

Wind Energy in the Yukon

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Jean-Paul Pinard, P.Eng., MSc., PhD Cand.

Boreal Alternate Energy Centre

Yukon Energy

EAS, University of Alberta

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Abstract

This presentation provides an overview of recent studies of the wind flow regimes in the mountainous regions of the Yukon.

There has been active wind energy research in the Yukon since 1990. Today our wind-monitoring program consists of no less than half-dozen stations that measure winds for a period of at least a year per location. The data from the sites that we have measured is analysed and will become part of a wind atlas for the Yukon. As part of our program we have been analysing weather balloon data in and around the territory and examining what other groups have done in mountain wind research. We have also been testing computer wind flow models as an important tool for helping us to explore wind energy in the mountainous regions of the Yukon.

Acknowledgement

In addition to the financial supporters I would also like recognise the people who have helped me the most. Those are: my partner Sally Wright for love and emotional support, J. D. Wilson for his knowledge, humour and optimism, John Maissan for giving me the opportunities, Dr Doug Craig for providing me the bridge for my passion in renewable energy research.

Introduction:

- Wind data analysis
- Monitoring program
- Modelling tools
- Future work

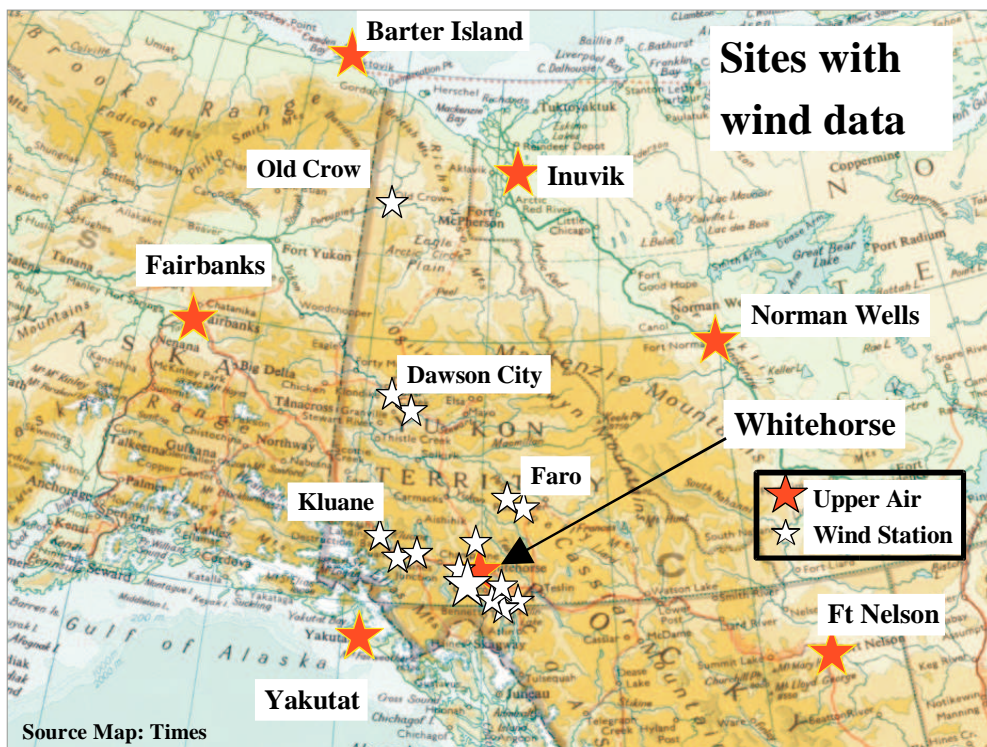


Introduction

The Yukon is located in northwestern Canada. It is bordered by Alaska to the west, British Columbia to the south, the North West Territories to the east, and the Beaufort Sea to the north.

Most of the population is located in the southern Yukon, and connected to the Whitehorse-Aishihik-Faro Grid, which is mostly powered by hydro-electric dams. Diesel generators make up what the dams cannot provide during the coldest part of the winter. There are a few small communities that are off the main grid and are diesel depend. Two communities, Burwash Landing-Destruction Bay and Old Crow, are showing promise of good wind energy potential.

Wind has the potential to meet our energy needs for the future. Part of the goal to meet that need is to understand and assess the potential for wind energy exploitation. In this presentation we take a broad look at the wind regime over the Yukon. Through the processing and analysis of weather balloon (upper air) data we look at a “picture” of the phenomenon that is the atmosphere above us. We also look at ground station data and what information they can provide us. We attempt to use modelling tools to help visualize wind flow over mountainous terrain. And we take a brief look at what building a wind atlas for the Yukon might entail.



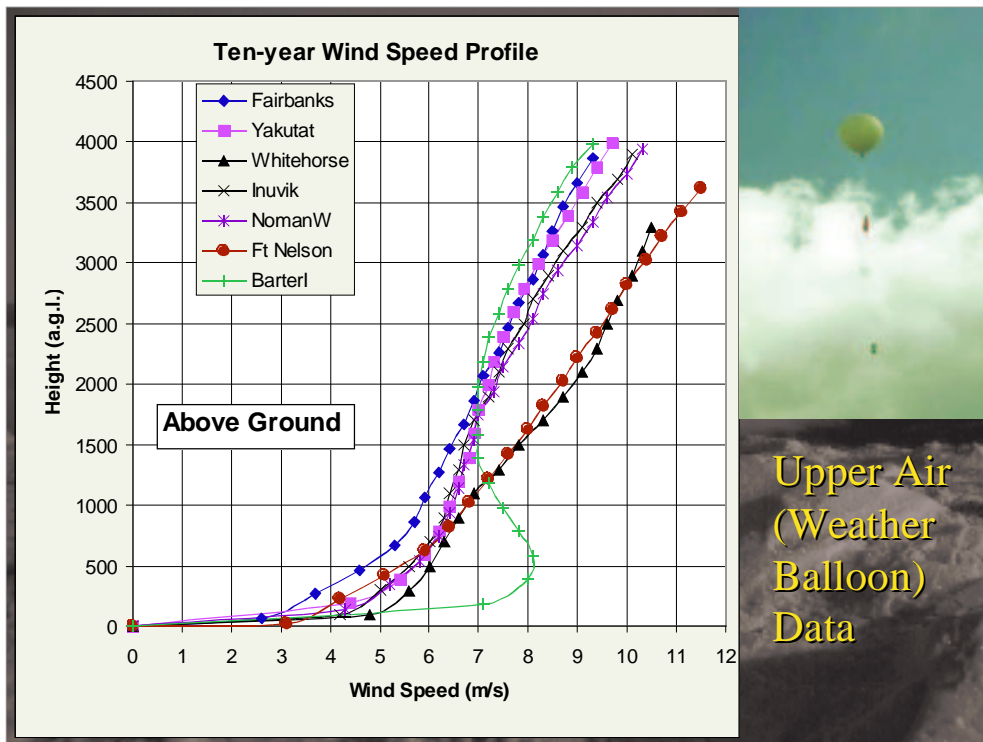
Study of Weather Balloon and Airport Data

The darker stars are locations where weather balloons are released every 12 hours. The white stars are locations at which instruments on towers have been setup to measure wind information for energy purposes.

