Snow-Course Measurement Methods,

North Slope, Alaska

Snow-course site in the Brooks Range, photo by Jeff Derry

by

Jeff Derry, Douglas Kane, Michael Lilly,

and Horacio Toniolo

December 2009

Sagavanirktok River/Bullen Point, Kuparuk Foothills, and

Umiat Corridor Hydrology Projects

Report No. INEWERC2009.07

Water and Environmental
Research Center

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by

Jeff Derry[2], Douglas Kane[1], Michael Lilly[2], and Horacio Toniolo[1]

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UNITS, CONVERSION FACTORS, WATER QUALITY UNITS, VERTICAL AND HORIZONTAL DATUM, ABBREVIATIONS AND SYMBOLS

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in)	25.4	millimeter (mm)
inch (in)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (mm)
mile (mi)	1.609	kilometer (km)
	Area	
Acre	43559.826	square feet (ft^2)
Acre	0.407	hectare (ha)
square foot (ft^2)	2.590	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3785	milliliter (mL)
cubic foot (ft^3)	23.317	liter (L)
Acre-ft	1233	cubic meter (m^3)
	Velocity and Discharge	
foot per day (ft/d)	0.3048	meter per day (m/d)
Square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/sec)
	Hydraulic Conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per day (ft/d)	0.00035	centimeter per second (cm/sec)
meter per day (m/d)	0.00115	centimeter per second (cm/sec)
	Hydraulic Gradient	
foot per foot (ft/ft)	5280	foot per mile (ft/mi)
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Density	
Slugs per cubic foot ($slug/ft^3$)	515.464	Kilograms per cubic meter (kg/m^3)

UNITS

For the purposes of this report, both English and Metric (SI) units were employed. The choice of "primary" units employed depended on common reporting standards for a particular property or variable measured. Whenever possible, the approximate value in the "secondary" units was also provided in parentheses. Thus, for instance, snow density was reported in kilograms per cubic meter (kg m^{-3}) followed by the approximate value in slugs per cubic feet (slug ft^{-3}) in parentheses.

Vertical Datum:

In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929), a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called *Sea Level Datum of 1929*.

Horizontal Datum:

The horizontal datum for all locations in this report is the North American Datum of 1983.

Abbreviations, Acronyms, and Symbols

ADOT&PF	Alaska Department of Transportation and Public Facilities
DNR	Department of Natural Resources
F	Fahrenheit (^oF).
ft	feet
GWS	Geo-Watersheds Scientific
kg	kilograms
km^2	square kilometers
m	meters
NGVD	National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
QA	quality assurance
QC	quality control
Sag	Sagavanirktok River
Slug	slug
SWE	snow water equivalent
UAF	University of Alaska Fairbanks
USGS	U.S. Geological Survey
WERC	Water and Environmental Research Center
WWW	World Wide Web
YSI	Yellow Springs Instruments

1. INTRODUCTION

Understanding the temporal and spatial variability of snow accumulation and ablation (snow melt) on the North Slope of Alaska is of crucial importance to agencies, industry, and scientists. Snow depth is vital for industry exploration during the winter operational season since the opening of tundra travel is dependant on having six inches (15.24 cm) of snow on the ground in the coastal plain and nine inches (22.86 cm) in the foothills region. On many scales of space and time, snow accumulation/ablation processes are heterogeneous principally due to topographic variability and wind redistribution. Precipitation in the form of snow is temporarily stored in the snowpack during the cold season, substantially affecting the surface energy balance and the degree of soil desiccation in the organic layer (Kane et al., 1978). Peak discharge results from snowmelt runoff for many rivers on the North Slope; hence, knowledge of snow water equivalent (SWE) distributions is vital for understanding a river's hydrologic response during ablation.

Accurate field observations of the snowpack are crucial before any assessment can be undertaken. Many projects and participants collect snow data along the North Slope of Alaska. Standardized and consistent data collection methods between multiple parties will improve the understanding of timing and amount of snow accumulation/ablation over a larger geographic area. The purpose of this document is to discuss snowpack data collection methods as practiced by University of Alaska Fairbanks, Water and Environmental Research Center (WERC) project participants over multiple projects with the intent that these methods serve as a guide for other groups participating in field snow data collection efforts.

