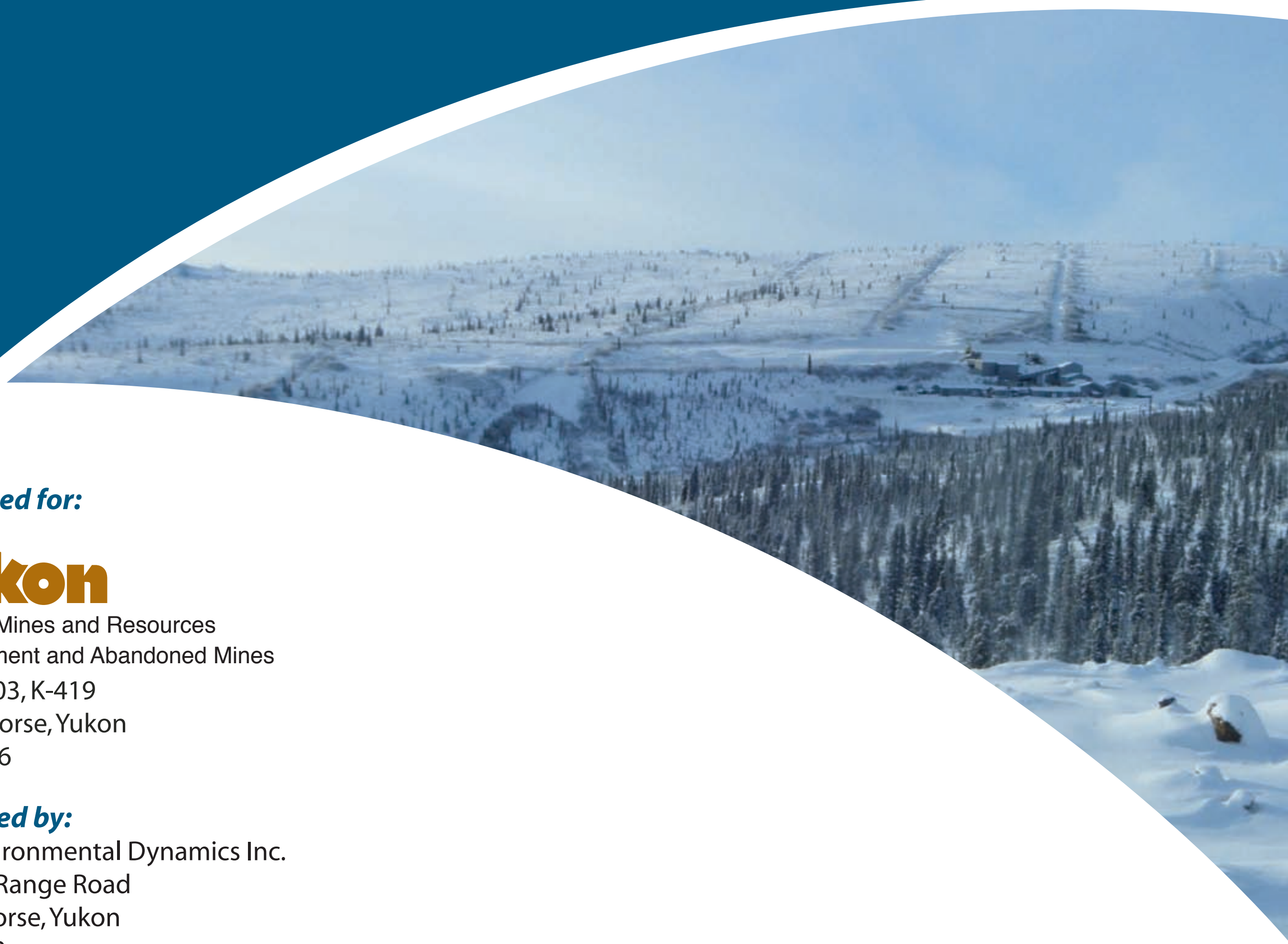
Mount Nansen Snow Survey Program 2011-2012



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2012 ENVIRONMENTAL EMPLOYER OF THE YEAR

EDI ENVIRONMENTAL DYNAMICS INC.

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EXECUTIVE SUMMARY

EDI Environmental Dynamics Inc. was retained in 2011 by Assessment and Abandoned Mines (AAM) to implement a monthly snow survey program at the Mount Nansen site through the winter of 2011/2012. To date, the Yukon Government (YG) Water Resources Branch (WR) and Department of Energy, Mines and Resources (EMR) have been conducting snow surveys at the Victoria Creek airstrip since 1976. The goal of the Mount Nansen Snow Survey Program was to gather snow data that represented the Dome Creek drainage and waste rock piles and to investigate relationships between snow water equivalent (SWE) and elevation, aspect, and mine disturbance.

Eight snow survey field visits were conducted between November and May 2012 in six snow survey areas. Within each snow survey area snow courses were established including: ten snow courses from low to high elevation along a transect in the Dome Creek valley; two snow courses on south-facing and two snow courses on north-facing slopes in the Dome Creek valley to characterize aspect variability; three snow courses on the waste rock piles to gather data for mine-disturbed areas; and four snow courses around the new meteorological station to aid with interpretation of the snow depth data collected from the sonic snow sensor. A replicate snow course was also established near the Victoria Creek airstrip to provide an estimate of the difference between by the Yukon Government and EDI snow surveys. EDI snow surveys were conducted with a metric Prairie Snow Sampler and spring scale to measure snow depth and SWE.

Air temperature over the winter ranged from a minimum of -30.7°C in January to 6.2°C in May. Snow depth at the meteorological station ranged from 10 cm in October to 77 cm in April. Average wind speeds ranged from 7 to 10 km/hr with gusting winds up to 56 km/hr recorded at the station. The predominant wind direction from November to May was from the southwest.

Based on the survey data, the total monthly snow depths for the Mount Nansen site ranged from 25.7 cm in November to 55.3 cm in March. Monthly SWE for the site ranged from 2.9 cm to 13.3 cm and snow density ranged from 12% to 25%. A strong relationship between SWE and elevation was difficult to define as there was variability in topography, wind and vegetation between sites along the Dome Valley transect, and the difference in elevation between sites was small (210 m). There was a difference between north- and south-facing aspects; the south-facing slopes generally had lower snow depths, snow water equivalents and snow densities than the north-facing slopes. Snow data from the waste rock pile was highly variable throughout the winter and extremely wind affected. Compared to undisturbed sites, snow at the waste rock piles also melted earlier than at undisturbed sites. The meteorological station and snow course area was highly influenced by wind which resulted in snow re-distribution. The resulting difference between the snow survey data and the snow sensor data was a maximum 25% difference for snow depth and up to 14% difference for SWE.

Historical records (37 years) from the Mount Nansen airstrip (YG WR) indicated that the winter of 2011/2012 was above average for snow depth in March and April, but below average for May. SWE was average for March, above average for April and below average for May.

ACKNOWLEDGEMENTS

EDI Environmental Dynamics Inc. (EDI) would like to thank AAM for their assistance and direction throughout the survey program, provision of the weather data, as well as their review of this report. Special thanks to Danny Skookum of the Little Salmon Carmacks First Nation (LSCFN) for assisting with field work. EDI would also like to thank Boreal Engineering for providing snowmobile tracking services.

AUTHORSHIP

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1 INTRODUCTION

In 2011, EDI Environmental Dynamics Inc. was retained by the Assessment and Abandoned Mines Branch (AAM) to implement a monthly snow survey program at the Mount Nansen site through the winter of 2011/2012.

Yukon Government (YG) Water Resources Branch (WR) and Department of Energy, Mines and Resources (EMR) have been conducting snow surveys at the Victoria Creek Airstrip (Elevation: 1,021 meters above sea level [m.a.s.l.]) since 1976. The goal of the Mount Nansen Snow Survey Program was to gather data that better represented the Dome Creek drainage and waste rock pile area. The snow surveys were designed to support the construction of a site water balance and meet water information requirements for the project proposal submission to the Yukon Environmental and Socio-Economic Assessment Board (YESAB).

This report describes the study design, site descriptions, methodology, results and discussion of the 2011/2012 snow survey program.

1.1 STUDY DESIGN

EDI worked with AAM and Lorax Environmental to design the Mount Nansen snow survey program in order to better represent variation across the site. Six snow survey areas were selected to characterize the relationships between snow water equivalent (SWE) and elevation, aspect and disturbance (Table 1). Snow water equivalent is the equivalent depth of water of a snow cover and calculated based on snow depth and snow density. The snow survey study area boundary was defined by the Dome Creek watershed with an additional site nearby the YG WR/EMR snow course.

Table 1. Six snow survey areas selected for the Mount Nansen Snow Survey Program.

Survey Area	Rationale
Dome Creek Valley Transect	To characterize the variability of the snowpack with respect to elevation within the Dome Creek Valley.
South-Facing Slopes	To characterize variability in snowpack associated with south-facing slope aspects in the Dome Creek Valley.
North-Facing Slopes	To characterize variability in snowpack associated with north-facing slope aspects in the Dome Creek Valley.
Waste Rock Pile	To characterize the snowpack on the waste rock pile and compare to areas undisturbed by mine activity.

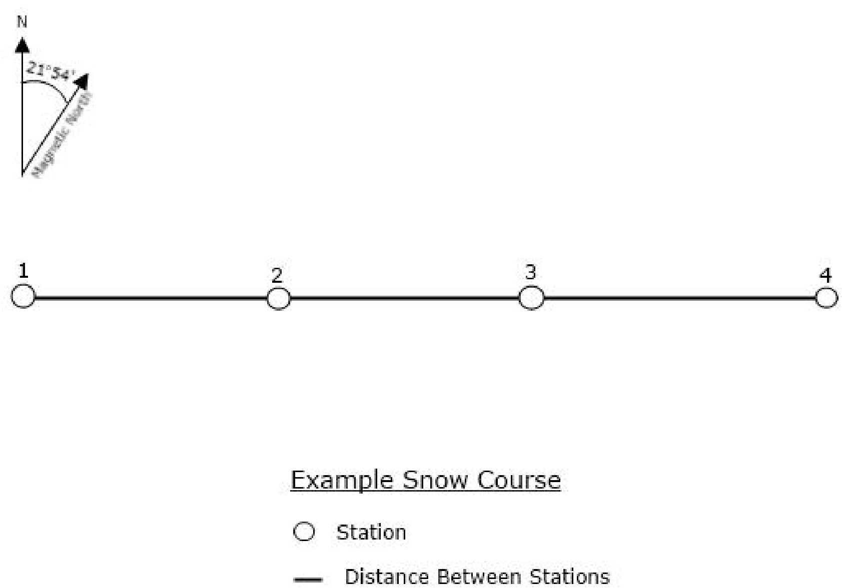
Survey Area	Rationale
Mount Nansen Meteorological Station	To validate the snow depth data collected by the sonic snow sensor at the new meteorological station.
Victoria Creek Airstrip	To estimate the difference between YG WR/EMR and EDI sampling programs, such that the Mount Nansen snowpack record may be extended using the YG WR/EMR historical dataset.

2 METHODS

Snow depth, snow density and SWE are the three most important physical properties of the snowpack. These snowpack properties vary both through time and across the landscape due to terrain, micro-climates and vegetation. Snow depth is simply the depth of the pack and may vary substantially through the winter season with re-distribution by wind, pack settling, melt and sublimation. Snow depth also varies from site to site depending on the presence, absence and type of vegetation. Similarly, snow density varies throughout the season; with lowest densities found in freshly fallen snow and highest densities found in settled and wind-affected snow packs. This report describes snow density as a percentage or ratio of SWE to snow depth per unit area. SWE is related to both snow density and snow depth, and represents the equivalent depth of water of a snowpack. The Mount Nansen site is highly affected by wind and aspect, therefore SWE is an appropriate metric to characterize the snowpack as it normalizes the variability of both snow density and depth.

Within each of the six snow study areas identified in Table 1, numerous snow courses were established. A snow course is a transect line along which snow sampling locations are established at fixed intervals and visited on a monthly basis. Each snow sampling location is referred to as a station where one snow core is taken. Figure 1 provides an example of a typical snow course layout.

EDI established snow courses in November and December 2011. Snow courses were situated in openings in the subalpine vegetation with limited potential for human disturbance and with some shelter from the wind; with the exception of the waste rock pile and meteorological station sites. Snow courses were marked with orange and blue flagging attached to a tree, shrub or piece of rebar. Each Mount Nansen snow courses is described in more detail below (Section 2.1) along with methodology.



Station	Distance (m)	Bearing
1		
	2	90°
2		
	2	90°
3		
	2	90°
4		

Figure 1. Theoretical snow course diagram with four stations (not to scale).

2.1 SITE DESCRIPTIONS

The ***Dome Creek valley transect*** included ten snow courses established along Dome Creek ranging in elevation from 1,015 m.a.s.l. (SC-DC-1) to 1,225 m.a.s.l. (SC-DC-10) (Figure 2). Snow courses in this transect were spaced approximately 350 m apart, with four stations per course (one snow core per station; Table 2). The snow courses were located in relatively undisturbed and sheltered locations along the valley bottom. SC-DC-1 and SC-DC-2 were located downstream of the Dome Creek road crossing (Figure 2). SC-DC-3 to SC-DC-6 were located upstream of the Dome Creek road crossing and downstream of the tailings pond. SC-DC-7 to SC-DC-9 were located upstream of the tailings pond and downstream of the mill, while SC-DC-10 was located upslope from the mill.

The ***north- and south-facing snow courses*** were each established at a mid-valley location around the tailings pond (SC-SF-1, elevation 1,132 m.a.s.l. and SC-NF-1, elevation 1,118 m.a.s.l.) and an upper-valley location near the mill (SC-SF-2, elevation 1,185 m.a.s.l. and SC-NF-2, elevation 1,233 m.a.s.l.) (Figure 2). Each snow course had five stations where cores were taken, which followed along the topographic contour (Table 2). The south-facing slopes were more sheltered with larger trees, while the north-facing slopes had smaller, stunted vegetation and more exposure to the wind and thus experience more wind re-distribution and wind loading.

Three snow courses were established on the ***waste rock piles*** near the open pit on the lower, middle and top benches (SC-WR-1 elevation 1,192 m.a.s.l., SC-WR-2 elevation 1,212 m.a.s.l., SC-WR-3 elevation 1,214 m.a.s.l.) (Figure 2). Each snow course had three stations (Table 2). All three snow courses were located in exposed locations subject to wind related snow transport processes: ablation, re-distribution and scouring.

The Mount Nansen site meteorological station is located in a clearing at 1,247 m.a.s.l on the north side of the Dome Creek watershed immediately downslope of the Mount Nansen Road. The station includes a snowcover depth sensor which was installed on October 17, 2011. The snowcover depth sensor is a sonar based system (SR50A Sonic Ranging Sensor, Campbell Scientific), where ultra-sonic pulses are emitted downward from a fixed mast elevation 1.975 m above the ground surface. The sensor uses air temperature to calculate the speed of sound in air which is used to calculate the distance to the top of the snowpack (spatially averaged over target area). The limitations of the sensor include anomalous measurements during falling or blowing snow, and the sensor cannot distinguish between newly fallen and low density snow. Under ideal conditions, the snowcover depth measurement has a measurement accuracy of +/-1 cm or 0.4 % of the distance to the target, whichever is greater.

