Mesonet and Blowing Snow measurements near Iqaluit, Nunavut Canada during the 2007/2008 STAR Project

Marna Melzer[1] , Peter Taylor [1], Mark Gordon[1], Sumita Biswas[1],
John Hanesiak[2],and Shannon Fargey[2].

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Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
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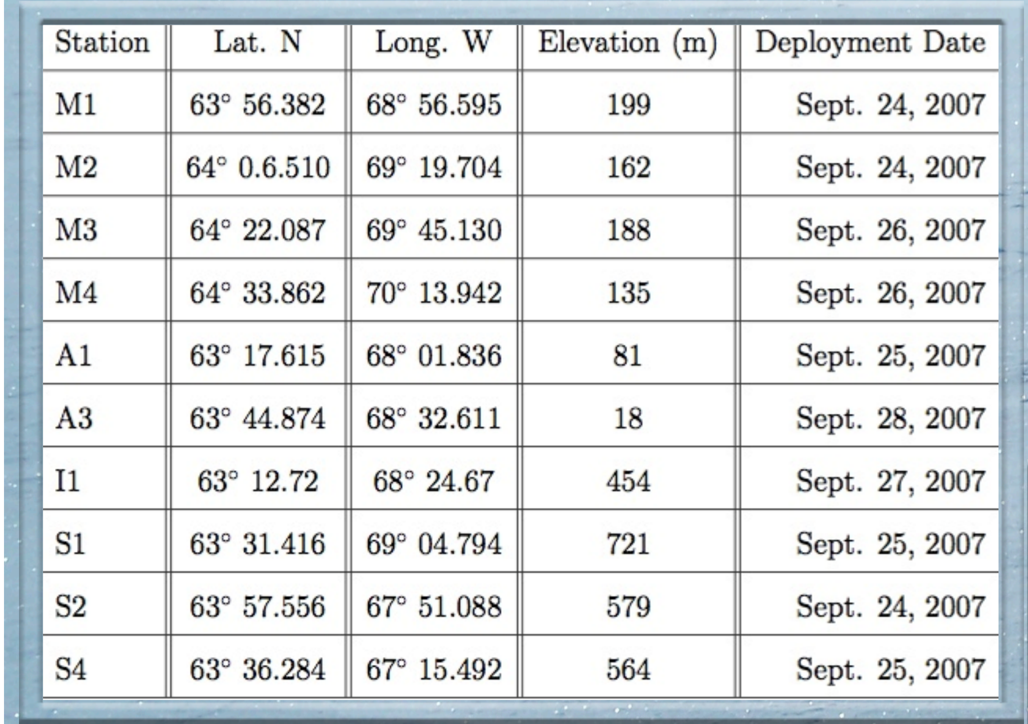
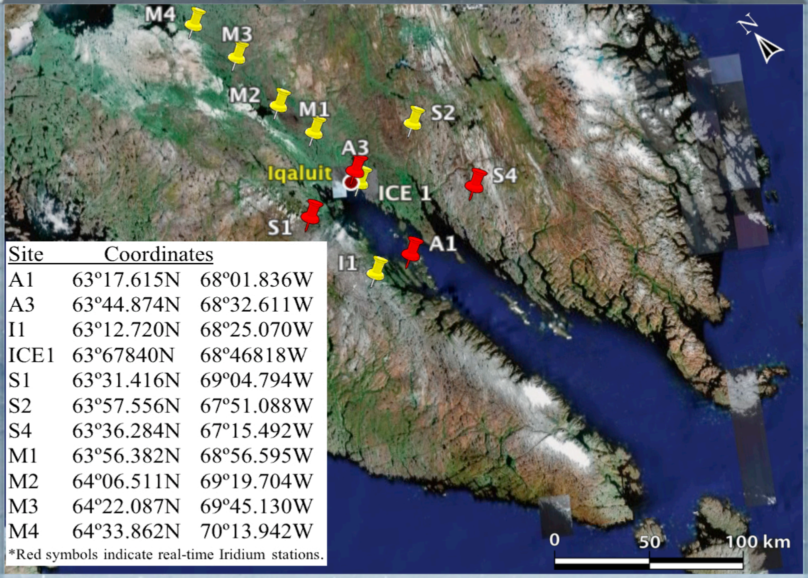
STAR project 2007/8 - Iqaluit



Station	Lat. N	Long. W	Elevation (m)	Deployment Date
M1	63° 56.382	68° 56.595	199	Sept. 24, 2007
M2	64° 0.6.510	69° 19.704	162	Sept. 24, 2007
M3	64° 22.087	69° 45.130	188	Sept. 26, 2007
M4	64° 33.862	70° 13.942	135	Sept. 26, 2007
A1	63° 17.615	68° 01.836	81	Sept. 25, 2007
A3	63° 44.874	68° 32.611	18	Sept. 28, 2007
I1	63° 12.72	68° 24.67	454	Sept. 27, 2007
S1	63° 31.416	69° 04.794	721	Sept. 25, 2007
S2	63° 57.556	67° 51.088	579	Sept. 24, 2007
S4	63° 36.284	67° 15.492	564	Sept. 25, 2007

Table from STAR Mesonet Installation Report, 2008



Site	Coordinates	
A1	63°17.615N	68°01.836W
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ICE1	63°67840N	68°46818W
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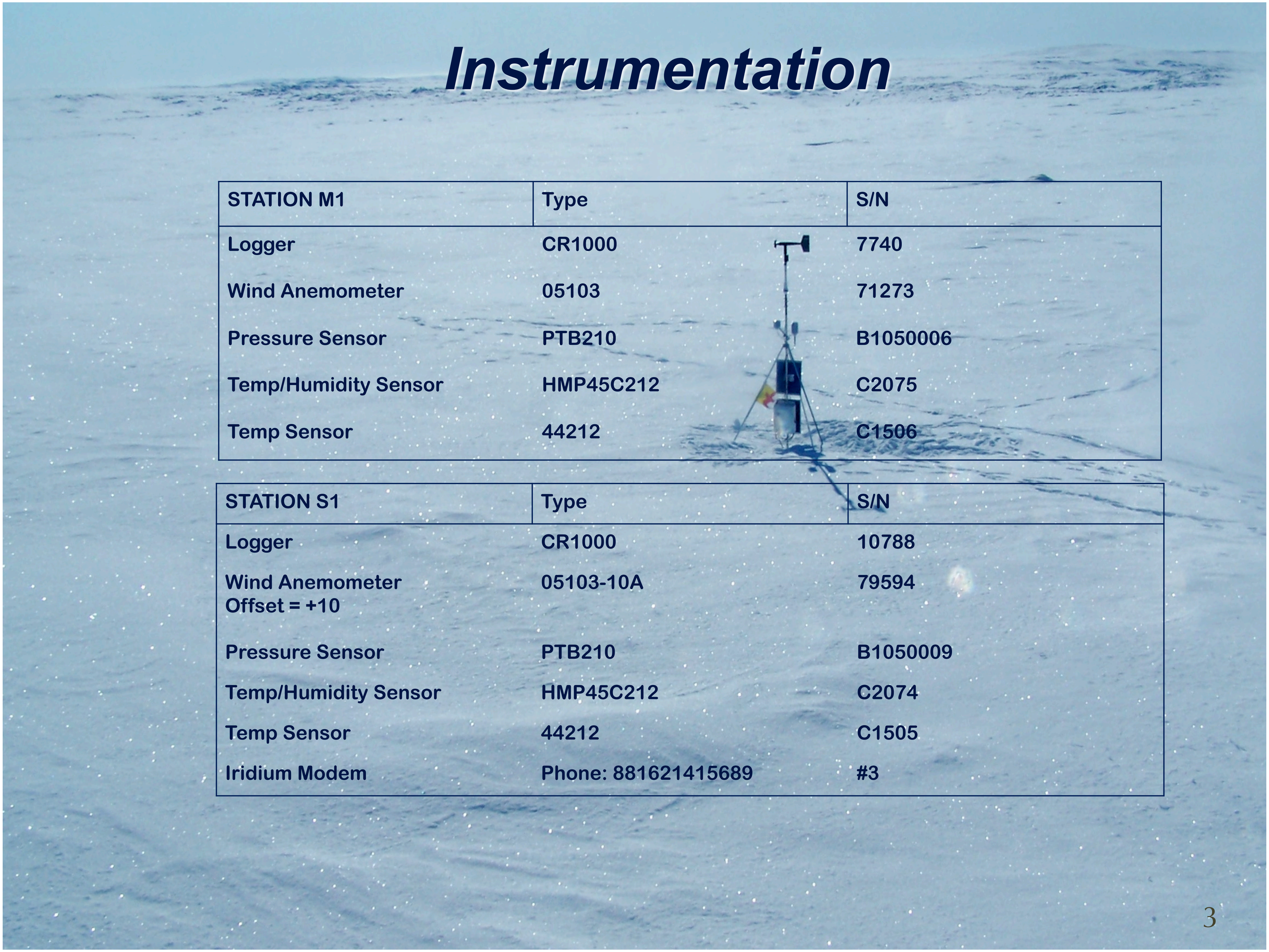
S2	63°57.556N	67°51.088W
S4	63°36.284N	67°15.492W
M1	63°56.382N	68°56.595W
M2	64°06.511N	69°19.704W
M3	64°22.087N	69°45.130W
M4	64°33.862N	70°13.942W

*Red symbols indicate real-time Iridium stations.

Instrumentation



STATION M1	Type	S/N
Logger	CR1000	7740
Wind Anemometer	05103	71273
Pressure Sensor	PTB210	B1050006
Temp/Humidity Sensor	HMP45C212	C2075
Temp Sensor	44212	C1506

STATION S1	Type	S/N
Logger	CR1000	10788
Wind Anemometer Offset = +10	05103-10A	79594
Pressure Sensor	PTB210	B1050009
Temp/Humidity Sensor	HMP45C212	C2074
Temp Sensor	44212	C1505
Iridium Modem	Phone: 881621415689	#3

Basic analysis of the Data

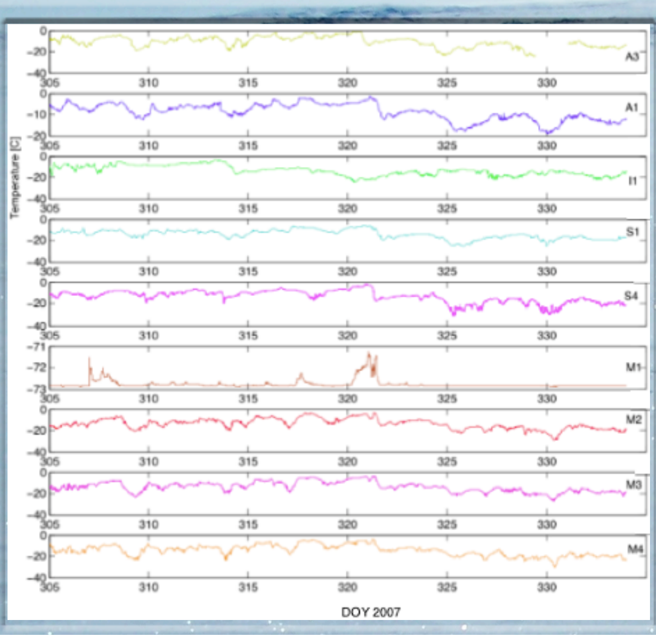
- Time Series
- Histograms
- Scatter plots

