 13-year (1996-2008) airport auto station data measured at 10 m AGL. The wind speed is referenced to the left side and the air density to the right.

Table 1: Monthly mean values based on airport station for the period 2001-2008. The wind speeds are measured at 10 m above ground level (AGL).

	Wind Speed (m/s)	Temperature (°C)	Pressure (kPa)	Density (kg/m^3)	Corrected Pow er Ratio
January	4.05	-26.6	101.3	1.43	1.17
February	3.91	-25.7	101.8	1.43	1.17
March	3.78	-24.3	102.2	1.43	1.17
April	4.25	-14.6	101.4	1.37	1.12
May	4.51	-3.6	101.6	1.31	1.07
June	4.34	6.8	101.1	1.26	1.03
July	4.29	10.9	100.8	1.24	1.01
August	4.28	9.1	100.8	1.24	1.02
September	4.40	3.7	101.1	1.27	1.04
October	4.28	-6.7	100.0	1.31	1.07
November	3.99	-17.8	101.8	1.39	1.13
December	3.74	-22.5	101.4	1.41	1.15
Annual	4.28	-9.2	101.5	1.34	1.09

Comparing the Wind Speed from Auto and Wind Monitoring Stations

The period chosen for the comparative study is approximately one year, from 29 September, 2007 to 1 December, 2008.

The wind speed correlation between the measurements of ARI wind monitoring site (WM #2) and the airport auto station was (Pearson) R= 0.89 when comparing the 30 m wind sensor to the auto station at 10 m AGL. Between the 10 m sensor at the wind monitoring station and the auto station's 10 m sensor that correlation increased to R=0.94. Whereas R=0 means no correlation and R=1 is perfect correlation, these correlations are considered to be excellent. This correlation coefficient (R=0.94) will be used in following sections to estimate the long-term mean for the wind monitoring site WM #2.

During this one-year period the auto station recorded a mean wind speed of 4.82 m/s whereas the ARI station at 10 m AGL was 2% faster at 4.93 m/s. In the previous report (Pinard, 2007) site WM #1 had measurements that were 5% higher than the auto station.

During the same one-year period the mean wind speed at 20 m AGL was 5.27, and at 30 m two anemometers measured 5.47 and 5.80 m/s (discrepancy between these two sensors will be discussed later). Those measurements are shown in Figure 10 along with other profiles discussed below.

Projecting to Higher Levels

Turbulent air flow over rough surfaces tends to generate a vertical profile of horizontal winds that are fairly predictable. The wind speed profile near the ground is dependent on neutral well mixed air conditions and the roughness of the ground surface. This vertical profile can be defined by the natural log law equation (see Stull, 2000):

$$u_2 = u_1 \frac{\ln(z_2/z_o)}{\ln(z_1/z_o)}$$

where u_1 is the known wind speed at z_1 (typically at 10 m AGL), and is projected to u_2 at the height z_2. The surface roughness is defined by z_o which as a rule of thumb is 1/10 the height of the grass or brush surrounding the site where the measurements are made. This equation is considered accurate up to approximately 100 m above the surface. The surface roughness z_o can be categorised by the type and size of vegetation as well as the hilliness of the ground itself. If we know the wind speeds at two heights of say 10 and 30 m then we can also find the value of z_o, look the value up on a roughness chart and compare the land description to the actual ground surrounding the station. With the known z_o we can use the log equation to predict the wind speed at higher elevations.

In the Tuktoyaktuk area the land surface is typically tundra, with knee-high brush (~50 cm) and with slightly undulating terrain with depressions that fill with snow during the winter (hence smoothing the surface and reducing z_o). The surface roughness is expected to range from 0.01 m (1 cm), which is the equivalent of an airport runway area, to 0.1 m (10 cm), which represents a roughly open area with a few obstacles. In the report Pinard 2007 the surface roughness z_o was calculated to be 0.004 m (0.4 cm at WM#1) which is considered to be the smoothness of pack ice or a snow-covered flat field. From visual observation of the land the calculation seems to under-predict the roughness of the actual surface.

At the current ARI wind monitoring site (WM #2), with new calibrated sensors, it appears that the new calculations of the surface roughness z_o = 0.01 m is more representative of the land surface. The vertical profile using this value and the measurements of the wind monitoring station (WM #2) are shown as "U log" in Figure 10.

Projecting to a Longer Term

In Figure 8 the annual mean wind speed over the last few years has been rather high compared to the last 13 years. From the one-year period in 2007-08 to the longer 5- and 10-year periods the auto station's mean wind speed decreases to 92 and 89% respectively of the recent monitoring period. Similarly for the wind monitoring station (WM #2), it is expected that the 10-year mean wind speed was likely 89% of the mean wind speed measured in the one-year period in 2007-08.

