Snow Survey Data for the Central North Slope Watersheds: Spring 2011

Ice Jam on the Chandler River near the UAF observation station on May 23, 2011

by

Sveta Stuefer, Emily Youcha, Joel Homan, Douglas Kane and Robert Gieck

Water and Environmental Research Center

September 2011

Umiat Corridor Hydrology Projects

Report No. INE/WERC 11.02

Snow Survey Data for the Central North Slope Watersheds: Spring 2011

by

Sveta Stuefer, Emily Youcha, Joel Homan, Douglas Kane and Robert Gieck

A report on research sponsored by the

Alaska Department of Transportation and Public Facilities

September 2011

Umiat Corridor Hydrology Projects

Report Number INE/WERC 11.02

Recommended Citation:

Stuefer, S.L., Youcha, E.K, Homan J.W., Kane, D.L. and Gieck, R.E. 2011. Snow Survey Data for the Central North Slope Watersheds: Spring 2011. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 11.02, Fairbanks, Alaska, 47 pp.

Fairbanks, Alaska

September 2011

For additional information write to:

Publications,
Water and Environmental Research Center
University of Alaska Fairbanks
Fairbanks, Alaska 99775
http://ine.uaf.edu/werc/

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

DISCLAIMER

The content of this report reflects the views of the authors, who are responsible for the accuracy of the data presented herein. This research was funded by the Alaska Department of Transportation and Public Facilities (AKDOT&PF). This work does not constitute a standard, specification, or regulation.

The use of trade and firm names in this document is for the purpose of identification only and does not imply endorsement by the University of Alaska Fairbanks, Alaska Department of Transportation and Public Facilities, or other project sponsors.

CONVERSION FACTORS, UNITS, 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 purpose of this report, both English and international engineering metric unit system (SI) units were employed. The choice of "primary" units employed depended on common reporting standards for a particular property or variable measured. In most cases, 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.

<u>Datum:</u>

The horizontal and vertical datum for all locations in this report is the World Geodetic System 1984 (WGS84).

Abbreviations, Acronyms, and Symbols

AAS	Alaska's Arctic Slope
AKDOT&PF	Alaska Department of Transportation and Public Facilities
cm	centimeters
F	Fahrenheit (°F).
ft	feet
in	inches
kg	kilograms
km^2	square kilometers
m	meters
mph	miles per hour
NGVD	National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
QA	quality assurance
QC	quality control
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

ACKNOWLEDGMENTS

This project was funded by grant ADN #2512023, Alaska Department of Transportation and Public Facilities. Ken Irving, Joel Bailey and many others from WERC/UAF participated in snow data collection. Contribution of Michael Lilly and Jeff Derry to the earlier snow reports (2008, 2009, 2010) is greatly appreciated.

Snow Survey Data for the Central North Slope Watersheds: Spring 2011

1. INTRODUCTION

This report is the sixth in a series of annual snow survey data reports, published each year since 2006 (Kane et al., 2006; Berezovskaya et al., 2007a and 2007b; Berezovskaya et al., 2008a and 2008b; Berezovskaya, et al., 2009; and Berezovskaya et al., 2010). Discussed in this report are the snow conditions observed during the 2011 end-of-winter snow surveys in the following watersheds: Chandler, Anaktuvuk, Itkillik, Kuparuk and western Sagavanirktok River watersheds. Snowpack field studies focused primarily on the maximum snow water equivalent (SWE) accumulation of the 2010–2011 winter and subsequent ablation. Field activities started at the end of April because, by then, the snowpack reflects nearly the maximum precipitation that has fallen minus sublimation (Benson et al., 1986) from October to April. Difficulties in quantifying snow precipitation and sublimation imply that measurements of snow accumulated on the ground provide the most reliable observational component of the net winter water budget for use in hydrologic studies.

Assessment of maximum snow accumulation at winter's end is critical information in snow hydrology studies. The seasonal snowpack constitutes winter storage of precipitation, induces considerable differences in surface energy balance, and affects the amount of soil desiccation that occurs within the organic layer overlying the permafrost (Kane et al., 1978). Snowmelt is a major hydrological event each year in the Arctic. For many larger river basins on Alaska's Arctic Slope, particularly in the larger basins like the Colville and Kuparuk Rivers, peak discharge of record is during snowmelt. These rivers drain a large area that extends from the Brooks Range through the northern foothills and across the coastal plain before flowing into the Arctic Ocean. Snow starts contributing to runoff in May in the southern foothills, and melting is usually complete within a month. Due to extremely high snowpack heterogeneity, knowledge of SWE spatial distribution is critical for understanding a river basin's hydrologic response during ablation. This report presents snow depth, snow density and snow water equivalent observational data for the central part of the Alaska's Arctic Slope (AAS). It summarizes 2011 data collection procedures, accuracy of observations, and spatial distribution.