Four snow courses were established at the ***meteorological station*** (SC-MET-1 to 4) with two on the east and two on the west side of the station (Figure 2). Each snow course had three stations where cores were taken (Table 2). These sites had some shelter provided by low vegetation, but were still exposed to wind. In addition, the close proximity to the site access road resulted in potential disturbance by snow plowing operations throughout the winter. Efforts were made to adjust the station locations during data collection if ploughed snow appeared to be present in the usual sampling locations.

The ***Victoria Creek airstrip snow course*** **(SC-AIR-1 to 5*)*** replicate site (Table 2) was established on the same terrace as the Mount Nansen snow course monitored by YG WR (09CA-SC1, elevation 1,021 m.a.s.l.). The replicate snow course had five stations where cores were taken.

For more detailed descriptions on each snow course refer to Appendix A, which has location information, photos of each station as well as details on snow core spacing and orientation.

Table 2. Snow course details including number of stations and cores taken per station.

Snow Study Area	# of Snow Courses	Snow Course Names	# of Stations per Course	Total # of Cores
Dome Valley Transect	10	SC-DC-1 to 10	4	40
North Facing	2	SC-NF-1 to 2	5	10
South Facing	2	SC-SF-1 to 2	5	10
Waste Rock	3	SC-WR-1 to 3	3	9
Meteorological Station	4	SC-MET-1 to 4	3	12
Airstrip Replicate	1	SC-AIR	5	5

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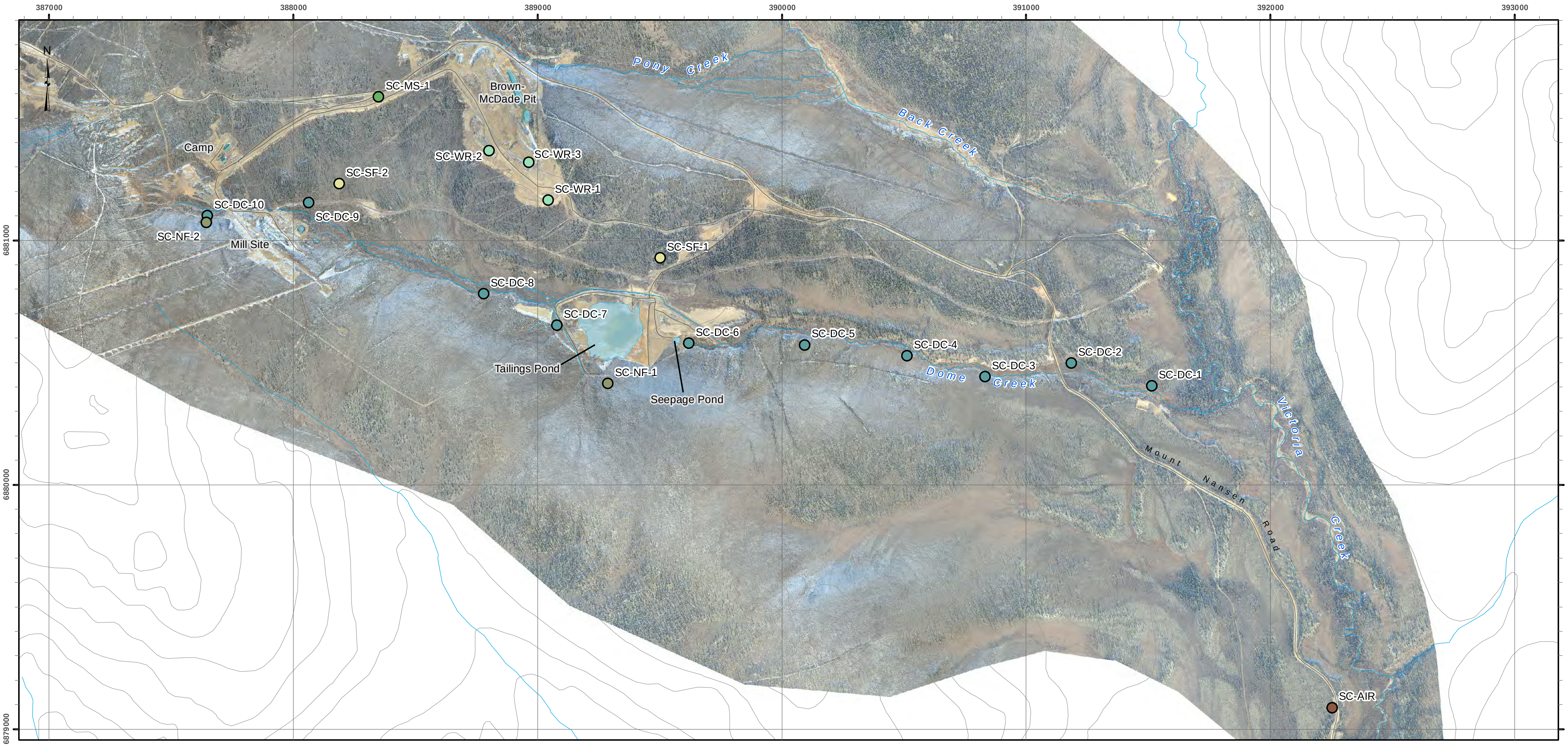

Overview of Snow Sampling Stations at the Mount Nansen Site Area

Legend

- Airport
- Met Stn
- North Facing
- South Facing
- Valley Transect
- Waste Rock
- Unpaved Road/Access
- Contours
- Watercourse
- Waterbody (pit pond and tailings)

1:250,000 topographic spatial data: Canvec and National Topographic Database (NTDB); courtesy of Her Majesty the Queen in Right of Canada, Department of Natural Resources. All Rights Reserved.

Digital Elevation Model provided by Geomatics - Yukon Government via online source (Corporate Spatial Warehouse) www.geomaticsyukon.ca.

Project data displayed is site specific. Data collected by EDI Environmental Dynamics Inc. (2011) was obtained using Garmin GPS technology.

This document is not an official land survey and the spatial data presented is subject to change.

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metres

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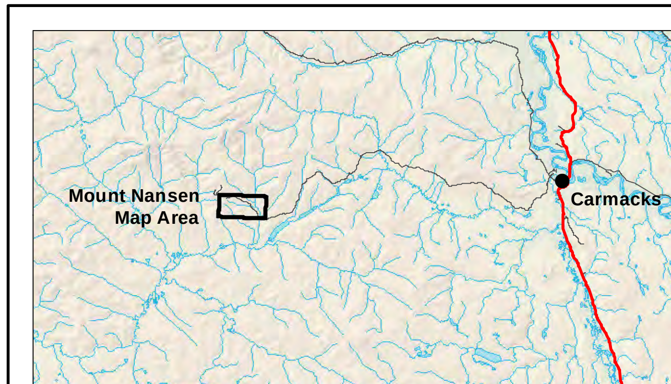
Map Projection: North American Datum 1983 UTM Zone 8N



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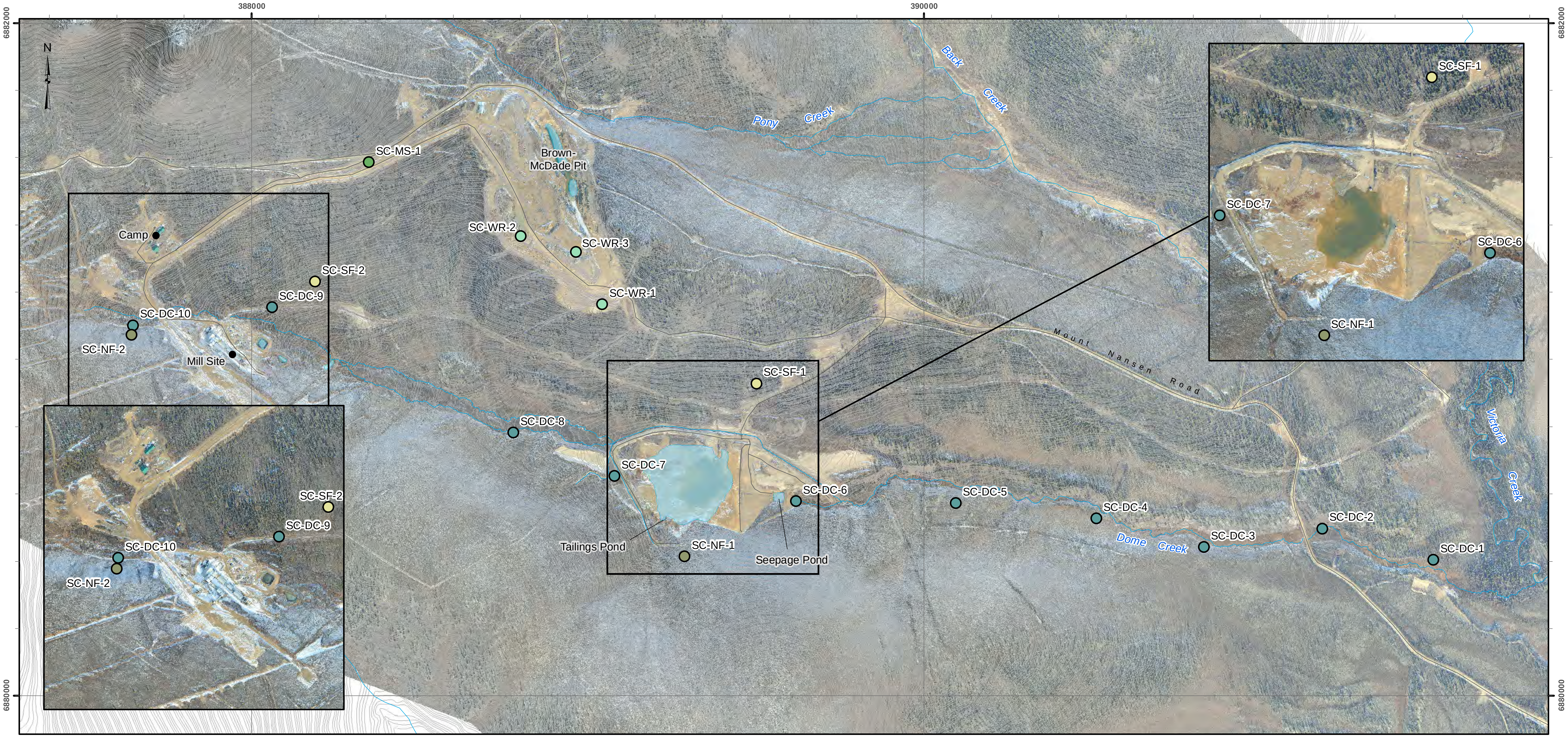

Dome Creek Watershed Snow Sampling Stations in the Mount Nansen Site Area

Legend

- Airport
- Met Stn
- North Facing
- South Facing
- Valley Transect
- Waste Rock
- Unpaved Road/Access
- Contours (1 metre)
- Watercourse
- Waterbody (pit pond and tailings)

1:250,000 topographic spatial data: Canvec and National Topographic Database (NTDB); courtesy of Her Majesty the Queen in Right of Canada, Department of Natural Resources. All Rights Reserved.

Digital Elevation Model provided by Geomatics - Yukon Government via online source (Corporate Spatial Warehouse) www.geomaticsyukon.ca.

Contours (1 metre) provided by Yukon Government Department of Energy, Mines and Resources (2012).
Project data displayed is site specific. Data collected by EDI Environmental Dynamics Inc. (2011) was obtained using Garmin GPS technology.

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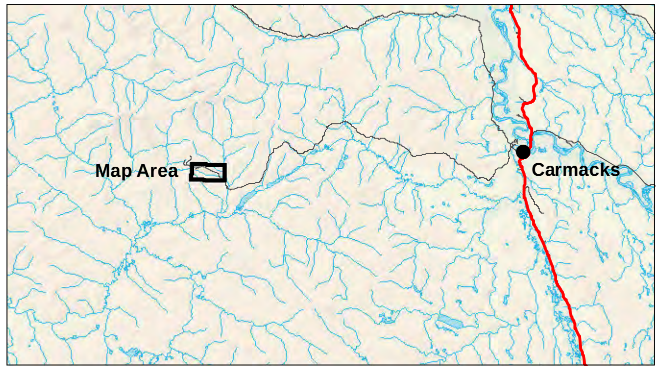

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2.2 SURVEY METHODOLOGY

Snow surveys were conducted on a monthly basis with an additional measurement obtained in April during the peak snowpack period, prior to snowmelt. The Airstrip snow course was only surveyed on two visits. General site information was recorded for each snow course station including date, time, weather conditions, snow conditions, and survey personnel.

Snow surveys were completed according to the British Columbia Ministry of Environment Snow Survey Sampling Guide (MOE 1981). At each station, snow depth, length of core[1], and SWE were recorded following MOE (1981) protocols. Personnel calculated water content and snow density which was then averaged for each station. Snow cores at each station were generally collected along a contour line, and bearings and distances between cores were recorded. Snow survey personnel wore snowshoes or skis to access the sites. All data was recorded on a standard form developed by EDI (based on MOE 1981) and then entered into a database (Microsoft Access). A quality assurance and quality control program was carried out on the database.

SWE measurements were obtained using the gravimetric method (MOE 1981). The historical data from YG WR/EMR indicated that the snowpack at Mount Nansen was less than 1 m deep therefore EDI used a metric Prairie Snow Sampler, designed for shallower snowpacks less than 1 m (based on the ESC 30 design). A spring scale was used for the snow course surveys. YG WR/EMR uses a Standard Federal Sampler to monitor snowpack at the Mount Nansen station (09CA-SC01). The Prairie Sampler used by EDI has a wider base (30 cm^2 cutting area) which is less prone to over-measurement than the Standard Federal Sampler, which over-measures SWE by 10% (Goodison *et al.* 1987). Goodison et al. (1987) provided a correction factor (CF = 0.91) for the Standard Federal sampler such that the results from YG WR/ EMR can be compared to the EDI measurements.

[1] **Snow depth** is measured while the coring tube is vertical in the snowpack whereas the **length of core** is measured after the coring tube is removed from the pack. The **length of core** measurement ensures the full core is removed from the snowpack for gravimetric measurement, however, the length of core is typically less than the snow depth, particularly in low density snowpacks.

3 RESULTS

3.1 WINTER METEOROGICAL SUMMARY

The meteorological data downloaded from the Mount Nansen meteorological station provided a continuous record of snow depth, air temperature, and wind speed and direction over the winter season. The data was recorded on hourly intervals and is summarized below.

Air temperature at the station ranged from a minimum of -30.7°C in January to a maximum of 6.2°C in May (Table 3). On average, January was the coldest month during the sampling period and May the warmest. Snow depth at the meteorological station ranged from a minimum of 7.1 cm in October to a maximum of 73.8 cm in March (Table 3). The highest average snow depth was for March at 66.4 cm. Average monthly wind speeds at the station ranged from 7.0 km/hr to 14.0 km/hr, with gusting winds up to a maximum of 55.8 km/hr (recorded on February 2, 2012). The prominent wind direction over the 2011/2012 winter season was from the southwest (Figure 4). Appendix B provides detailed figures of hourly and monthly meteorological data.

Table 3. Average monthly air temperature, snow depth and wind speed at the Mount Nansen meteorological station from October 2011 to May 2012.

