Snow Data Collection Methods Related to Tundra Travel, North Slope, Alaska: 2009

Field Crew at 2L Pad Snow Measurement Site, Kuparuk Operating Field, photo by Michael Lilly.

by

Jeff Derry, Michael Lilly, Gary Schultz, and Jessie Cherry

December 2009

Arctic Transportation Networks Project

Report GWS.TR.09.05

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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 (m)
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, stream flow was reported in cubic feet per second (cfs) followed by the value in cubic meters per second (m^3/s) in parentheses.

<u>Vertical Datum:</u>

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*.

<u>Horizontal Datum:</u>

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

<u>Snow Water Equivalent (SWE):</u>

Water content, expressed as water depth, of a given column of snow is determined by knowing the depth of the snowpack and density.

$$SWE = d_s * \rho_s \;/\; p_w$$

where:

d_s = snow depth

ρ_s = snow density

p_w= density of water (p_w= 1)

Abbreviations, Acronyms, and Symbols

AC	Actual conductivity
AAS	Alaska's Arctic Slope
ADOT&PF	Alaska Department of Transportation and Public Facilities
ADNR	Alaska Department of Natural Resources
ASTM	American Society for Testing and Materials
atm	atmospheres
ATN	Arctic Transportation Networks
C	Celsius
cm	centimeters
DO	Dissolved oxygen
DNR	Department of Natural Resources
DVM	digital voltage multi-meter
F	Fahrenheit (^{o}F).
ft	feet
GWS	Geo-Watersheds Scientific
in	inches
kg	Kilograms
km^2	square kilometers
kPa	kilopascal
lb/in^2	pounds per square inch
m	meters
mg/L	milligrams per liter
μg/L	micrograms per liter
mi^2	square miles
mm	millimeters
μS/cm	microsiemens per centimeter
mV	Millivolt
NGVD	National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
ORP	oxygen-reduction potential
ppm	parts per million
QA	quality assurance
QC	quality control
Sag	Sagavanirktok River
SC25	specific conductance at 25°C
SWE	snow water equivalent
UAF	University of Alaska Fairbanks
USACE	U.S. Army Corps of Engineers, Alaska District
USGS	U.S. Geological Survey
WERC	Water and Environmental Research Center
WWW	World Wide Web
YSI	Yellow Springs Instruments

1. INTRODUCTION

A majority of oil and gas development and exploration on the North Slope takes place in winter when the tundra surface is stable (i.e. frozen). Therefore, knowledge of snow accumulation and its ablation, both temporally and spatially, in the high latitude environment of the Central North Slope Alaska is of vital importance to both industry and research scientists. DNR requirements for the opening of tundra travel in the Coastal Tundra Opening Areas is dependent on having 15.24 cm (6 in) of snow on the ground and 23° F (-5°C) soil temperatures at a depth of 30 cm (11.8 in) (Bader, 2004).

Many projects and participants collect snow data – according to their particular method - along the North Slope. The purpose of this document is to outline the current snow data collection methods as practiced by Geo-Watersheds Scientific (GWS) and the Department of Natural Resources (DNR). Documented sampling methods will allow standardized and consistent snow data collection practices and documentation to be adhered to between multiple parties. In addition - within the context of the Arctic Transportation Networks project (ATN) - clear understanding of sampling protocols is a priori to determine if results vary significantly and whether or not the data-sets can be integrated.

Accurate field observations of the snowpack are necessary before any assessment for industry or research applications can be undertaken. Having no method to forecast snow conditions, opening date is dependent on agency personnel visiting field sites to verify snow and soil conditions. From a research perspective, understanding and quantifying the role of snow in the hydrologic cycle and energy budgets is crucial for scientific research and modeling efforts. Precipitation in the form of snow is temporarily stored in the snowpack during the cold season with peak discharge for many rivers on the North Slope resulting from snowmelt runoff. The presence or absence of snow substantially affects the surface energy balance and underlying soil conditions (Kane et al., 1978). Increased understanding of the temporal and spatial distribution of snow has multifaceted benefits and applications.

2. GWS SNOW SAMPLING METHODS

GWS snow sampling methods are described in detailed below. Careful site selection, diligent measurement methods, and consistent documentation are important when interpreting snow data from various field campaigns and multiple parties.