The vertical profile U(log) shown in Figure 10 is adjusted to a five- and ten-year mean U(long-term) using the MCP method of measuring, correlating, and predicting the long-term mean winds. The formula is:

$$E_s = \mu_s + \frac{R \cdot \sigma_s}{\sigma_r}(E_r - \mu_r),$$

where E_s is the estimated long term wind speed at the site of the wind monitoring station WM #2, μ_s is the measured wind speed at the site, μ_r is the measured reference wind speed, and E_r is the measured long-term mean wind speed at the reference (auto) station. The other variables in the equation are the correlation coefficient R and the standard deviation for the reference station, σ_r, and the wind monitoring site, σ_s. These values are listed in below (Table 2).

From the above formula the 10-year (1999-2008) projected mean of site WM #2 at 37 m AGL is 5.35 m/s. The five-year (2004-08) projected mean of the new site at 37 m above ground is 5.50 m/s. At the airport's auto station the 10-year mean wind speed projected to 37 m AGL is 5.08 m/s. At site WM #1 a projection using the method above shows that the 10-year mean wind speed at the original site was 5.29 m/s at 37 m AGL. The vertical profile of estimated long-term mean for the wind monitoring site WM #2 is shown (Figure 10 and Table 3). The time series data (Figure 8) shows that the wind speed can be somewhat variable from year to year, this is discussed in the following section.

Errors and Uncertainties in Measurement, Correlation, and Prediction

In making measurements, long-term predictions, and projections, errors are likely to exist. The typical error in the anemometer measurements from the wind (30-m towers) monitoring station is less than 0.1 m/s for wind speed ranging 5 to 25 m/s, which is less than a 2% error. The airport measurements are also considered better than 2% and thus within 0.1 m/s. Recently a presentation by Baker (2008) discussed the potential for error due to drag resistance in Maxi-40 anemometers (Maximum #40 anemometers made by NRG Systems, which are used for the ARI wind monitoring program). It was stated that in some of the Maxi-40 anemometers that they tested these drag resistance errors could cause the wind speed sensors to underreport the actual wind speed by 0.3-0.6 m/s in the range 4 to 10 m/s. For the Tuktoyaktuk wind monitoring, in the case of the 30 m anemometer (on a 1.1 m boom) that is reporting a mean wind speed of 5.47 m/s it is possible that it is underreporting due to drag resistance.

So for this anemometer we will account for a maximum of 0.6 m/s (more likely 0.3 m/s, error bars on measurements shown in Figure 10) in possible wind speed reduction in that sensor.

Table 2: Details of values in the evaluation of the long-term mean wind speed of the wind monitoring station WM #2 using the MCP method.

5-year

Measure-Correlate-Predict	10 m AGL	
Estimated Long-term mean at site Es =	**4.62**	m/s
Estimated Long-term mean at reference Er =	4.43	m/s
Measured site u_s =	4.93	m/s
Measured reference u_r =	4.82	m/s
Measured cross-correlation coefficient R =	0.94	
measured standard deviation at site $theta_s$ =	2.79	m/s
measured standard deviation at reference $theta_r$ =	3.32	m/s

10-year

Measure-Correlate-Predict	10 m AGL	
Estimated Long-term mean at site Es =	**4.49**	m/s
Estimated Long-term mean at reference Er =	4.27	m/s
Measured site u_s =	4.93	m/s
Measured reference u_r =	4.82	m/s
Measured cross-correlation coefficient R =	0.94	
measured standard deviation at site $theta_s$ =	2.79	m/s
measured standard deviation at reference $theta_r$ =	3.32	m/s

To reduce further errors due to shadow effect (slowing down anemometers) by towers the anemometers have been placed on 1.1 m booms that are angled strategically to be most exposed to the dominant wind directs. At the tower top, however, one of the anemometers is placed on a vertical 30 cm long boom directly above the tower top. In this case there is an additional source for error that is due to the tower top causing a speed-up effect on the speed sensor. According to Perrin (2006) the mean speed up caused by the tower can be 1.5% of the mean wind speed. At an average wind speed this represents an increased reported mean wind speed of 0.1 m/s. We will simply assume that the wind is then 0.1 m/s less than the measured speed for tower-top sensor: thus, 5.7 instead of 5.8 m/s. These errors are shown in Figure 10 associated with the measurements.

Errors must also be accounted for when projecting the wind speed upwards from lower levels above ground. The error from wind speeds projected to a higher level above ground was calculated by matching logarithmic profiles to the ±0.1 m/s extremes of the mean wind speeds at 10 and 30 m. In this study the projection error is estimated to be ±0.14 m/s for the wind speed estimate at 37 m AGL.