2. STUDY AREA

The study domain covers a 200-by-240-km region of Alaska's Arctic Slope (AAS) that is bound by the Brooks Range on the south and the Arctic Ocean on the north, and includes the Chandler, Anaktuvuk, Itkillik, Kuparuk and western part of the Sagavanirktok River basins. The Chandler River, located in the far west of the study area, drains from the high elevation Chandler Lake and is approximately 225 km long with a drainage area of 5800 km^2 (above our hydrologic observation station). It empties into the Colville River below Umiat. The Anaktuvuk River, which is 215 km long and has a drainage area of 7000 km^2 (above our hydrologic observation station), flows from a glacier in the Endicott Mountains to the Colville River. The upper Itkillik has a basin area of approximately 1900 km^2 and is 153 km long (above our hydrologic observation site, which is located in the upper part of basin near the proposed bridge crossing). The Kuparuk River is 240 km long and has a drainage area of about 8140 km^2. Headwaters of the Kuparuk River include small area of the Brooks Range. Most of the watershed is located in the Foothills and on the Coastal Plain. The Sagavanirktok River is about 290 km long and has a drainage area of about 14,900 km^2, mainly in the Brooks Range. The Kuparuk and Sagavanirktok Rivers flow directly into the Beaufort Sea, while the other streams flow first into Colville River.

The southern and northern boundaries of the domain are at 68°10′N and 70°15′N latitude, respectively. The western and eastern boundaries of the domain are at 150°00′W and 148°00′W longitude, respectively. Elevation within the study area ranges from sea level to 2675 m (0 to 8025 ft). The topography is characterized by a flat northern portion (generally referred to as *Coastal Plain*) and by gently rolling hills and valleys (*Foothills*) and mountain ridges (*Mountains*) of the Brooks Range to the south (Figure 1).

Vegetation consists of sedge tussocks and mosses, which cover much of northern Alaska. Mountains vegetation consists of alpine communities, while the vegetation of the coastal plain is mostly grasses and sedge tussocks. Occasional groupings of willows, approximately 1 m (3 ft.)

high, occur in hillside water tracts and in valley bottoms. The surface organic soils vary from live organic material at the surface to partially decomposed organic matter between 10 and 20 cm (4 in.–8 in.) in depth. The mineral soil in the glaciated areas is silt overlying glacial till (Kane et al., 1989). In the mountainous regions, weathered bedrock may be exposed at the surface. Overall, the topography and vegetation of the domain are representative of the AAS region.