Parameter		OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Air Temperature (°C)	Mean	**-4.5**	**-15.9**	**-8.9**	**-17.7**	**-8.0**	**-9.8**	**0.1**	**-0.2**
	Min	-12.0	-30.1	-17.6	-30.7	-18.4	-21.5	-9.1	-4.8
	Max	0.4	0.1	5.3	-2.5	-0.9	3.1	6.2	6.1
Snow Depth[2,3] (cm)	Mean	**8.7**	**21.9**	**36.0**	**46.4**	**55.0**	**66.4**	**46.5**	**12.9**
	Min	7.1	12.9	25.5	38.7	51.8	60.0	20.9	0.0
	Max	13.7	28.4	42.4	59.5	63.8	73.8	65.8	24.5
Wind Speed (km/hr)[4]	Mean	**7.2**	**7.4**	**9.7**	**8.0**	**10.2**	**7.0**	**8.5**	**14.0**
	Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	Max	29.9	25.6	43.7	30.2	55.8	24.5	27.1	34.7

[2] The snow depth sensor is 1.975 m above the ground surface (NorthernAVCom).
[3] The snow depth data was adjusted -2.9cm to reflect mean observed offset with barren ground at the end of winter.
[4] The wind speed and wind direction sensors are located 9.5 m above the ground surface.

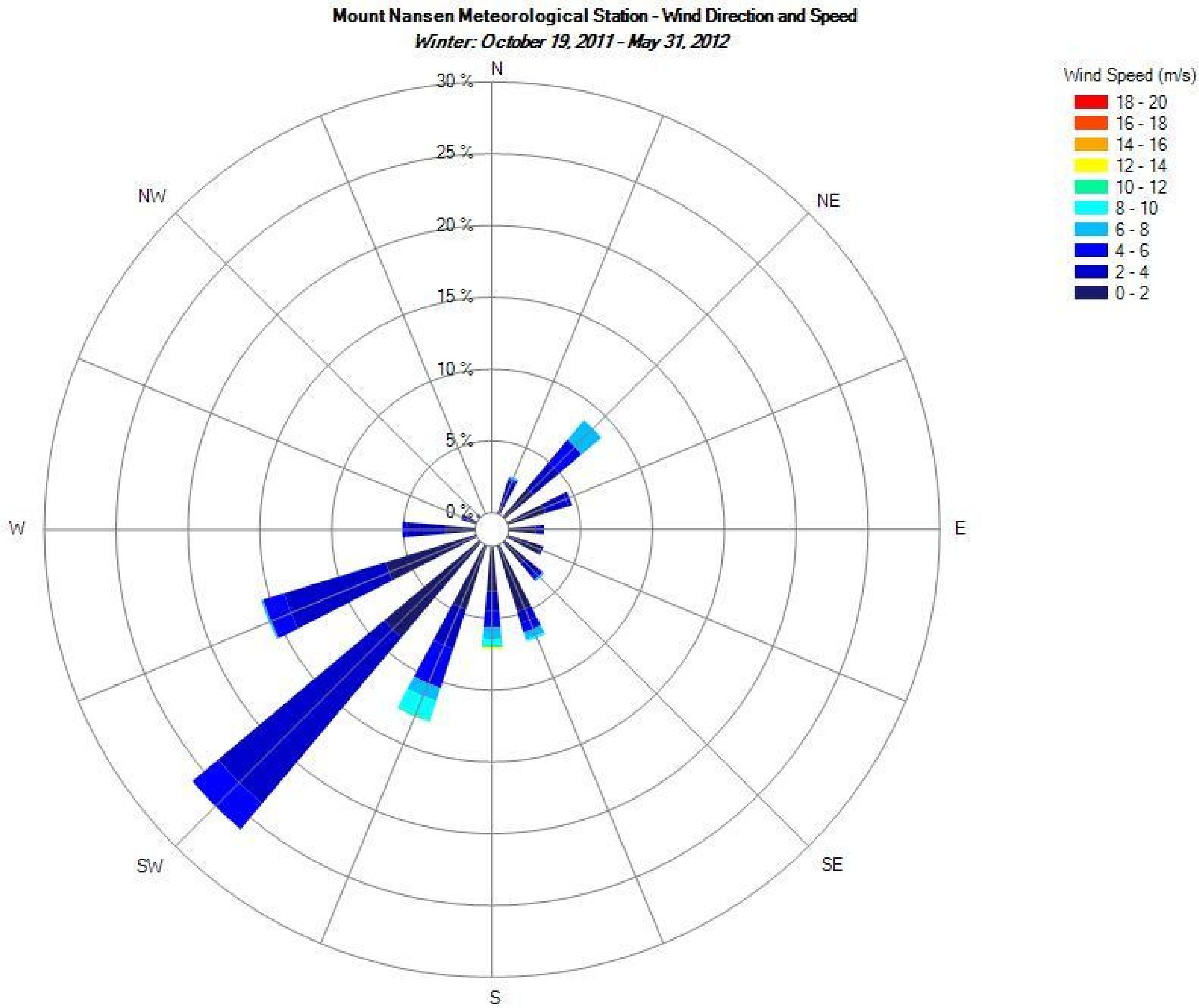

Figure 4. **Winter season wind direction, magnitude, and frequency (percent time) recorded at the Mount Nansen meteorological station (el. 1,247 m.a.s.l.) between October 19, 2011 and May 31, 2012.**

3.2 SNOW SURVEY RESULTS

Based on all stations in the snow survey program, the average snow depth for the Mount Nansen site ranged from 25.7 cm in November to 55.3 cm in March (Appendix C). Snow depth peaked in March or April for most snow courses.

Average SWE for the site ranged from 2.9 cm in November to 13.3 cm in April. Average snow density for the site ranged from 12% in November to 25% in mid-April. Variability between snow courses is associated with spatial factors such as elevation, aspect, vegetation and ground surface topography. Overlapping with these factors is the interaction of the landscape surface with local meteorology. The resultant snowpack reflects both snowfall amounts and the site specific micro-climate. Results for individual snow survey areas are described in more detail below with data provided in Appendix C.

3.2.1 Dome Valley Transect

Average monthly snow depth for the Dome Valley snow courses ranged from 18.1 cm in November at SC-DC-2 to 72.6 cm in April at SC-DC-10 (Appendix C). Snow water equivalent ranged from 1.9 cm at SC-DC-2 in November to 18.5 cm at SC-DC-1 in April. Snow density ranged from 6% in November at SC-DC-4 to 34% at SC-DC-1 in May.

The Dome Creek valley transect design rationale was to characterize snowpack-elevation relationships. Results indicated that influences of micro-climates and the relative openness of the tree cover were also important factors. Towards April, the snow courses that started melting the earliest were those located in more open, such as SC-DC-9 along the transmission line road, SC-DC-6 below the seepage pond, and SC-DC-2 just downstream from the Dome Creek crossing. The SC-DC-2 snow course was free of snow during the May survey.

In general, snow depth and SWE throughout the winter were lowest at the lower elevation snow courses (SC-DC-1 and SC-DC-3) and highest at the higher elevation snow courses (SC-DC-10 and SC-DC-09; Figure 5). However, there were several exceptions to this pattern throughout the winter. SC-DC-1, the lowest elevation snow course, had the highest SWE of any site in early April. SC-DC-5 located at mid-elevation had the highest snow depth during the March survey. The peak snowpack SWE for March and April were plotted against elevation. There was a relatively good fit for the March survey data (R^2 = 0.56) but a much poorer fit for the April data (R^2 =0.03; Figure 6) indicating that the influence of elevation less prominent once snowmelt begins.

Across the Dome Valley transect there was only a 210 m difference in elevation, and some snow courses had less than a 10 m difference in elevation. The low magnitude of difference in elevation between snow courses, combined with the high degree of site variability in terms of topography, vegetation, and resulting wind patterns, reduces the strength of a potential relationship between elevation and SWE. Some sites were more exposed compared to others, for example SC-DC-4 was located in a relatively sheltered, undisturbed location, whereas SC-DC-7 was located in a more disturbed area, open and exposed to the wind.

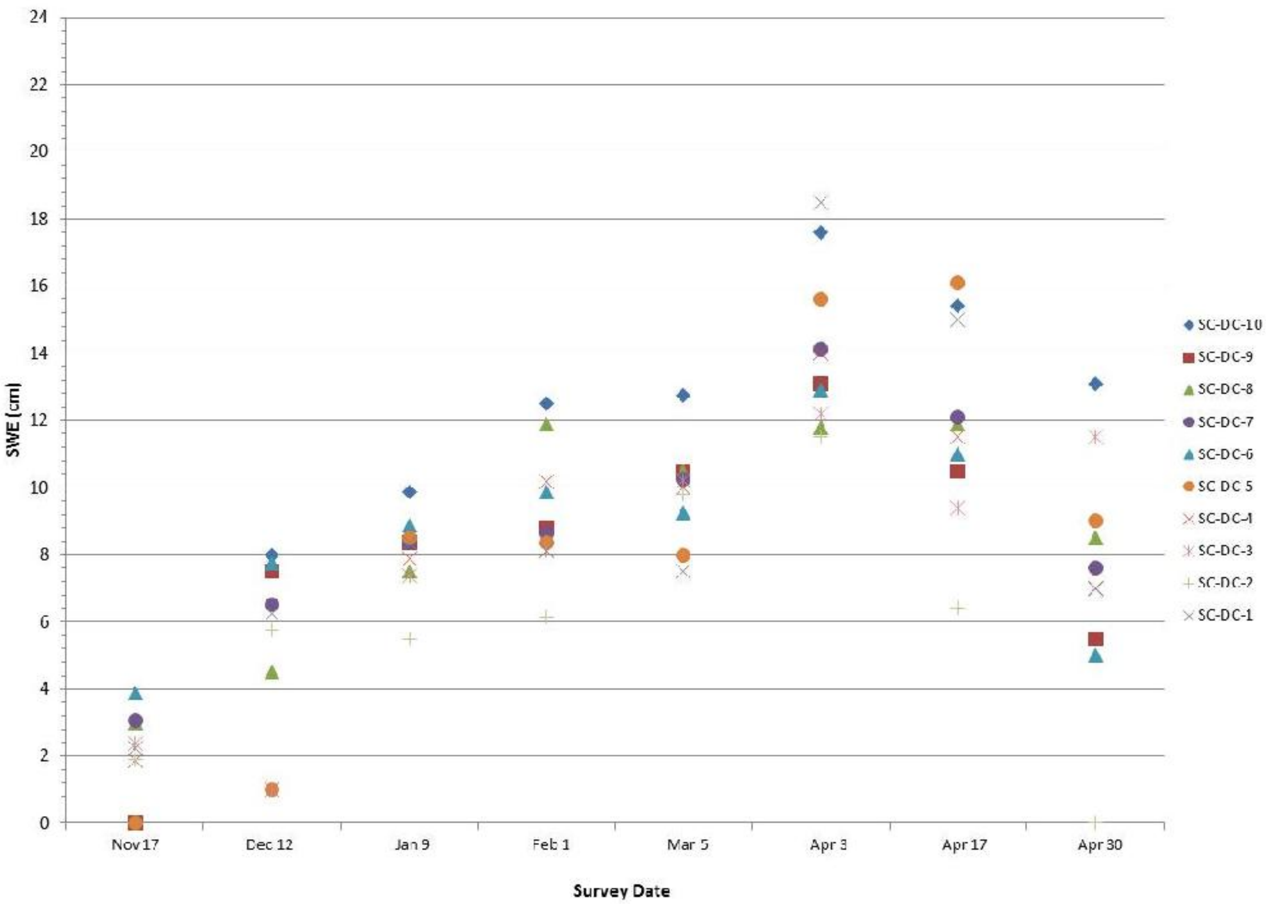

Figure 5. SWE for all sites along the Dome Valley transect snow course from November 2011 to May 2012.

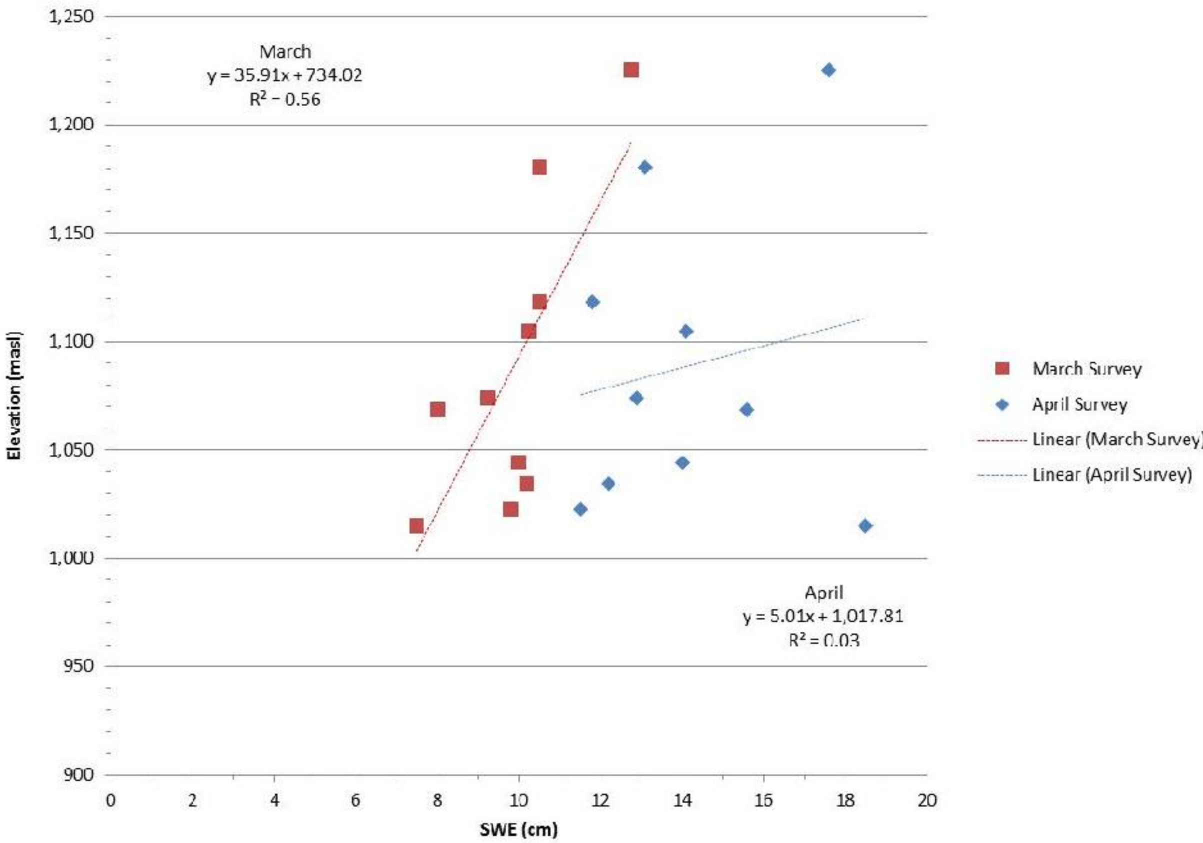

Figure 6. Relationship between elevation and SWE along the Dome Valley Transect snow course during the March 2012 survey (red) and the April 2012 survey (blue).