2.1 Site Selection

Site selection of sampling locations depends on accessibility and purpose of sampling site. Sampling sites used to ascertain end-of-winter snow accumulation over a particular area of a study domain are typically visited only once in late Spring – when snow accumulation is near it's maximum – and are usually remote and accessible only by helicopter. Sampling sites established with the intent of being visited multiple times during the winter and spring season are located within vehicle or foot accessibility. These sites are often co-located with meteorological stations equipped with a snow depth sensor (SR50 or SR50A) and/or soil temperature sensors so that observed snow depths from snow-course data (having a relative larger areal extent yet lower temporal resolution) can be compared to the hourly point data of the station sensor (having a smaller areal extent yet higher temporal resolution) as well as soil conditions.

A snow-course is a particular location where an established amount of snow depths and snow densities are collected. A snow survey is defined as a field campaign designed to visit multiple snow-courses with the intent to estimate snow conditions over a given study domain. A snow depth transect is where snow depths (quantity dependent on length of transect) are collected along a linear route.

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 (Figure 1). Take into consideration vegetation, topography, snow deposition 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 sampling site is located near a meteorological station with a snow sensor, conduct measurements near station in a representative environment.
- Note coordinates of the location using a Global Positioning System (GPS) that is WAAS enabled (see GPS settings). Typical coordinate system used is NAD 83.
- When returning to a previously established 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, and ending points to ensure consistency between visits.
- If the site is marked, avoid disturbing the snowpack over multiple visits by systematically moving measurements approximately 1 m (3.3 ft) in one direction from the previous.

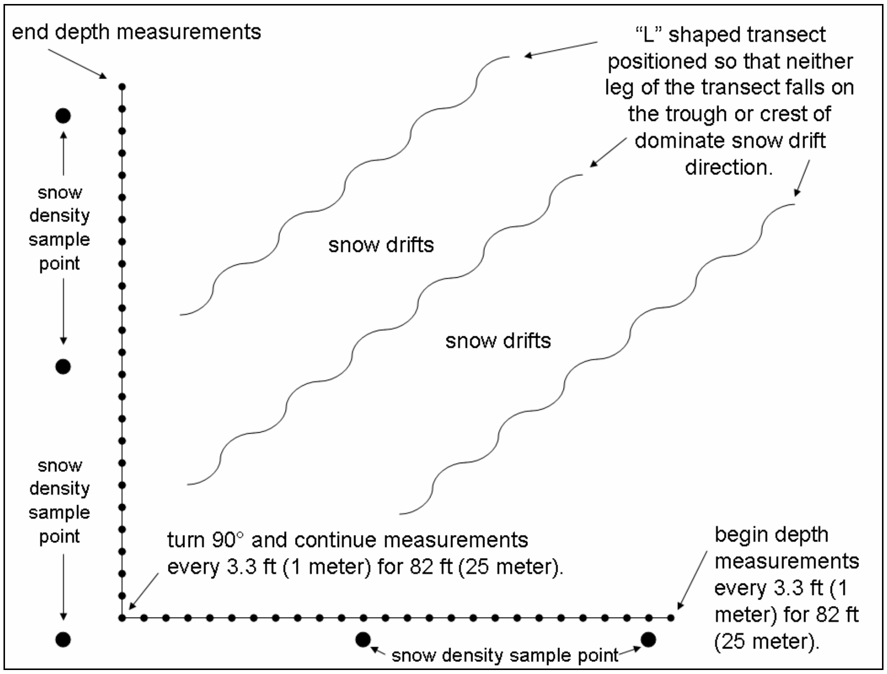

Figure 1. Diagram of an "L" shaped transect along which snow depth measurements and density samples are collected.

2.2 Snow-Course

GWS follows snow sampling procedures established in cooperation with the Water Environmental Research Center (WERC) at the University of Alaska Fairbanks (Derry et al. 2009). A snow-course, which includes collecting snow depth as well as snow density, is a method referred to as “double sampling”. With this information, 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, in terms of water depth, is defined as:

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

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 $p_w = 1$ is the density of water.

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, a snow-course consists of collecting 50 snow depths and 5 densities.

Snow depths are collected at 1 m (3.3 ft) sampling intervals in a 25 m by 25 m (82 ft by 82 ft) “L” shaped transect, resulting in a total of 50 snow depth values. This method usually accounts for snowdrifts and topographic features in the sampling area.

Snow-course instructions:

- Select a direction based on mentioned criteria in previous section, take a depth measurement every meter for 25 meters (Figure 1).
- 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 25th sample is not at the corner stake, go to the corner stake before continuing with the 26th depth measurement.