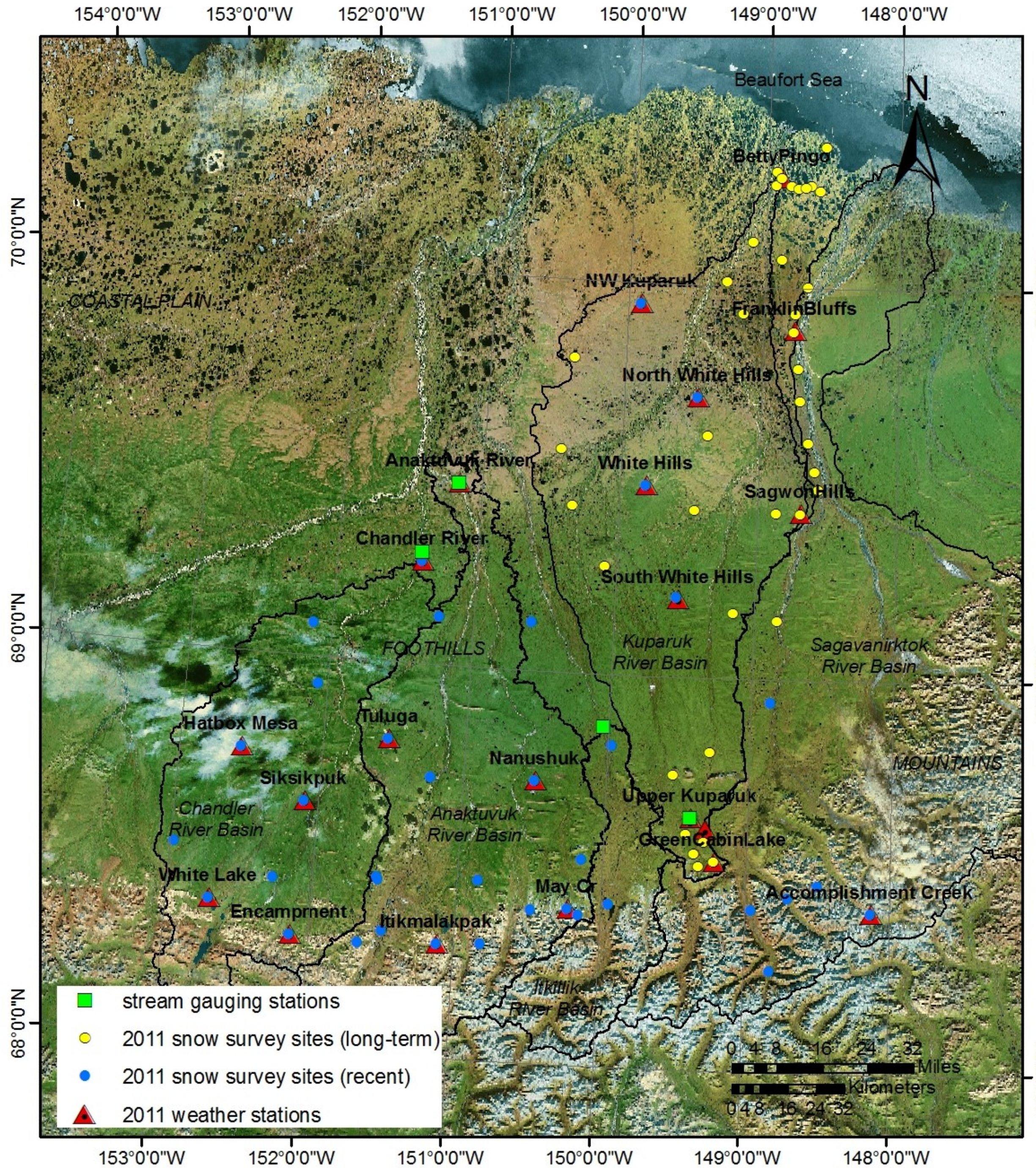

Figure 1. Geographical map of study area shows weather stations (they also double as snow survey sites) and snow survey sites visited in April, 2011. Long-term snow survey sites (10 or more years of data) are highlighted in yellow. Plotted watershed boundaries above hydrologic observation stations were derived from the digital elevation model by WERC researchers.

3. SAMPLING METHODS

Snow surveys are made at designated locations throughout the domain to determine snow depth, as well as vertically integrated density and snow water equivalent. Except when making ablation measurements (see Section 3.2), most of the sites are visited once a year near the peak of snow accumulation, generally the last week of April. Our observations show that the onset of ablation is typically in May. The end of April is a good time to capture end-of-winter SWE. March, April, and May are often the months of lowest precipitation, and therefore there is usually little accumulation between the end of winter snow surveys and the onset of ablation.

In addition to snow surveys, snow depths are collected continuously throughout the winter at meteorological stations, which are equipped with SR50 snow depth sensors. Snow depth sensor readings can be collected in near real time or downloaded in the field directly from a data logger.

3.1 Snow Survey

Our snow surveys include gravimetric SWE sampling and snow depth measurements collected over a 25-m-by-25-m area; this technique is often referred to as *double sampling*. The Alaskan snowpack is extremely heterogeneous, with snow depth being more variable than density (Benson and Sturm, 1993). Usually, double sampling yields an areal SWE estimate with a lower variance than is possible using collected snow cores only. Rovansek et al. (1993) showed that double sampling provides improved SWE estimates; they recommended sampling 12 to 15 snow depths for each snow core. This optimal ratio of snow depths to water equivalent, however, appeared to vary greatly (from 1 to 23), depending on site, weather and snow conditions. Currently, we use an optimal ratio of 10; that is, 50 depths accompany 5 snow cores.

Snow cores are sampled using a fiberglass tube ("Adirondack") with an inside area of 35.7 cm^2, equipped with metal teeth on the lower end to cut through dense layers of snow. The advantage of the Adirondack for shallow snowpack is that its diameter is larger than many other types of snow tubes (like the Mt. Rose); thus, it provides a larger sample of the shallow Arctic snowpack. To obtain a complete snow core, the Adirondack tube is pushed vertically through the snow while turning, until soil is encountered. At this point, snow depth is recorded. The tube is then driven further into the organic layer and tipped sideways, retaining a vegetation plug; this ensures that the complete snow column was sampled. The vegetation plug is removed and the snow is either collected for weighing later in the laboratory or weighed in the field. Five snow cores are usually taken to estimate average snow density.

We use constant 50-m lengths for the snow depth course, with a 1-m sampling interval along an L-shaped transect. Twenty-five depth measurements are made on each leg of the L; this strategy is used to account for the presence of snowdrifts in the area of measurement. The directions of measurement are chosen randomly. Snow depth measurements are collected using a T-shaped graduated rod (T-probe). The probe is simply pushed through the snow to the snow–ground interface.

Snow water equivalent is defined as:

$$SWE = (SD * \rho_s) / \rho_w \qquad (1)$$

where ρ_s is average snow density from the 5 snow core samples, ρ_w is water density, and *SD* is an average of 50 snow depths.

3.2 Snow Ablation

Starting with the 2007 Kuparuk Foothills snow survey data report, we have summarized long-term snow ablation observations (Table 1) that have been conducted continuously since 1985 from earlier funded National Science Foundation, Office of Polar Programs projects. The data is presented in Appendix B.

Table 1. Summary of snow ablation sites from north to south.

Site Name	Period of Record	Comments
Betty Pingo	1993 to 2011	Surveyed near NRCS precipitation gauge.
West Dock	1999 to 2009	150 m east of West Dock–GC1 Road, approximately one mile south of West Dock Meteorological Site.
Franklin Bluffs	1988 to 2011	Surveyed near Met site 1988 to 1998 (with some missing years), snow site moved west 700 m along access road 1999 to 2010.
Anaktuvuk	2011	10 meters north (upstream) of Anaktuvuk hydro-meteorologic station
Sagwon Hill	1988 to 2011	Adjacent to the Sagwon Meteorological Site
Chandler	2011	Helicopter landing area near Chandler River meteorological station on bluff above the river
Happy Valley	1999 to 2011	Survey site 150 m west of Dalton Highway from Happy Valley Airfield.
Oil Spill Hill	2010	Surveyed 250 m west of pullout on top of Oil Spill Hill along the Dalton Highway.
Itkillik	2011	Right bank on lower terrace, 200 meters north of Itkillik River surface-water observation station
Upper Kuparuk	1999 to 2011	Adjacent to the Upper Kuparuk Meteorological Site.
Imnavait basin	1985 to 2009	Snow ablation measured at 4 sites on west-facing slope at mid-basin 1985 to 1988, at a 6-site mid-basin transect 1989 to 1997 and at a 6-site transect along UTM 612800 northing from 1999 to 2010.
Galbraith	2010	West of Galbraith Airport, adjacent to gravel pit access road.
Atigun Pass	2010	30 meters north of NRCS precipitation gauge.