Wind Charts

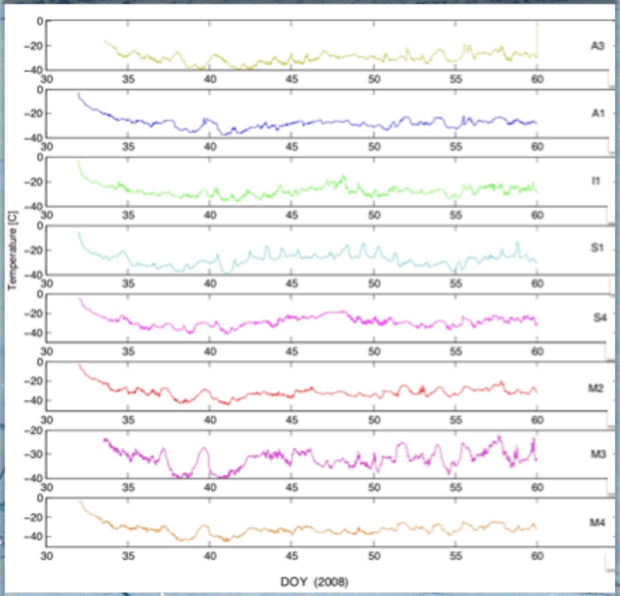
Animal problems, M1

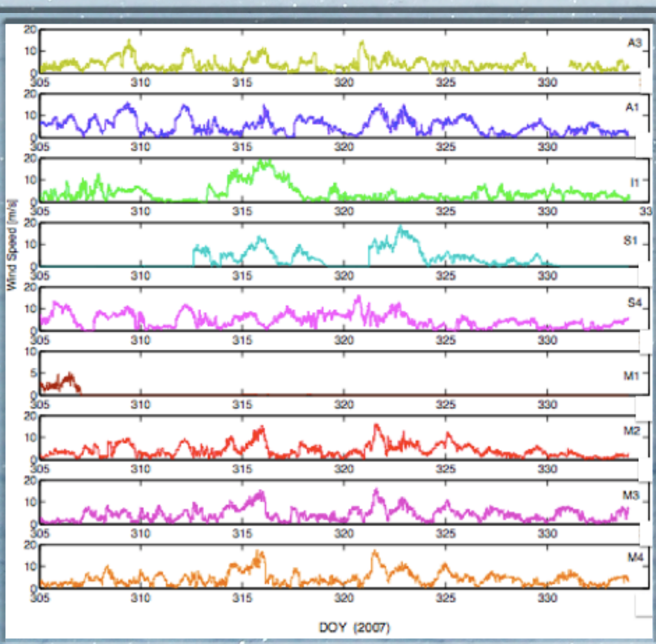
Icing problems,
S1 at elevation
721 m

Time Series



Tavr Nov = -20 C





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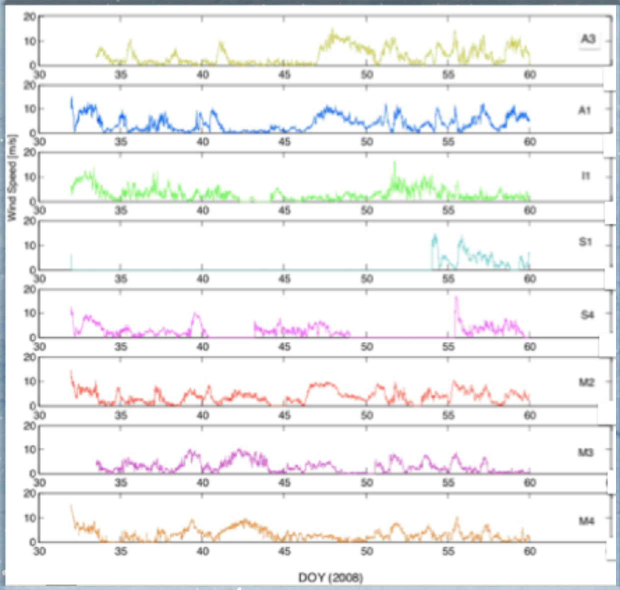
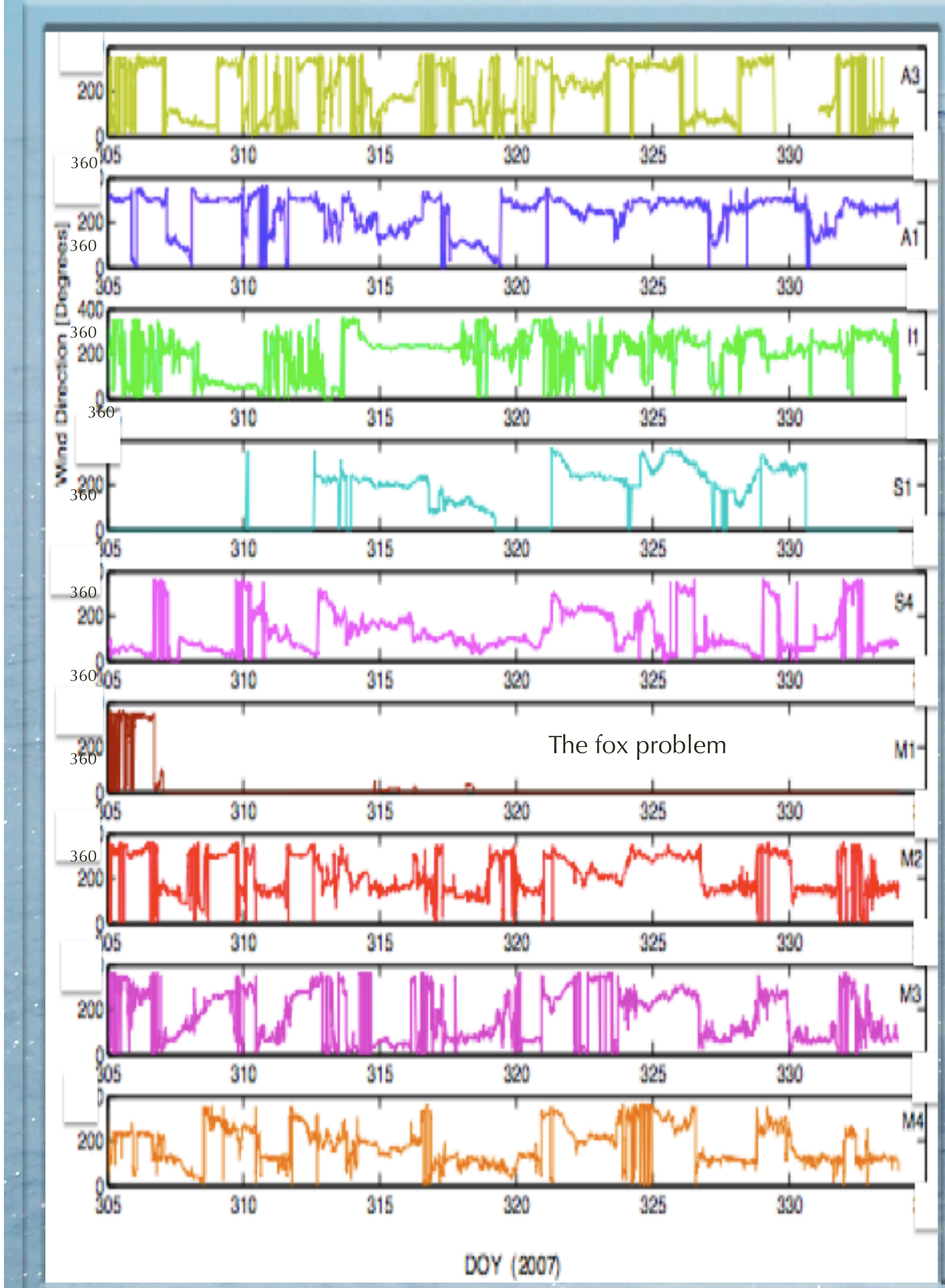
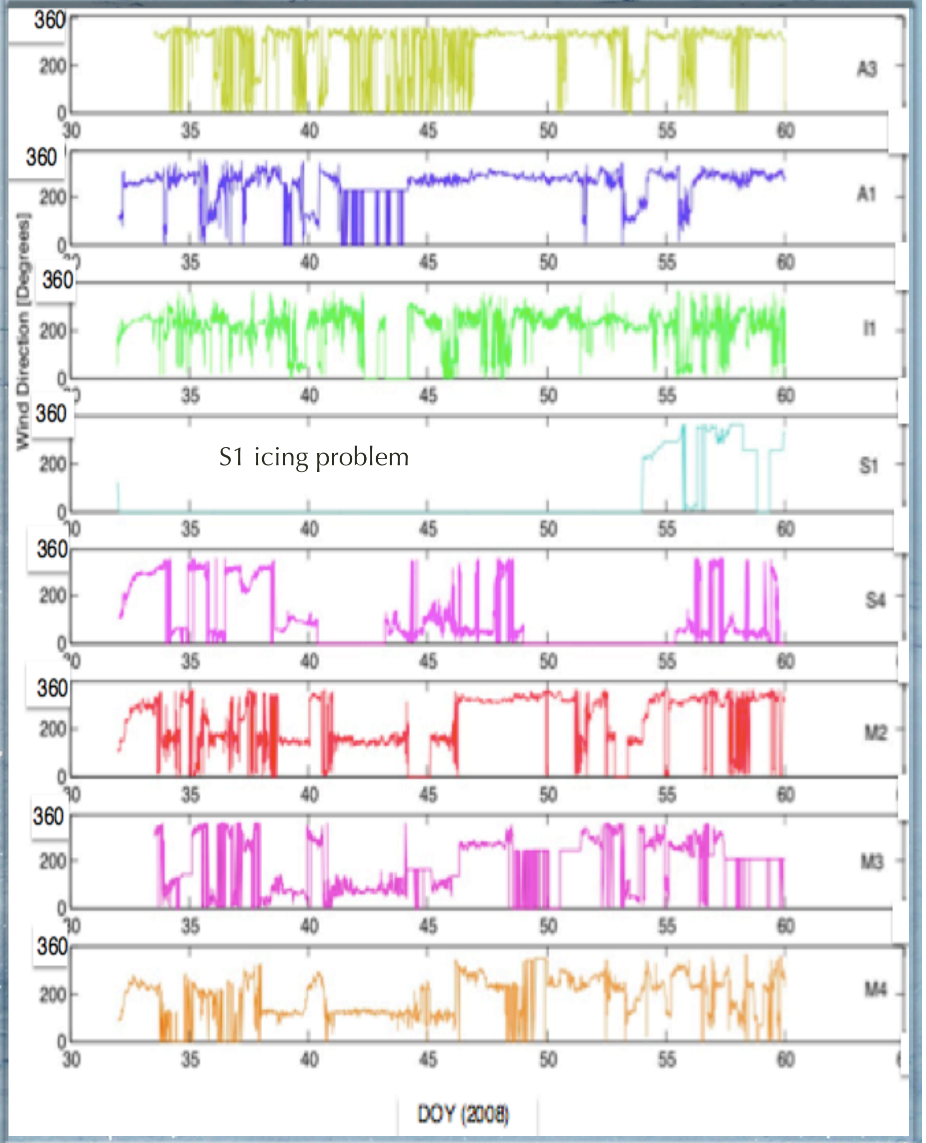


Direction Time Series



The fox problem

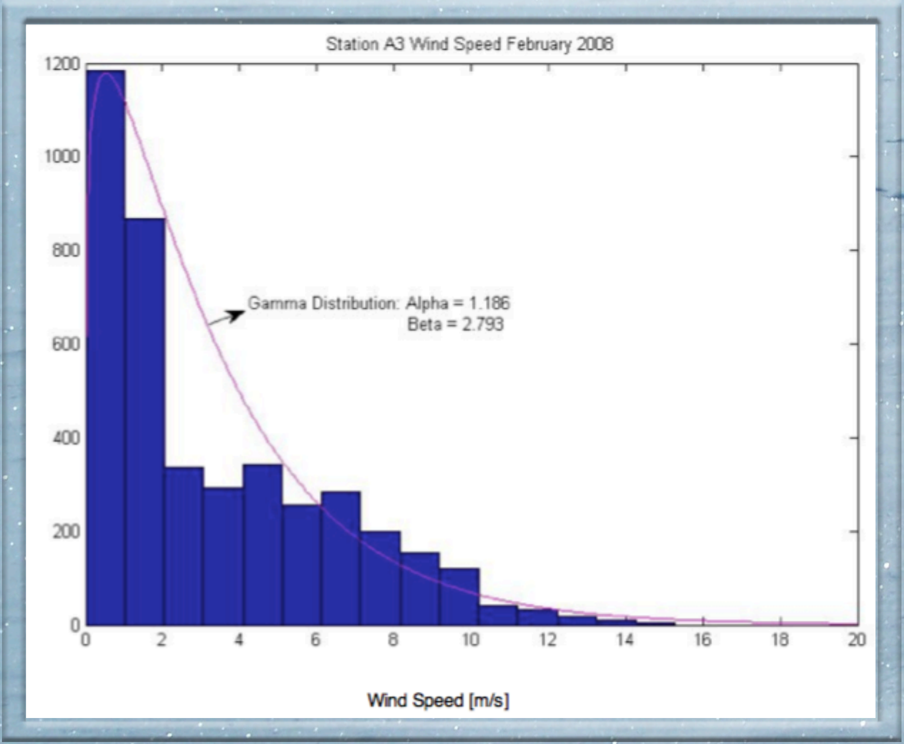
Tavr Nov = -20 C

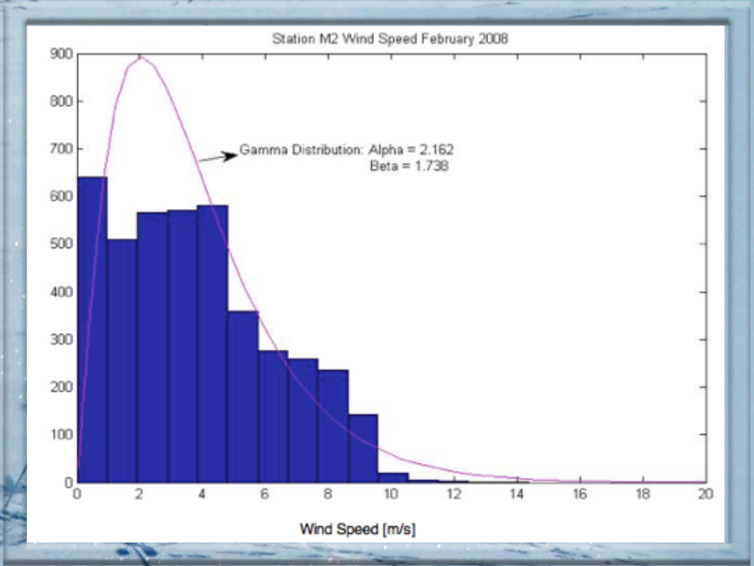


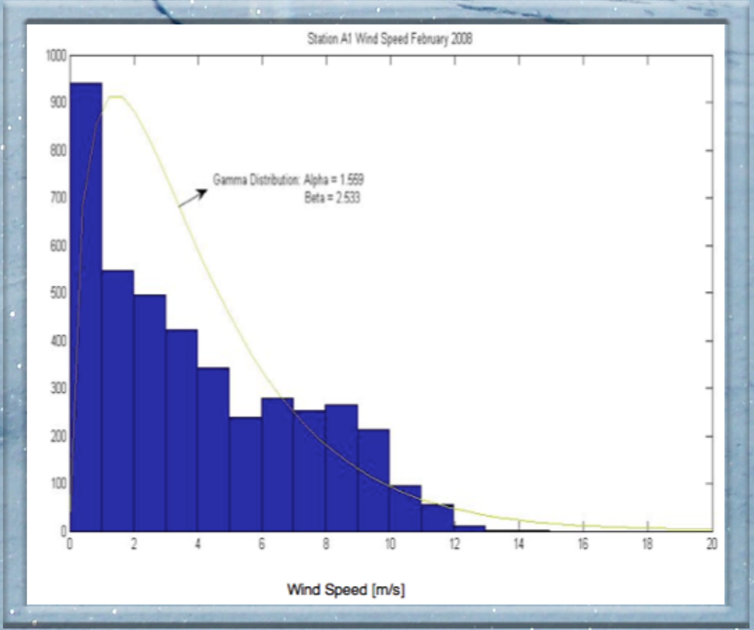
S1 icing problem

Tavr Feb= -30 C

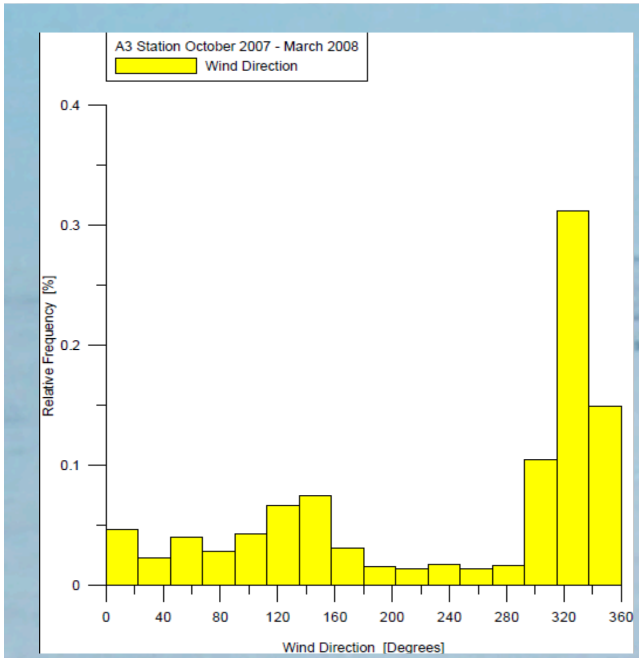
Gamma Distributions for February Winds A1, M2 and A3

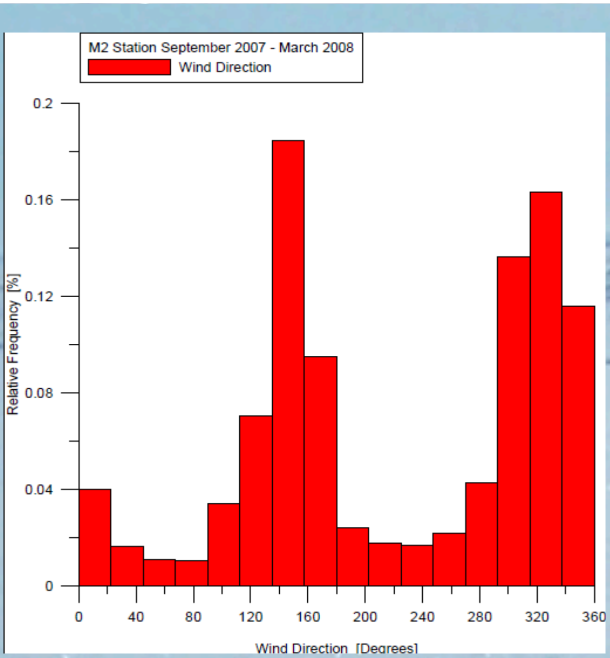


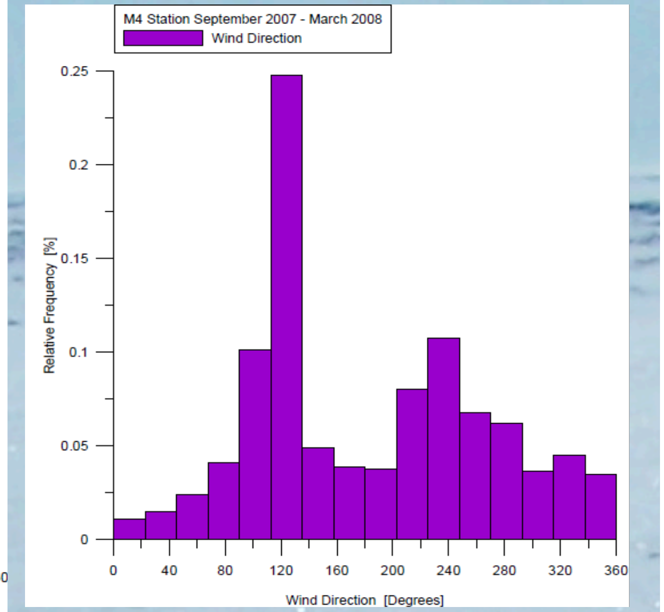


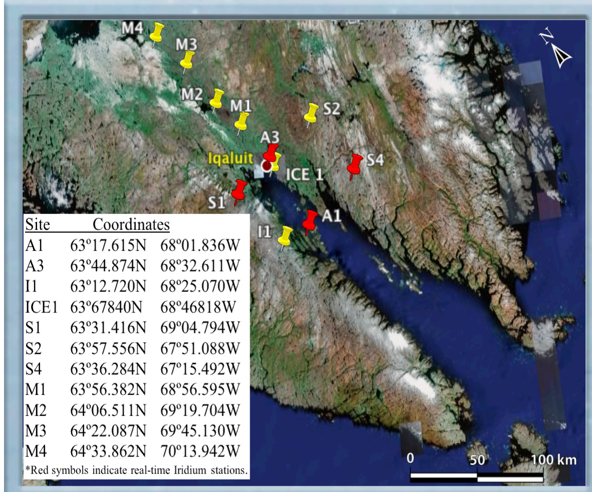


Axis Y = Number of counts taken every 10 min
Axis X = Wind Speed [m/s]