Typically, depth measurements are done using a T-shaped graduated rod (T-probe) marked in centimeters. 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 (Figure 2).

Snow density is collected with an Adirondack snow sampler preferably marked at centimeter intervals (Figure 3). 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, collects a larger sample and introduces less error in the shallow Arctic snowpack (Berezovskaya and Kane, 2007; Woo, 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 not frozen, insert the tube until the ground is detected and note depth on tube, then insert further into ground thereby cutting a soil plug, remove tube and, with a zip-lock plastic bag over the top (non-cutting end), invert tube, thereby emptying the snow into the bag, and remove the soil plug from bag. 2) If the ground surface is frozen, 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, empty the snow sample into a zip-lock plastic bag held over the other end of the tube (Figure 4). If possible keep snow samples below freezing until they are weighed. Remove small debris (e.g. vegetation, soil clumps) before weighing. Be sure to tare scale to account for the weight of the zip-lock bag.

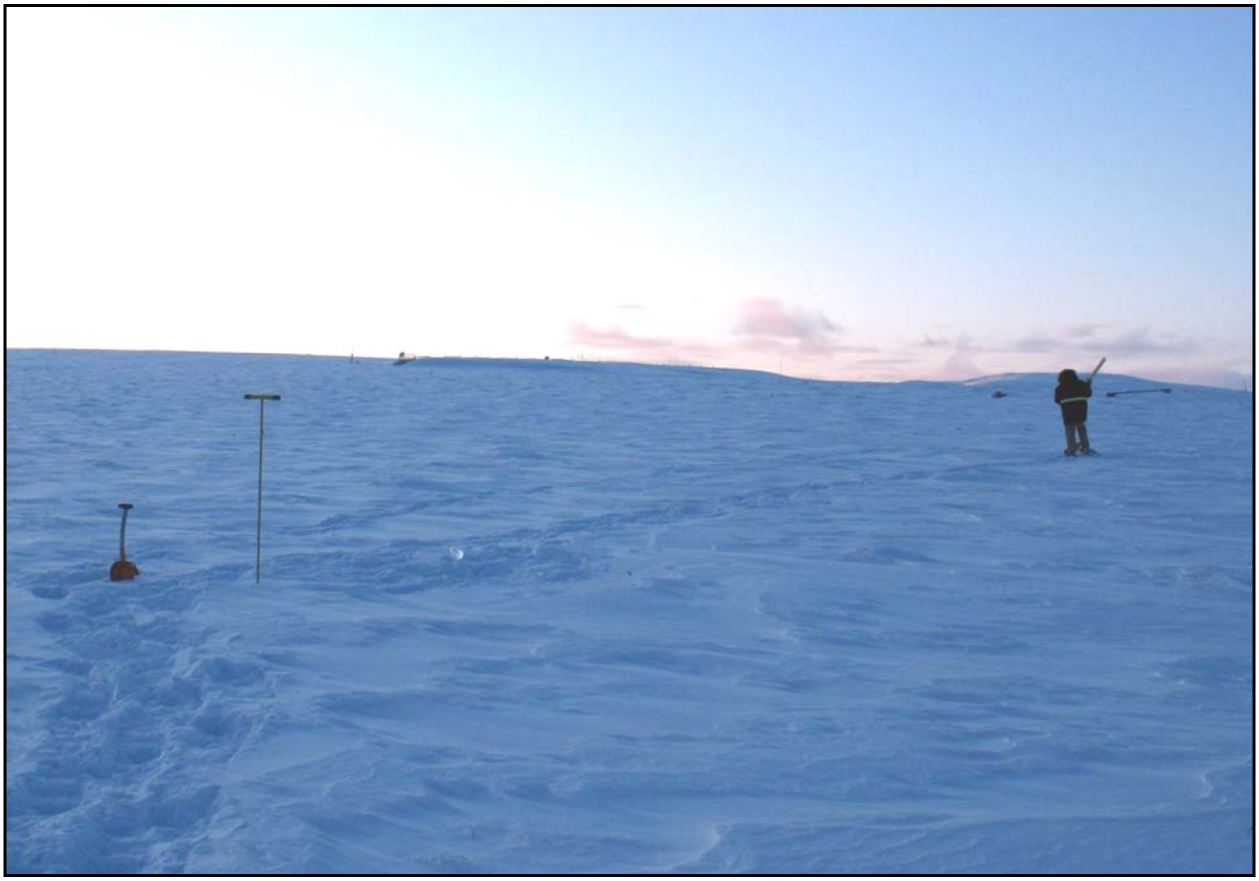

Figure 2. Jeff Derry collecting snow density samples along snow course, T-handle probe for measuring snow depth in foreground, Toolik Lake NRCS index site. Photo by Michael Lilly, November 21, 2009.