3.2.1 Observations from 1985 to 2010

Measurement methods have changed over time as techniques have been modified to improve sampling accuracy and as the study area has expanded. From 1985 to 1992, SWE was estimated from 10 randomly collected snow cores. These cores were sampled using Adirondack tubes and weighed using mechanical scales, calibrated in inches of water. To overcome the difficulty of weighing samples in frequent high-wind conditions, cores were placed in bags in the field and weighed indoors, using the Adirondack mechanical scale and, after 1999, digital scales. Following Rovansek et al. (1993), the double sampling technique, which was adopted in 1996, is still used (Section 3.1). During the transition period (1993–1995), 5 to 20 snow cores were taken, along with 50 snow depths. Snow depths have been measured using a variety of devices, such as the Adirondack snow tube, avalanche probes, T-handled graduated probes, MagnaProbe, and ski poles and rods with added graduated scales.

A number of observational sites have changed over time (Table 1). In 1985, SWE and ablation were observed only in the Imnavait Creek basin. Sagwon Hill (SH) and Franklin Bluffs (FR) sites were added in 1986 (although measurements were often lacking). Snow surveys at the Sagwon site were usually made just east of the meteorological site. The Franklin Bluffs sampling site was located from 1986 through 1998, adjacent to the meteorological site 1 km east of the Dalton Highway. In 1999, the snow survey and ablation site was moved west approximately 300 m from the highway. The Betty Pingo site on the Prudhoe Bay Oilfield was established in 1992. This snow survey site is located near the NRCS Wyoming snow gauge about 200 m north of the Kuparuk Pipeline Road between P-Pad and Gathering Center 2. Upper Kuparuk, Happy Valley, and West Dock snow survey and ablation sites were added in 1999. Three snow ablation sites at Oil Spill Hill, Galbraith and Atigun Pass were monitored only one year in 2010.

Imnavait Creek basin (IB) differs from others in that it has the longest period of record and more detailed observations. Several sites were sampled across the basin to capture basin average SWE. From 1985 through 1997, the Imnavait basin SWE was determined from a transect made across the basin, perpendicular to the stream channel. At that time, snow ablation was tracked only at the west-facing slope adjacent to 4 runoff plots (Hinzman, 1990). In 1989, two additional sites were added: one in the valley bottom and one on the low east-facing slope of the basin. To provide consistent identification of sites, the transect has been aligned with the 7612800 northing (NAD27, UTM6) since 1999.

3.2.2 Observations from 2011

Snow ablation measurements were supported by the WERC/UAF project "Long-term measurements in the Kuparuk River Watershed" funded by National Science Foundation since 2005. Support from this NSF project was no longer available since spring 2010, which had resulted in the reduction of the snow survey and ablation sites. Ablation observations were discontinued at the West Dock (WD), and at 6 sites across the Imnavait basin (IB1–IB6). Instead, three more sites (Itkillik, Anaktuvuk, and Chandler) were added in 2011. These sites were visited daily or every other day to capture the net volumetric decrease in SWE. We took 5 snow density and 50 snow depth measurements at each site. The snow depth course during snowmelt has an assigned location because of numerous repeated measurements.

3.3 Snow Depth Sensors

The study domain includes sixteen meteorological stations each equipped with a sonic snow depth sensor. Four stations in the Sagavanirktok and Kuparuk River basin were established in August 2006 (Table 2, Figure 1). Five stations were established in the Anaktuvuk River basin in June 2009 and five stations were installed in the Chandler River basin in September 2010. The snow depth sensor type is Campbell Scientific Sonic Ranger SR50 or SR50(A). The only difference between the SR50 and SR50(A) is the housing encasing the ultrasonic sensor. The sensor emits a 50 kHz sound pulse and measures the time the pulse takes to return to the sensor. Ultrasonic sensors can measure the distance to any reflective surface like the ground or water, but sensitivity of the SR50(A) is designed for measuring distance to a snow surface.

Table 2. Meteorological stations with an SR50 snow depth sensor included in this report.

	Site Name	General Location
1	Accomplishment Creek (DBM1)	Sagavanirktok River, Brooks Range
2	South White Hills (DFM1)	Kuparuk River, Foothills
3	White Hills (DFM2)	Kuparuk River, Foothills
4	North White Hills (DFM3)	Kuparuk River, Foothills
5	Northwest Kuparuk (DFM4)	Kuparuk River, Foothills
6	Itikmalakpak (DUM1)	Anaktuvuk River, Brooks Range
7	Upper May Creek (DUM2)	Anaktuvuk River, Brooks Range
8	Nanushuk (DUM3)	Anaktuvuk River, Foothills
9	Tuluga (DUM4)	Anaktuvuk River, Foothills
10	Anaktuvuk (DUS2)	Anaktuvuk River, Foothills
11	Encampment Creek (DUM5)	Chandler River, Brooks Range
12	White Lake (DUM6)	Chandler River, Brooks Range
13	Hatbox Mesa (DUM7)	Chandler River, Foothills
14	Siksikpuk (DUM8)	Chandler River, Foothills
15	Chandler River Bluff (DUS3)	Chandler River, Foothills