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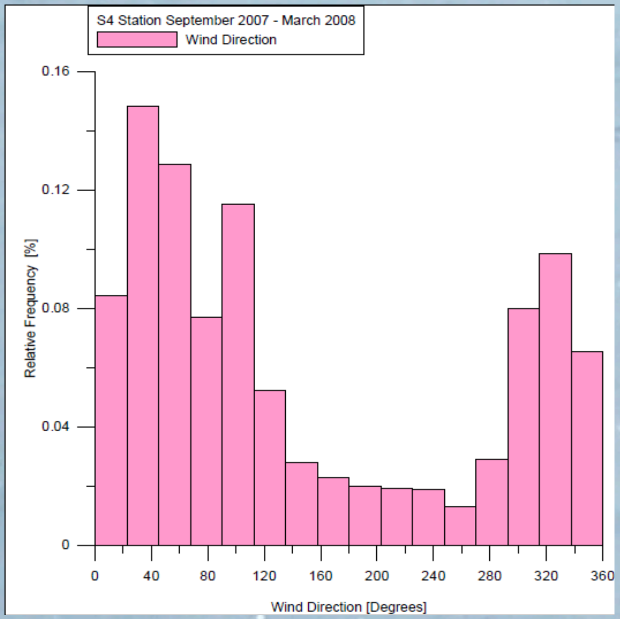
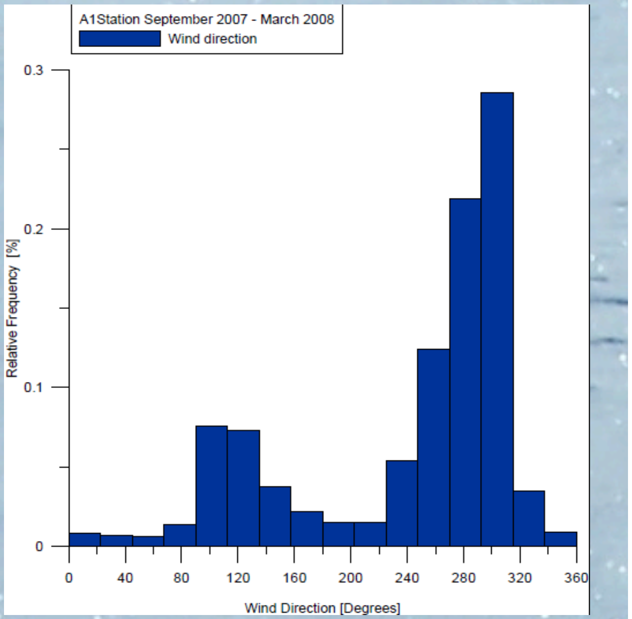
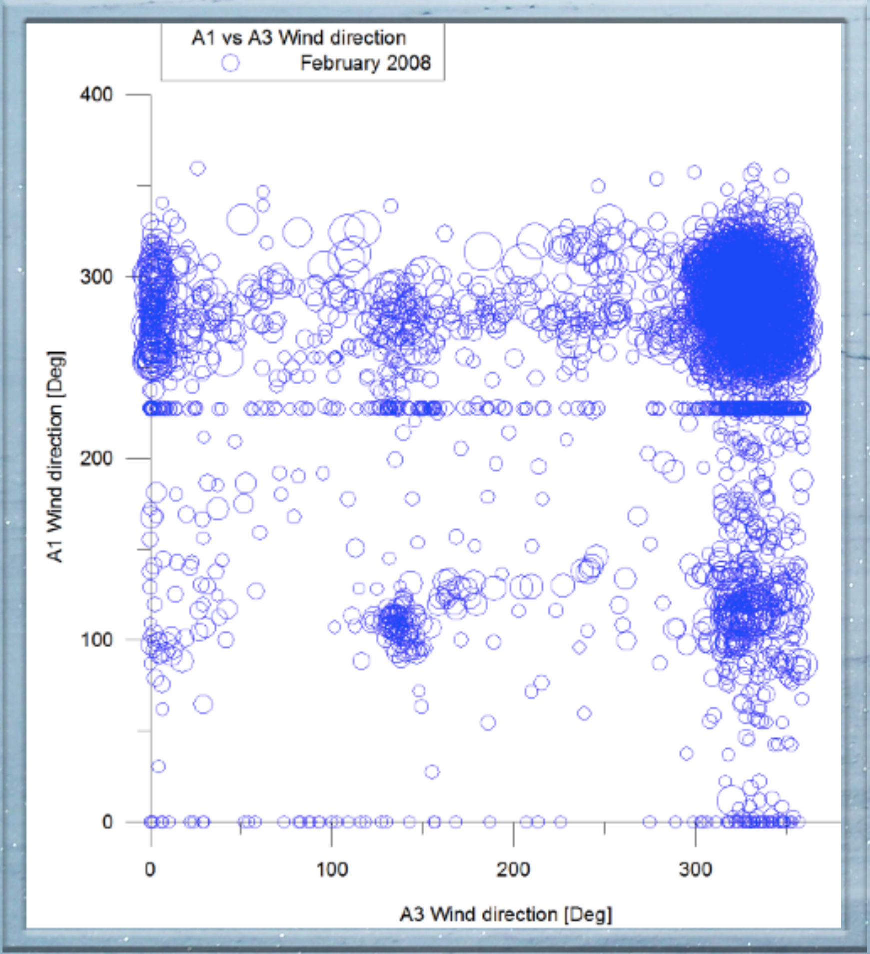
M3	64°22.087N	69°45.130W
M4	64°33.862N	70°13.942W

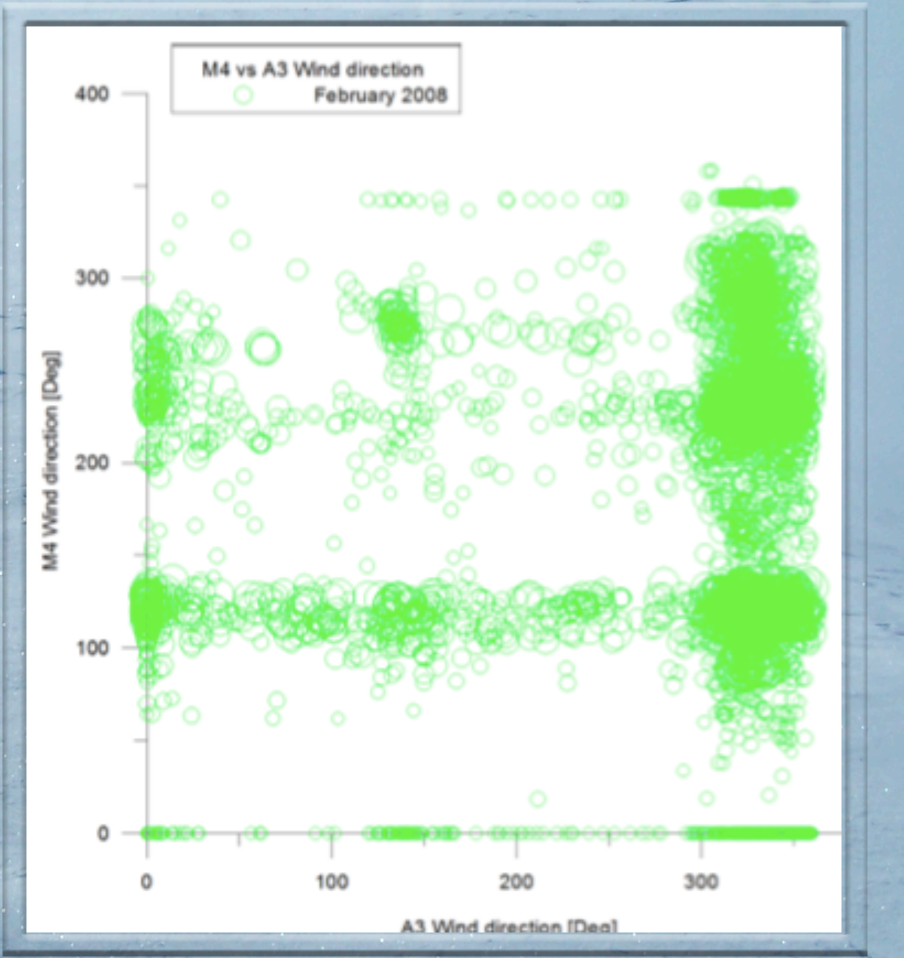
*Red symbols indicate real-time Iridium stations.





Joint PDFs

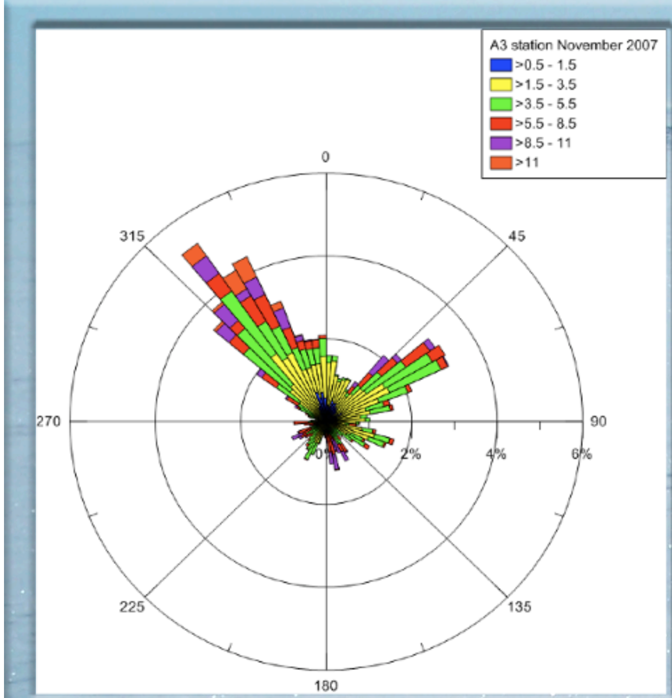


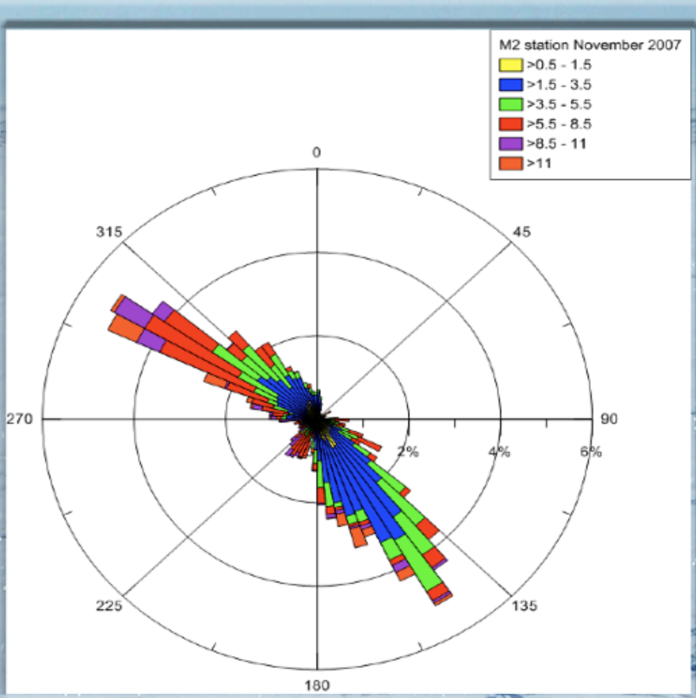


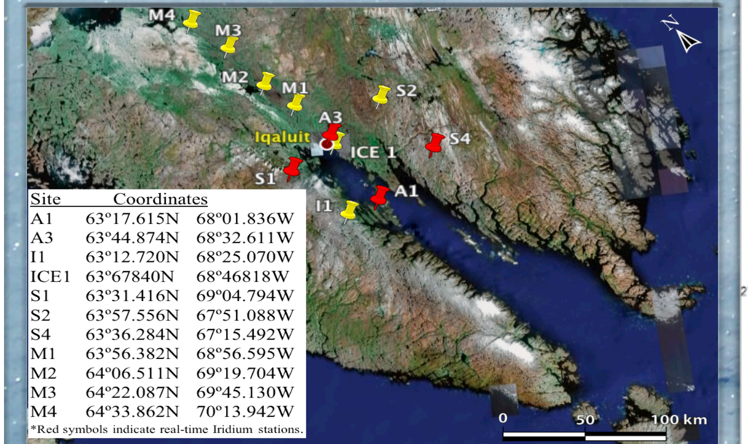
V avr = 3.99 m/s
T = -27.9 C

V avr = 2.9 m/s
T = -32.08 C

Wind Rose Charts







Site	Coordinates	
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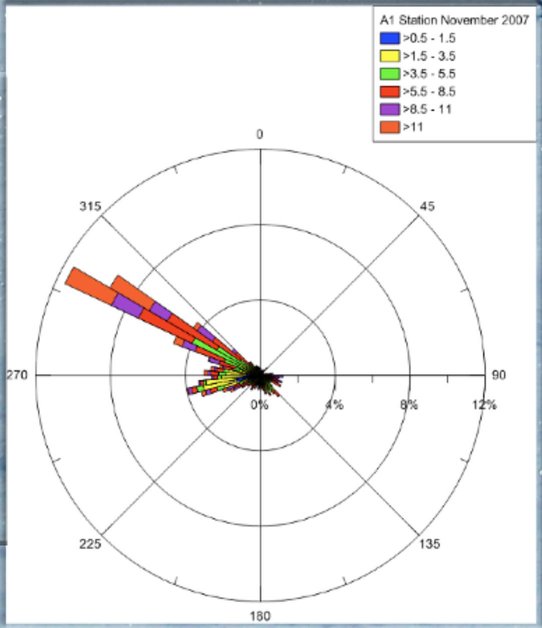
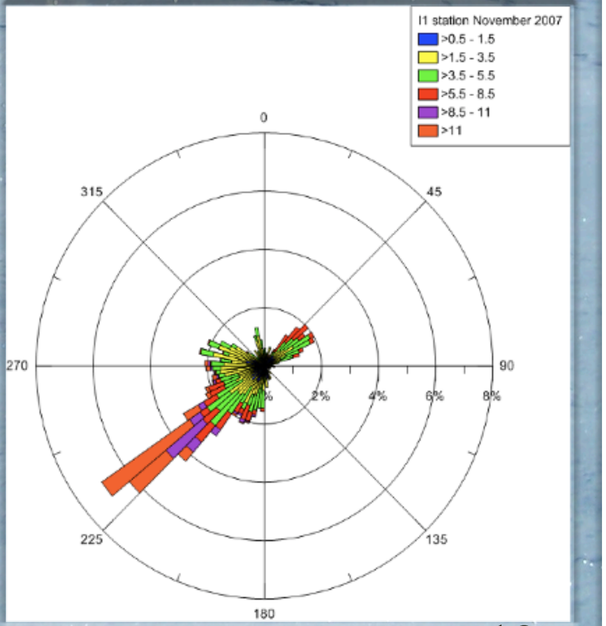
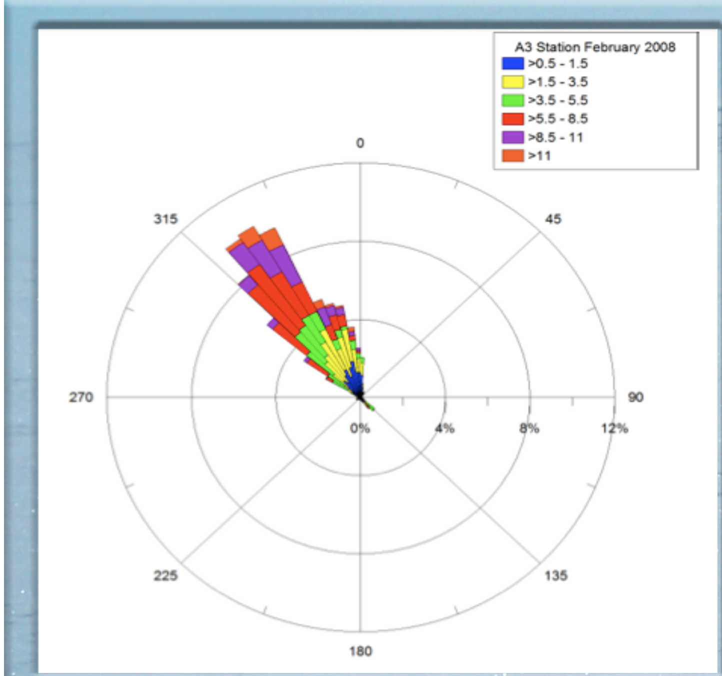
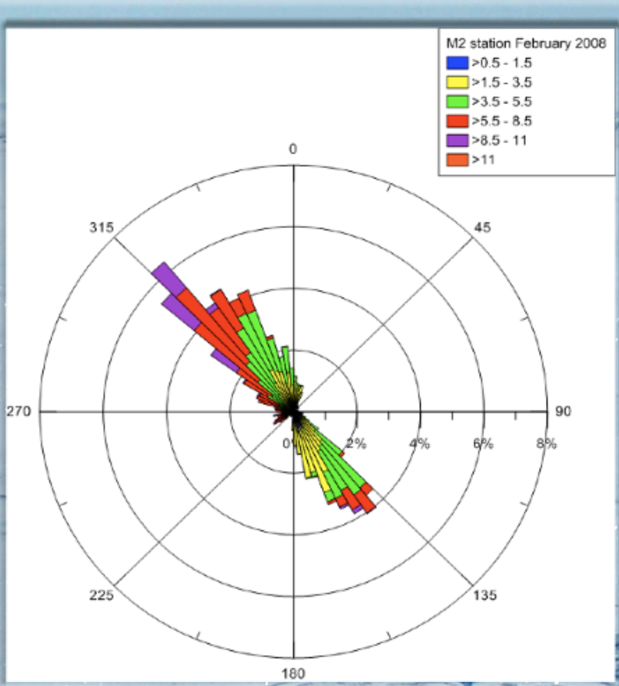
M3	64º22.087N	69º45.130W
M4	64º33.862N	70º13.942W