Figure 3. Adirondak snow tube inserted to snow/ground interface and snow depth recorded.

Figure 4. Jeff Derry getting ready to invert an Adirondack snow sampler to empty snow sample into plastic zip-lock bag. Site located due south of Toolik Research Camp. Photo by M. Lilly, November 21, 2009.

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 information (i.e. time, weather conditions, location, personnel), as well as any relevant conditions or observations in field form “F-012” (see Appendix B) while on site.
- 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). The first two digits for year, then two digits for month, and the last two digits for 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 keeping form label “F012” with the name, such as “Shaviovik_F012_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. DNR SNOW SAMPLING METHODS

Snow sampling protocols practiced by DNR personnel are detailed below.

3.1 Site Selection

Snow (and co-located soil temperature monitoring) sampling is carried out at pre-established sites accessible by vehicle throughout the winter season. A total of 20 sites cover an area south near Slope Mountain and north to the coast (Figure 5).

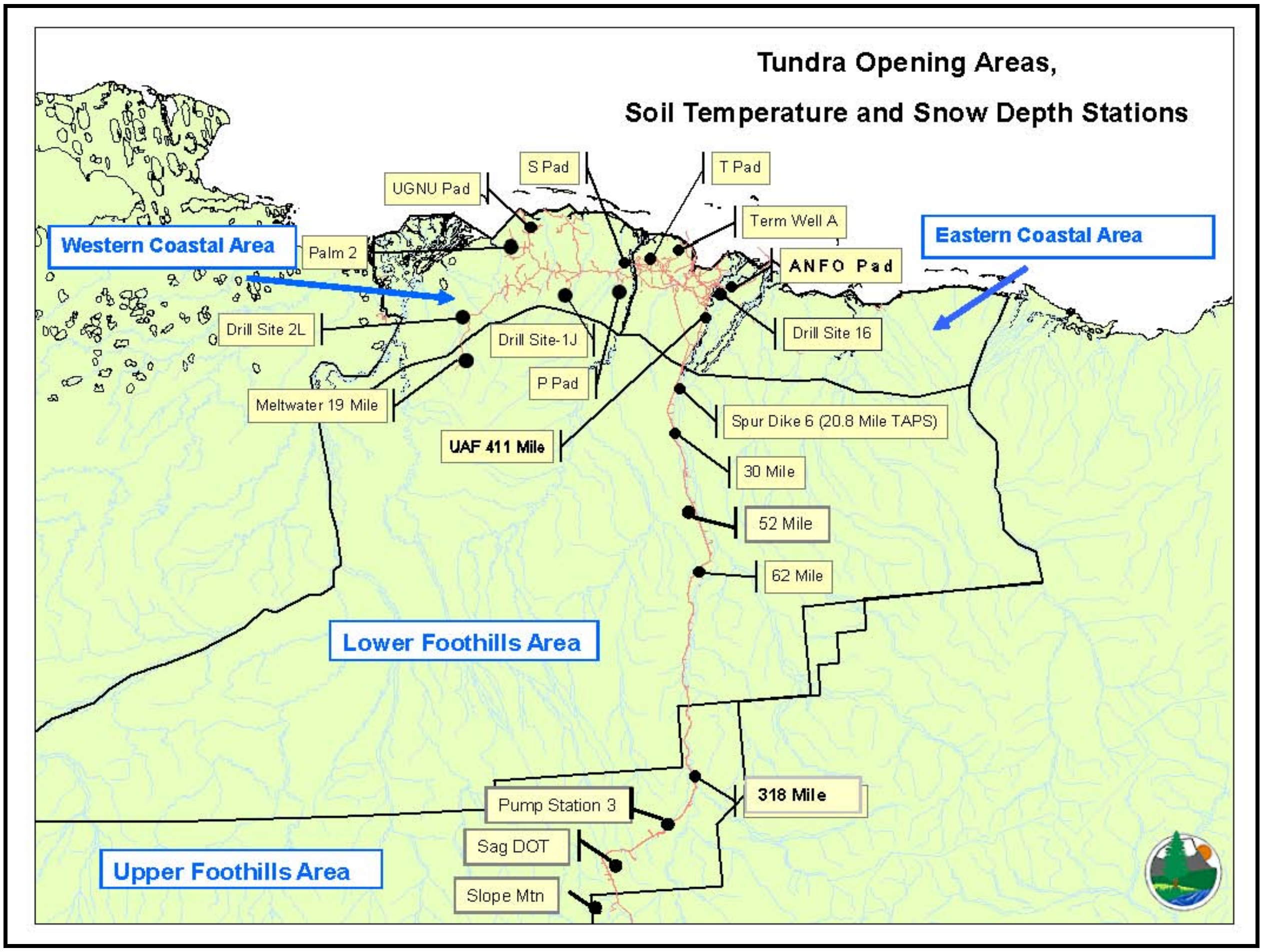

Figure 5. Map of DNR snow sampling and soil temperature sites on the North Slope, Alaska (DNR, 2009).