3.2.2 North- & South-Facing Slopes

Average snow depth for the north-facing slopes ranged from 53.9 cm in December to 65.9 cm in April (Appendix C). Average snow depths for the south-facing slopes were slightly lower ranging from 49.2 cm in December to 58.7 cm in March (Appendix C). Snow density ranged from 13% to 29% for the north-facing slopes and 13% to 21% for the south-facing slopes throughout the winter. SWE for the north-facing slopes ranged from 7.1 cm to 14.0 cm and for the south-facing slopes from 6.4 cm to 10.4 cm (Figure 7). Snow depth and SWE decreased on the south-facing slopes from April to May, whereas there was a much more gradual decline in SWE and snow depth on the north-facing slopes (Figure 7).Based on field observations and the meteorological data, the characteristics of the snowpack with respect to aspect appears related to both exposure to wind (i.e. wind loading and re-distribution), tree cover (i.e. more trees are present on the south aspects) and direct solar radiation (i.e. melt).

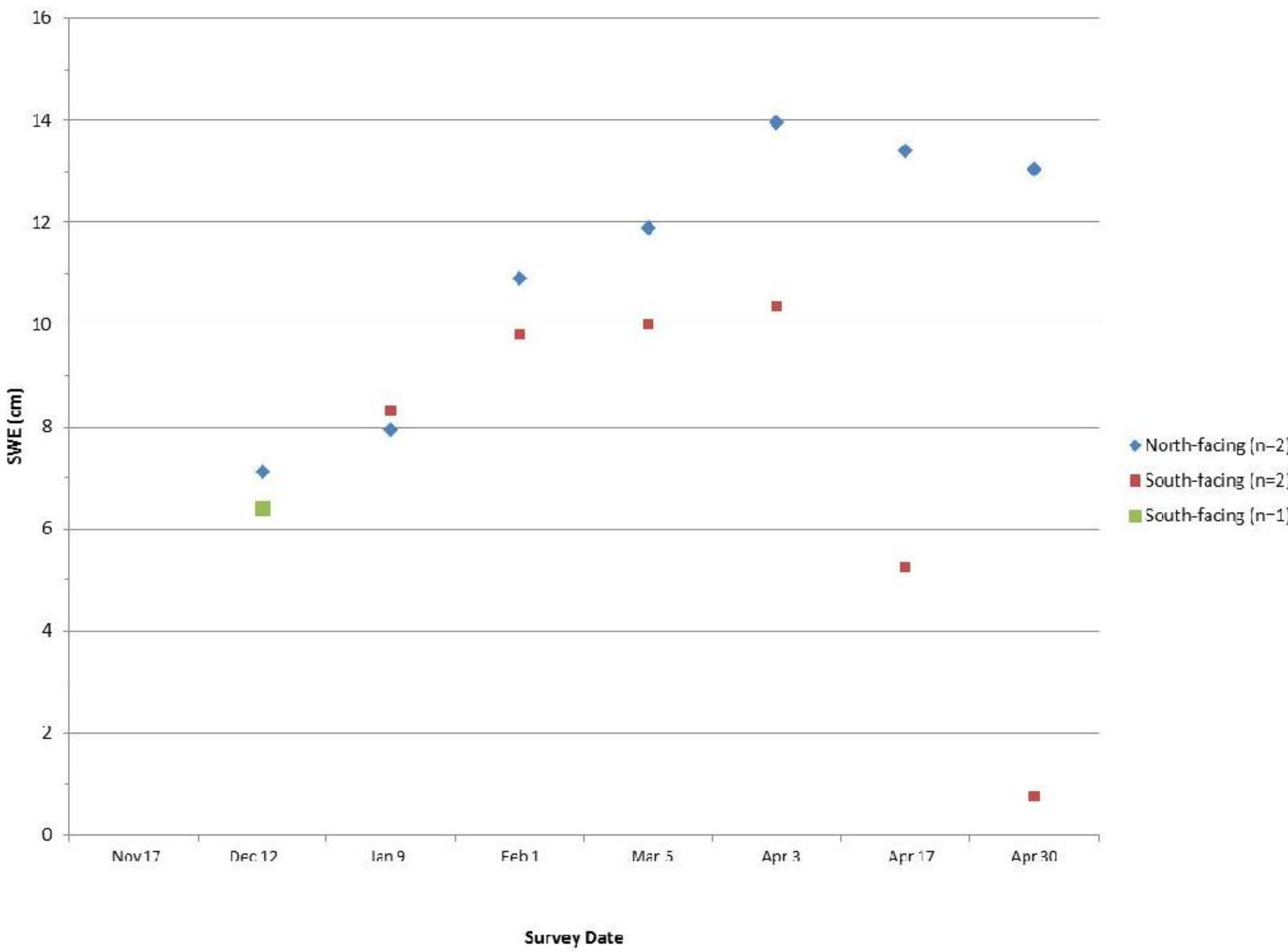

Figure 7. SWE for the north- and south-facing slope snow courses from December 2011 to May 2012. Note: December value for south-facing slope is based on one snow course, all other data is averaged for two snow courses.

3.2.3 Waste Rock Pile

The average snow depth for all three waste rock snow courses ranged from 23.7 cm in November to 47.7 cm in February (Appendix C). Average SWE equivalent ranged from 3.5 cm to 11.4 cm and snow density ranged from 15% to 36%.

There was considerable variability in snow depths, SWE, and snow densities between the three waste rock snow courses. The SC-WR-2 snow course, located on the middle elevation bench of the pile, had higher SWE and snow depths compared to the other two waste rock snow courses (Figure 8). This snow course was oriented towards the west aspect and had more uneven ground surfaces with depressions and large rocks compared to other locations on the pile (southerly aspects). Another difference between snow courses was that the lower waste rock course (SC-WR-1) generally had lower snow densities than the other sites throughout the winter (Appendix C). SC-WR-1 was often heavily windblown with drifting snow depositing on the base of the slope directly north of the snow course, while the other waste rock snow courses were more prone to wind deposition, resulting in a deeper, harder-packed, denser snowpack.

The waste rock pile snow survey area was included in this study to investigate potential differences in SWE between mine-disturbed areas and undisturbed areas. For this purpose, the waste rock data was compared to the south-facing slope data, as they were located at similar elevations and aspects. When SWE from both study areas were compared, the data showed similar trends (Figure 9); however, the waste rock snow courses showed greater variability through the winter (Figure 9). There were also similar results for snow density (Figure 10). This may suggest that mine-disturbed areas are subject to much greater snowpack variability due to the effects of wind whereas; undisturbed areas show less variability through the winter. In addition, snow melt appears to occur more rapidly on disturbed sites, as there was no snow left at the three waste rock snow courses during the May survey, while there were still snow patches remaining at one of the south-facing stations (SC-SF-2).

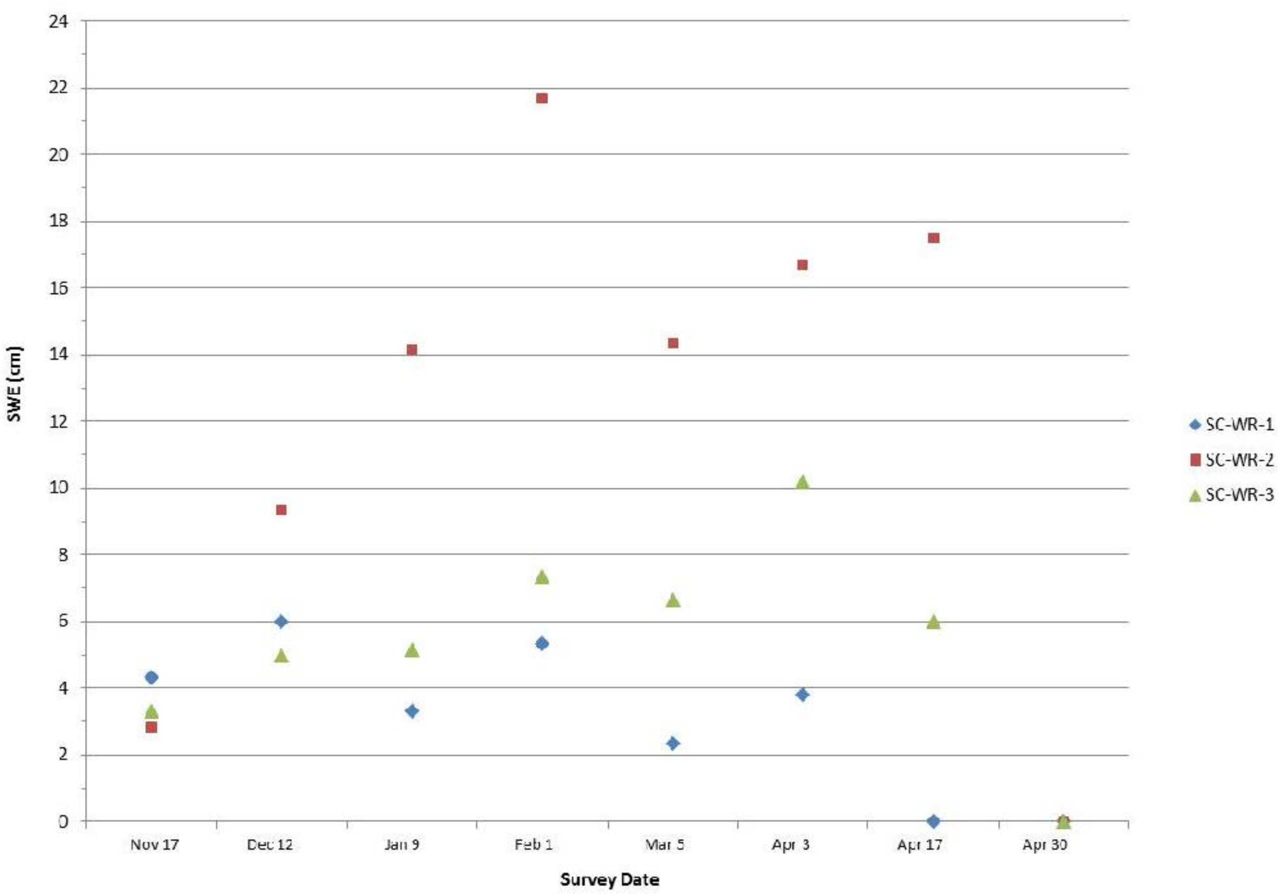

Figure 8. SWE for the three waste rock pile snow courses from November 2011 to May 2012.

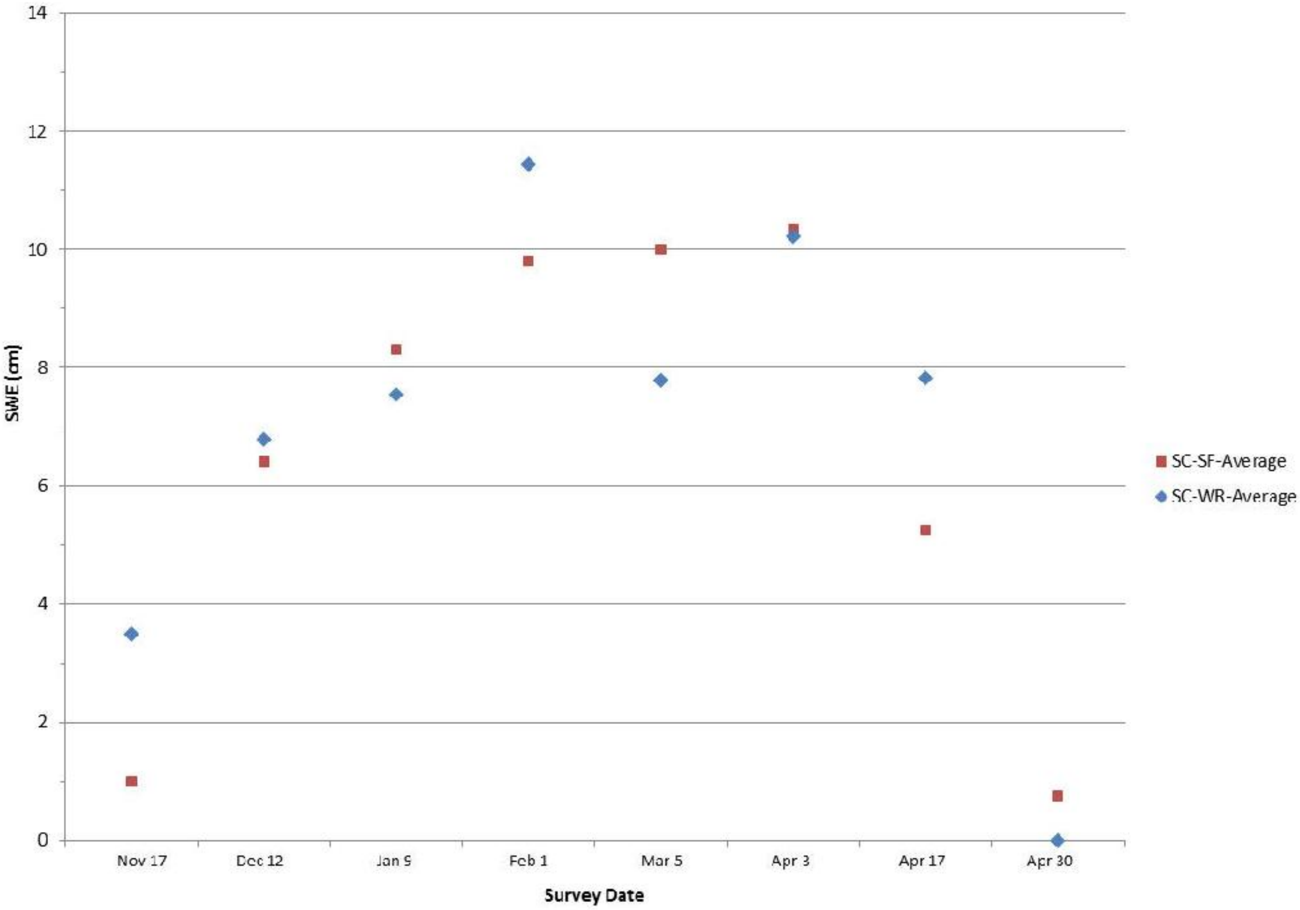

Figure 9. **Average SWE for the waste rock snow courses compared to the south-facing snow courses from November 2011 to May 2012.**