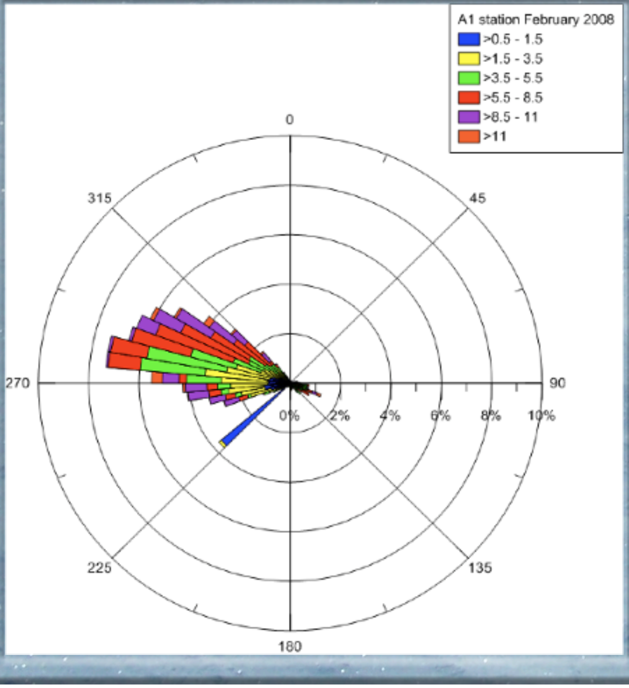
*Red symbols indicate real-time Iridium stations.

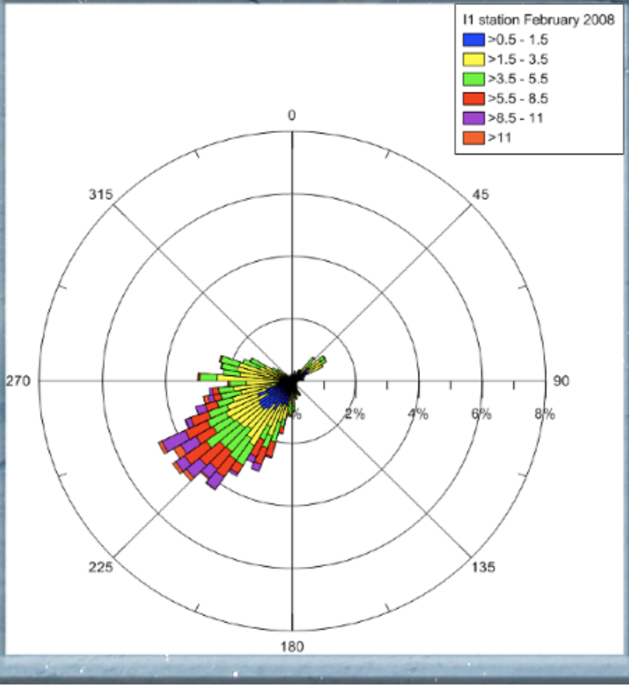




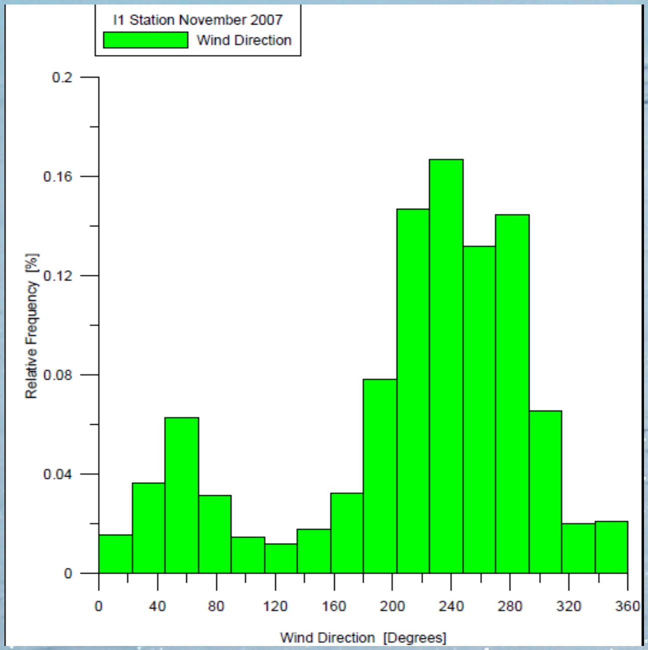

A3 Station February 2008
🟦 >0.5 - 1.5
🟨 >1.5 - 3.5
🟩 >3.5 - 5.5
🟥 >5.5 - 8.5
🟪 >8.5 - 11
🟧 >11
0
45
90
135
180
225
270
315
0%
4%
8%
12%

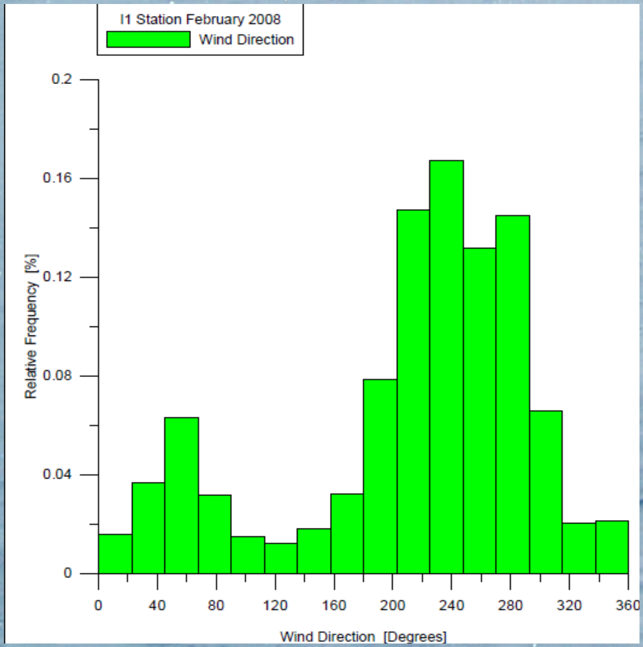

M2 station February 2008
🟦 >0.5 - 1.5
🟨 >1.5 - 3.5
🟩 >3.5 - 5.5
🟥 >5.5 - 8.5
🟪 >8.5 - 11
🟧 >11
0
45
90
135
180
225
270
315
0
2%
4%
6%
8%

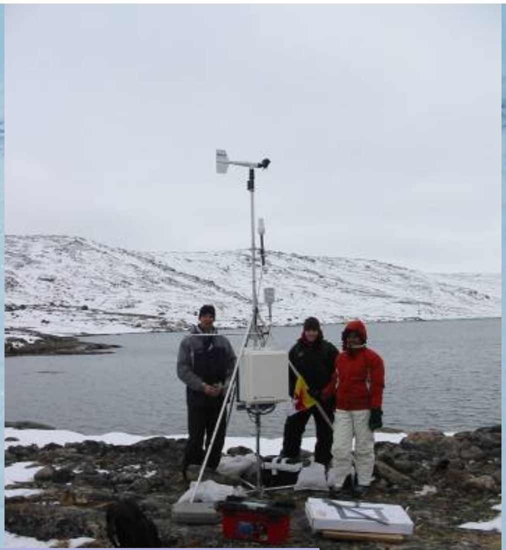

A1 station February 2008
🟦 >0.5 - 1.5
🟨 >1.5 - 3.5
🟩 >3.5 - 5.5
🟥 >5.5 - 8.5
🟪 >8.5 - 11
🟧 >11
0
45
90
135
180
225
270
315
0%
2%
4%
6%
8%
10%

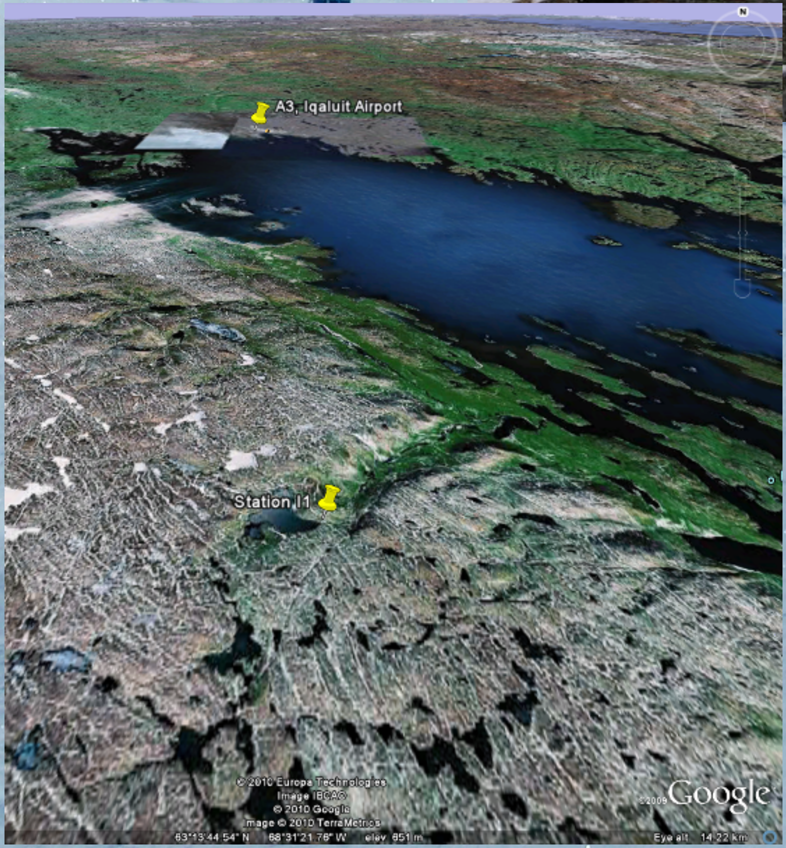

I1 station February 2008
🟦 >0.5 - 1.5
🟨 >1.5 - 3.5
🟩 >3.5 - 5.5
🟥 >5.5 - 8.5
🟪 >8.5 - 11
🟧 >11
0
45
90
135
180
225
270
315
2%
4%
6%
8%

Station I1


I1 Station November 2007
🟩 Wind Direction
Relative Frequency [%]
0.2
0.16
0.12
0.08
0.04
0
0
40
80
120
160
200
240
280
320
360
Wind Direction [Degrees]


I1 Station February 2008
🟩 Wind Direction
Relative Frequency [%]
0.2
0.16
0.12
0.08
0.04
0
0
40
80
120
160
200
240
280
320
360
Wind Direction [Degrees]




A3, Iqaluit Airport
Station I1
© 2010 Europa Technologies
Image IBCAO
© 2010 Google
Image © 2010 TerraMetrics
63°13'44.54" N 68°31'21.76" W elev 651 m
©2009 Google
Eye alt 14.22 km

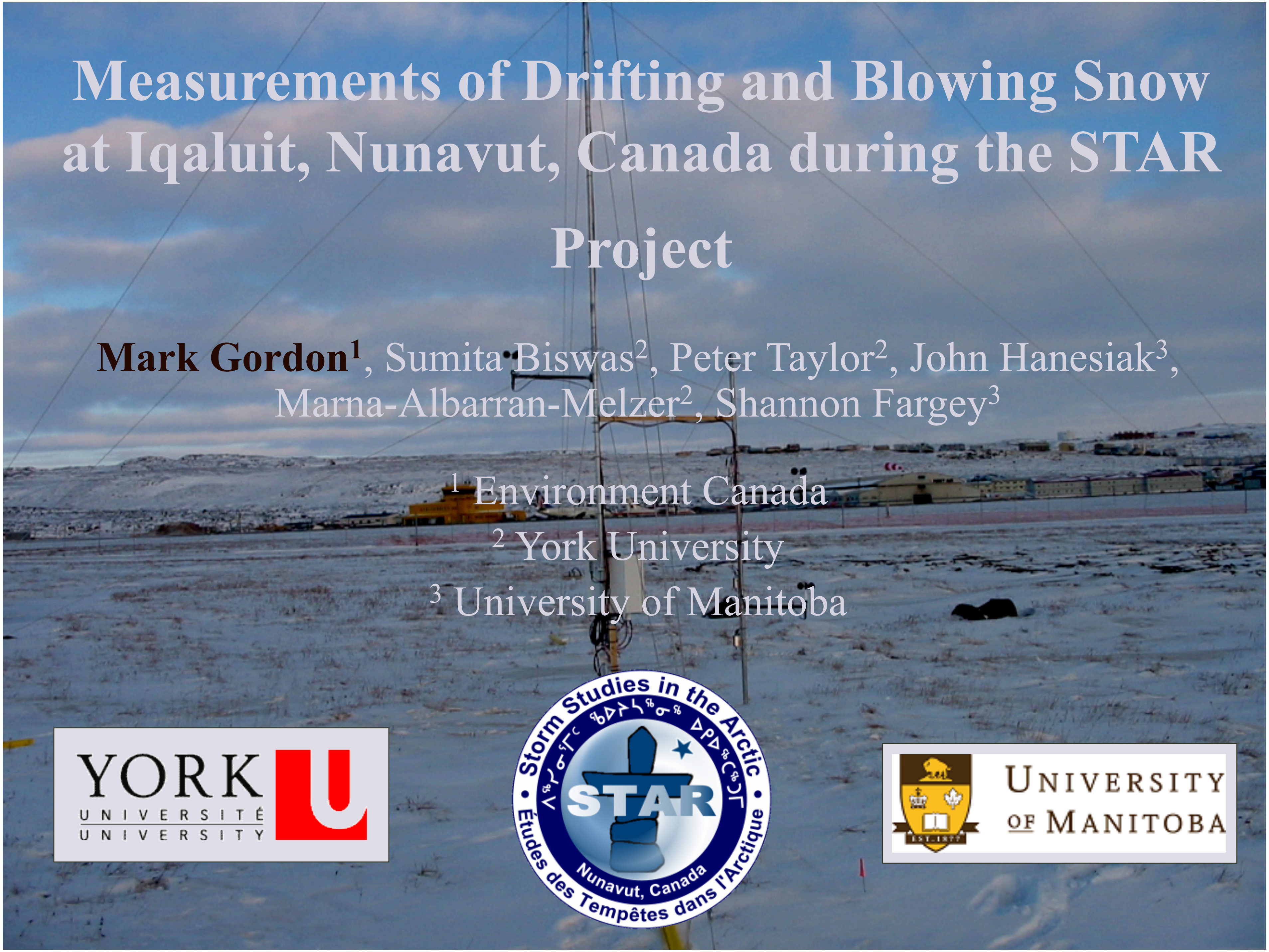
Conclusions

- After analysis of time series plots for the stations, we saw that for wind speed and temperature, the stations showed variations because the different topography of the places where they where set up.

- The correlation between wind direction and wind direction from the stations in a comparative way to A3, the station placed at the airport, shows how most of the time winds tend to match with the direction of winds from A3, which is very interesting since A3 is located almost in the heart of the Iqaluit valley.

- the winds at stations A1, A3, M2 often aligned at the same direction, with winds blowing from NW - SE, although, stations that are outside the valley, along Frobisher bay present winds more westerly that those inside the valley, but they presented strong winds (5.5 m/s - 11 m/s) during the few storms showed up during February.