There is only one weather balloon station located within the Yukon, but there are several just outside the territory. These stations are located relatively close to the Yukon, and are therefore helpful in projecting wind information across the territory.

The data from the weather balloon (see NOAA in references) contain information on wind speed, wind direction, temperature, dewpoint temperature, pressure and elevation (note:the temperature profile in the atmosphere has a strong influence on the way the wind flows over terrain).

Analyses to date show interesting trends that are discussed in the following pages.

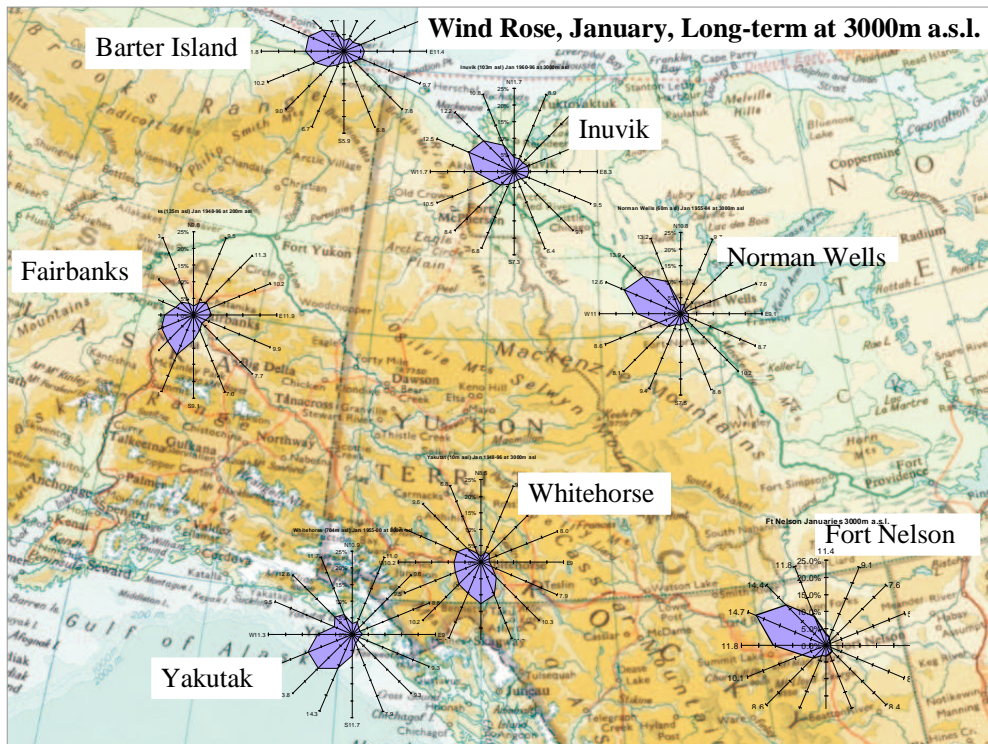


The vertical profiles can be grouped together by their shape and magnitude. Barter Island stands out with its unusually high wind speed that is at a maximum of over 8m/s at about 500m above ground level (a.g.l.). Barter Island is located on the coast of the Beaufort Sea and experiences low-level jets (Barry, 1981, p95).

Whitehorse and Fort Nelson are similar to each other in that wind speeds are higher than average at above 800m (a.g.l.).

The Fairbanks station has low wind speeds below 2000m (a.g.l.) The city is situated in a basin at the southern foot of a mountain range and there is a long east-west valley draining from the east towards Fairbanks. A study of wind roses at different elevations above Fairbanks shows that winds below 2000m (a.g.l.) generally come from the North-east and East whereas above 2000m they are from the South-west and West. This phenomenon is particularly marked during the cold winter seasons.

At elevations above 2000m two other groups stand out in the station profiles. One group is Inuvik and Norman Wells which are in the North West Territory. These two stations see winds mostly from the Beaufort Sea in the north-west. The final group is Fairbanks and Yakutat. Fairbanks is in south central Alaska and Yakutat is on the Pacific Ocean just south of Kluane National Park. Both of these stations see winds from the south-west.

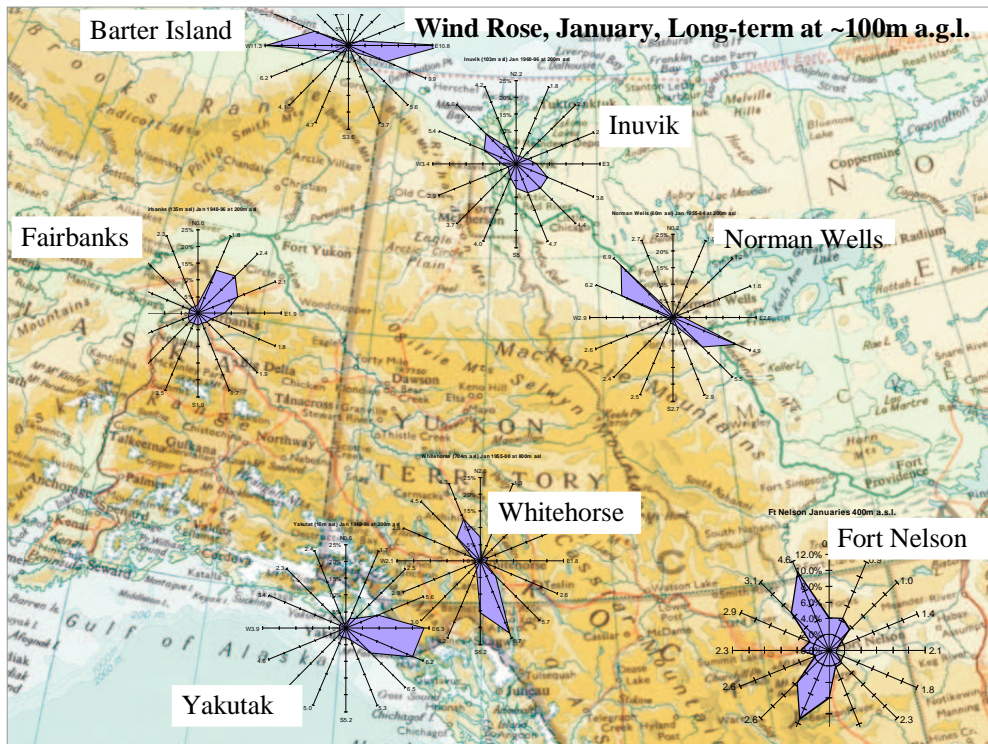


In this slide and the next, we look at the wind rose at two heights, for each station.