2. SAMPLING METHODS

Snow-courses are carried out at pre-established sites throughout the North Slope to determine snow depth, vertically integrated snow density, and SWE. Careful site selection, diligent measurement methods, and accurate documentation are important when integrating different data collection methods from various field campaigns for analysis (Figure 1).

2.1 Site Selection

When establishing a snow-course site:

- Select a location away from the influence of any man made formation or structure.
- Select a site that represents the surrounding natural environment in terms of underlying ground surface and overlying snow distribution. Taking into consideration; vegetation, topography, snow deposition, exposure, and melt patterns. A location that will be flooded prior to completion of snowmelt should be avoided.
- The directions of measurement are chosen somewhat randomly, but with consideration of snow drift frequency and direction in order to capture natural variability.
- If the snow-course is co-located near a meteorological station with a snow sensor, conduct snow-course near station in a representative environment.
- Note the coordinates of the location using a Global Positioning System (GPS) that is WAAS enabled. The default coordinate system used on WERC projects is NAD 83.
- When returning to a previously established snow-course site, navigate to site using GPS, landmarks detailed in field-books, and knowledge from previous field trips.
- If the site will be visited multiple times over a season it may be desirable to mark (with lathe) the beginning, corner point, and ending point of the snow-course to ensure consistency between visits.
- If the site is marked, avoid disturbing the snowpack over multiple visits by systematically offset measurements approximately 1 m in one direction from the previous measurement pattern.