- it seems to be that strong winds at Iqaluit and in Frobisher bay are channeled by the topography. Studies relating these surface winds to upper level winds are planned.



Measurements of Drifting and Blowing Snow at Iqaluit, Nunavut, Canada during the STAR Project

Mark Gordon[1], Sumita Biswas[2], Peter Taylor[2], John Hanesiak[3], Marna-Albarran-Melzer[2], Shannon Fargey[3]

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[2] York University
[3] University of Manitoba

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Winnipeg, Manitoba

[Original manuscript received 23 April 2009; accepted 18 December 2009]

ABSTRACT *A 10 m meteorological tower near Iqaluit Airport was operational from late October 2007 to early April 2008. Measurements included wind speed, temperature, pressure, humidity, visibility, and blowing snow number flux. Number flux measurements give a frequency of blowing and drifting snow of approximately 10% for the duration of the study, while meteorological observations from the Iqaluit weather office give a frequency of approximately 5%. Winter winds were predominantly from the northwest, and some strong southeasterly winds were also observed, especially in early spring. The average roughness length determined from the variance of wind speed is $z_0 = 0.14$ mm. Threshold wind speeds for the onset of blowing snow ranged from 7 m s^{-1} to 12 m s^{-1}, excluding events with falling snow. Measurements of visibility correlate well with the measured number density ($R^2 = 0.83$), assuming a constant particle diameter of $d = 100$ μm at a height of 2 m. A camera system was used during blowing snow events in February to measure the size of blowing snow particles and the mass flux of blowing snow. At a height of 0.35 m, the particle size distribution can be approximated by a gamma distribution with shape parameter $4.4 < \alpha < 6.4$ and an average particle diameter of $70 < d < 148$ μm. The particle size at a height of 0.35 m increases linearly with the 10 m wind speed ($R^2 = 0.69$). Mass flux measurements demonstrate a power law relation with height between 0.1 and 0.9 m, with a negative exponent of approximately 2.5. Blowing snow density follows a power law relation with height between 0.85 and 1.85 m, with a negative exponent of approximately 1.3 for friction velocity $0.25 < u_* < 0.55$ m s^{-1}. In February 2008, a field mill was installed, which measured electric field strengths as high as 26.2 kV m^{-1} at a height of 0.5 m.*

RÉSUMÉ *[Traduit par la rédaction] Une tour météorologique de 10 m près de l'aéroport d'Iqaluit a été en fonction de la fin d'octobre 2007 jusqu'au début d'avril 2008. Les mesures portaient, entre autres, sur la vitesse du vent, la température, la pression, l'humidité, la visibilité et le flux en nombre de la poudrerie élevée. Les mesures de flux en nombre donnent une fréquence de poudrerie élevée et basse d'environ 10 % pour la durée de l'étude alors que les observations météorologiques provenant du bureau météorologique d'Iqaluit donnent une fréquence d'environ 5 %. Les vents dominants en hiver étaient du nord-ouest et de forts vents du sud-est ont aussi été observés, surtout au début du printemps. La longueur de rugosité moyenne déterminée d'après la variance de la vitesse du vent est $z_0 = 0{,}14$ mm. Les vitesses de vent seuils pour les événements de poudrerie variaient de 7 m s^{-1} à 12 m s^{-1}, à l'exclusion des cas où il tombait de la neige. Les mesures de visibilité concordent bien avec la densité en nombre mesurée ($R^2 = 0{,}83$), en supposant des particules de diamètre constant $d = 100$ μm à une hauteur de 2 m. Un système à caméra a été utilisé durant les événements de poudrerie élevée pour mesurer la taille des particules de poudrerie et le flux en masse de la poudrerie. À une hauteur de 0,35 m, la distribution de la taille des particules peut être approximée par une distribution gamma avec un paramètre de forme $4{,}4 < \alpha < 6{,}4$ et un diamètre moyen des particules de $70 < d < 148$ μm. La taille des particules à une hauteur de 0,35 m augmente linéairement avec la vitesse du vent à 10 m ($R^2 = 0{,}69$). Les mesures de flux en masse exhibent une relation de loi de puissance avec la hauteur entre 0,1 et 0,9 mètre, avec un exposant négatif d'approximativement 2,5. La densité de la poudrerie élevée suit une relation de loi de puissance avec la hauteur entre 0,85 et 1,85 m, avec un exposant négatif d'approximativement 1,3 pour une vitesse de frottement $0{,}25 < u_* < 0{,}55$ m s^{-1}. En février 2008, un moulin à champ a été installé et cet instrument a mesuré des intensités de champ électrique allant jusqu'à 26,2 kV m^{-1} à une hauteur de 0,5 m.*

1 Introduction

Blowing snow is a frequent weather event in Arctic regions. Hanesiak et al. (2003) found that there were between 500 and 600 hours with blowing snow events per year (6–7%) between 1953 and 2002, measured at 20 weather stations in

the Canadian Arctic. Hanesiak and Wang (2005) found the frequency of blowing snow to be as high as 25% in northeast Canada; however they note that the frequency has been decreasing over the last four or five decades. Déry and Yau (1999) used the European Centre for Medium-range Weather Forecasts' re-analysis data to infer an average blowing snow frequency of 6% throughout the year, over the entire northern hemisphere.

Studies of blowing snow using particle counter instruments have been undertaken in Antarctica (Budd et al., 1966; Dover, 1993; Nishimura and Nemoto, 2005), Japan (Sato et al., 1993), Wyoming, USA (Schmidt, 1981, 1982), Churchill, Manitoba, Canada (Gordon and Taylor, 2009a), and Franklin Bay, Northwest Territories, Canada (Savelyev et al., 2006; Huang et al., 2008; Gordon et al., 2009). Measurements demonstrated that the blowing snow size distributions were best fit by gamma distributions and that particle size decreases with height (Budd et al., 1966; Dover, 1993; Schmidt, 1981; Gordon and Taylor, 2009a). It has also been shown that blowing snow number density can be used to determine visibility (Savelyev et al., 2006; Huang et al., 2008).

Accurate modelling of blowing snow requires knowledge of particle sizes and knowledge of distribution of particle number and mass with height. Both Schmidt (1981) and Dover (1993) found that modelled particle sizes were smaller than observed. Measured particle sizes are varied for different locations and conditions (see Gordon and Taylor, 2009a for a summary). Schmidt (1986) found that the transport rate of blowing snow was greater over hard snow and ice than over soft, fresh snow. Hence, measurements may be very specific to location. Although measurements have been made in Antarctica, Japan, Wyoming, Churchill, and over sea ice at Franklin Bay, there is a need for further observations in the Arctic, especially on land near populated areas.

Iqaluit, Nunavut (NU), Canada is significantly affected by blowing snow. Reduced visibility due to blowing snow creates dangerous flying conditions and freight is only available by air transport during the winter months. Accurate prediction of blowing snow events could reduce flight risk. Building design must also take into consideration the loads of snow drifts caused by blowing snow (Moore et al., 1994). Improvements in blowing snow models could improve the prediction of these loads. Blowing snow transport to and from the nearby sea ice and sublimation of blowing snow may significantly affect the ice surface energy balance (Bintanja and Van Den Broeke, 1995; Bintanja, 2001). Hence, better knowledge of blowing snow at Iqaluit could also lead to more accurate prediction of the annual sea-ice melt.

The Storm Studies in the Arctic (STAR) project, described in Hanesiak et al. (2010), took place in Iqaluit, NU, Canada and the surrounding area in the fall and winter of 2007–08. During that study a meteorological tower and various instruments were installed near the Iqaluit airport to study blowing snow. In addition to these automated instruments, measurements were taken by observers during the month of February 2008. This paper presents these measurements, providing an overview of blowing snow characteristics at Iqaluit, including threshold wind speeds, blowing snow particle size, mass density profiles, visibility reduction, and the generation of an electric field.

2 Background

Assuming neutral stratification, the wind speed, u, will change with height, z, as

$$u(z) = \frac{u_*}{\kappa}\ln\left(\frac{z}{z_0}\right), \qquad (1)$$

where $\kappa = 0.4$, z_0 is the roughness length, and u_* is the friction velocity. The friction velocity is used to represent the shear stress as $u_* = \sqrt{\tau/\rho_a}$, where τ is the surface stress and ρ_a is the density of air. During blowing snow, saltating particles will absorb momentum from the boundary layer and transfer it to the surface. This results in an increased roughness length as the amount of blowing snow increases. On the Ritscherflya plateau in Antarctica, Bintanja (2001) measured roughness lengths ranging from $z_0 = 0.1$ mm at $u_* \approx 0.25$ m s^{-1} to $z_0 \approx 1.8$ mm at $u_* \approx 0.8$ m s^{-1}.

The motion of blowing snow particles is generally separated into two regimes: the saltation layer and the suspension layer (e.g., Pomeroy and Gray, 1990). In the saltation layer, particles are ejected from the surface and follow a parabolic trajectory under the influence of gravity. Some of these particles are carried aloft by turbulent eddies into the suspension layer. Although there is no clearly defined boundary between the two layers, the transition between the two regimes is at a height of order 100 mm (Sato et al., 2001; Gordon et al., 2009). In the suspension layer, assuming there is no net influx of particles from the surface and ignoring sublimation, a balance between upward transport by turbulent diffusion and downward settling of particles for a given radius gives a blowing snow mass density of

$$\rho_s(z) = \rho_{s,r}(z)\left(\frac{z}{z_r}\right)^{-\gamma}, \qquad (2)$$

where $\rho_{s,r}$ is a reference blowing snow density for a given radius at height z_r, and $\gamma = \omega/\kappa u_*$, where $\kappa = 0.4$ and ω is the settling velocity for a given radius.

During blowing snow, temperature gradients in ice particles produce an electric field. Schmidt et al. (1999) and Gordon and Taylor (2009b) demonstrated that the strength of the field decreases with height. The results of Schmidt et al. (1998) demonstrate that the field can produce acceleration in particles comparable to the acceleration due to gravity. Hence, the electric field may significantly affect the transport of blowing snow and the mass distribution given by Eq. (2). Gordon and Taylor (2009b) show that the field strength at a given height correlates well with the wind speed. They propose a model for the electric field strength in the suspension layer which gives

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Canadian Meteorological and Oceanographic Society

Blowing Snow Study Goals

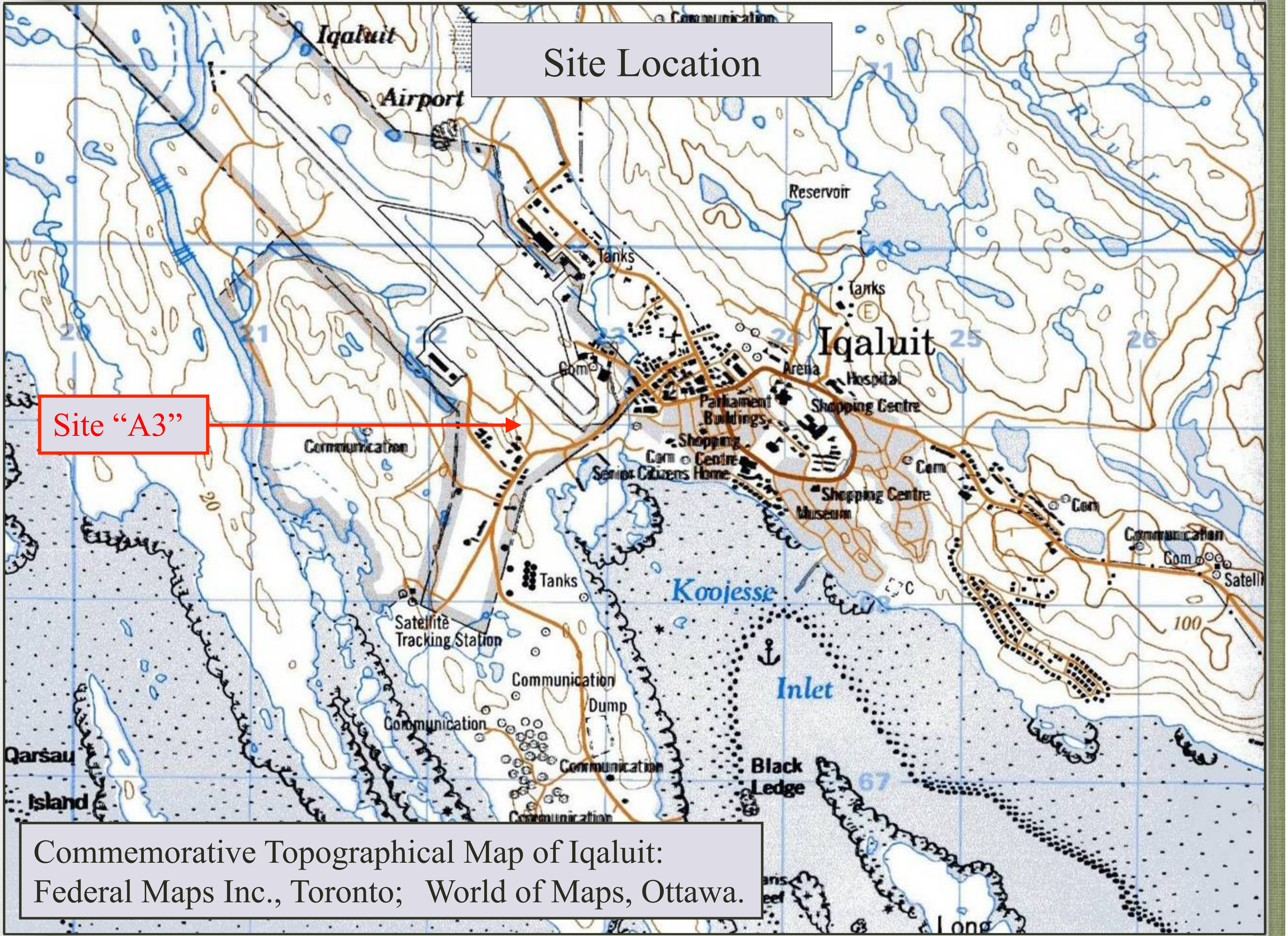
Predictive / Forecasting:

- Threshold Wind Speeds ~ f (T, Rh)
- Wind Speed to Blowing Snow Density
- Blowing Snow Density to Visibility

Modelling:

- Particle Size ~ f (U, z)
- Mass and Number Flux ~ f (U, z)
- Electrostatic Field

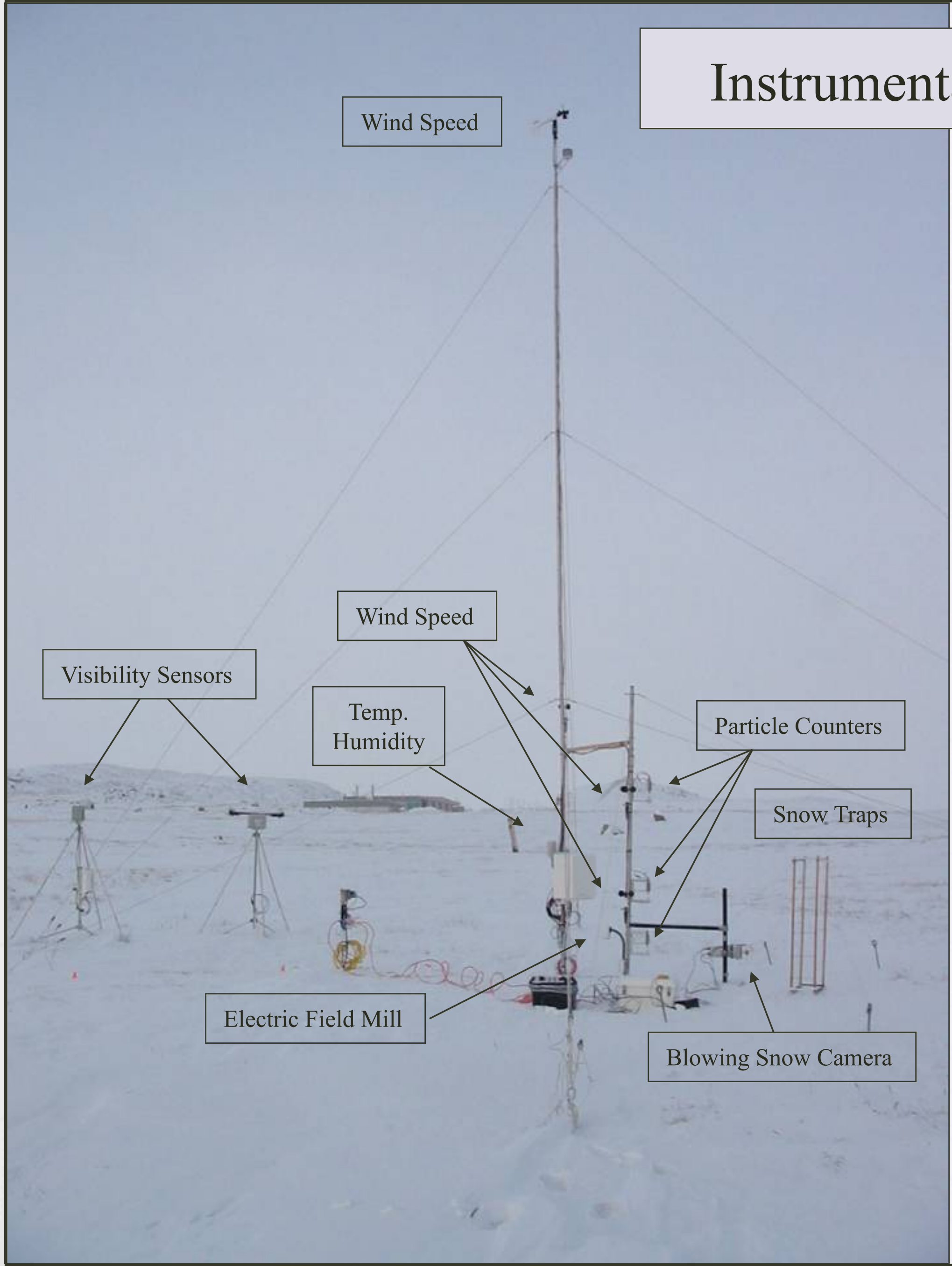
Site Location



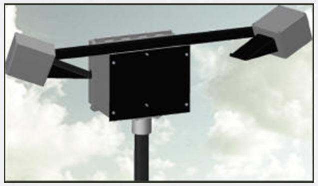
Site “A3”

Commemorative Topographical Map of Iqaluit:
Federal Maps Inc., Toronto; World of Maps, Ottawa.