The wind roses above are produced from weather balloon data interpolated to 3000m above sea level (a.s.l.). This level lies above the boundary layer, which generally extends to of order 1km above the terrain. Terrain in many parts of the Yukon peaks at about 2000m (a.s.l.).

The boundary layer is the layer directly influenced by the ground surface. Above this layer the wind is less affected by surface friction, and controlled more by the pressure gradient and Coriolis forces.

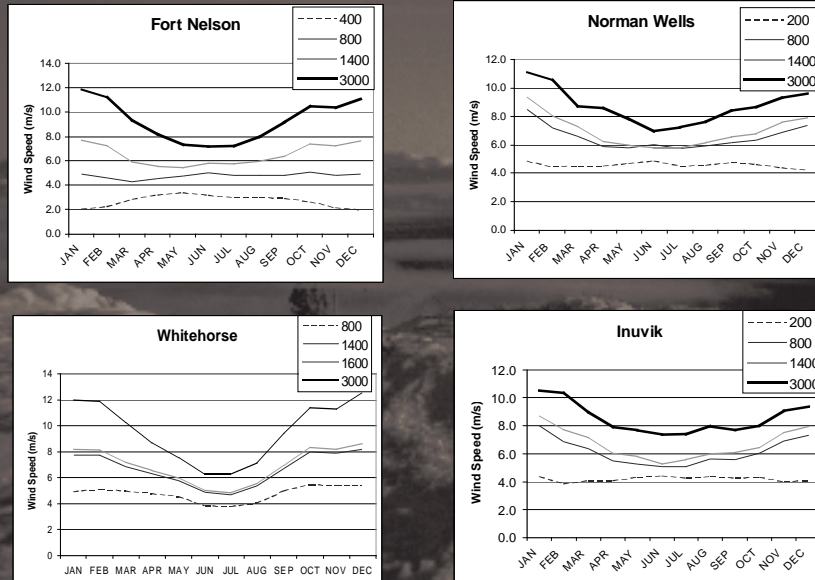
As shown on the map the 3000 m (a.s.l.) level winds are generally from the west. On the north coast the winds are more northerly, from the Beaufort Sea, and in the south they are more southerly, from the Pacific ocean.



In this slide we can see that the winds just above the valley floor are from very different directions than those above the boundary layer.

In each location the winds tend to follow the valley or the coast line.

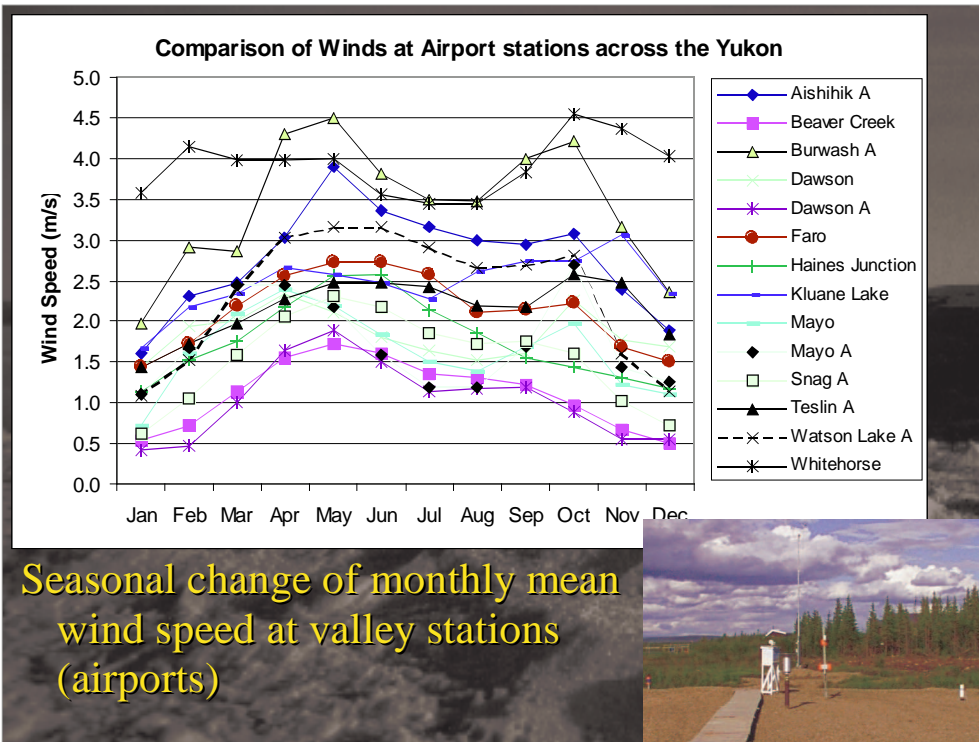
Seasonal Change in Monthly Mean Wind Speed at Different Elevations (a.s.l.)



These graphs show long term averaged mean monthly winds, interpolated from weather-balloon soundings; elevations are relative to sea level (a.s.l.). At each station, the terrain lies no more than 100m **below** the lowest data-level indicated on the graph.