Sites are visited approximately nine times a season with snow sampling performed at a slightly different location each visit (Figure 6). Note that a station is not visited again once it has met the criteria for tundra opening.

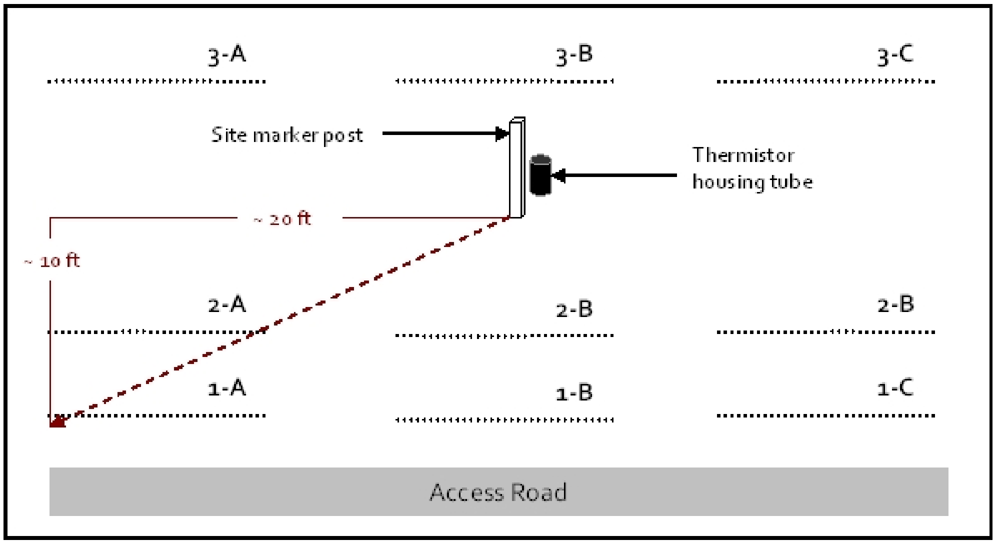

Figure 6. Typical layout of DNR snow and soil sampling site. Up to nine snow depth transects are performed throughout the winter, with the first transect starting at 1-A and final visit being at 3-C (DNR, 2009).

3.2 Snow Depth, Density, and Hardness Measurements

For each site DNR personnel collect snow depth, snow density, and snow hardness data at the appropriate transect location for each visit. Snow depth measurements are along an 11 meter transect. Transects are selected based on an assessment of typical areas that equipment would travel. Areas of large drifts or deep polygon troughs are avoided. Depths are measured every 0.5 meter (1.5 ft) totaling 20 depth values per transect. Two snow densities are collected near transect with a Federal Snow Sampler. The Sampler is pushed through the snowpack to the tundra surface and the depth is recorded to the nearest inch. The protocol includes cutting into the tundra surface, thereby collecting a tundra plug if possible, to ensure the entire snow column is collected. If the tundra is too hard then a trowel/shovel or hand is placed under the sampler to prevent snow from falling out while transferring sample into a plastic bag placed in a bucket. It is later weighed upon returning to the field office so that density can be calculated.