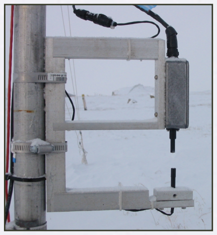
Instrumentation



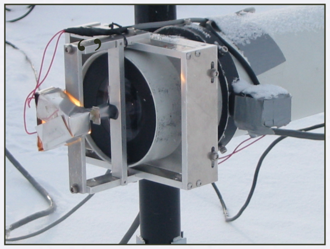
- 10-m Wind Speed and Dir.
- 3-m Wind Speed
- 2-m ‘’ ‘’
- 1-m ‘’ ‘’
- 1.5-m Air Temp.
- 1.5-m Air Humidity
- 1.5 / 9-m Δ Temp.
- Snow Temperature



- 2-m Visibility (x2)



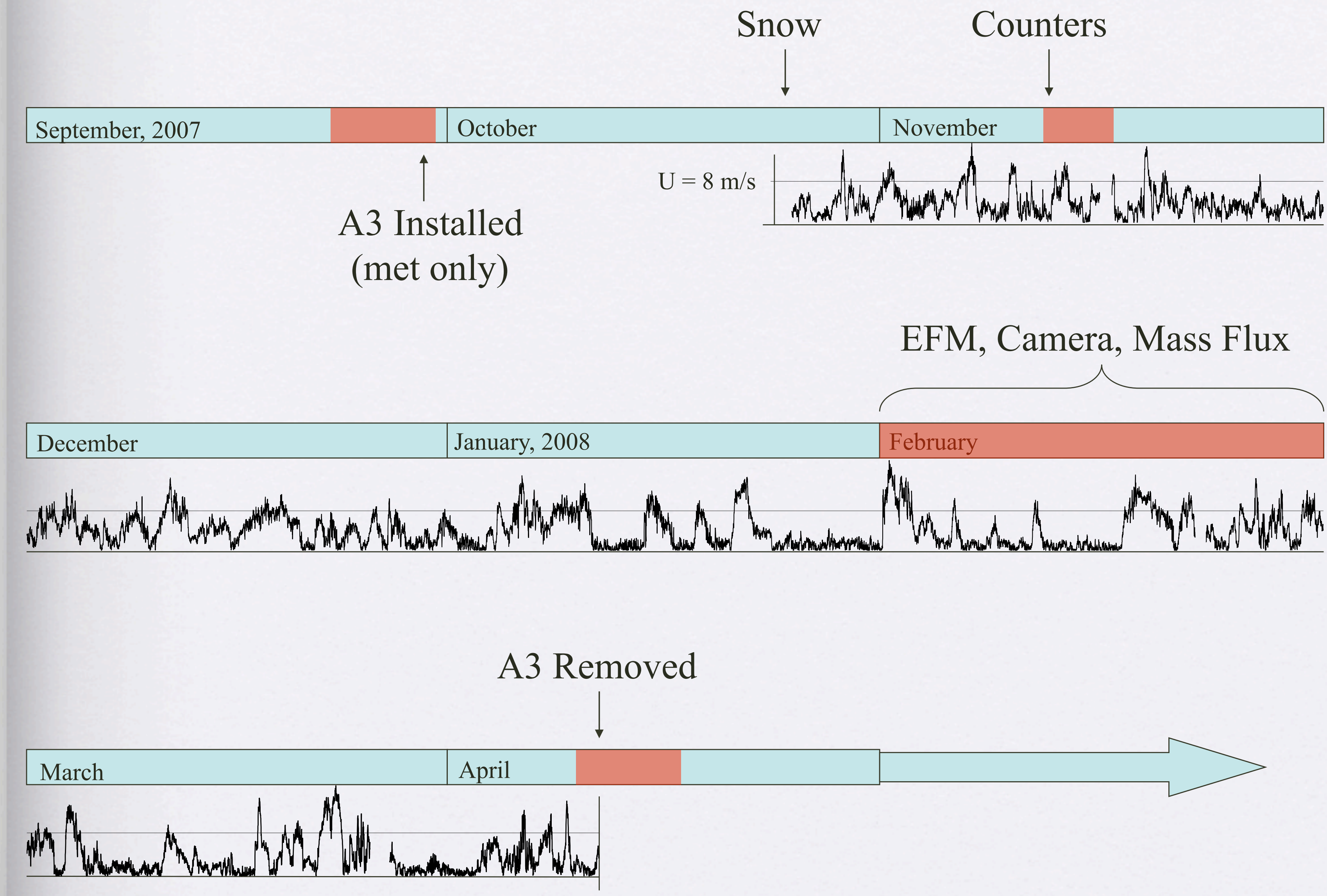
- 2-m Particle Number Flux
- 1-m ‘’ ‘’ ‘’
- 0.5-m ‘’ ‘’
- Snow Traps



- Particle Number and Size

- Electric Field Strength

Winter 2007 to Spring 2008



Snow

Counters

September, 2007

October

November

U = 8 m/s

A3 Installed
(met only)