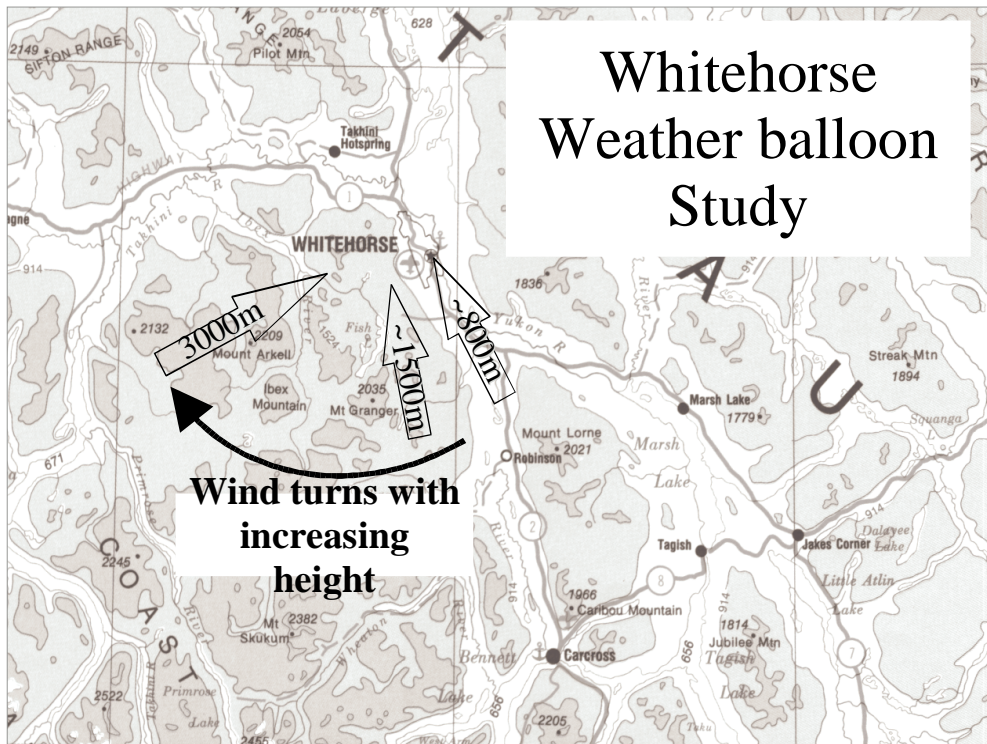
In January the wind speeds at higher elevations are lower in the summer months than they are in the winter.

The wind speed near the surface for Fort Nelson shows the opposite effect than the higher elevation winds. Fort Nelson is located in northern BC. In Norman Wells (on the Mackenzie River) and Inuvik (on the Mackenzie Delta) the wind is steady throughout the year. In Whitehorse the wind near ground following the winds pattern in the upper levels. Whitehorse is located near the Pacific Coast and is at 700m a.s.l.

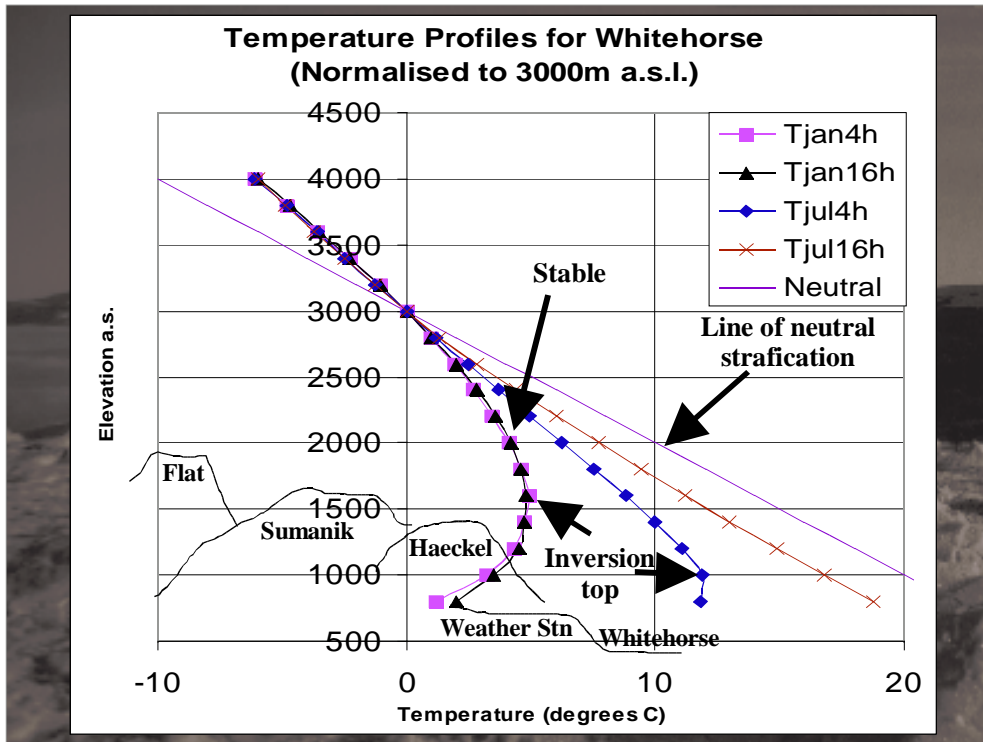


This slide shows monthly mean wind speeds at airports across the territory. The mean wind speeds are all below 5m/s, and such low winds these would be considered unpromising for wind energy production. However, these stations are at airports, which are not usually located in windy areas for obvious reasons.

The seasonal variation for all of the Yukon communities, with the exception of Whitehorse, show that the winds in the valleys are lower in the winter than in the summer.

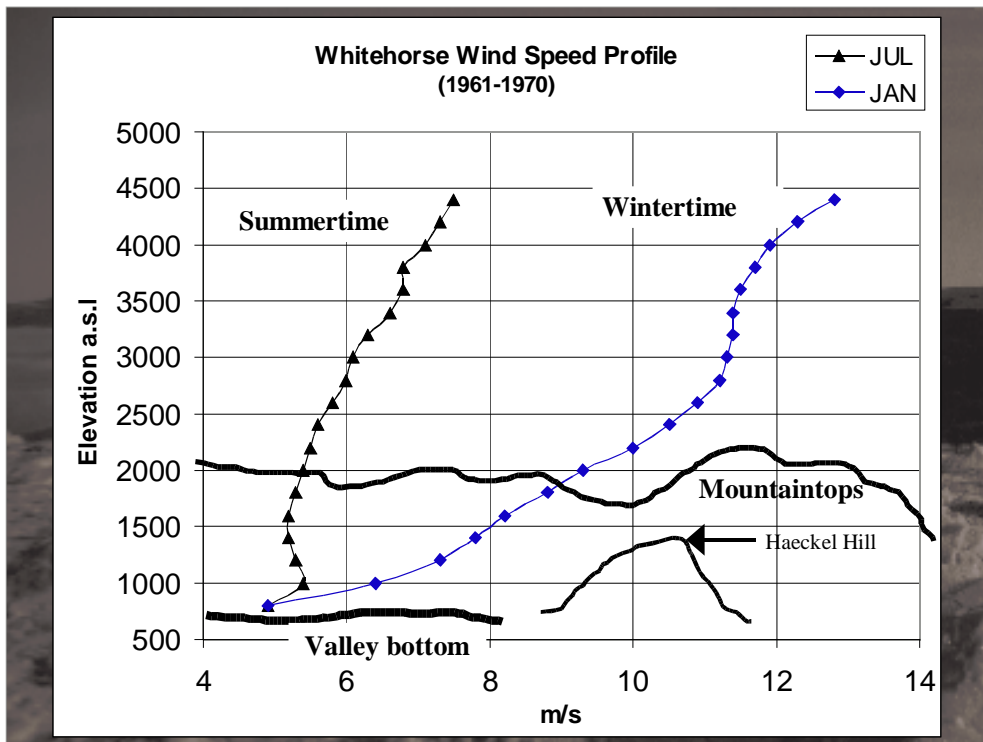


Observations by weather balloon at Whitehorse show a clockwise turning of the wind with increasing elevation. The prevailing winds observed in the valley and on Haeckel Hill are mainly from the SSE east with the exception of some northwind episodes, which occur mostly in the wintertime. Whereas above the mountaintops the winds are mostly from the SW.