The method for measuring snow depth with the SR50 is simple subtraction. When there is no snow on the ground, the distance measured is the sensor's height above the ground. When snow has accumulated under the sensor, the distance measured is to the snow surface. The difference between distance-to-ground and distance-to-snow surface yields snow depth. For example, if the sensor's height above the ground is 50 inches and 10 inches of snow accumulates, the new distance to surface will be 40 inches. Hence, 40 inches subtracted from 50 inches gives a depth of 10 inches under the sensor. The ultrasonic pulse has a measurement cone circumference of 22º from the bottom of the sensor. The program for the SR50 records measurements at one minute intervals and reports hourly averages.

4. ACCURACY OF OBSERVATIONS

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

4.1 Snow Water Equivalent

Snow density and SWE are estimated using snow core sampling. Woo (1997) showed that a larger tube diameter increases the accuracy of density determination; Woo also showed that the Canadian sampler (similar to the Adirondack in diameter) captures snow density within 5% of snow pit estimates. Our field comparison of Adirondack-to-snow-pit density gives similar results.

The accuracy of a single snow depth measurement depends on properties of underlying organic material. In the area of well-developed organics on top of the mineral soils, snow depth is often overestimated (Berezovskaya and Kane, 2007). While measuring, the probe can easily penetrate low-density organic material, so this additional depth often is incorporated inadvertently into the snow depth measurement. Any type of correction to existing snow depth records is difficult to perform because the error varies strongly from observer to observer and depends on snow and soil conditions at each site.

Whereas snow depths show a systematic overestimation error, snow core densities tend to be close to true value or slightly underestimated. The difficulty in SWE accuracy interpretations is that actual, accurate SWE is unknown. Comparing different sampling methods, Berezovskaya and Kane (2007) concluded that the SWE of tundra snow, estimated with the double sampling technique, has an error of ±10%.

4.2 Snow-Depth Sensors

High frequency, small amplitude noise is inherent in ultrasonic snow depth sensors and can be an impediment to accurate snow accumulation measurements (Brazenec, 2005). Since the speed of sound in air is affected by the temperature of the air it is traveling in, an air temperature is measured to correct distance readings. Sensor mounting height can influence data quality with higher mounting heights resulting in noisier data. Manufacture's stated accuracy is ±1 cm or 0.4% of distance to snow surface, whichever is greater (Campbell, 2008). Inaccuracies can be caused by difficulty in establishing a zero point due to tussocks/uneven ground, vegetation growth, neglecting periodic maintenance requirements (replacement of sensor transducer), high wind, falling snow, low density snow, blowing snow, and change in sensor height due to ground heave.

Sonic snow depth records in this report were adjusted manually to account for both field observations and erroneous data points. Typically, erroneous data occurred during high wind/blowing snow events as well as beginning and end of seasonal transition periods. Just prior to the 2008-2009 snow season, the ground surface under the snow sensors was trimmed of vegetation and leveled with wood bark. This resulted in improved clarity when deciphering the timing and amount of snow accumulation at the beginning and end of the season.

Diligent field practices are essential for accurate measurements and post-processing data corrections and QA/QC purposes. Our field procedures during site visits include:

- Measuring distance from the sensor to the ground during snow free season. Measuring snow depth under the sensor.
- Measuring distance from sensor to snow surface. Conduct snow survey near the sensor.
- Inspect sensor and supporting structure for proper leveling and structural soundness.
- Inspect sensor for corrosion, ice on sensor, replace if it is necessary.

We usually visit these sites twice per year, once in the fall when there is no significant snow and once in the spring about the time of maximum SWE. If we visit these sites in the winter, we take all of the measurements mentioned above. On-site checks during field visits ensure proper operation and accuracy of the snow sensor.

5. SPATIAL DISTRIBUTION OF SNOW SURVEY SITES

Snow survey sites are chosen to represent snow characteristics over a wide range of vegetation and terrain conditions (Figures 2 and 3). Snow water equivalents are measured at elevations from 5 m to 1478 m (16.4 ft to 4849 ft. To determine regional average SWE, snow sites are classified as Coastal Plain, Foothills and Mountains (Appendix A1–A3). This classification is based on elevation and surrounding topography. Coastal sites are generally located below an elevation contour of 500 ft (152 m). Foothills sites are located above 500 ft (152 m) and below elevation contour of 3300 ft (1000 m). Elevation alone is not always representative for the classification of Mountains sites, because many of them are located in lower elevation valley bottoms where a helicopter can safely access the site. We selected Mountains sites either based on elevation (above an elevation of ~3300 ft (1000 m)) or based on surrounding topography. If the mountain ridges around the snow survey site are above 3300 ft (1000 m), we classified this site as Mountains even if the site itself is located at the lower elevation (Appendix A1–A3).

Overall, 77 sites were visited in 2011. This number includes 16 sites located in the Mountains, 40 sites in the Foothills, and 21 sites on the Coastal Plain.