Snow hardness is estimated in the DNR procedures. This is accomplished by digging two snow pits (one to two meters in length) near the snow depth transect. For each pit, a column of snow is analyzed and the following items recorded:

- Total snow depth to the nearest inch from a column of snow selected in the snow pit.
- Loose surface snow presence, strength, and thickness to the nearest inch.
- Slab presence, strength, and thickness to the nearest inch. If there is more than one slab, record the combined total of slab thickness.
- Depth hoar presence, strength, and thickness to the nearest inch.
- Does the slab cap the tussocks (in tussock tundra only).

Layer strength is estimated using the following table (**Table 1**). The index applies when firm, steady pressure breaks through the slab being tested.

Table 1. Snow slab penetration method and number allocation for each (DNR, 2009).

None	Fist	3 Fingers	1 Finger	Pencil	Knife
0	1	2	3	4	5

3.3 Data Documentation

Data collected at DNR sampling locations are recorded in formatted spreadsheets. The spreadsheet includes multiple tabs, one for each of the 9 visits throughout the season. Each tab contains data collected from each field location as well as formatted cells to compute density, SWE, and mean snow depth.

3.4 DNR Sampling Methods Prior to 2009/10

Previous year's snow data collection methods varied from current methods detailed above. Prior to 2005, DNR sampled 25 monitoring stations. Variables sampled included snow depth and ground hardness (using a slide hammer penetrometer) to 30.48 cm (1 ft) depth. In 2005, DNR stopped measuring ground hardness and installed thermistors to measure soil temperature. At this time the number of sites was reduced to that currently monitored. From 2005 until 2008, 10 snow depth measurements were taken along a 10 meter (32.8 ft) transect spaced at 1 meter (3.3

ft) intervals. Density measurements were not collected until the winter of 2008/2009, when DNR began using the method currently in use.

4. METHOD COMPARISON

In an effort to increase understanding related to the applicability of different snow collection methods practiced by GWS and DNR, many GWS sampling sites for the ATN project are co-located with DNR sampling sites. Data from these co-located sites will be analyzed and compared throughout the season. The objective is to determine if the results vary significantly between the two methods described herein, and whether the data collected by using the these two different methods can be integrated, thus allowing for increased temporal and spatial coverage across the North Slope.

5. SUMMARY

Understanding the timing and amount of snow accumulation and its ablation is essential for industry, agencies, and scientific investigations. Certain snow conditions are required before industry can begin tundra travel operations, which is crucial for exploration and logistics. The snowpack is a major factor of the surface energy balance, soil and vegetation processes, and most streams experience peak discharge as a result of the snowmelt in spring. The objective of this document is to report the snow sampling protocol as practiced by GWS and DNR. Documented sampling methods will seek to improve understanding of procedures to be carried out in the field and applicability of integration of data from multiple entities.

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APPENDIX A. GWS Snow-Course Standard Operating Procedure

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

SNOW-COURSE STANDARD OPERATING PROCEDURES

GW Watershed Scientific

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

METHODS:

Site Selection

- For established, yet unmarked, snow-course sites, navigate to the point using a combination of knowledge from previous field trips, landmarks detailed in fieldbooks and utilization of coordinates using a Global Positioning System (GPS). Ensure GPS is WAAS enabled. The typical coordinate system is NAD 83.
- 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.

APPENDIX B. Example GWS Snow-Course Data Entry Spreadsheet and Filled in Spreadsheet for Illustrative Purposes.

A formatted excel spreadsheet like the one shown below can be downloaded from the Arctic Transportation Networks Project website. Following the blank spreadsheet is a real, completed spreadsheet for illustrative purposes. An example spreadsheet can also be requested from the main author of this report by contacting Jeff Derry at jderry@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:

The Excel entry spreadsheet is formatted to calculate summary statistics. An actual snow-course form from an ATN project field campaign is shown below. A few items to consider:

- Cells highlighted in light green require information be entry from field person(s) collecting the data. For some sites, much of this information – site name, survey objective, coordinates, elevation, drainage basin, vegetation type – can be supplied to field crew by ATN personnel and this information can be used for all subsequent sampling for a given location.
- Cells highlighted in peach color are information automatically calculated in the spreadsheet from the information supplied in the light green cells.
- "Slope Direction and Slope Angle" is intended to communicate if sampling was done on a hill, and if so then the angle and direction of the slope estimated by field crew. For sampling in the Coastal Region this will almost always be "Flat".
- "Weather Observations" is the general conditions while sampling, including actual temperature and wind values is not required.
- "Snow-Survey Team Names" is needed in case questions or clarification is required for processing and analyzing the information.
- "Data Entered By and Data QA/QC" cells denotes the person who entered the data in the spreadsheet and who double checked the entries and verified they are correct based on what was recorded in the field book.
- "Reference Markers" refers to if the sampling is done at a marked location.
- "Other" is a good location to note anything that may be of interest or informative, such as condition of snowpack, "snow extremely hard packed", for example.