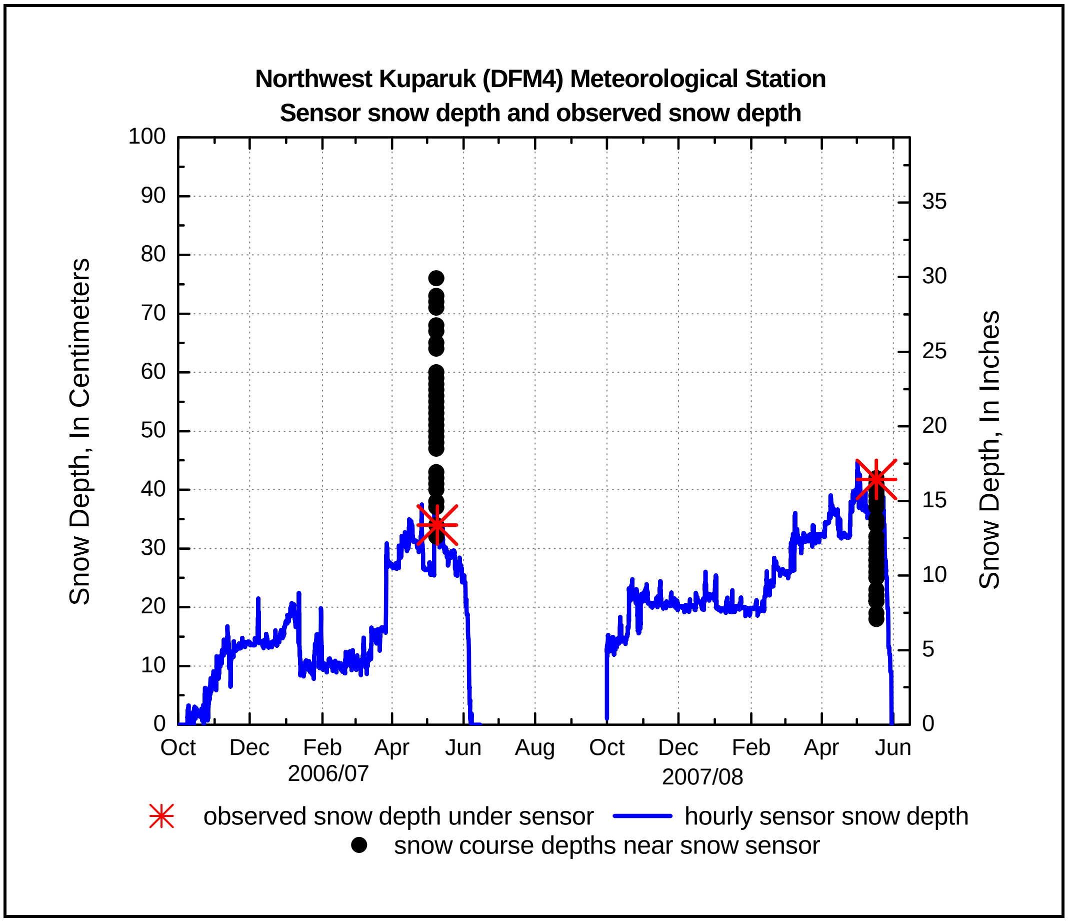

Figure 1. Snow-course depth values, average observed snow depth under automated snow depth sensor, and hourly snow depth sensor values. The middle of May between 2006/07 and 2007/08 winter season observed and reported measurements under sensor were approximately within 8 cm (3 in.), yet the range of snow-course depths are very different, likely since the snow-course was conducted at different locations from one year to the next.

2.2 Snow-Course

A snow-course involves collecting snow depth as well as snow density, a technique known as “double sampling”; with this information SWE can be calculated. The heterogeneous Arctic snowpack is more variable in depth than in density (Benson and Sturm, 1993); hence, more depth measurements are required relative to density measurements. Double sampling has been shown to improve SWE estimations, as opposed to solely collecting snow densities, with the optimum sampling ratio of 12-15 snow depths per each density measurement (Rovansek et al. 1993). To standardize sampling efforts, a ratio of 10 depths to one density is used. In total, our snow-course consists of collecting 50 snow depths and 5 densities.

Snow depths are collected at 1 m sampling intervals in a 25 m by 25 m “L” shaped transect, resulting in a total of 50 snow depth values. This method accounts for snowdrifts and topographic features in the sampling area.

Snow Course Instructions:

- Select a direction based on mentioned criteria, take a depth measurement every meter for 25 meters.
- Turn 90° and take a depth measurement every meter for 25 meters.
- If the snow-course has been conducted previously at this location, orient the “L” pattern in the same direction.
- On a staked snow-course, if the 25^{th} sample is not at the corner stake, go to the corner stake before continuing with the 26^{th} depth measurement.

Typically, depth measurements are done using a T-shaped graduated rod (T-probe). The probe is pushed vertically into the snowpack to the snow-ground interface and the depth recorded to the nearest 0.5 centimeter. Occasionally with hard packed snow the probe penetrates the tundra surface, when this happens gently raise and lower the probe until the surface is detected and then record depth.

Snow density is collected with an Adirondack snow sampler (Figure 2) preferably marked at centimeter intervals. The tube has an inside area of 35.7 cm^2 (5.53 in^2) and has metallic teeth on the lower end to cut through dense snow layers. The large diameter of the Adirondack, as opposed to the Standard Federal Sampler, is more accurate and introduces less error in the shallow Arctic snowpack; this is because of the larger sample collected (Woo et al. 1997). Five densities are collected in undisturbed locations equally spaced along the “L” shaped transect. The tube is inserted vertically until the ground surface is encountered and then the snow depth is recorded. Once the snow depth has been recorded, there are two methods of collecting the snow sample which depend on the hardness of ground surface; 1) If the ground surface is organic material, insert the tube until the ground is detected and note depth on tube, then insert further into ground thereby cutting an organic soil plug, remove tube and, with a zip-lock plastic bag over the top (non cutting end), invert tube emptying snow into bag and remove soil plug from bag. 2) If the ground surface is frozen, mineral soil, rock, ice or other hard surface, dig down to the tube/ground interface and, slide a flat object (like a flat shovel or hand) under the tube so sintered snow particles cannot escape, invert the tube and empty the snow sample into a zip-lock plastic bag held over the non-cutting end of the tube. If there is any doubt about whether snow in the tube has been lost, the sample should be redone from the starting point. If possible keep snow samples below freezing until they are weighed. Be sure to tare scale to account for the weight of the zip-lock bag.

The snowpack density multiplied by the snow depth results in the snow water equivalent (SWE) of that particular column of snow. To calculate average SWE for a snow-course, the average of 50 snow depths are multiplied by the average of 5 snow density samples.

Snow water equivalent is defined as:

$$SWE = d_s * \rho_s / p_w \quad (1),$$

where ρ_s is the average snow density from 5 snow core samples, and d_s is the average of 50 snow depth measurements, and p_w is the density of water.