6. SNOW SURVEY DATA

We observed in 2011 that the average Coastal Plain snow density (0.543 slug ft^{-3}, 280 kg m^{-3}) is higher than the Foothills snow density (0.448 slug ft^{-3}, 231 kg m^{-3}) and Mountains snow density (0.471 slug ft^{-3}, 243 kg m^{-3}) (Appendix A1–A3).

In 2011, the average Coastal Plain SWE is 5.1 in. (13.0 cm), and snow depth is 18.0 in. (45.7 cm). The average Foothills SWE is 4.9 in. (12.3 cm), and average snow depth is 20.2 in. (51.4 cm). The average Mountains SWE is 3.7 in. (9.5 cm), and average snow depth is 14.9 in. (37.8 cm); both these measurements are generally lower than those of the Coastal Plain and Foothills. Figure 2 and Figure 3 show the snow depth and SWE at each snow survey site.

Observations from year to year suggest that regional end-of-winter SWE and snow depth of the Foothills and Coastal Plain are generally higher than those of the Mountains. Similarly, the average Coastal Plain snow density is generally higher than the Foothills and Mountains snow density.

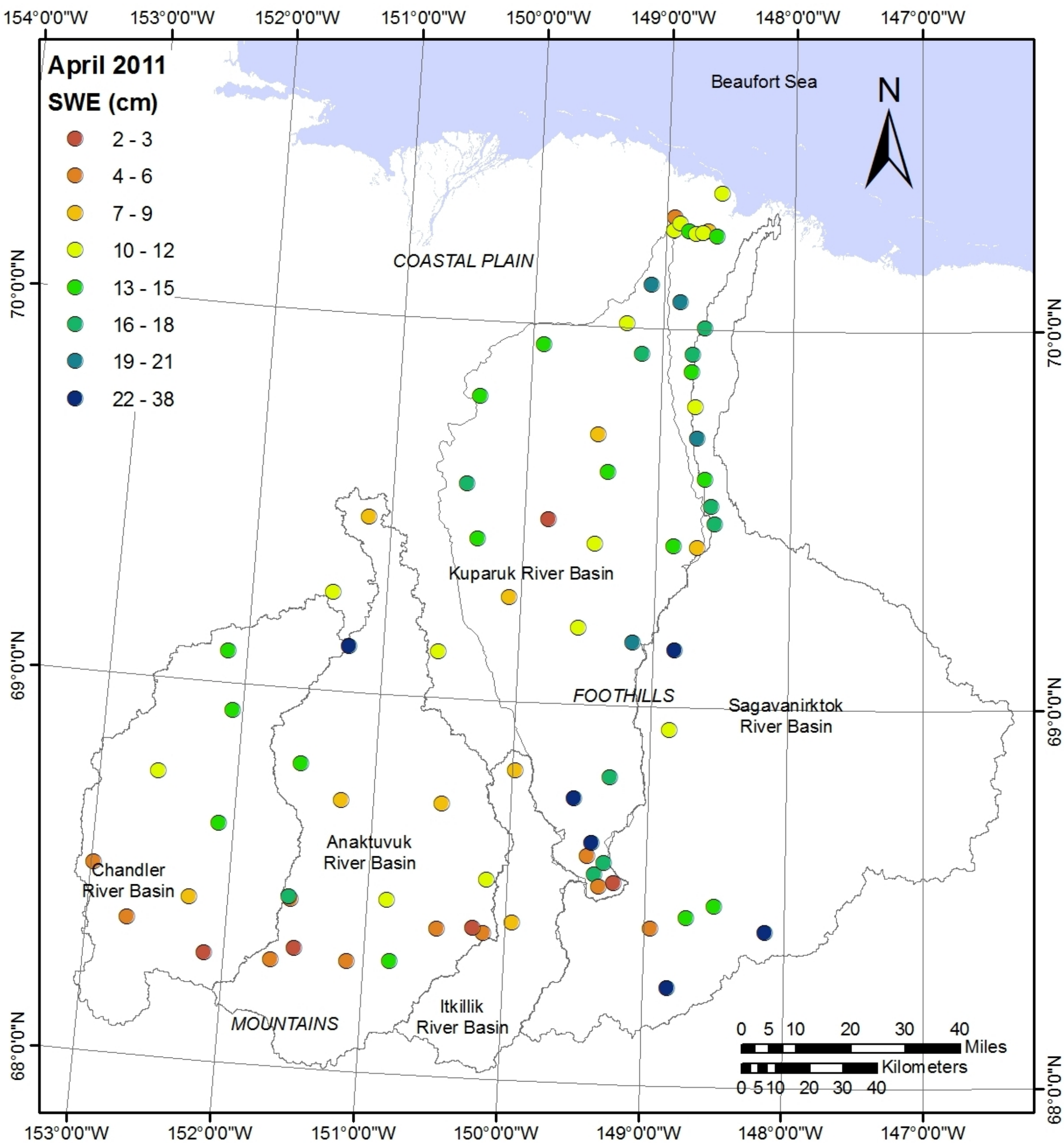

Figure 2. End-of-winter snow depth (cm) in the Central North Slope of Alaska in spring 2011. Each point represents average from 50 snow depths.