Arctic Transportation Networks Project
Form F-012: Snow Survey Form

Project ID:	**ATN**	Site Location/Lake ID:	**L9312 - Tundra**
Survey Purpose:	**Determine snow depth/SWE**	Date: 11/19/2009	Time: 9:00

Location Description:	On tundra on staked course, adjacent and north of L9312 weather station.				
Survey objective:	Determine snow depth and density for application to lake recharge studies, and tundra travel management.			Weather Observations:	Dark, cold
Latitude:	N 70° 19.995'	Longitude:	W 150° 56.918'	Datum:	NAD 83
Elevation:	7 ft	Elevation Datum:	BPMSL	Reference Markers:	Orange stakes
Drainage Basin:	Colville River	Slope Direction:	Flat	Vegetation Type:	Lowland Wet Sedge Tundra
Slope Angle:	Flat	Access Notes:	snowmobile	Other:	Snow pack was fairly uniform, some slabbing
Snow Depth Probe Type:		T-probe		Snow-Survey Team Names:	
Snow Tube Type:	Adirondack Snow Tube			Jeff Derry, Jack (LCMF)	

Snow Course Depths (cm)

	1	2	3	4	5
1	16.0	10.0	21.0	19.0	21.0
2	22.0	9.0	18.0	18.0	35.0
3	26.0	9.0	19.0	14.0	58.0
4	21.0	15.0	17.0	14.0	56.0
5	47.0	18.0	10.0	10.0	51.0
6	22.0	20.0	19.0	21.0	45.0
7	14.0	29.0	11.0	17.0	47.0
8	15.0	27.0	11.0	11.0	38.0
9	13.0	24.0	29.0	13.0	34.0
10	12.0	17.0	21.0	17.0	32.0

	(cm)
Average snow depth =	**22.7**
Maximum snow depth =	58.0
Minimum snow depth =	9.0
Standard variation =	12.6

	(inches)
Average snow depth =	**8.9**
Maximum snow depth =	22.8
Minimum snow depth =	3.5
Standard variation =	5.0

Snow Sample Depths and Weights

Bag #	Snow Depth (cm)	Weight (g)	Volume (cm^3)	Density (g/cm^3)	Organic Plug (cm)
D5	18	197.3	642.6	0.31	
D1	16	110.8	571.2	0.19	
D2	14	93.4	499.8	0.19	
D3	22	205.1	785.4	0.26	
D4	55	671.9	1963.5	0.34	

Average Density =	**0.258**	
Average Snow Water Equivalent (SWE) =	**5.9**	cm H2O
Average Snow Water Equivalent =	**2.30**	inches H2O
Average Snow Water Equivalent =	**0.19**	feet H2O

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

Data entered by: Jeff Derry Date: 11/19/09
Data QA/QC by: Michael Lilly Date: 11/19/09

APPENDIX C. Snow Depth Measurement Standard Operating Procedure

Below is a snow depth measurement procedure and is intended to be printed and inserted into field notebook.

SNOW DEPTH COLLECTION PROCEDURE

GW Watershed Scientific

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

METHODS:

Site Selection

- For established, yet unmarked, sites, navigate to the point using a combination of knowledge from previous field trips, landmarks detailed in fieldbooks and utilization of coordinates using a Global Positioning System (GPS). Ensure GPS is WAAS enabled. The typical coordinate system is NAD 83.
- If there is *not* an established and marked 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. 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 measurements near sensor and in a representative environment.

Snow Depth Measurements

- 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). Orient the "L" pattern in the same direction as done in previous visits.
- 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 25^{th} sample is not at the corner stake, return to the corner stake before continuing with the 26^{th} sample.
- Record depths to the half centimeter.

Field Forms

- Fill in all required information in the most current formatted field form (APPENDIX D), 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".
- Copy and paste two photos of the overall sampling area in the field form. If photos are sent separately in an e-mail, 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 depth measurements 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.