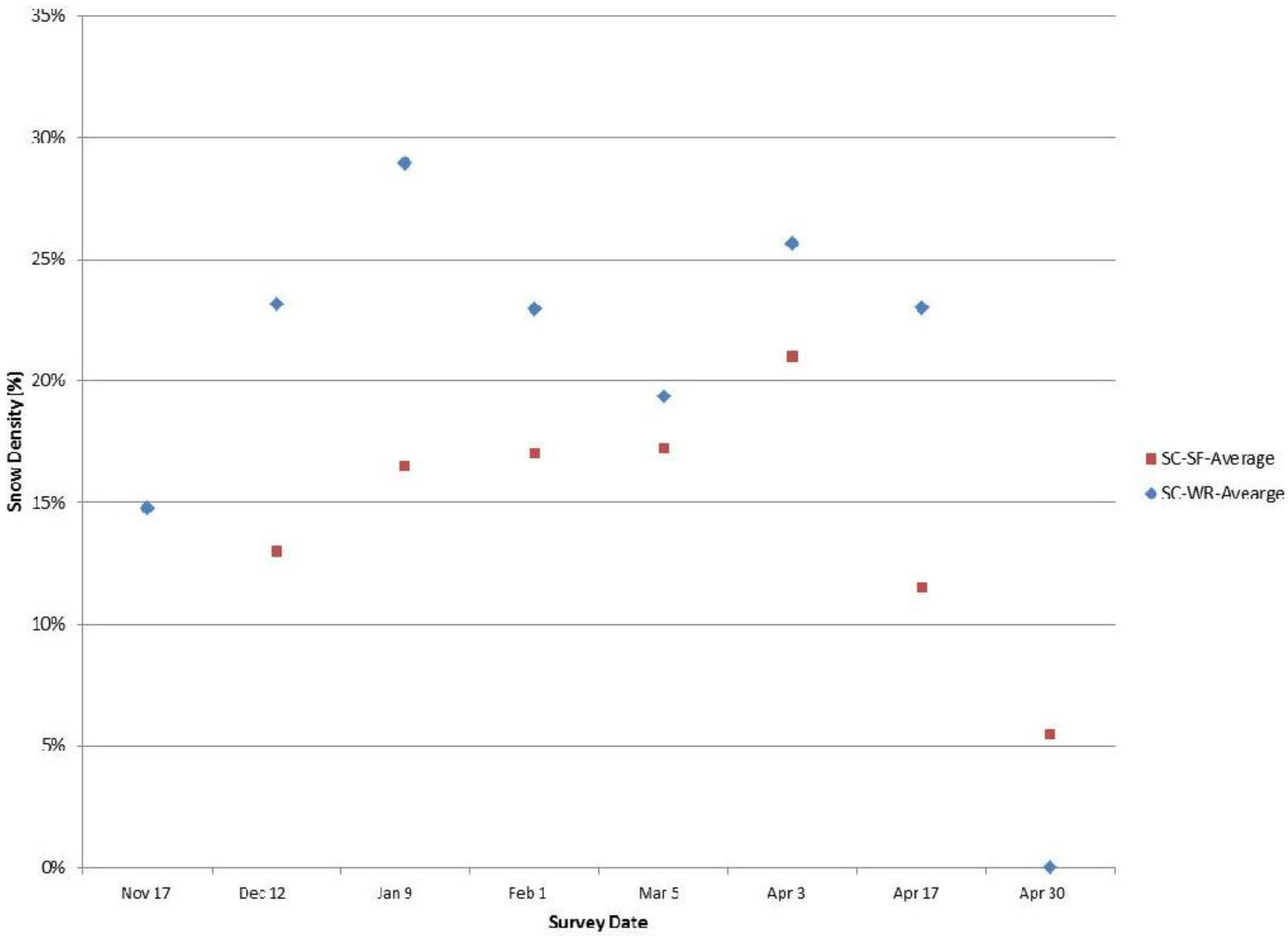

Figure 10. Average snow density for the waste rock snow courses compared to the south-facing snow courses from November 2011 to May 2012.

3.2.4 Meteorological Station

Average snow depth at the SC-MET snow courses ranged from 27.3 cm in November to 60.1 cm in March (Appendix C). SWE ranged from 8.3 cm in December to 14.3 cm in early April and snow density ranged from 19% in December to 30% in mid-April.

Snow depths for the four SC-MET snow courses were compared to those collected by the snow sensor at the meteorological station in order to validate the sensor data. Snow survey data was compared to the sensor data for the same date and time as the monthly surveys. The snow sensor accuracy is decreased with extremely low density snow because the target surface is a poor reflector of sound. The less dense, early season snowpack from November to January measured by the snow survey showed greater snow depths than the automated snow sensor (3.4 cm and 6.9 cm greater) (Figure 11). This corresponds with up to a 23% difference in the early season and likely the result of site variability on the micro-scale and measurement errors. Between February to April the snow sensor snow depths were 3.4 cm to 12.3 cm greater than those measured by the manual snow survey (Figure 11) corresponding with up to a 25% difference with the manual snow survey data. Snow course data is also subject to measurement error associated with the core location while the snow sensor collects a snow depth measurement from a static location.

The snow sensor snow depth data was converted to SWE based on the average monthly snow density for the meteorological station snow course (Table 4). This assumes that the snow density at the sensor is similar to that from the SC-MET snow course and functions to normalize the data for analysis (Figure 12).

The general equation for SWE is:

$$SWE = \text{snow depth} * \text{snow density}$$

The SC-MET manual snow survey measurement showed that the SWE was between 8.3 cm and 9.3 cm (December and January). Using the above assumptions, the difference in SWE between SC-MET and the snow sensor in the early season snow pack corresponds with a 11%-14% difference. Later in the season January to mid-April, the SWE measured in the snow survey was less than that calculated using the snow sensor data and ranged from 9.9 cm to 14.3 cm corresponding with a 1% to 14% difference. At the end of April the SWE at the snow course was 8% greater than that estimated by the sensor.

This analysis using the 2011/2012 data indicates that the snow depth measurements collected by the sensor were up to 25% different than those of the snow course surveys; whereas the SWE was up to 14% different. These differences are interpreted to be the result of measurement error and site variability on a site where wind regularly re-distributed snow.

Table 4. Estimated SWE for the meteorological station snow sensor data based on snow depth collected by the sensor and the assumed snow density from the SC-MET snow course.

Survey Dates	Sensor Snow Depth (cm)	Assumed Snow Density at Sensor (%) [1,2]	Estimated SWE at Sensor (cm)
17-Nov-11	21.1	n/a	n/a
12-Dec-11	38.6	19%	7.3
09-Jan-12	42.0	19%	7.9
01-Feb-12	54.4	20%	11.1
05-Mar-12	62.1	20%	12.4
03-Apr-12	64.4	25%	16.2
17-Apr-12	44.3	30%	13.1
30-Apr-12	22.2	24%	5.4

[1]- The snow coring tube was damaged on Nov. 17, 2012 and cores at SC-MET could not be obtained therefore snow density could not be calculated.

[2] - Based on % average snow density from the four SC-MET snow courses.

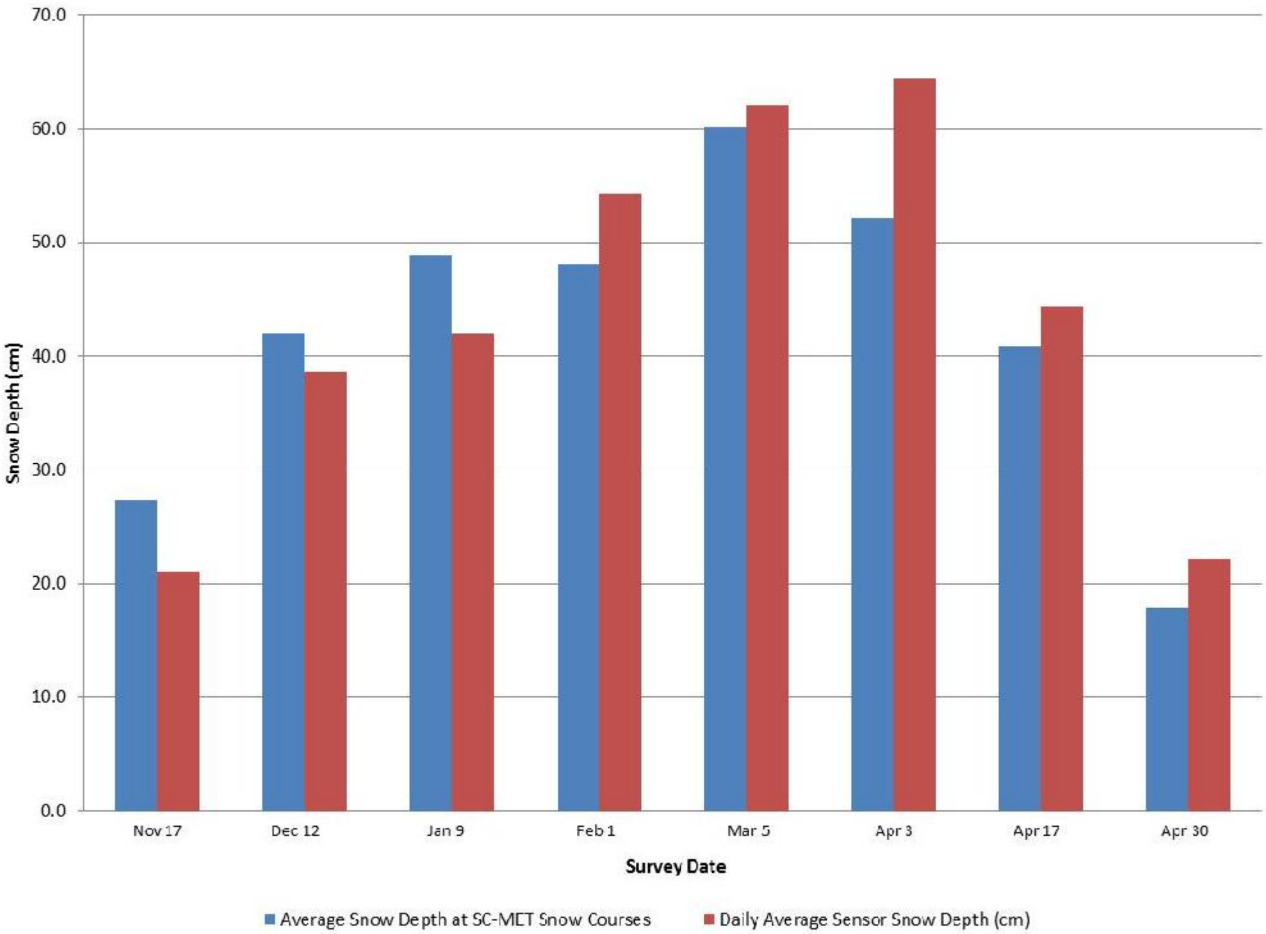

Figure 11. Comparison between snow depths measured at the snow sensor and from the snow survey SC-MET.

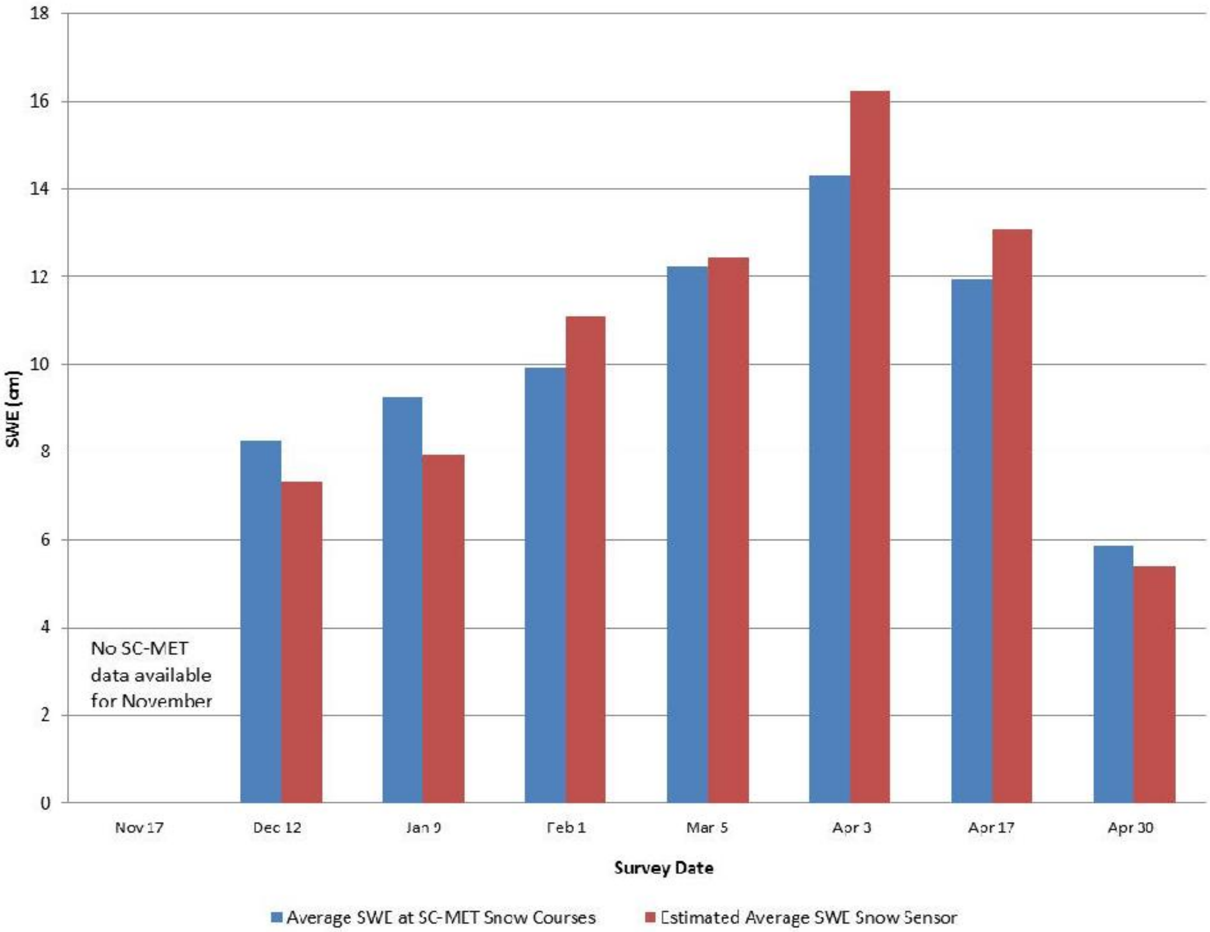

Figure 12. Comparison between estimated SWE for the snow sensor and SWE for the snow survey SC-MET

3.2.5 Mount Nansen Airstrip

EDI conducted two snow surveys for the SC-AIR snow course on March 6 and April 17. YG WR/EMR conducted their Mount Nansen snow survey at the Victoria Creek airstrip (09CA-SC1) on February 27, March 26 and April 25, 2012. The March 6/February 27 and April 17/April 25 pairing are considered sufficiently close to be compared. The locations and snow core sampler used by EDI were not exactly the same as YG, however assumptions and corrections are described below:

- The YG snow course is located near the airstrip and was approximately 450 m southeast of the SC-AIR snow course established by EDI closer to the Mount Nansen Road. Both snow courses are at similar elevations in relatively open forest with relatively flat topography, therefore aspect and wind exposure are similar at both sites.

- YG uses a Standard Federal Sampler for their snow surveys (*pers. comm.* J. Kolot 2012), which required that a correction factor of 0.91 (Goodison *et al.* 1987) be applied to all SWE data collected by YG in order to compare it to data collected by EDI with a Metric Prairie Sampler.
- The YG snow course includes ten snow cores taken at 15 m intervals, while the EDI SC-AIR snow course included five cores taken at 2 m intervals.

Table 5 summarizes the measurements collected by YG (09CA-SC1) and EDI (SC-AIR). The February 27, 2012 measurement (YG, SWE = 6.2 cm) and the March 6, 2012 (EDI, SWE = 10.5 cm) are reasonably similar considering the variability among sites observed elsewhere in the snow surveys, however the April 25, 2012 (YG, SWE = 0 cm) and April 17, 2012 (EDI, SWE = 10 cm) are less reasonably similar. The temperature sensor located at the meteorological station (approximately 260 m elevation higher than SC-AIR and 09CA-SC1) indicates (Appendix B) that daytime air temperatures began to regularly rise above 0 ˚C in the beginning of April indicating that the snowpack would begin to melt. The smaller difference between the SWE measurements for the February 27/March 6 are likely indicative of the micro-climate variability between the sites whereas the difference in SWE for the April 17/25 measurements are may be a combination of micro-climate variability and differential melt patterns.