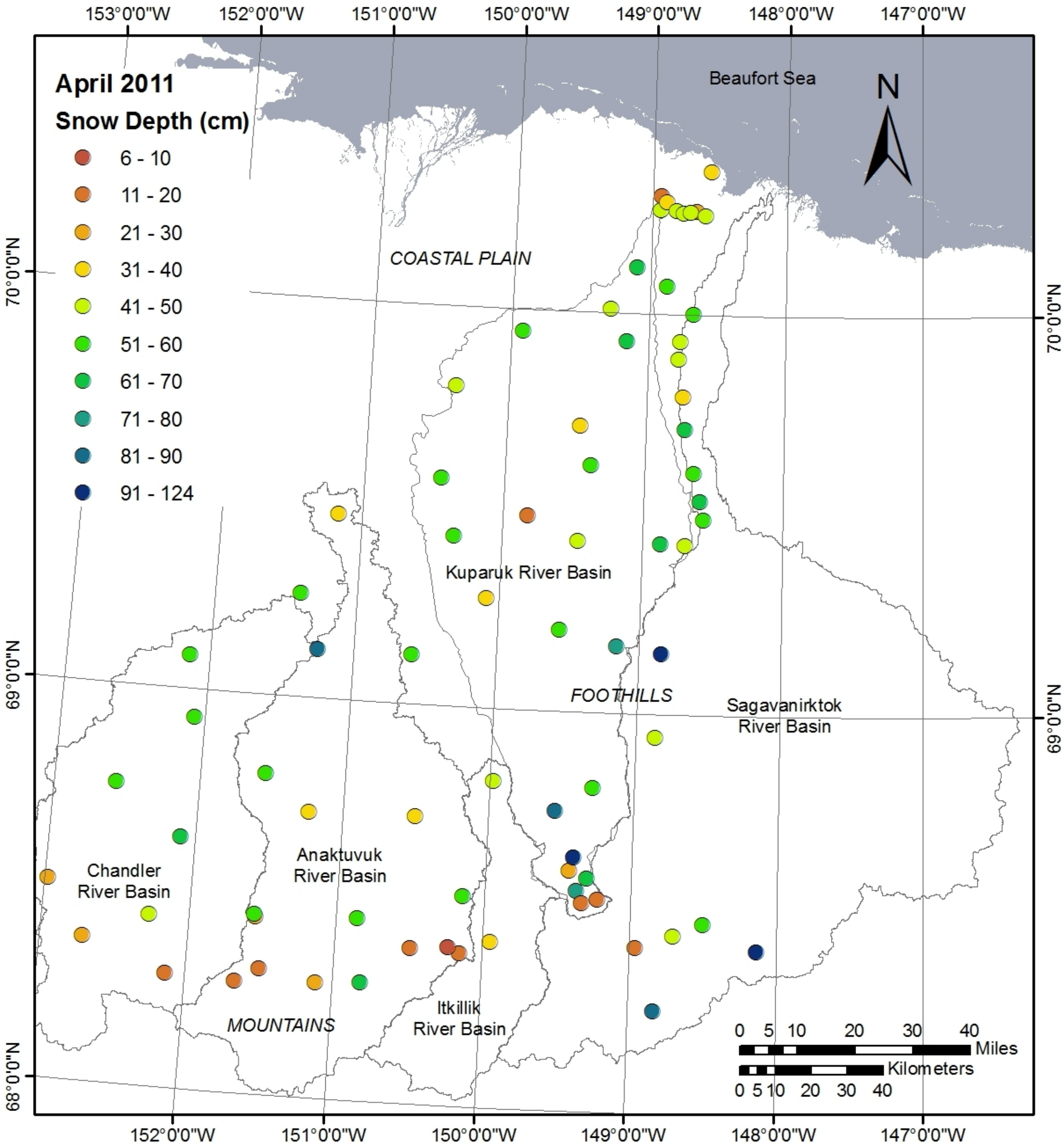

Figure 3. End-of-winter snow water equivalent (cm) in the Central North Slope of Alaska in spring 2011.

The number of visited snow survey sites at each basin varies from year to year because weather conditions do not always allow access to all the stations by helicopter; also research funding varies from year-to-year. The SWE average, presented in Table 3, should be interpreted with care as a slightly different number of stations is visited each year. Note, this year we added six new sites in the Chandler River basin and one new snow survey site in the Itkillik River watershed. Additionally, we no longer measure snow water equivalent at most of the former Sagavanirktok and further east sites.

The Anaktuvuk and Chandler River watersheds have similar end-of-winter SWE in 2011 when compared to 2010 (98% and 95% of the 2010 SWE). Kuparuk and Sagavanirktok have more end-of-winter SWE in 2011 compared to the previous year (122% to 187% of the 2010 SWE). Overall, the watershed averaged SWE showed an increase in end-of-winter SWE as compared to 2010.

Table 3. Basin average Snow Water Equivalent (SWE) for 2011.