Figure 2. Adirondak snow tube inserted to snow/ground interface and snow depth recorded.

2.3 Data Documentation

Thorough documentation of observed conditions while in the field is critical for reporting data in an accurate and confident manner. Procedures for data documentation are as follows:

- Fill in all required information (i.e. time, weather conditions, location, personnel), as well as any relevant conditions or observations in field form "UAF-WERC F-012" (see Appendix A) while on site. Using the forms as a guide, all of this data can be entered in a field book and then entered electronically at the end of the day.
- Ensure all applicable information is noted particularly vegetation type and amount. Example, "70% tussock tundra, 30% low lying shrubs".
- Photos are helpful. Each image should be labeled according to location and date (year, month, day). As an example, "FrankBluffs_080528.JPG". This naming convention helps to keep images organized over multiple years.
- Include specific notes that will allow future personnel to conduct snow-courses at the same location, with the "L" pattern oriented in the same direction. Besides noting cardinal directions, it is helpful to note landmarks on the horizon for

direction. For example, “started just east of L9312 meteorological station, headed towards Alpine pad for 25 depth measurements, turned 90° to left (away from lake) and continued for another 25 measurements”.

- Enter all information in excel spreadsheet that evening upon returning to camp, label spreadsheet similar to photos, such as “Shaviovik_080522.xls”.
- After data is entered by person who took observations in field, have a qualified person QA/QC the entries and verify that it is complete and accurate. Both people sign their name and date at bottom of formatted spreadsheet.

3. ACCURACY OF OBSERVATIONS

This section reports the problems of measuring and processing observational snow data, so the reported dataset can be used properly.

3.1 Snow Water Equivalent

Potential errors exist in estimating snow depth and density. For example, in well-developed organics overlaying mineral soils the snow depth probe can easily penetrate this material resulting in a greater depth being measured than the actual snow depth (Berezovskaya and Kane, 2007). Accuracy of density measurements between different snow tube types is also a concern. Of particular significance for the shallow Arctic snowpacks, work by Woo et al. (1997) found a larger tube diameter increases accuracy of the sample. Compared to snow pit estimations (considered the most accurate field method we use) Woo et al. (1997) found the Canadian sampler - which is similar to the Adirondak - captures snow density within 5%. WERC comparisons between snow pit density and the Adirondak gave similar results (Berezovskaya et al. 2008).

It is difficult to make accurate comparisons between methods when the actual SWE is unknown. However, snow depths tend towards an overestimation error while snow core densities, if in error at all, tend toward underestimation. Comparison of different sampling methods on tundra surfaces has shown the double sampling technique has an error of ± 10 % (Berezovskaya and Kane, 2007).

4. SNOW-COURSE APPLICABILITY EXAMPLE

Snow-course data, by itself or used in conjunction with other observational data, improves knowledge of snow accumulation and its distribution. As an example, the watershed of Lake L9312 (Figure 3) near the Alpine facility is a site of intense data collection efforts and thus we can make inferences about snowpack conditions throughout the cold season:

- In November 2007, hourly snow depth sensor (SR50) data was in the 0.10 percentile, percentage of snow-course data co-located near station that equal or fall below the given sensor value. For December thru May, sensor data was in the 0.20, 0.40, 0.52, 0.49, 0.37, and 0.43 percentile, respectively.
- As winter progressed, sensor data improved its representation of the mean co-located snow-course depth. This is likely due to depressions in the tundra just beginning to be filled with snow at the start of the season while in the mid and latter part of the season an equilibrium develops resulting in more uniform accumulation.
- Snow-course depths in the southwest portion of the watershed indicated similar accumulation amounts as did the snow-course near the meteorological station.
- Nearby lake surface snow depths were consistently less than tundra measurements; hourly snow depth sensor values typify the maximum values of lake snow depths, being in the 0.93 percentile or greater.