The long-term mean (1961 - 1970) temperature profiles, taken in January and July at 4am and 4pm, indicate a stable atmosphere in the boundary layer - except for summer daytime, when the atmosphere (in the mean) is "conditionally unstable" (this indicates the possibility of moist convection). In January, there is a negligible diurnal cycle. This observation is typical of northern conditions.

This characteristic stability of the Yukon atmosphere near ground has an implication for the wind: the cold (and so, heavy) near-ground air will tend to resist being lifted over ridges, a factor which will enhance windspeed in passes, over saddles, around the ends of ranges.



The profile of wind speeds for July shows a considerable wind reduction compared to January. At 1500 m the the average wind speed is about 8 m/s in January where as in July it reduces to 5 m/s.

In the July profile there is a low-level jet near the 1000m a.s.l. level (300m a.g.l.).

The winter wind profile shows several layers. Below the moutaintops, we see a relatively large and constant windspeed gradient ("wind shear"). Centred around 3200 m is a layer of reduced shear; and above 3500m, the shear increases again.



This is one of the many sites where wind monitoring has been done as part of the Yukon Community Wind Program. Starting in 2000, five wind stations have been established on the private properties of owners who expressed interest in wind monitoring, and whose sites showed promise of a good wind regime. Each site has been monitored for one year, at the end of which the station is dismantled and moved to another site for another year of measurements. The towers vary in height from 10 to 20m.

The site shown here is on Lake Laberge, approximately 30km north of Whitehorse. Both views are to the south, from which comes the prevailing wind.



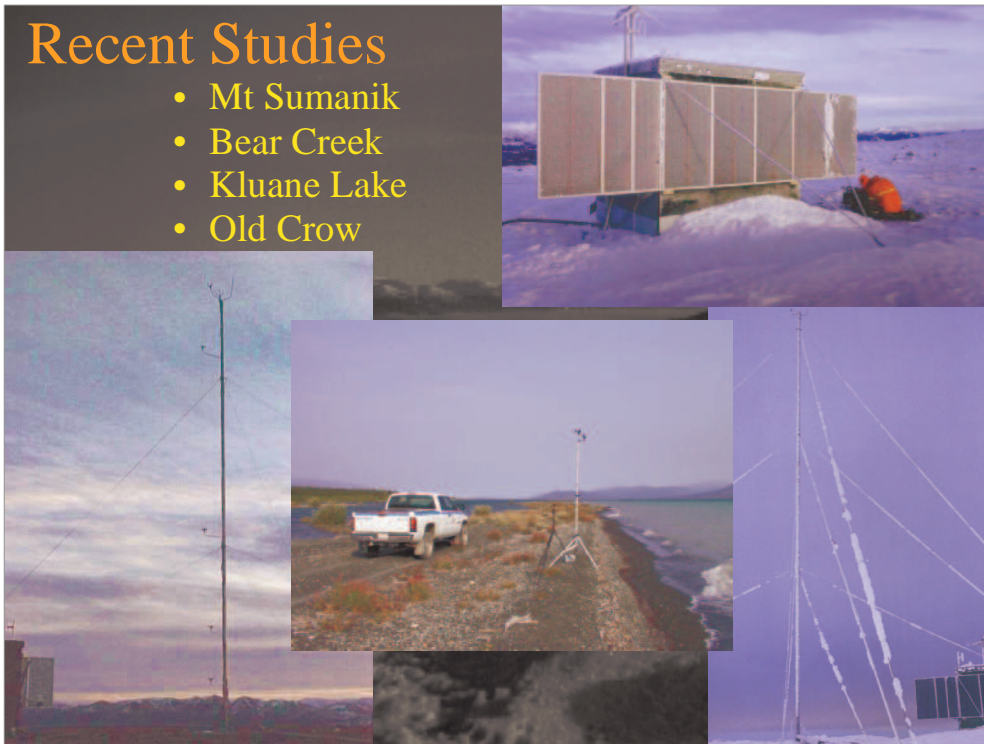
The photo on the left is another Community Wind site, located at the south end of Fox Lake, approximately 50km north of Whitehorse.

The photos on the right show Northwestel towers, which in several locations of the Yukon, are 100m tall.

There are presently collaborations between the communications company and Yukon Energy for wind monitoring using these towers.

Recent Studies

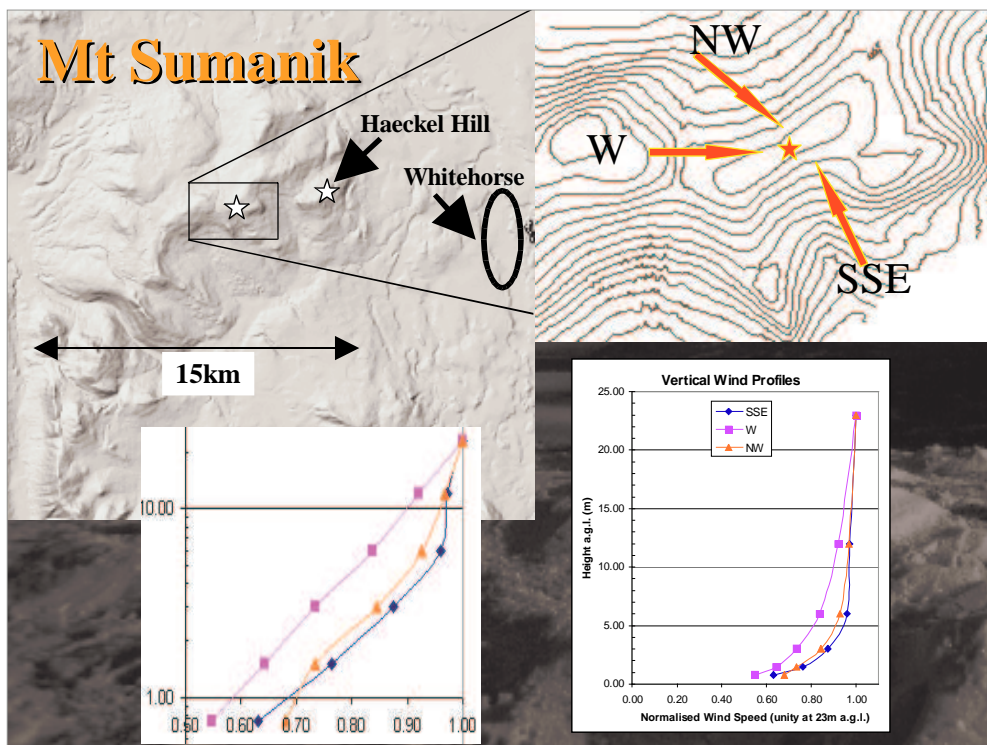
- Mt Sumanik
- Bear Creek
- Kluane Lake
- Old Crow