The reason for projecting wind speeds to long-term is to reduce errors in the long-term variability over the shorter term measurements. The MCP method described above is meant to reduce such error. There is still however some variability in the long-term measurements, Pinard (2007) describes that the variability in the annual mean wind speed is less than 6% for measurements periods of five years or more. Looking at the more conservative estimates of the ten-year mean of 5.35 m/s (at 37 m AGL) the variability is estimated at ±0.32 m/s (6% of 5.35 m/s). In summary we should expect the annual mean wind speed at the WM site #2 to range from 5.03±0.14 to 5.67±0.14 m/s at 37 m AGL in any given year.

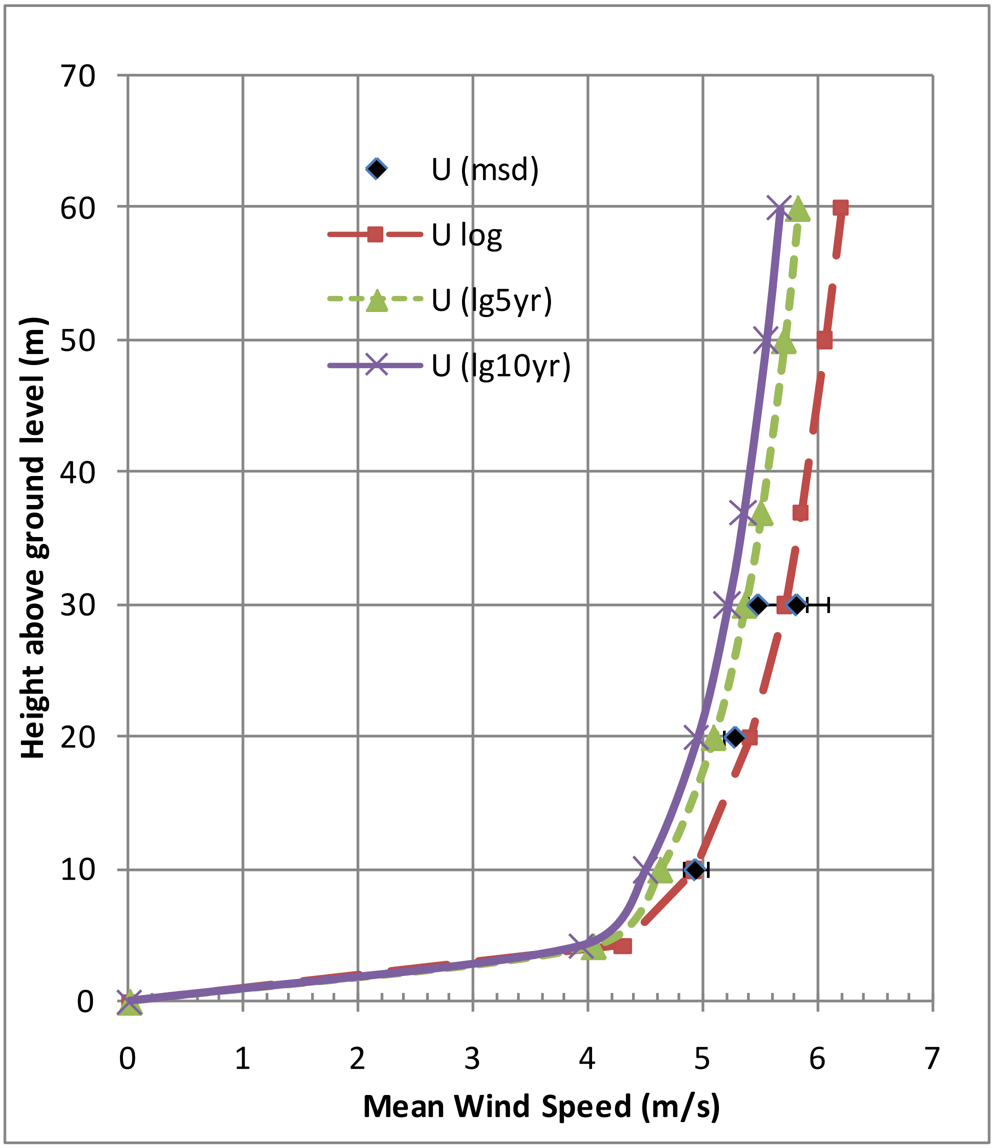

Figure 10: Vertical profiles of the horizontal wind speed at the wind monitoring station (WM #2). The vertical profile "U log" is fitted to the measurements "U (msd)" and then adjusted to long-term 5 year (lg5yr) and 10 year (lg10yr). Black whiskers indicate errors due to sensor drag as discussed earlier, the winds may be higher by up to 0.6 m/s than the measurements indicate.

Table 3: Details of measurements and their projection to longer term and to higher elevations. Bold values indicate the long-term (5- and 10-year) mean wind speed at the site of WM #2, which are estimated from correlating to the auto station's long-term measurements. The 10-year mean is the more conservative value and is used in concluding this study.