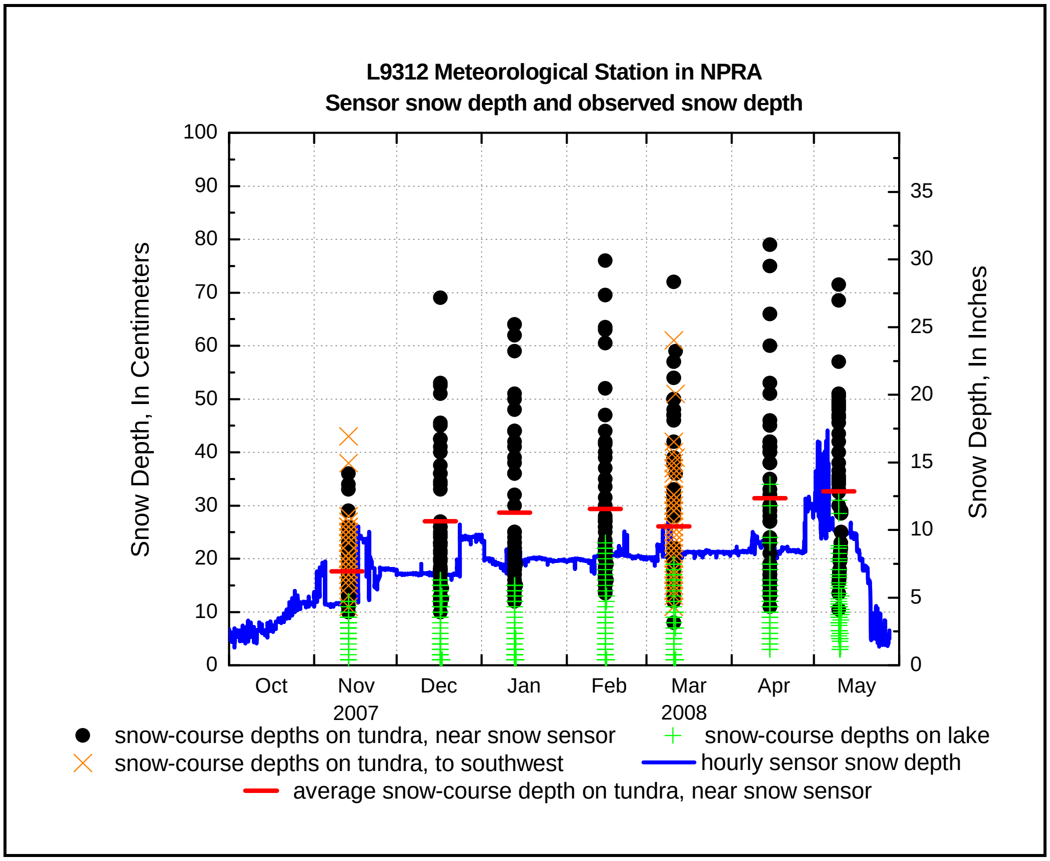

Figure 3. Snowpack observations in the L9312 watershed for winter 2007/08.

5. SUMMARY

Diligent snowpack data collection methods and practices are essential for accurate assessment of the magnitude and timing of snow depth, density, and snow water equivalent as well as its spatial distribution. This document details the procedures followed by UAF/WERC staff and project partners when collecting snowpack data in the field. A snow-course as practiced by WERC project participants includes; 1) Careful site selection. 2) Consideration of snow-drift frequency and direction as well as underlying ground surface. 3) 50 snow depth measurements collected at 1 m intervals in an "L" shaped transect. 4) 5 density measurements collected equally spaced along "L" shaped transect. 5) Thorough documentation of site conditions, procedures, and data collected. The details of this procedure are outlined in Appendix B.

Consistently following standardized procedures will result in improved evaluation of snow distributions over a large geographic area and over time by multiple parties and participants.

6. REFERENCES

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APPENDIX A. Example snow-course data entry spreadsheet.