Some of the recent studies that we have done in the past few years are listed above. The picture in the top right corner is of the Mt. Sumanik station, near Whitehorse. The solar panels have a steel sheet backing that allows the panels to “flop” in the winter wind, and thus shed rime ice from their surfaces.

The tower shown on the left, standing on Mt. Sumanik, is equipped with cup anemometers to measure the variation of wind speed with height. This tower failed, due to heavy rime ice loading coupled with flaws in its design. The picture on the right is the replacement tower on Mt Sumanik, shown under heavy rime ice conditions.

The picture at the centre is a NW view along the shoreline of Kluane Lake.

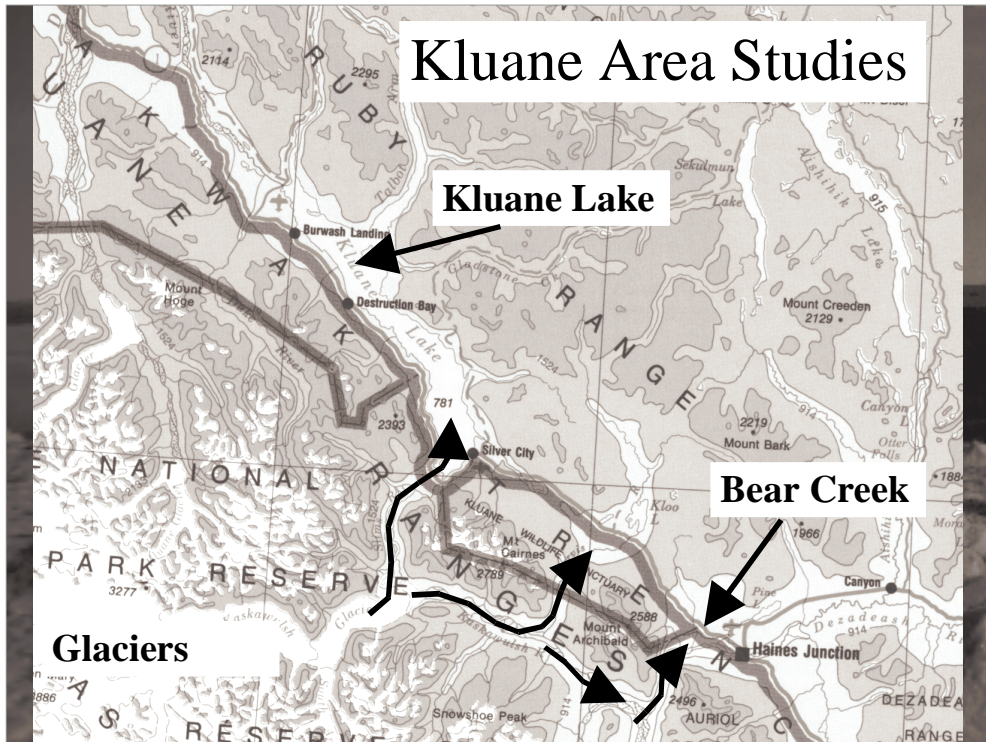


Measurements of the vertical profile of wind speed over Mt. Sumanik were made in 1999. The data discussed here, and shown above normalised to 23m a.g.l., stem from periods when windspeed at the top of the tower exceeded 5m/s, with the wind coming from the west, the south-east, or the north-west.

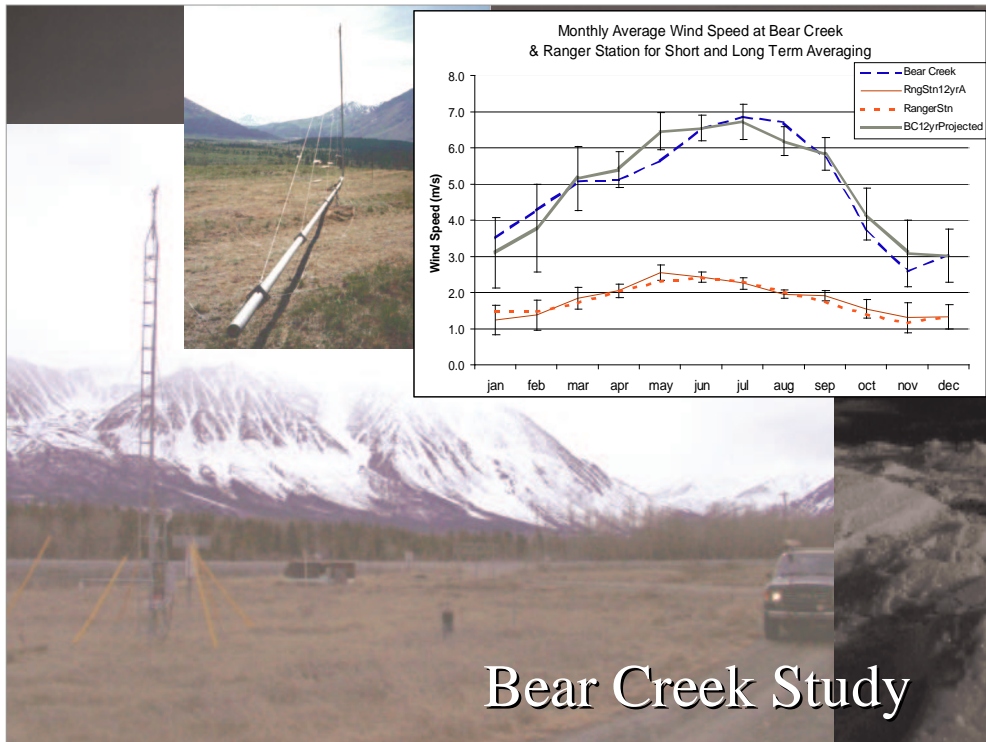
A west wind blows *parallel* to the ridge on which the station is located, and the observed wind profile (squares) resembles what is seen over *level terrain*. In other words, the profile of wind speed during W winds is a “log profile”, with a surface roughness length of $z_0 = 0.01\text{m}$.