Location and measurement period	Height	Wind speed	
Tuktoyaktuk Airport 29 Sept 07 to 1 Dec 08	10 m AGL	4.82	m/s
WM #2 from 29 Sept 07 to 1 Dec 08	10 m AGL	4.93	m/s
	20 m AGL	5.27	m/s
	30 m AGL	5.47	
	30 m AGL	5.80	m/s
Tuktoyaktuk Auto 5-year (2004-08) mean	10 m AGL	4.43	m/s
Ratio of 5-year to short-term means		0.92	
WM #2 wind projected to 5-year mean (2004-08) at	10 m AGL	**4.62**	m/s
	20 m AGL	**5.09**	m/s
	30 m AGL	**5.36**	m/s
	37 m AGL	**5.50**	m/s
	50 m AGL	**5.70**	m/s
	60 m AGL	**5.82**	m/s
Tuktoyaktuk Auto 10-year (2004-08) mean	10 m AGL	4.27	m/s
Ratio of 10-year to short-term means		0.89	
WM #2 wind projected to10-year mean (1999-2008) at	10 m AGL	**4.49**	m/s
	20 m AGL	**4.94**	m/s
	30 m AGL	**5.21**	m/s
	37 m AGL	**5.35**	m/s
	50 m AGL	**5.54**	m/s
	60 m AGL	**5.66**	m/s

Numerical Modelling with MS-Micro

Since we only have two locations in this study that are measured we need other tools to help estimate the mean wind speed at other locations. To achieve this we use a numerical wind modelling tool called MS-Micro. Originally based on boundary-layer wind field theories of Jackson and Hunt (1975) it was modified and made into a useable computer wind modelling tool by Walmsley et al. (1986).

MS-Micro was run for the Tuktoyaktuk area using a data elevation model from the Municipal and Community Affairs (MACA) centre. The surface roughness were estimated with lakes and ocean being z_o = 0.00001 m (ice surface) and the ground surface z_o = 0.01 m. The model area within which calculations are made has an area that is 6 km square within a larger domain that is 12 km square. The model grid used for wind calculations is about 50 m (horizontal grid of 256 by 256 points).

The winds that are applied in the model simulation are normalised, arbitrary winds speed, and eight main wind directions are applied to the model: those being 68, 90, 113, 135, 270, 293, 315, 338 degrees for eight main wind directions measured by the wind monitoring station. The model is run eight times and the resulting wind speed output are blended into a single output using a scaling based on the wind energy rose of the long-term auto station. The blended output is a normalised wind speed output whose contours are scaled and calibrated to the estimated 37 m wind speed of 5.35 m/s at the wind monitoring site. The results of the MS-Micro modelling are shown (Figure 11).

The model results suggest that the winds at the airport should be about 5.31 m/s (at 37 m AGL), from the auto station measurements of 4.27 m/s at 10 m AGL, the wind speed projected to 37 m is 5.08 m/s. This new estimate is about 0.2 m/s or 4% less than the MS-Micro results, which is very reasonable. It is expected that the airport's auto station would have a lower wind speed because of its coarse method of measuring on the hour (compared to the ARI station measuring at 2 second intervals and averaging to 10 minutes or 1 hour).

The MS-Micro tool estimates the wind speed at the proposed wind park to be from 5.32 to 5.4 m/s at 37 m AGL. This really does not deviate much from the measurements (5.35 m/s at 37 m AGL, estimated from measurements at 30 m AGL) made at the ARI wind monitoring station.

Figure 11: Tuktoyaktuk mean wind speed contours based on the numerical model MS-Micro. The wind speeds are modelled at 37 m AGL. The contour interval is 0.02 m/s. The black solid line is 5.3 m/s, the dotted lines are below 5.3 m/s, and the dashed lines are above 5.3 m/s. The sites are labelled with wind speeds estimated from the model.

Conclusion

About one year (September 2007 to December 2008) of wind data from the ARI station at the new site WM #2 was correlated with the automated station at the airport.

The 10-year mean wind speed at site WM #2 is estimated to be 5.35 m/s at 37 m AGL. The airport's auto station and the original ARI site by the shooting range (site WM #1) were estimated to have a 10-year mean wind speed of 5.08 and 5.29 m/s respectively.

A computer wind flow model was made for the Tuktoyaktuk area and calibrated to the ARI site WM #2. The model projects the long-term mean wind speed at the proposed wind park location to range from 5.3 to 5.4 m/s. The annual mean wind speed will likely vary by as much as ±0.3 m/s from year to year.

Recommendations

With the eventual building of the wind farm it is recommended that the wind monitoring station be moved to the site of the wind turbines when the project begins. The station can continue to measure the wind climate and monitor the performance of the wind turbines.

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