A formatted excel spreadsheet like the one shown below can be downloaded from the Arctic Transportation Networks Project website. An example spreadsheet can also be requested from the main author of this report by contacting Jeff Derry at jderry@gwscientific.com.

http://atn.gwscientific.com

Arctic Transportation Networks Project

Form F-012: Snow Survey Form

Project ID: **ATN Project** Site Location/Lake ID: ____________

Survey Purpose: **Determine Snow Depth and SWE** Date: ________ Time: ________

Location Description:					
Survey objective:				Weather Observations:	
Latitude:		Longitude:		Datum:	
Elevation:		Elevation Datum:		Reference Markers:	
Drainage Basin:		Slope Direction:		Vegetation Type:	
Slope Angle:		Access Notes:		Other:	
Snow Depth Probe Type:				Snow-Survey Team Names:	
Snow Tube Type:					

Snow Course Depths (cm)

	1	**2**	**3**	**4**	**5**
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

(cm)

Average snow depth = ________

Maximum snow depth = ________

Minimum snow depth = ________

Standard variation = ________

(inches)

Average snow depth = ________

Maximum snow depth = ________

Minimum snow depth = ________

Standard variation = ________

Snow Sample Depths and Weights

Bag #	Snow Depth (cm)	Weight (g)	Volume (cm^3)	Density (g/cm^3)	Organic Plug (cm)

Average Density =

Average Snow Water Equivalent (SWE) = ________ cm H2O

Average Snow Water Equivalent = ________ inches H2O

Average Snow Water Equivalent = ________ feet H2O

SWE = avg. snow depth*(density snow/density water)

Data entered by: Date:

Data QA/QC by: Date:

APPENDIX B. Snow-Course Standard Operating Procedure

The following page is condensed snow-course standard operating procedure and is intended to be printed and inserted into field notebook.

SNOW-COURSE STANDARD OPERATING PROCEDURES

Water and Environmental Research Center, University of Alaska Fairbanks

OBJECTIVE: To collect snow depth and density measurements that best represent the surrounding area, in terms of topography and spatial extent.

METHODS:

Site Selection

- If there is *not* an established, marked, snow-course site, then select a representative location for the area. Attempt to capture natural snow variability, taking into consideration vegetation, topography, deposition patterns, and melt patterns. A location that will be flooded prior to completion of snowmelt should be avoided. When documenting site location, explicitly state the coordinate system used. Record accuracy (error) if GPS reports it.
- If there is a meteorological station with a snow sensor, conduct snow-course near sensor and in a representative environment.

Conducting Snow-course

Snow depth

- Snow depths are conducted in an "L" shaped pattern. Pick a direction (note on snow form), take depth measurements, then turn 90 degrees and continue (noting direction on form). If this snow-course has been conducted previously, orient the "L" pattern in the same direction as previously noted.
- Snow depth measurements are taken every meter for twenty-five meters, turning 90 degrees, and continuing for another twenty-five meters – for a total of 50 depth measurements. On a staked snow-course, if the 25th sample is not at the corner stake, return to the corner stake before continuing with the 26th sample.
- Record depths to the half centimeter.

Density

- Snow densities are collected with an Adirondack snow sampler, preferably with centimeter depth markings. Five densities should be collected from undisturbed points along representative locations near, but not on the "L" shaped transect. Minimize disturbance to the "L" shaped transect so that future measurements will be of a minimally disturbed snowpack.
- When taking densities, make sure that snow does not fall out of the tube and that all sintered snow is collected near bottom of snowpack.
- There are two ways to collect snow in a sample bag: 1) Insert tube until it sits on ground surface, note depth on outside of tube, push tube further into the ground cutting a soil plug, remove tube and, with a ziplock bag over the top (or none cutting end), invert tube emptying snow into bag, remove soil plug from bag. 2) If ground surface is frozen, do as in previous instructions but instead of collecting a soil plug, dig down to tube/soil interface and while holding snow in place with a hand, empty snow into bag that is placed on opposite end of tube.
- Put snow in plastic bag and weigh whenever convenient, tare the bag weight, record weight in grams. Densities are averaged to ascertain a representative density.

Field Forms

- Fill in all required information in the most current formatted field form (UAF-WERC F012), i.e. time, weather conditions, location, personnel.
- Fill in all information while on site.
- Ensure information is noted as to vegetation type and amount. Example, "70% tussock tundra, 30% low lying shrubs".
- Photos are helpful. Each image should be labeled according to location and date (year, month, day). As an example, "FrankBluffs_070528.JPG".
- Any and all conditions or observations please note on form.
- Include specific notes that will allow future personnel to conduct snow-courses at the same location, with an "L" pattern oriented in the same direction. Besides noting cardinal directions, it is helpful to note landmarks on the horizon for direction.