Table 5. Comparison of snow data between YG and EDI data collected in 2011/2012 (correction factor was applied to YG SWE data).

Snow Survey Station	Date	SWE (cm)	Snow Depth (cm)
YG – 09CA-SC1	27-Feb-12	6.2	57
	26-Mar-12	10.2	63
	25-Apr-12	0	0
EDI – SC-AIR	6-Mar-12	10.5	65
	17-Apr-12	10.0	46

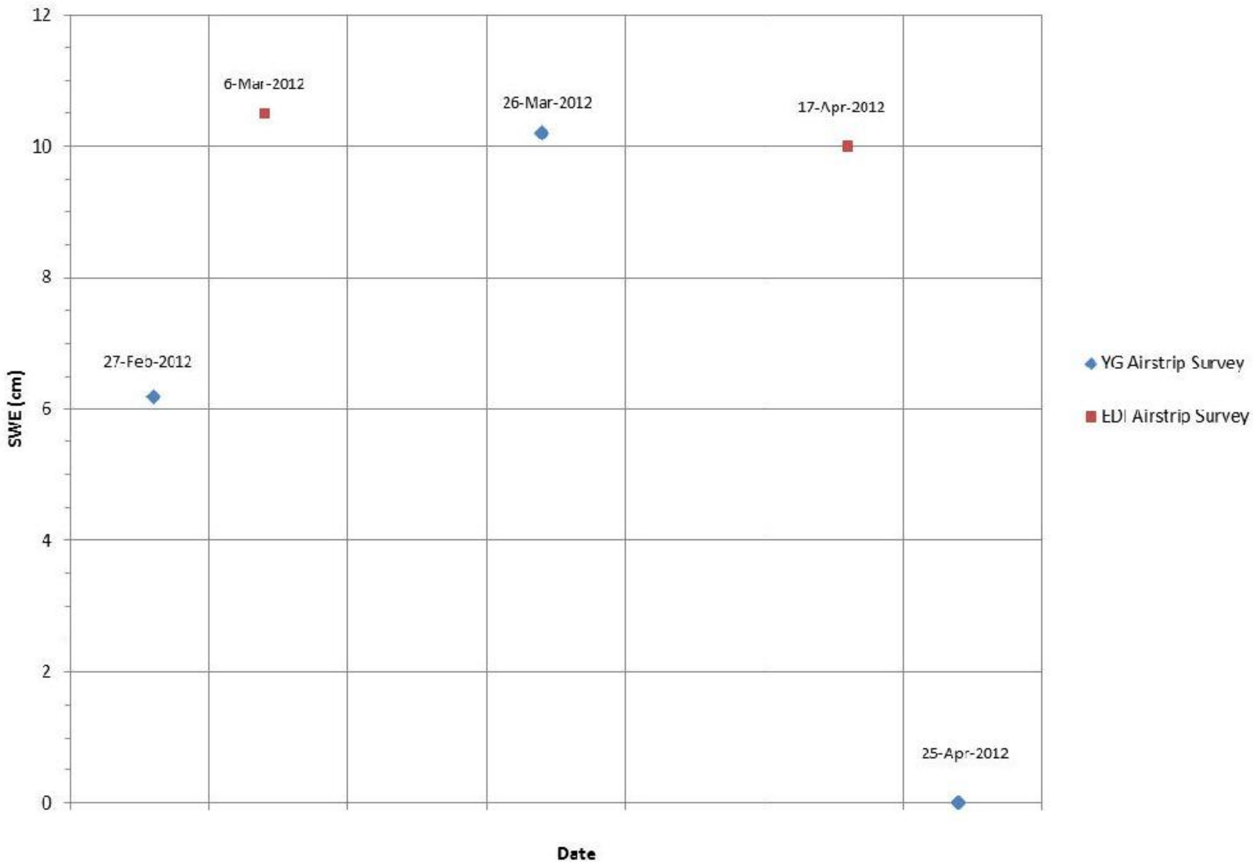

Figure 13. **Comparison of snow data between YG and EDI data collected in 2011/2012 (correction factor was applied to YG SWE data).**

3.2.5.1 Historical Comparison

For comparison to historical data collected by YG WR since 1976, the 2012 season was above average for snow depth for the March and April surveys and below average for May survey (Table 6; Figure 14). SWE was average for the March survey, above average for the April survey, and below average for May survey.

Table 6. SWE and snow depth for the YG snow course, comparing the 2012 surveys with the 37-year average (correction factor has been applied to all SWE data).

YG Survey	2012 Survey		37-Year Average	
	SWE	Snow Depth	SWE	Snow Depth
March	6.2	57	6.2	43
April	10.2	63	7.4	81
May	0	0	1.7	8

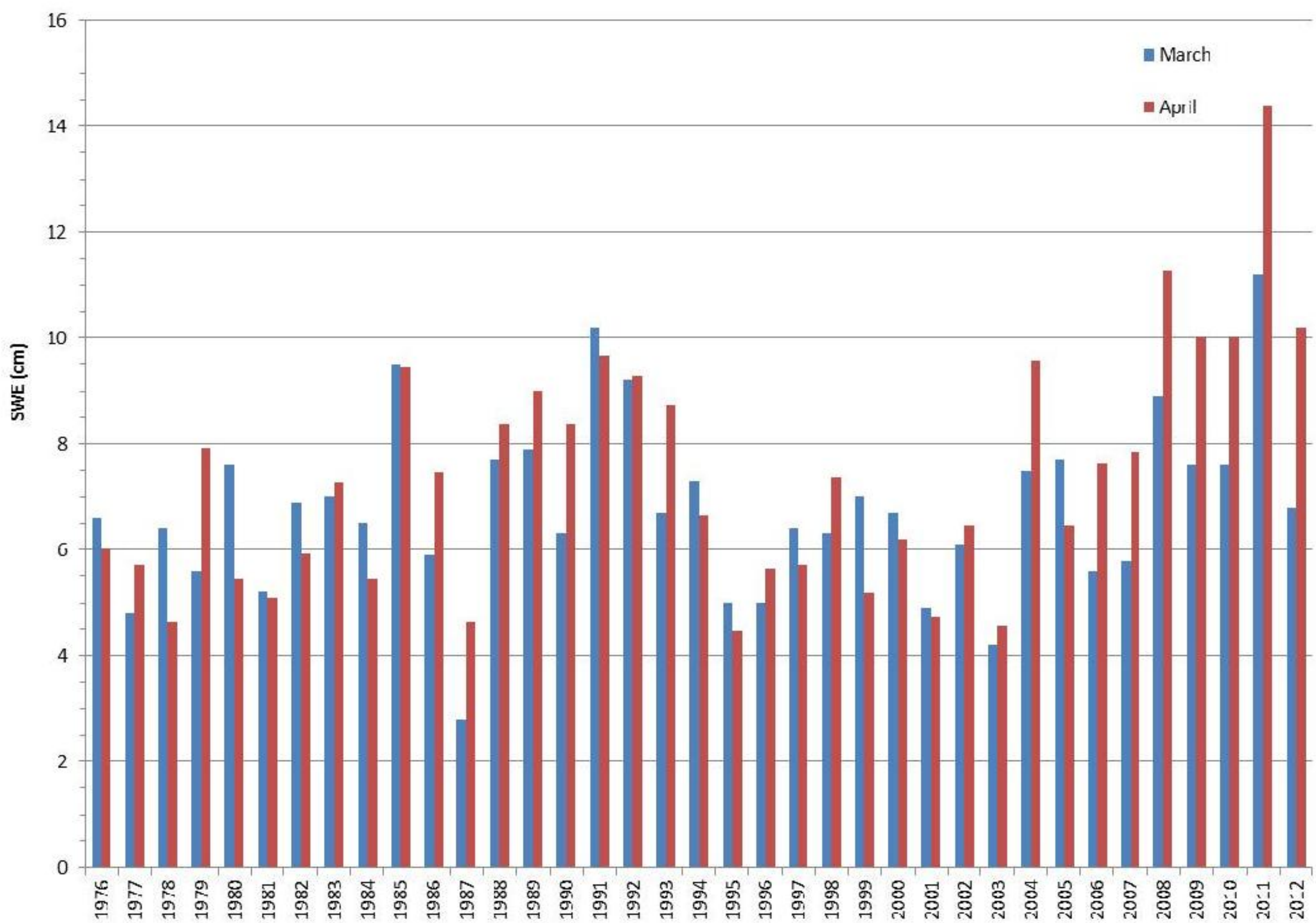

Figure 14. Historical SWE for the Mount Nansen (09CA-SC1) Victoria Creek Airstrip from 1976 to 2012 for the March and April surveys (correction factor applied).

4 SUMMARY & RECOMMENDATIONS

The 2011/2012 Mount Nansen Snow Survey Program has provided a more site specific and detailed understanding of snow depth, SWE and snow density across the Mount Nansen site than the single snow course monitored by YG near the Mount Nansen airstrip. During the winter of 2011/2012 there was a high degree of variability at the site. All snow survey parameters are highly influenced by wind and sun angle effects, which are in turn related to aspect, topography, and vegetative cover.

The 2011/2012 snow survey data did not identify a strong relationship between elevation and SWE which may be related to the relatively small difference in elevation among stations along the Dome Valley transect as well as the variability in topography, vegetation, and site disturbance along the transect.

Comparing data for north- and south-facing slopes, snow depth, SWE and snow density were all slightly lower on the south-facing slopes than the north. Snow depth and SWE also declined more rapidly on the south-facing slopes during the spring (April to May).

Differences between mine-disturbed and undisturbed areas were also investigated in 2011/2012 by comparing data from the waste rock pile snow course with that of the south-facing slope snow course. The data suggested that the mine-disturbed areas were subject to much greater variability in snow depth, SWE and snow density throughout the winter due to higher wind exposure. The snowpack on mine-disturbed areas also appeared to melt more rapidly than undisturbed areas in the spring.

The meteorological station snow course was also subject to a high degree of variability due to wind exposure. This led to differences of up to 25% between the snow survey data and the snow sensor data throughout the winter. The difference may be reduced if the meteorological station snow courses are located within the meteorological station compound, however care must be taken to ensure snow near the sensor is not disturbed.

In general, the SWE values measured near the airstrip (SC-AIR) were greater than the measurements collected by YG in 2012 on similar dates, however during April when the snow pack was beginning to melt the differences increased. Given the small data set for this comparison, additional data should be collected next year at SC-AIR. The SC-AIR SWE measurements were slightly greater than the historical averages and snow depths were below average for March, above average for April. This variability is likely attributed to seasonal variations, site micro-climates and wind re-distribution.

If feasible, it is recommended to review the snow survey sampling program with the Project Design Team before beginning sampling for the 2012/2013 snow season to determine if any adjustments should be made to the overall sampling design.

5 REFERENCES

5.1 LITERATURE CITED

Ministry of Environment [MOE]. 1981. Snow Survey Sampling Guide. Surface Water Section, Water Management Branch, Ministry of Environment, Province of British Columbia. Parliament Buildings, Victoria, BC. V8V 1X5. SS13-81. 27 pp.

Goodison, B.E., J.E. Glynn, K.D. Harvey, and J.E. Slater. 1987. Snow surveying in Canada: a perspective. Canadian Water Resources Journal, Vol. 12(2): 27-42.

5.2 PERSONAL COMMUNICATIONS

Jonathan Kolot 2012. Hydrology Technologist, Water Resources Branch, Environment Yukon. Contacted May 11, 2012.

5.3 SPATIAL DATA

1:50,000 CanVec topographic data from Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information. Geogratis website (http://geogratis.cgdi.gc.ca).

1:20,000 TRIM positional files from the Land and Resource Data Warehouse (http://lrdw.ca). Copyright belongs to Her Majesty the Queen in Right of the Province of British Columbia.

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Maps presented in this document are a geographical representation of known features. Although the data collected and presented herein has been obtained with the utmost attention to quality, this document is not an official land survey and should not be considered for spatial calculation. EDI Environmental Dynamics Inc. does not accept any liability for errors, omissions or inaccuracies in the data.

APPENDIX A SNOW COURSE DESCRIPTIONS

SC-DC-01	**DOME CREEK VALLEY TRANSECT**			**8V 391514, 6880404**	
Description	Lowest elevation snow course on Dome Creek Valley Transect, closest to confluence with Victoria Creek. Access is from the Dome at Road WQ/H site walking downstream about 350 m. Station is on a bench up from the left downstream bank (LDB) of the creek in an open, mature spruce forest. There is a rebar marker with flagging next to an old spruce tree. This site became inundated slightly with overflow ice from Dome Creek, and was moved slightly to higher ground (marked with flagging).				
Number of Stations	4	**Distance**	1 m	**Bearing**	357 degrees


SC-DC-02	**DOME CREEK VALLEY TRANSECT**			**8V 391184, 6880497**	
Description	Located on downstream side of Dome Creek road crossing (40 m from road), just down from Dome at Road hydrometric station. Site is on a small mound on the right downstream bank (RDB) of the creek. Some small willow vegetation, with one willow flagged. Overflow ice required that all stations were on top of mound.				
Number of Stations	4	**Distance**	0.5	**Bearing**	206 degrees


SC-DC-03	DOME CREEK VALLEY TRANSECT			8V 390849, 6880483	
Description	Upstream of the Dome Creek road crossing. Area has significant overflow ice covering most of valley floor. Snow cores taken from base of south-facing slope up from LDB. South facing slope quite steep with the odd aspen and spruce tree. Sporadic willow shrubs on valley floor. This site was MOVED later in winter (MARCH) due to overflow ice and was moved to other side of creek (RDB) with a willow flagged. It is above all overflow impacts.				
Number of Stations	4	Distance	1.5 m	Bearing	284 degrees

SC-DC-04	DOME CREEK VALLEY TRANSECT			8V 390501, 6880533	
Description	Located on an upper bench, up from RDB of Dome Creek. Scattered old spruce trees and shrubs. Was not flagged so use GPS coordinates to locate site. Terrain quite hummocky so be aware of where snow core is placed, do not need to turn very many times.				
Number of Stations	4	Distance	1.5 m	Bearing	144 degrees

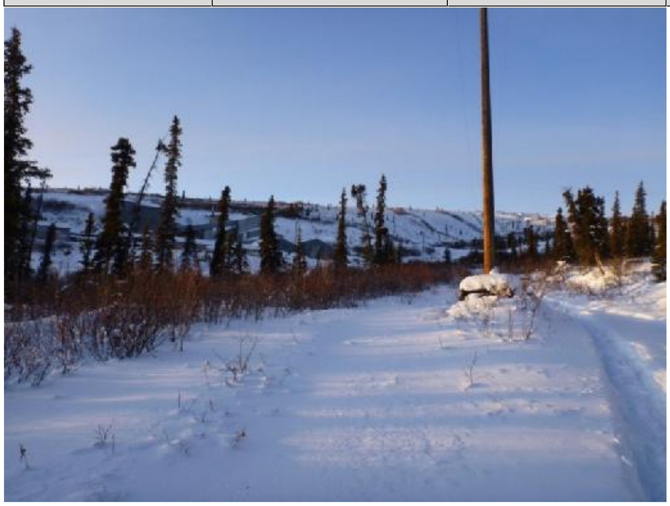
SC-DC-05	DOME CREEK VALLEY TRANSECT		8V 390038, 6880617		
Description	Accessed either down from Seepage or up from Dome at Road. Long walk - use snowmobile packed trail if possible. Site is between two larger spruce trees.				
Number of Stations	4	Distance	2 m	Bearing	275 degrees