However SSE and NW winds blow *perpendicular* to the ridge, and the corresponding profiles show there is a “speed up” occurring over the top of the hill; this is precisely what is expected theoretically, when winds blow perpendicular to a ridge. From these profiles on Mt. Sumanik, we cannot determine at which elevation maximum speed-up occurred, for our topmost anemometer was only 23m above ground. Calculations, using methods in Troen et al. (1989), suggest that maximum speed-up, on Mt. Sumanik, might lie at approximately 20m a.g.l.

Using the wind model MS-Micro/3R, we simulated wind profiles for the three wind directions. The model domain size was 18km x 18km, resolved using 256 x 256 grid points; terrain relief over this area is 650m. To get the profiles to match the measured values required changing the far field surface roughness to $z_0 = 0.0001\text{ m}$ (local $z_0 = 0.01\text{ m}$), which is unrealistically small. This produced simulated profiles that were close to, but more conservative than, those measured in all three directions.



The icefields of the Kluane National Park produce strong downslope winds that flow out through valleys that cut across the Kluane Ranges. These strong winds were measured at Bear Creek, which is at the mouth of the Asek Valley, and at Kluane Lake, which is fed by the Slims River Valley.

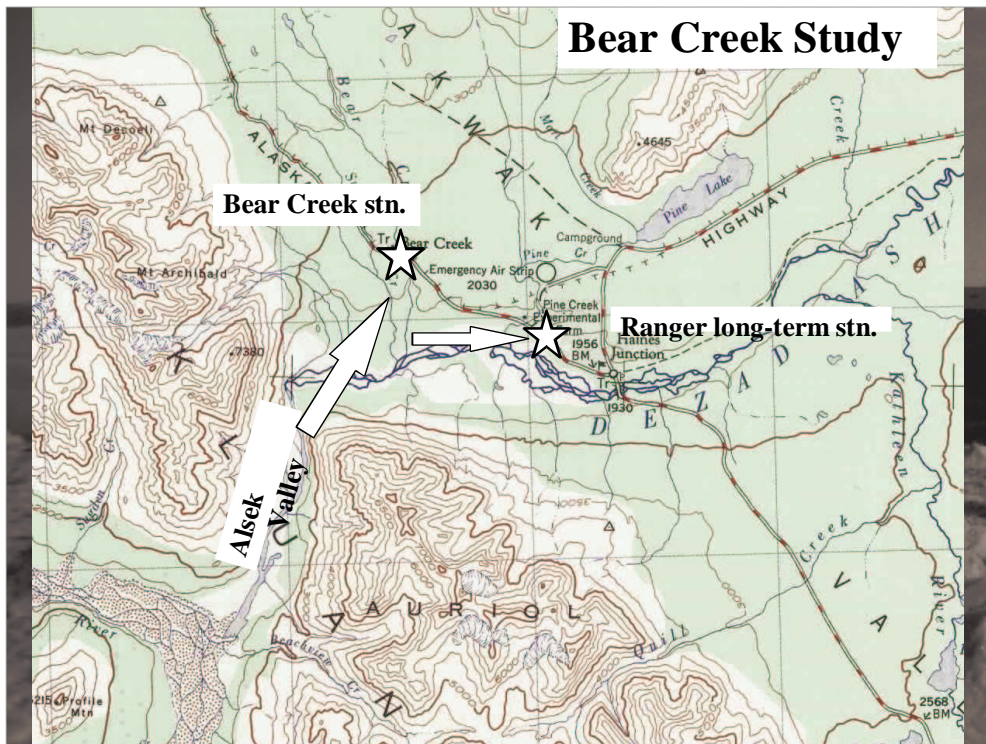


The views of the pictures above are of the Alsek Valley. The larger image is a SW view of the long-term monitoring station (10m tower) situated at the Kluane Park ranger station.

The insert in the middle is a south view of the 26m tower and the Alsek Valley (taken before the tower was raised). The Bear Creek station operated from June 1998 to May 2000.

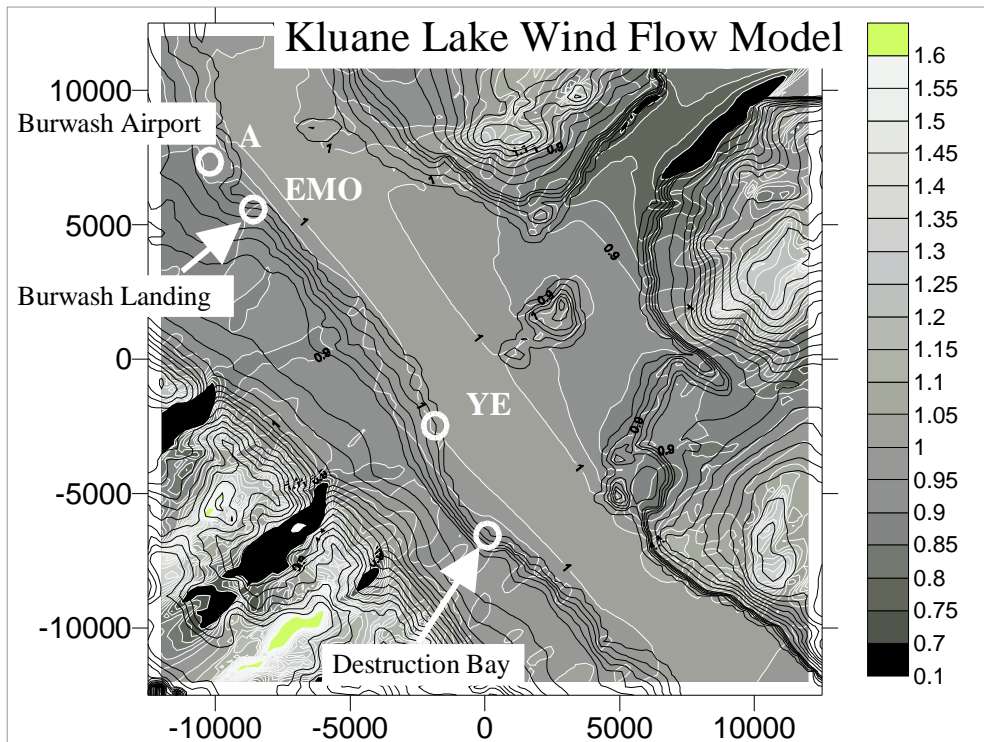
The graph compares the Bear Creek station to the ranger station. The monthly mean wind speed at Bear Creek is above 5m/s during seven summer months of the year, the yearly average being 4.6m/s. The annual mean at the ranger station is only 1.8m/s.