EFM, Camera, Mass Flux

December

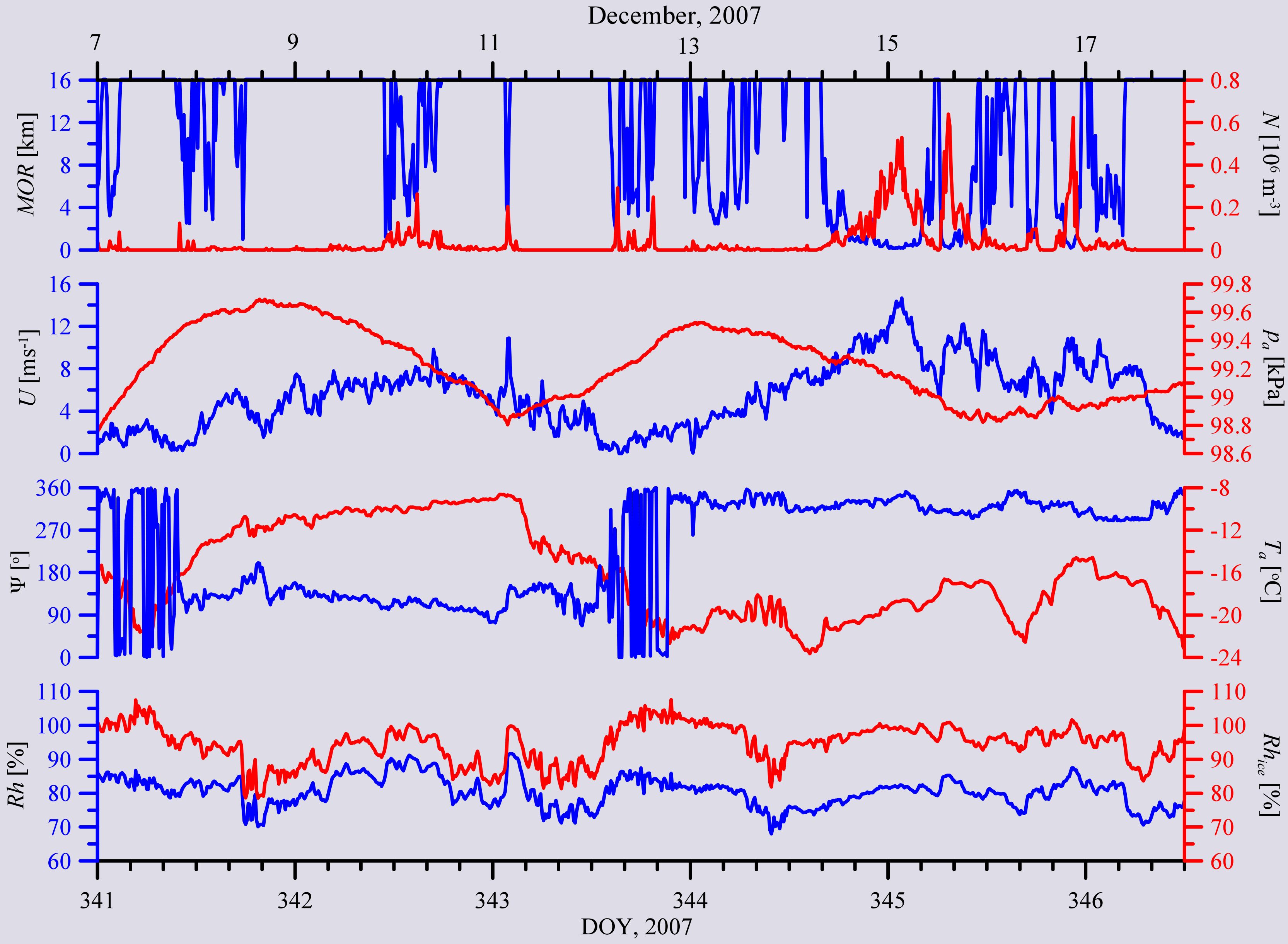
January, 2008

February

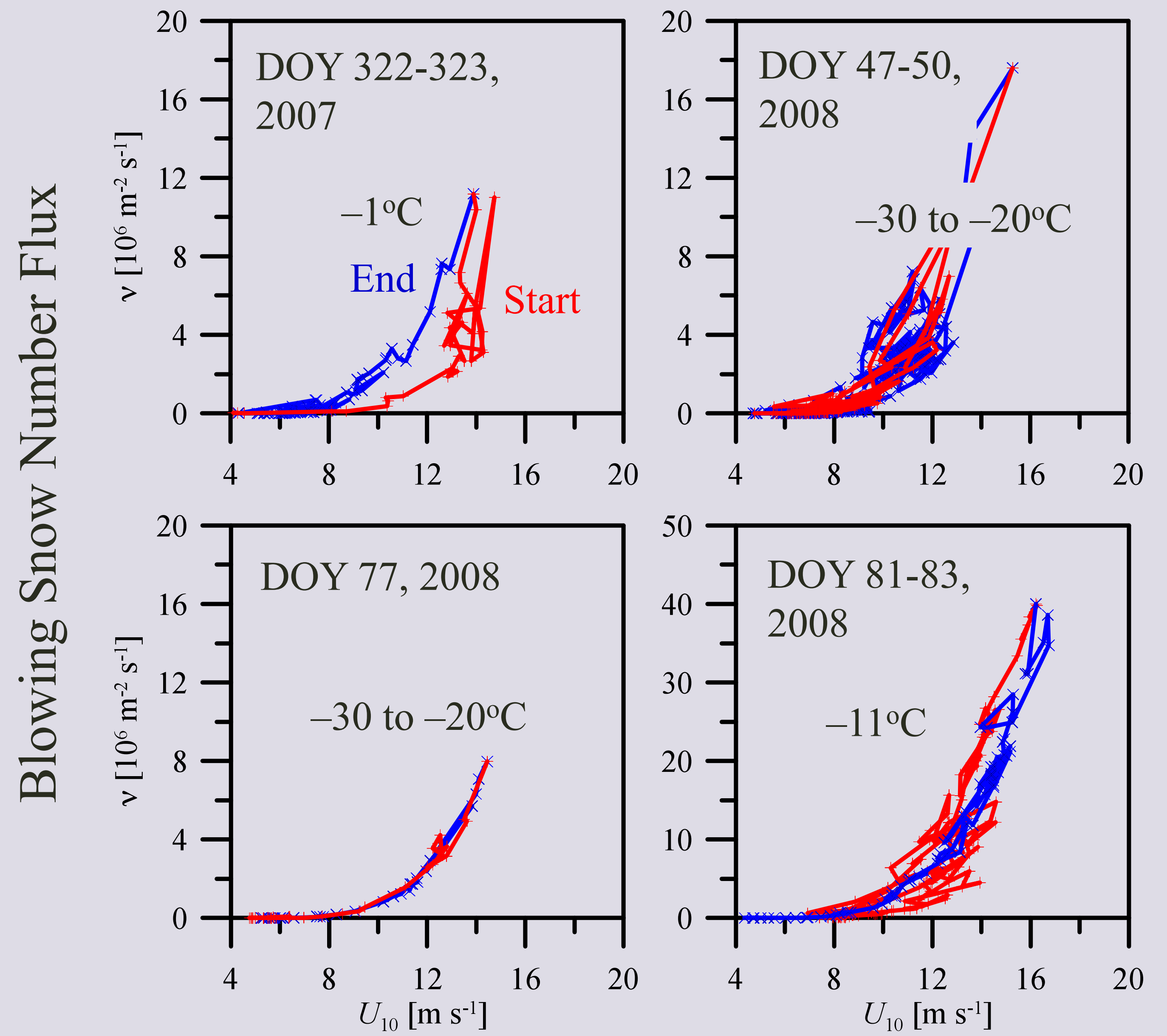
A3 Removed

March

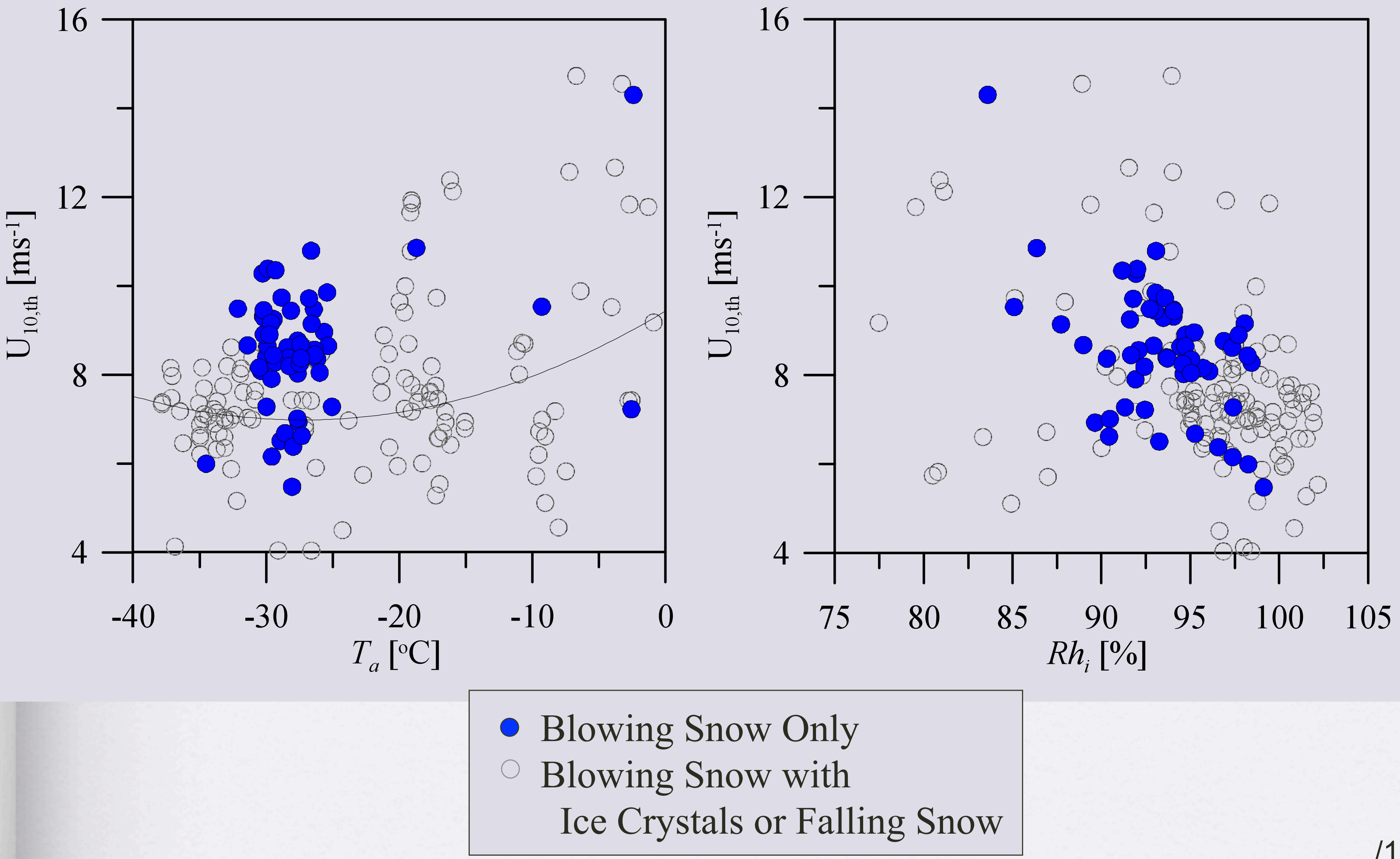
April


December, 2007
7
9
11
13
15
17
MOR [km]
16
12
8
4
0
N [10^6 m^{-3}]
0.8
0.6
0.4
0.2
0
U [ms^{-1}]
16
12
8
4
0
P_a [kPa]
99.8
99.6
99.4
99.2
99
98.8
98.6
Ψ [°]
360
270
180
90
0
T_a [°C]
-8
-12
-16
-20
-24
Rh [%]
110
100
90
80
70
60
Rh_{ice} [%]
110
100
90
80
70
60
341
342
343
344
345
346
DOY, 2007

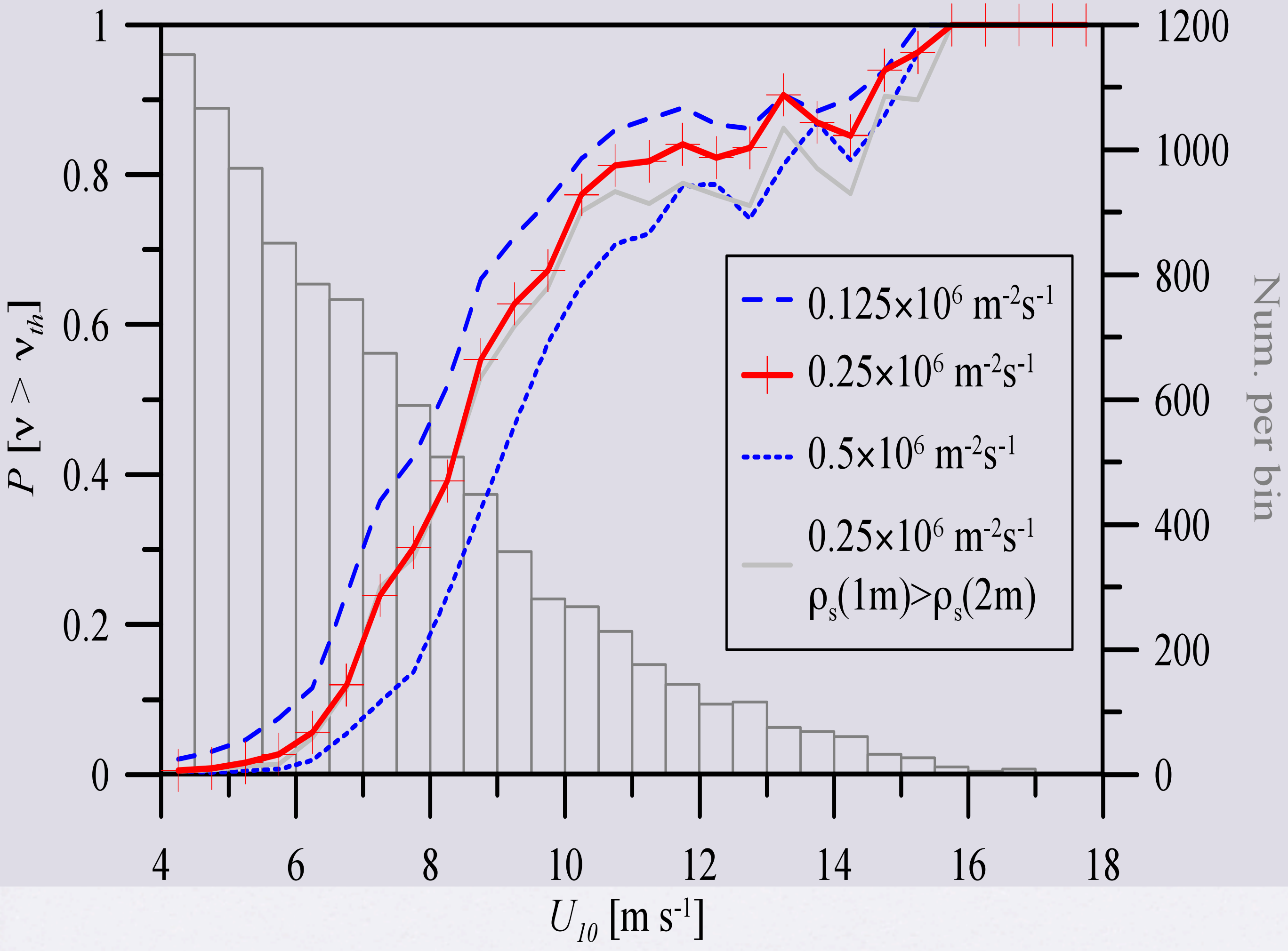
Threshold Wind Speed



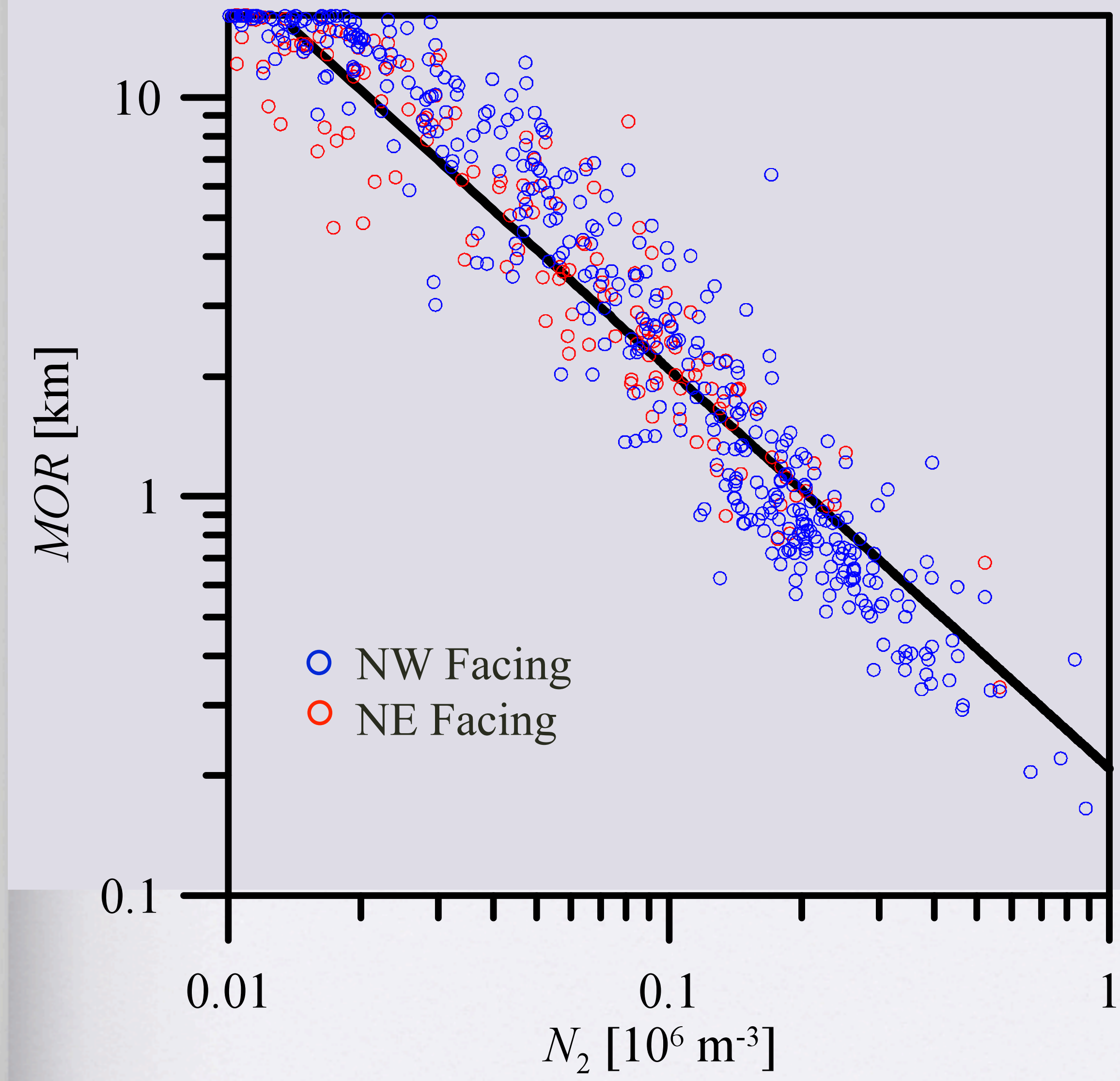
Threshold Wind Speed

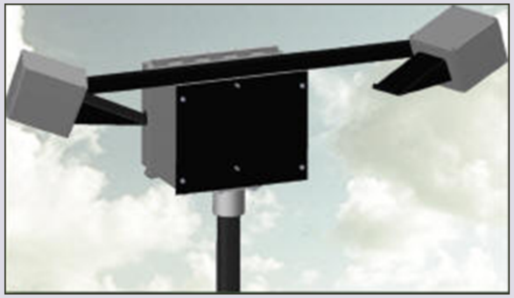


Threshold Wind Speed



Visibility





$U_{10} > 6$ m s^{-1}

Observations:

Clear,

Cloudy,

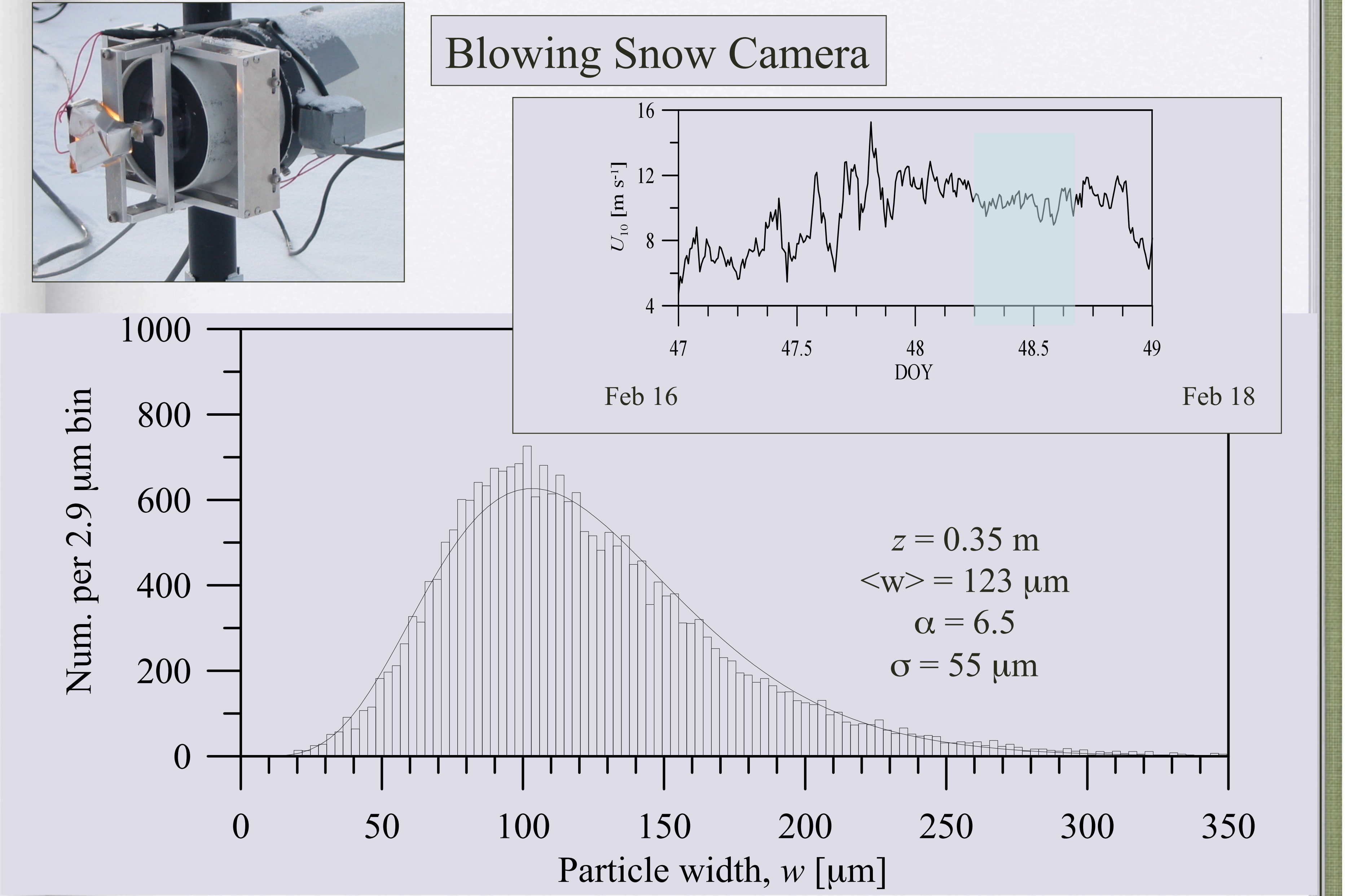
Blowing Snow

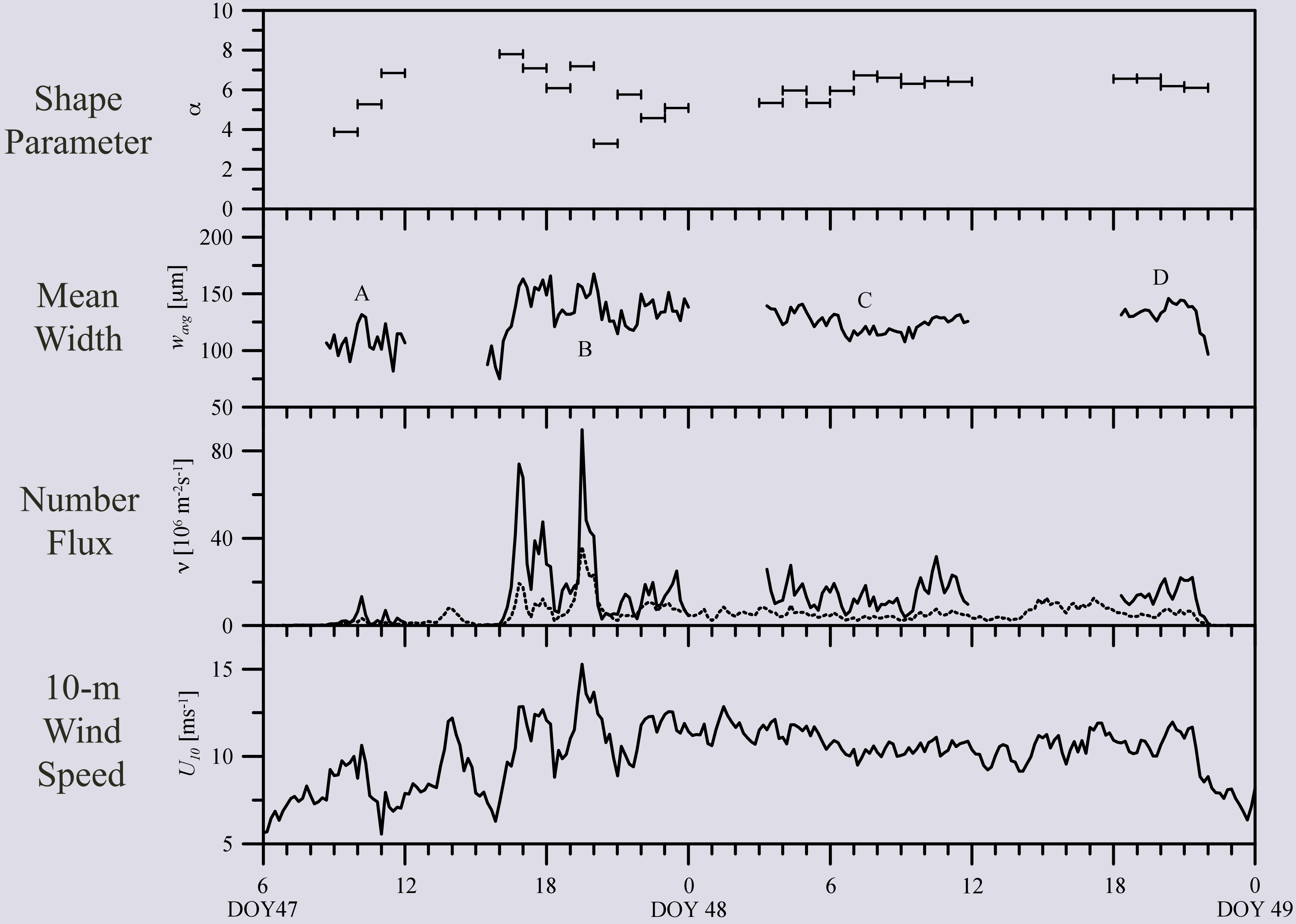
Best-fit:

$MOR = 1.96 / (N \pi d_m^2)$

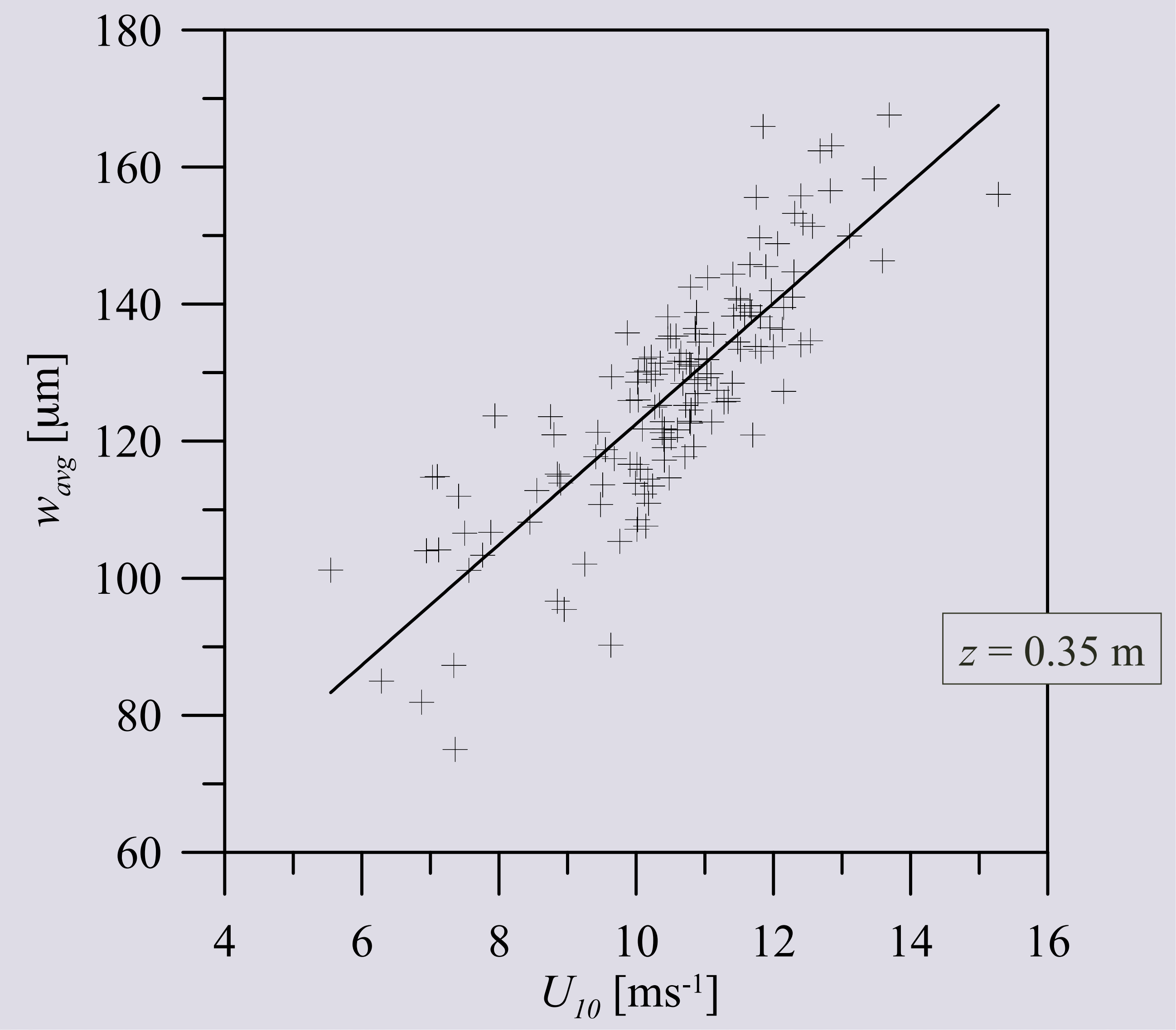
gives $d_m = 109$ μm

Blowing Snow Camera

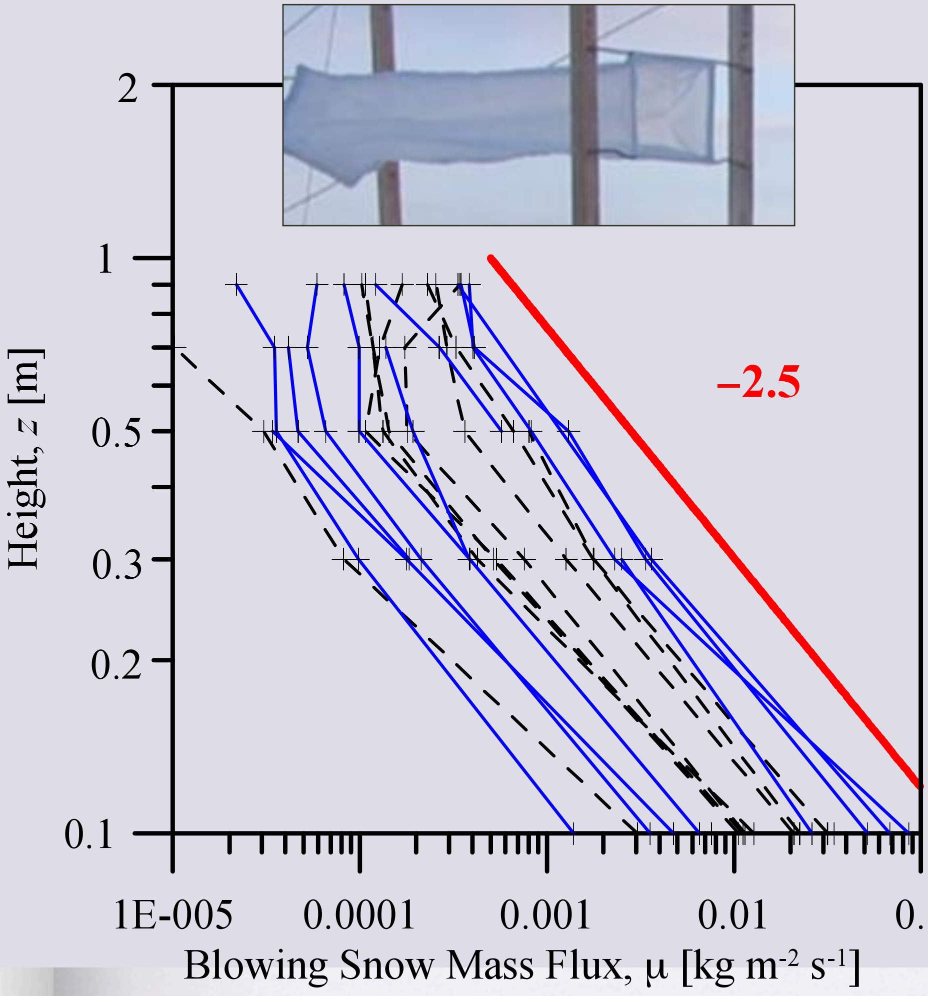


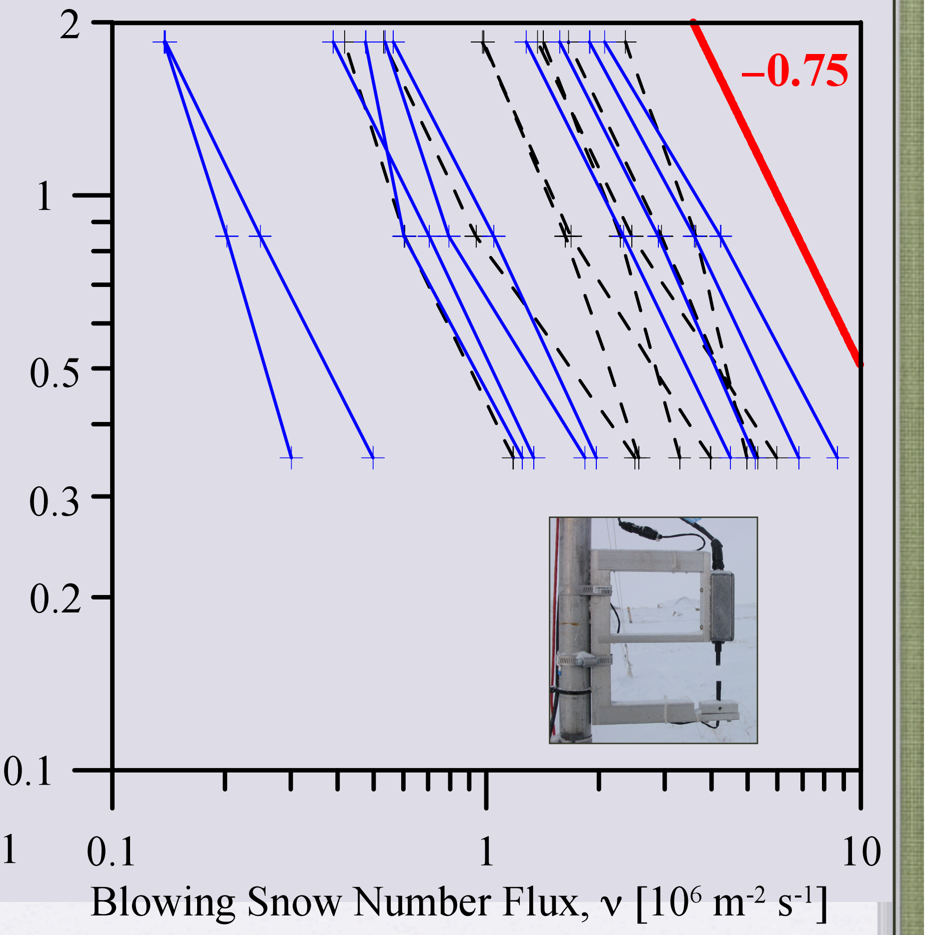

Shape Parameter
α
10
8
6
4
2
0
Mean Width
w_{avg} [μm]
200
150
100
50
A
B
C
D
Number Flux
ν [10^6 m^{-2}s^{-1}]
80
40
0
10-m Wind Speed
U_{10} [ms^{-1}]
15
10
5
6
12
18
0
6
12
18
0
DOY47
DOY 48
DOY 49

Blowing Snow Particle Size



Number and Mass Flux Profiles





Blowing Snow Model

Gamma size distribution from camera measurements:

$$f(d) = \frac{N\, d^{\alpha-1} \exp\left(-\alpha d / \bar{d}\right)}{\left(\bar{d}/\alpha\right)^{\alpha} \Gamma(\alpha)},$$

Diffusion model:

$$\mu(z,d) = \mu_{ref}(d)\left(\frac{z}{z_{ref}}\right)^{-\gamma}$$

$$\gamma = \omega_s \Big/ \kappa u_*$$

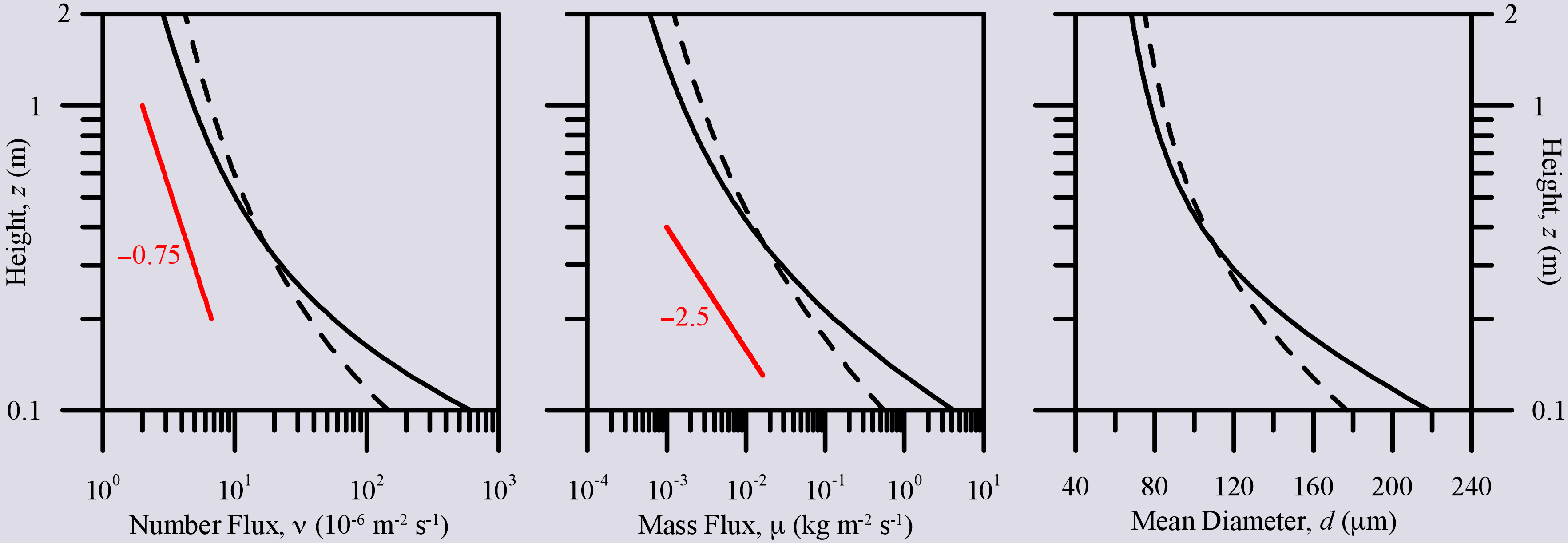
Solid line:

$\omega_s = \omega_T$

Dashed line:

$\omega_s = 0.7\omega_T$

(or $u_* =$?)



Conclusions

Observations:

- Blowing snow occurs with strong, cold NW winds and weaker, warmer SE winds

Predictive / Forecasting:

- Hysteresis at high temperatures
- Higher threshold than Prairie parameterizaion, near 8.5 m s^{-1} (> 30 kph)
- MOR varies with inverse of number density ($1/N$) with $d \approx 110$ µm

Modelling:

- Gamma distribution with $3 < \alpha < 8$
- Particle size varies linearly with wind speed
- Mass and number flux follow power-law profile
  Consistent with diffusion-based model with settling = 70% terminal velocity
- Electrostatic field within range of previous measurements; generally weak vs. g