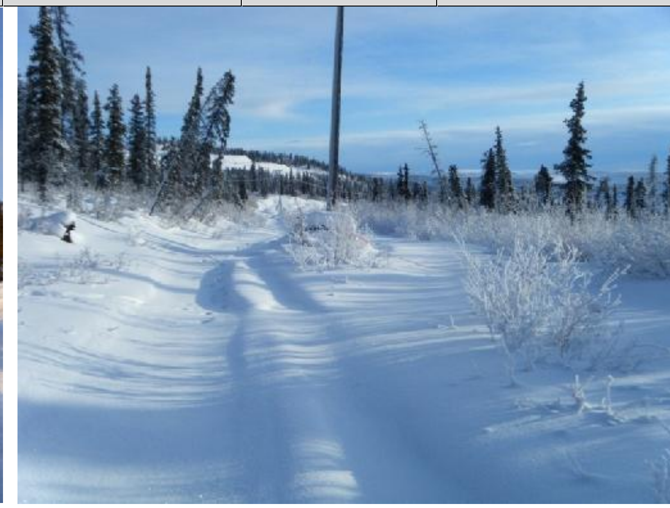

SC-DC-06	DOME CREEK VALLEY TRANSECT		8V 389619, 6880578		
Description	Located south of Seepage Discharge WQ sampling site, below Seepage Pond. Start at a red, metal groundwater monitoring well and move in a downstream direction, there is also a willow marked with flagging tape.				
Number of Stations	4	Distance	1m	Bearing	114 degrees


SC-DC-07	DOME CREEK VALLEY TRANSECT		8V 389080, 6880653		
Description	Site is located in a flat open area, upstream of Tailings Pond area, south of Upper Dome Creek. Drive to end of road around Tailings Pond and access on foot from there. A willow is flagged marking the location.				
Number of Stations	4	**Distance**	1.5 m	**Bearing**	254 degrees

SC-DC-08	DOME CREEK VALLEY TRANSECT		8V 3887800, 6880782		
Description	Walk along the base of the north facing slope from Station 7, above the RDB of Dome Creek. Site is approximately 350 m northwest from Station 7. A willow is flagged marking the station. There are a couple larger mounds sheltering the area from the north side. Sparse vegetation, some willow and scattered spruce.				
Number of Stations	4	**Distance**	1.5 m	**Bearing**	267 degrees

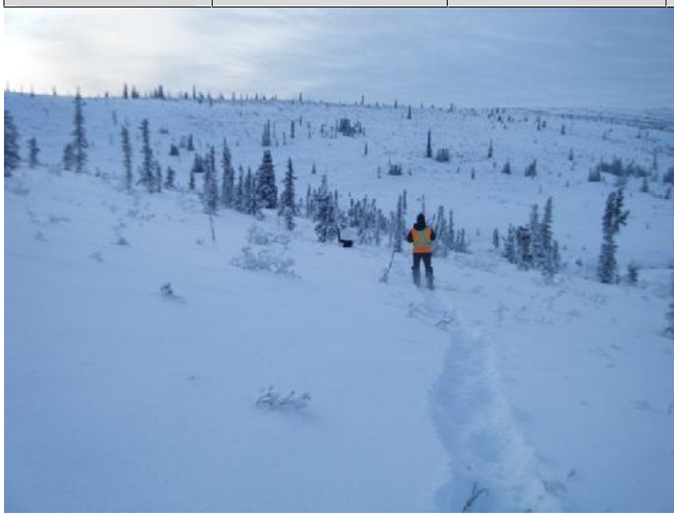
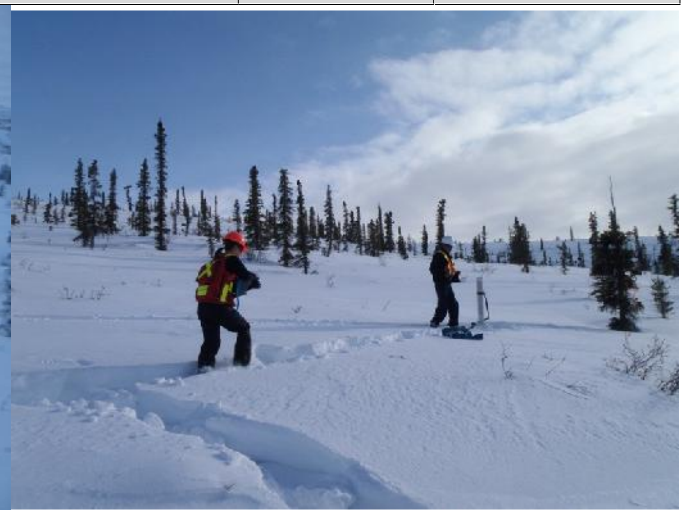
SC-DC-09	DOME CREEK VALLEY TRANSECT		8V 388063, 6881155		
Description	Site is accessible by parking near the Mill, and following the road/transmission line down to the D1 WQ sampling location. Snow course takes place near a power pole. Site boundary is flagged.				
Number of Stations	4	Distance	2 m	Bearing	100 degrees





SC-DC-10	DOME CREEK VALLEY TRANSECT		8V 387649, 6881101		
Description	Accessed from a trail leading up above the mill, near the DX water quality sampling location. This station is the highest elevation site along the Dome Valley Transect. Site is somewhat north facing on a bit of a slope (10 degrees). There are willow shrubs and spruce trees. Site is flagged with orange flagging.				
Number of Stations	4	Distance	2 m	Bearing	273 degrees

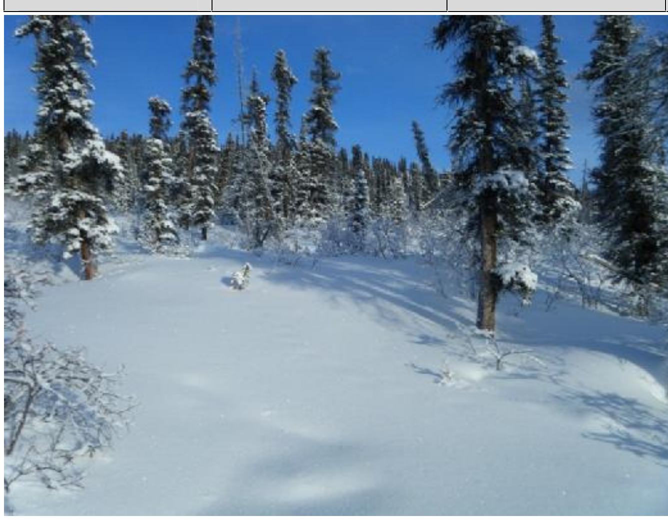
SC-NF-1	NORTH FACING SLOPE		8V 389288, 6880414		
Description	Above Tailings Pond area. Very sparse trees, flagged a tree with a sparse leader. Access probably easiest from SC-DC-7 (at north end of Tailings Pond).				
Number of Stations	5	Distance	2 m	Bearing	90 degrees

SC-NF-2	NORTH FACING SLOPE		8V 387645, 6881073		
Description	Easiest access from SC-DC-10 (about 50 m apart) using trail above Mill Site.				
Number of Stations	5	Distance	2 m	Bearing	81 degrees


SC-SF-1	SOUTH FACING SLOPE			8V 387645, 6881073	
Description	Access from tailings/seepage access road before crossing bridge. There is a slight pull off after downhill before bridge. Access directly up hill to flagged spruce tree.				
Number of Stations	5	**Distance**	2 m	**Bearing**	99 degrees


SC-SF-2	SOUTH FACING SLOPE			8V 388125, 6881209	
Description	Up on south facing slope, above SC_DC_09. Accessible from road/transmission line that leads to D1 water sampling location from Mill. 60 m up from power line post.				
Number of Stations	5	**Distance**	2 m	**Bearing**	109 degrees




SC-WR-1	WASTE ROCK PILE			8V 389044, 6881164	
Description	Lower bench of waste rock pile. There is some flagged rebar at site and two pieces of bent rebar sticking out of ground.				
Number of Stations	3	Distance	2 m	Bearing	165 degrees

SC-WR-2	WASTE ROCK PILE			8V 388802, 6881366	
Description	Middle bench of waste rock pile. Accessible from across road from SC-WR-1. Flagged rebar.				
Number of Stations	3	Distance	2 m	Bearing	324 degrees

SC-WR-3	WASTE ROCK PILE			8V 388965, 6881319	
Description	Site is just above from Pit. There is a side road that leads to the site and an open flat area with some waste rock piling on south side.				
Number of Stations	3	**Distance**	2 m	**Bearing**	340 degrees


SC-MET-01-04	METEOROLOGICAL STATION			8V 388350, 6881586	
Description	Survey area started out as four snow courses arranged as a grid around the four corners of the Meteorological Station. However, over the winter some of the area was affected by grader debris and the snow courses were moved to the south side of the met station, with two snow courses on either side. SC-MET-01 and SC-MET-03 started 3 m from either side of south corners of fencing, and then SC-MET-02 and SC-MET-04 started 6 m from either side.				
Number of Stations	3 per snow course	**Distance**	0.5 m *(all)*	**Bearing**	64 degrees *(SC-MET-01-02)* 244 degrees *(SC-MET-03-04)*


SC-AIR	AIRSTRIP REPLICATE			8V 392251, 6879088	
Description	The site is accessible off the Mount Nansen Road west of the Victoria Creek crossing. The site is in a relatively open forest on a similar bench as the YG Airstrip snow course.				
Number of Stations	5	Distance	2 m	Bearing	165 degrees


APPENDIX B WEATHER DATA

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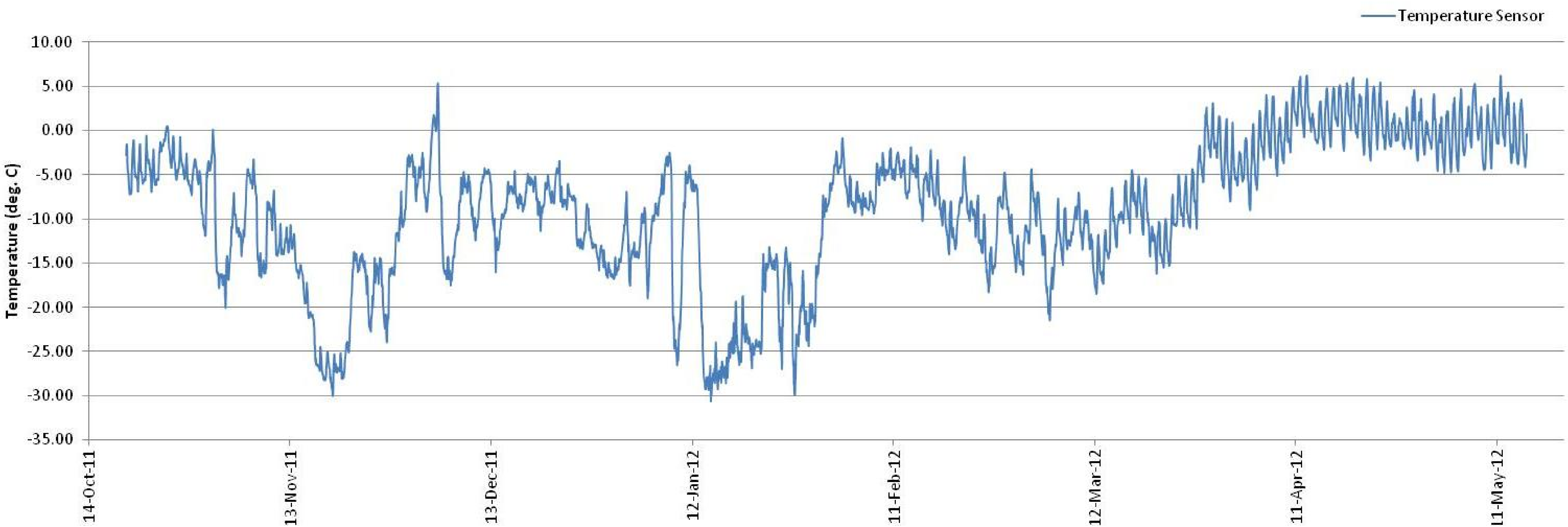

Figure B-1. Mount Nansen meteorological station data from October 19, 2011 to May 15, 2012 - average hourly air temperature.

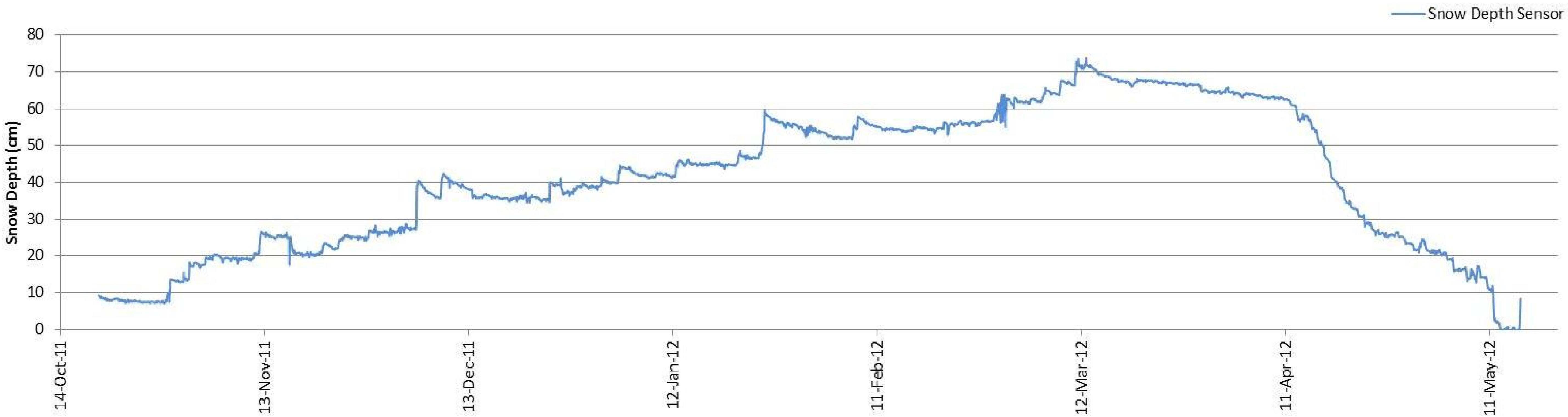

Figure B-2. Mount Nansen meteorological station data from October 19, 2011 to May 15, 2012 - snow depth.