APPENDIX D. Example Snow Depth Data Entry Spreadsheet and Filled in Spreadsheet for Illustrative Purposes.

A blank formatted excel spreadsheet like the one shown below can be downloaded from the Arctic Transportation Networks Project website. Following the blank spreadsheet is a real, completed spreadsheet for illustrative purposes. An example spreadsheet can also be requested from the main author of this report by contacting Jeff Derry at jderry@gwscientific.com.

Arctic Transportation Networks Project
Snow Depth Form

Project ID: ____________ Site Location/Lake ID: ____________

Survey Purpose: **Determine Snow Depth** 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 Measurement Team Names:					

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 = ____________

Photographs of Sampling Area

Data entered by: Date:
Data QA/QC by: Date:

The Excel entry spreadsheet is formatted to calculate summary statistics. An actual snow-course form from an ATN project field campaign is shown below. A few items to consider:

- Cells highlighted in light green require information be entry from field person(s) collecting the data. For some sites, much of this information – site name, survey objective, coordinates, elevation, drainage basin, vegetation type – can be supplied to field crew by ATN personnel and this information can be used for all subsequent sampling for a given location.
- Cells highlighted in peach color are information automatically calculated in the spreadsheet from the information supplied in the light green cells.
- "Slope Direction and Slope Angle" is intended to communicate if sampling was done on a hill, and if so then the angle and direction of the slope estimated by field crew. For sampling in the Coastal Region this will almost always be "Flat".
- "Weather Observations" is the general conditions while sampling, including actual temperature and wind values is not required.
- "Snow-Survey Team Names" is needed in case questions or clarification is required for processing and analyzing the information.
- "Data Entered By and Data QA/QC" cells denotes the person who entered the data in the spreadsheet and who double checked the entries and verified they are correct based on what was recorded in the field book.
- "Reference Markers" refers to if the sampling is done at a marked location.
- "Other" is a good location to note anything that may be of interest or informative, such as condition of snowpack, "snow extremely hard packed", for example.
- Insert two photographs of general sampling environment (e.g. general landscape, footprints showing sampling directions, drifting, weather conditions, etc) .

Arctic Transportation Networks Project
Form F-012: Snow Survey Form

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Drainage Basin:	Colville River	Slope Direction:	Flat	Vegetation Type:	Lowland Wet Sedge Tundra
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6	22.0	20.0	19.0	21.0	45.0
7	14.0	29.0	11.0	17.0	47.0
8	15.0	27.0	11.0	11.0	38.0
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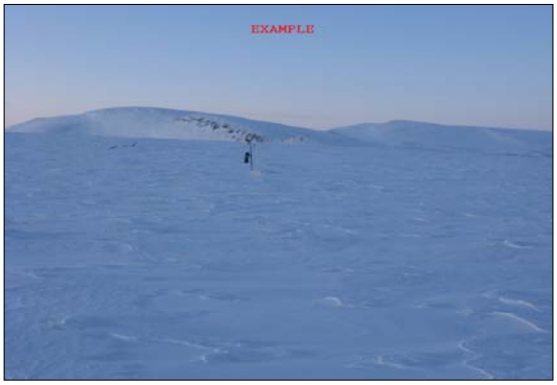
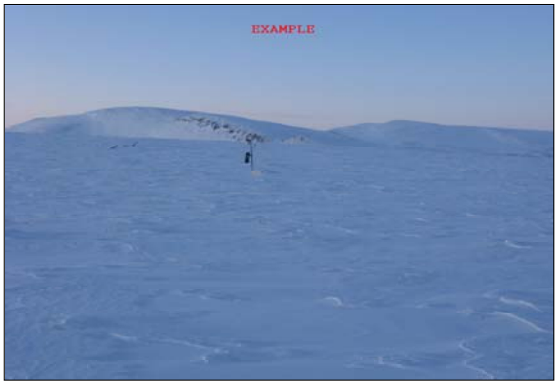
10	12.0	17.0	21.0	17.0	32.0

	(cm)
Average snow depth =	**22.7**
Maximum snow depth =	58.0
Minimum snow depth =	9.0
Standard variation =	12.6

	(inches)
Average snow depth =	**8.9**
Maximum snow depth =	22.8
Minimum snow depth =	3.5
Standard variation =	5.0

Photographs of Sampling Area





Data entered by: Jeff Derry — Date: 11/19/09
Data QA/QC by: Michael Lilly — Date: 11/19/09