Using the power curve for the Danish Bonus 150 wind turbine generator, a plant factor of 23% was calculated for the year. Depending of the economics of the location, usually a plant factor of at least 20% is required for economic feasibility.



The measurements made at Bear Creek revealed strong summertime winds coming from the direction of the Aisek Valley (Pinard, 2001a) lying to the SSW.

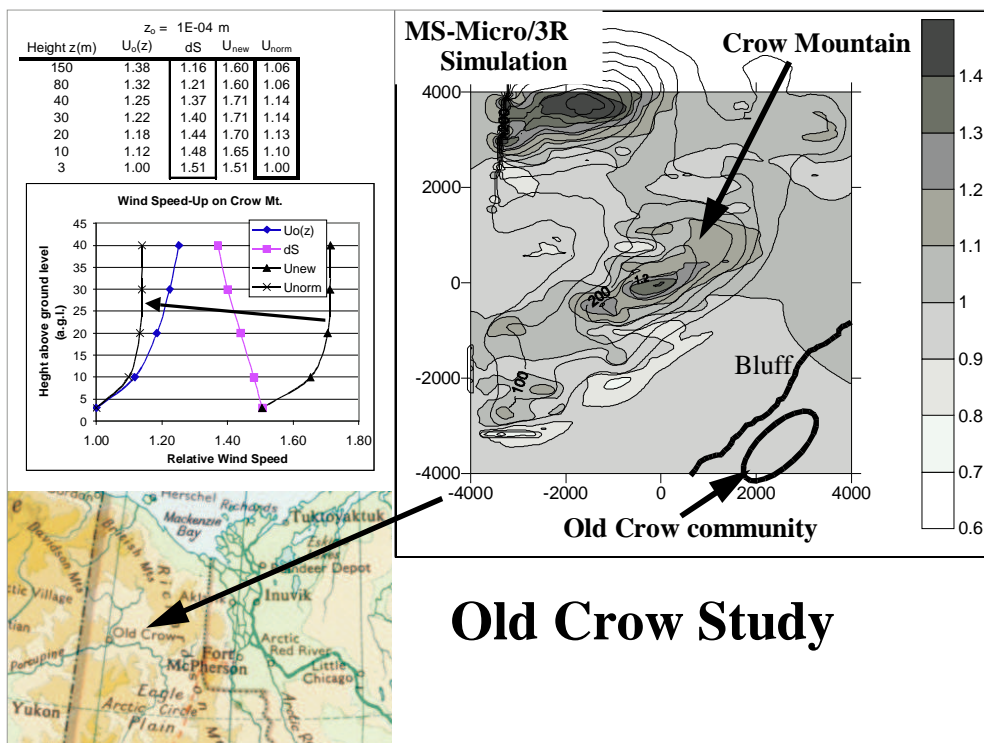
The long-term wind data from the ranger station show winds coming from the west, with a seasonal trend similar to that at Bear Creek, in that the winds were stronger in summer than in winter.



The above map is produced from the MS-Micro/3R wind flow simulation model. The black lines are elevation contours and the white lines represent wind speed contours. The contour labelled "1" represents the highest (model) wind speed (at 30m above surface); this contour follows the shoreline; winds decrease as we progress inland. The relief in this model is of the order 1000 m.

There have been a number of wind monitoring efforts established at Kluane Lake. These are described in Pinard (2001c). The most important program is that of Yukon Energy, which is indicated as YE. The wind speeds at this site indicated a yearly average wind speed of around 5m/s. The monthly mean is higher during summer than in winter (which is consistent with what was shown on an earlier slide, for winds in the valleys). The airport shows a yearly average of 3.6m/s, again the monthly mean being better in the summer.

A simulation using the MS-Micro/3R wind flow model used a domain of 44 x 44km surrounding this area. Model winds did not agree well with the measurements, but did correctly indicate that windspeed on peninsulas jutting out into the lake would be high.



Old Crow is situated in the northern Yukon. The winds that the community generally experiences are from the north-east. Crow Mountain is situated 4km NW of the community and experiences winds mostly from the north according to measurements made from a 3-m high station (Pinard, 2001b).

The graph shows four profiles, the line with diamonds is U_0 is the incoming upstream log wind profile. The second line is dS which is the wind speed-up at the mountaintop, and the third is U_{new} is the sum of the first two profiles. The fourth one is U_{new} normalised to the wind speed at 3 m for comparison with the first original wind profile.

MS-Micro/3R model was used to project wind speed from the 3m height measurement height to an elevation of 30m (nominal hub height of a wind generator). This adjustment is shown in the graph at top left; the simulation is for a far field roughness length of 0.0001m (which is certainly unrealistic), which value however gave a realistic wind profile relative to the observations on Mt Sumanik.

Based on 3m wind observations and their height-extrapolation according to the model, projected annual wind speed (at hub height) is better than 6.5m/s. This value may well be an **underestimate**, for the anemometer experienced rime icing problems.

Computer Models

Why Meso-scale?

- WindMap | Mass flow
 - MS-Micro/3
 - WAsP
 - MSFD-PC
 - ARPS
 - RAMS
 - MC2
- Linearised, for small hills
- Mesoscale, prognostic models for mountain scale
- >> 10km domain,
 - 1000m relief
 - turbulent wind flow
 - Coriolis important
 - Atmospheric stability

It has been shown that a wind model, provided it is realistic, is a useful complement to field observations of wind. To date, we have used MS-Micro/3R to this end. Some salient characteristics of models which one might consider using are listed above.

The author has been evaluating ARPS (Advanced Regional Prediction System) developed by the Center for Analysis and Prediction of Storms at the University of Oklahoma. This model is user friendly and easy to install on a PC-based Linux operating system. The documentation is very extensive, and the inputs are relatively straight forward.

Yukon Wind Atlas

Suggested plan for a Yukon Wind Atlas:

- Follow methods in the European Wind Atlas and Wind Energy Resource Atlas of the United States
- Proposed contents of the Atlas:
 - Wind speed and direction correlation between long- and short-term sites
 - A & k values projected to where unmeasured
 - Monthly mean, diurnal hourly mean, annual mean time series
 - Use of meso-scale models for flow simulations
 - use of NCAR Reanalysis

References

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