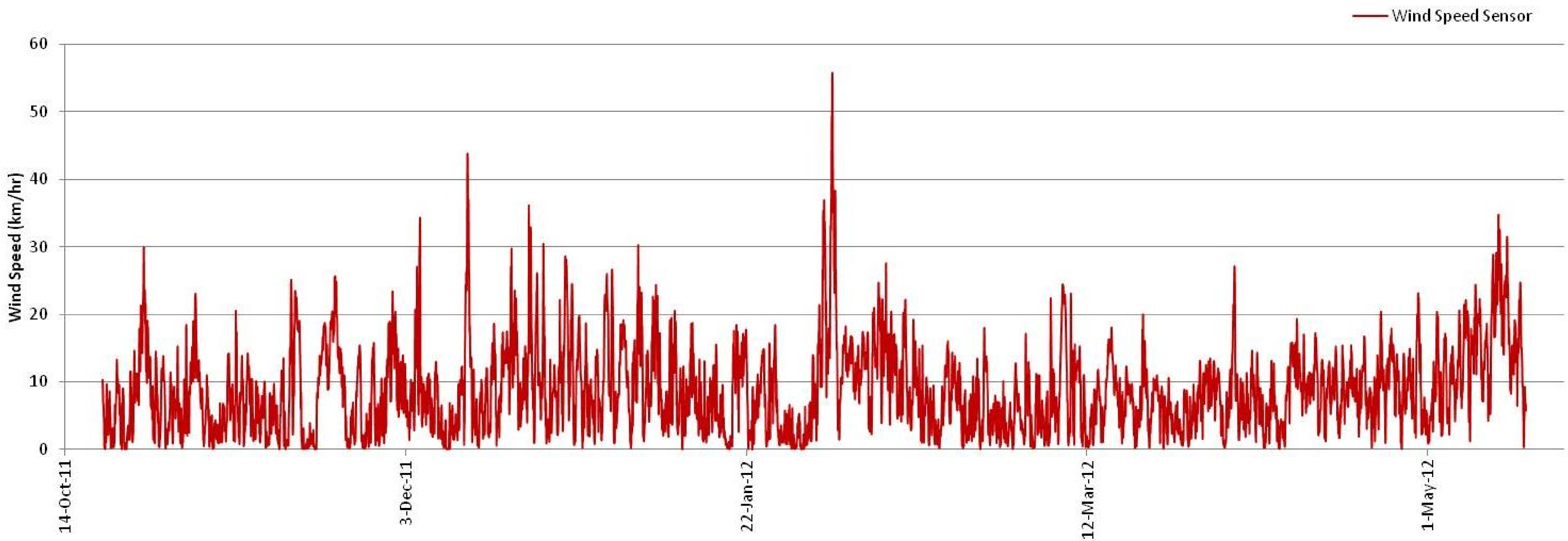

Figure B-3. Mount Nansen meteorological station data from October 19, 2011 to May 15, 2012 - wind speed.

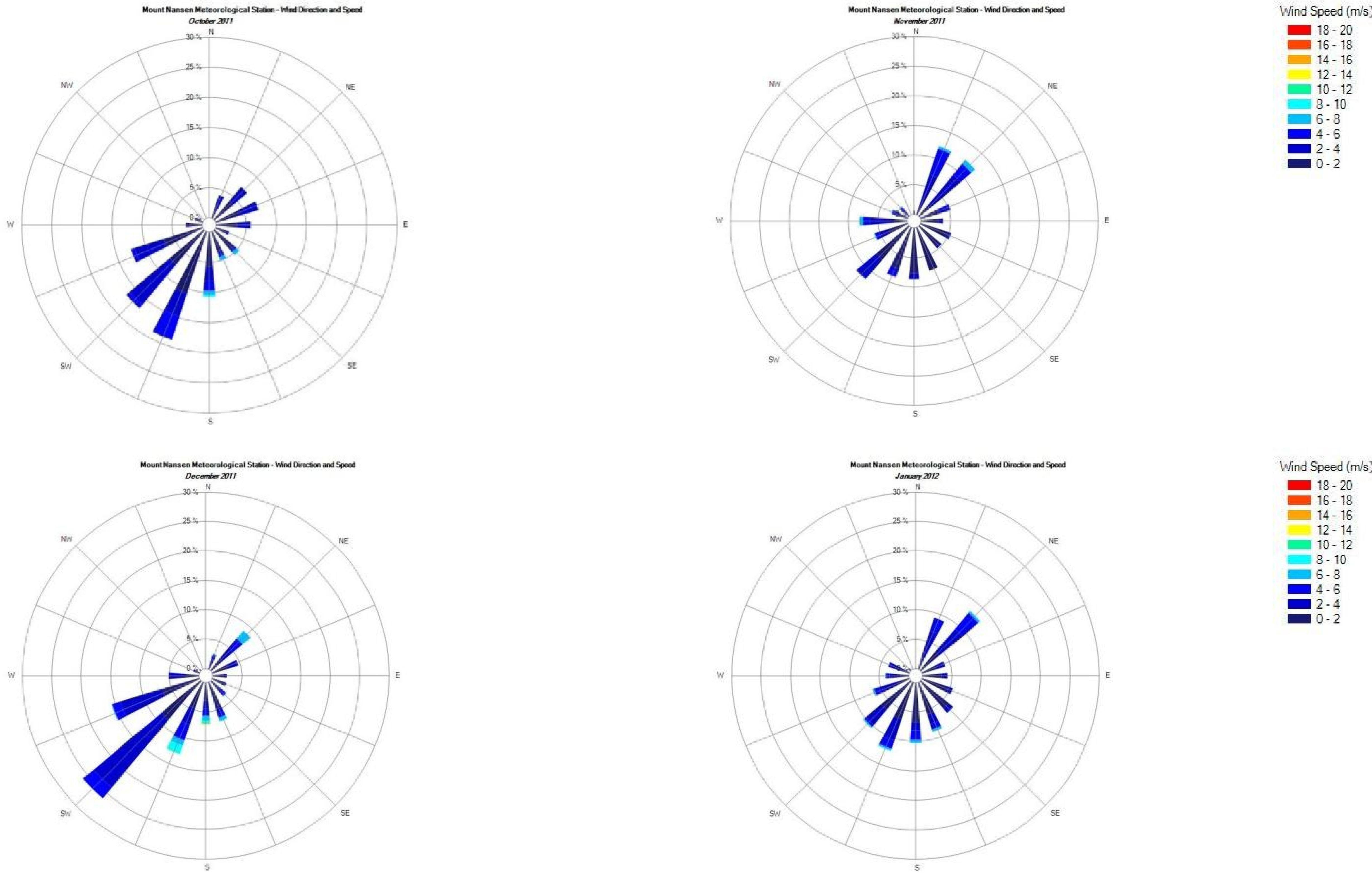

Figure B-4. **Monthly wind direction, magnitude, and frequency (percent time) recorded at the Mount Nansen meteorological station (el. 1,247 m.a.s.l.) between October 19, 2011 (October = partial month) and January 31, 2012.**

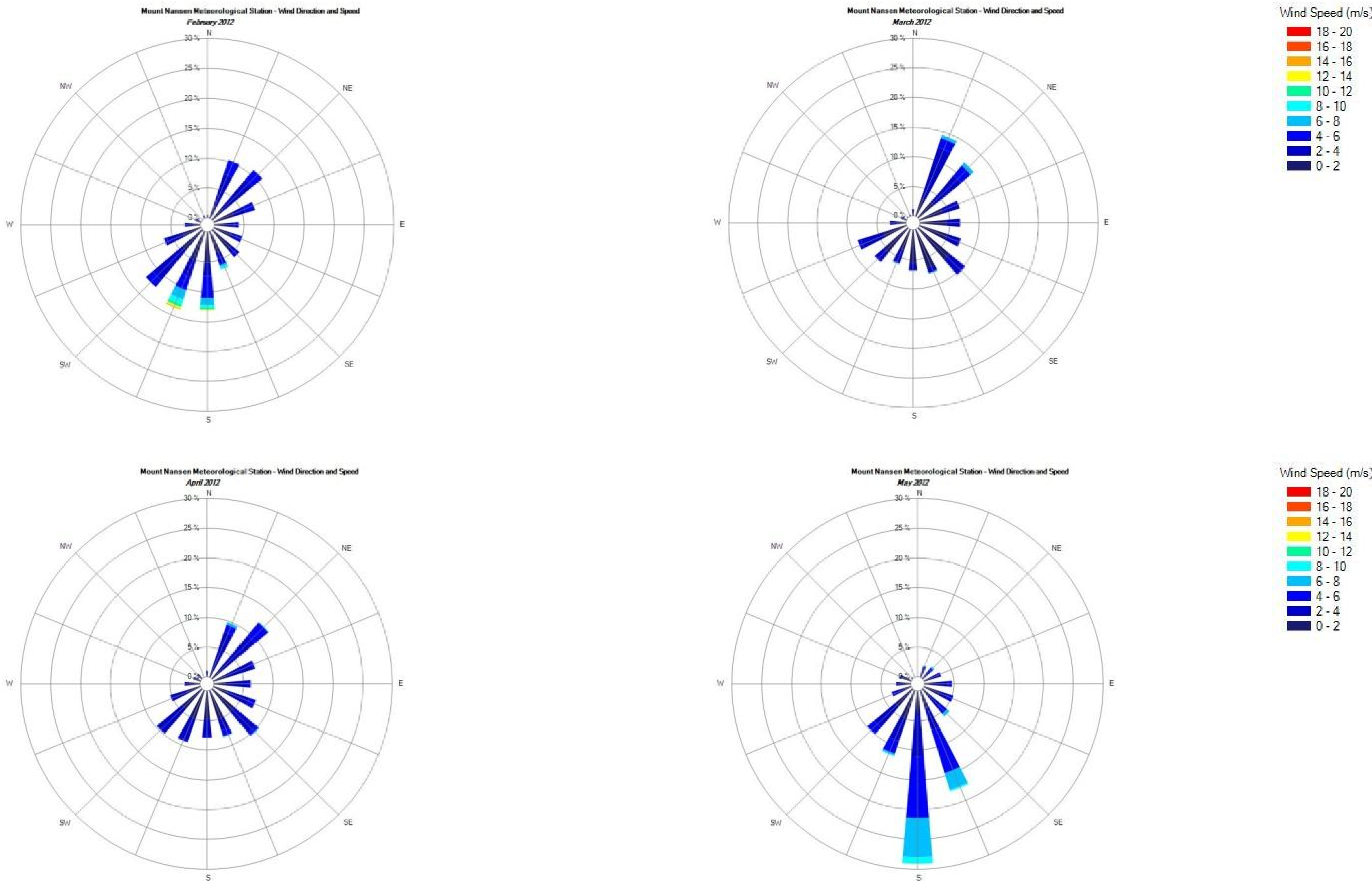

Figure B-5. **Monthly wind direction, magnitude, and frequency (percent time) recorded at the Mount Nansen meteorological station (el. 1,247 m.a.s.l.) between February 1, 2012 and May 31, 2012.**

APPENDIX C SNOW SURVEY DATA

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Table C-1. Average snow depth, SWE and snow density at all sites from November 2011 to May 2012.

SC ID	Elevation	Average Snow Depth (cm)								Average SWE (cm)								Average Snow Density (%)							
		Nov	Dec	Jan	Feb	Mar	Apr	Apr-Mid	May	Nov	Dec	Jan	Feb	Mar	Apr	Apr-Mid	May	Nov	Dec	Jan	Feb	Mar	Apr	Apr-Mid	May
SC-DC-01	1,015	23.0	40.5	42.1	33.5	41.0	67.8	46.4	26.6	2.3	6.3	8.4	8.1	7.5	18.5	15.0	7.0	10%	15%	20%	16%	18%	27%	32%	34%
SC-DC-02	1,022	18.1	30.5	38.1	40.3	44.8	42.3	21.3	0.0	1.9	5.8	5.5	6.1	9.8	11.5	6.4	0.0	11%	19%	14%	15%	22%	27%	30%	0%
SC-DC-03	1,034	20.3	-	42.6	47.9	45.8	58.8	49.5	42.6	2.4	-	7.4	8.1	10.2	12.2	9.4	11.5	12%	-	18%	17%	17%	21%	19%	26%
SC-DC-04	1,044	33.1	-	44.0	57.6	59.5	57.3	52.3	31.3	1.9	-	7.9	10.2	10.0	14.0	11.5	7.0	6%	-	17%	18%	16%	24%	22%	23%
SC-DC-05	1,068	-	-	43.0	50.4	64.5	55.0	48.1	32.0	-	-	8.5	8.4	8.0	15.6	16.1	9.0	-	-	20%	17%	18%	29%	33%	28%
SC-DC-06	1,074	27.1	45.8	46.9	54.8	57.0	61.3	44.1	22.8	3.9	7.8	8.9	9.9	9.3	12.9	11.0	5.0	14%	17%	19%	18%	16%	21%	25%	26%
SC-DC-07	1,104	26.1	40.0	46.0	53.4	54.3	58.1	45.8	25.6	3.1	6.5	8.4	8.6	10.3	14.1	12.1	7.6	12%	16%	18%	16%	19%	24%	26%	30%
SC-DC-08	1,118	29.6	39.0	53.3	55.3	60.5	58.1	49.3	32.4	3.0	4.5	7.5	11.9	10.5	11.8	11.9	8.5	10%	12%	14%	21%	18%	20%	24%	26%
SC-DC-09	1,181	-	45.0	53.4	57.5	60.5	63.9	44.9	19.2	-	7.5	8.4	8.8	10.5	13.1	10.5	5.5	-	17%	16%	15%	17%	20%	23%	29%
SC-DC-10	1,225	-	48.3	57.5	54.1	63.3	72.6	61.4	50.1	-	8.0	9.9	12.5	12.8	17.6	15.4	13.1	-	17%	17%	23%	20%	24%	26%	26%
SC-NF-1	1,117	-	49.6	52.9	35.0	64.0	64.3	61.7	48.2	-	8.0	7.6	12.4	11.4	14.2	10.9	11.6	-	16%	14%	38%	18%	22%	28%	25%
SC-NF-2	1,232	-	58.3	58.8	47.5	65.4	67.5	67.3	66.9	-	6.3	8.3	9.4	12.4	13.7	15.9	14.5	-	11%	14%	20%	19%	20%	24%	22%
SC-SF-1	1,134	-	-	44.4	55.2	54.4	44.5	0.0	0.0	-	-	7.6	9.2	10.0	9.6	0.0	0.0	-	-	17%	17%	18%	22%	0%	0%
SC-SF-2	1,186	-	49.2	56.6	60.1	63.0	65.3	40.0	5.5	-	6.4	9.0	10.4	10.0	11.1	10.5	1.5	-	13%	16%	17%	16%	20%	23%	11%
SC-WR-1	1,191	26.1	28.0	9.0	25.0	15.2	18.5	0.0	0.0	4.3	6.0	3.3	5.3	2.3	3.8	0.0	0.0	17%	21%	37%	21%	14%	20%	0%	0%
SC-WR-2	1,212	24.0	38.3	57.0	84.8	60.7	57.7	50.3	0.0	2.8	9.3	14.2	21.7	14.3	16.7	17.5	0.0	12%	24%	25%	26%	24%	29%	36%	0%
SC-WR-3	1,214	21.0	21.0	20.7	33.2	32.0	36.3	26.5	0.0	3.3	5.0	5.2	7.3	6.7	10.2	6.0	0.0	16%	24%	25%	22%	21%	28%	33%	0%
SC-MET	1,248	27.3	42.1	48.9	48.1	60.1	52.1	40.9	17.8		8.3	9.3	9.9	12.3	14.3	12.0	5.9		19%	19%	20%	20%	25%	30%	24%
SC-AIR	986	-	-	-	-	65.0	-	46.0	-	-	-	-	-	10.5	-	10.0	-	-	-	-	-	32%	-	22%	-
AVERAGE		25.7	41.3	45.9	49.4	55.3	55.0	41.7	22.4	2.9	7.1	8.3	9.9	10.8	13.3	10.9	6.0	12%	18%	19%	20%	19%	24%	25%	19%