Basin	Number of sites	2011		Percent of last year
		SWE (cm)	Std. Dev. (cm)	%
Chandler	9	10.4	5.7	98
Anaktuvuk	15	7.6	4.3	95
Itkillik	2	8.8	0.05	135
Kuparuk	25	12.6	6.1	122
Sagavanirktok	13	17.3	8.4	187

Long-term observations snow observations

The longest snow survey record on the AAS has been maintained by the U.S. Department of Agriculture (USDA) since the 1970s, based on few snow survey sites visited along the Dalton Highway. Our snow survey dataset covers shorter period of time (2000–2011), but it has more detailed spatial coverage: 42 snow survey sites that represent SWE at the different topographic and vegetation conditions. Long-term snow survey sites cover the Kuparuk River watershed and different landscape units along the Dalton Highway, located in the Sagavanirktok and Putuligayuk River watersheds (see snow survey site highlighted in yellow on Figure 1). These sites are visited every year, if the weather allows. In addition, the short-term snow dataset (six or less years of data) are not included in basic statics of Table 4 and the discussion below.

End-of-winter SWE in 2011 accounts for 129% of the 12-year basin average SWE. The 2011 end-of-winter SWE for the Foothills and Coastal Plain are higher than average and represent 116% and 128%, respectively, of the 12-year basin average SWE. The Foothills and Coastal Plain had the highest 12-year SWE average (15.4 and 13.4 cm, 6.1 and 5.3 in.) in 2009 (Table 4). SWE in 2011 is the second highest in the record – 13.6 cm (5.4 in) in the Foothills and 12.9 cm (5.1 in.) on the Coastal Plain. In 2010, the number of long-term observational sites in the Kuparuk River basin was decreased by 50%. Only one snow survey site was visited in the Mountains in 2010 and 2011. Usually, SWE in the Mountains region was lower than the Foothills and Coastal Plain regions. Note that the reduced number of sites in the Mountains affects domain averages, making them slightly higher. This database has become long enough that we can start to analyze variability from year to year (Table 4). The highest snow accumulations were observed in 2003, 2009 and 2011, whereas 2001, 2006, 2008 were relatively low snow years.

Table 4. Maximum, minimum, and average snow water equivalent in the Coastal Plain, Foothills, and Mountains of the Kuparuk, Sagavanirktok, and Putuligayuk regions from the long-term measurements (2000–2011, n=12). The statistics below do not include short term (less than six years of data) snow survey sites.

Region	2011		Maximum		Minimum		Average	
	cm	in.	cm (year)	in.	cm (year)	in.	Cm	in.
Mountains	-	-	14.7 (2003)	5.8	3.5 (2008)	1.4	8.1	3.1
Foothills	13.6	5.4	15.4 (2009)	6.1	8.9 (2006)	3.5	11.7	4.6
Coastal Plain	12.9	5.1	13.4 (2009)	5.3	8.4 (2001)	3.3	10.1	4.0
Domain average	13.2	5.2	13.2 (2011)*	5.0	7.3 (2008)	2.9	10.2	4.0

***** domain average SWE in 2011 is affected by lack of measurements in the Mountains

7. SONIC SNOW DEPTH DATA

Snow sensor data used in conjunction with snow survey data can enhance and expand the information gained from both sampling methods. Since an ultrasonic sensor records snow depth at a single point, the additional fifty snow depth measurements near each station represent local-scale variability relative to the measurement area under SR50 sensor (Table 5 and Figures 4-18). There is considerable variability in terms of how well snow sensors represent local snow course depths from year-to-year, which in large part is dependent on the location the snow depth sensor. For example, the SR50 sensor at North White Hills (DFM3) station (Figure 7) consistently records a lower snow depth than the fifty observed depths near the station.

Table 5. Snow depth information from meteorological stations and co-located snow surveys.

Meteorological Station	Snow Survey Depth Range (cm)	Snow Survey Depth Average (cm)	Observed Depth Under SR50 (cm)	SR50 Reported Depth at Time of Observed Depth (cm)	Difference Between Observed and SR50 Reported Depth (cm)
Accomplishment Creek (DBM1)	28-141	102.4	79	82.3	-3.3
South White Hills (DFM1)	41-76	55.2	NA	50.1	NA
White Hills (DFM2)	0-21	12	16	16	0
North White Hills (DFM3)	15-52	30.6	22	26	-4
Northwest Kuparuk (DFM4)	28-79	51.5	61	61.4	-0.4
Itikmalakpak (DUM1)	16-51	26.5	18	16	2
Upper May Creek (DUM2)	1-15	6.4	5	4.3	0.7
Nanushuk (DUM3)	5-66	32.9	17	15.2	1.8
Tuluga (DUM4)	11-87	53.5	54	53.6	0.4
Encampment Creek (DUM5)	0-37	12.2	1	NA	NA
White Lake (DUM6)	10-45	23.1	27	24.9	2.1
Hatbox Mesa (DUM7)	38-64	53.4	85	84	1
Siksikpuk (DUM8)	31-87	60.6	77	76.7	0.3
Anaktuvuk (DUS2)	21-51	37.4	37	39.9	-2.9
Chandler (DUS3)	35-70	55.6	48	NA	NA

The SR50 sensor at Northwest Kuparuk (DFM4) station (Figure 8) records a lower depth in winter 2006-2007, a higher depth in winter 2007-2008, and close to average depths for the winters of 2008-2009, 2009-2010, and 2010-2011. This is an example of the challenges associated with siting the sensor and using SR50 snow depth data for quantitative analysis.

During the 2010-2011 winter, SR50 measurements were recorded at seventeen meteorological stations. Of those stations, seven (DBM2 – DBM8) were removed from the Sagavanirktok, Kadleroshilk, and Shaviovik basins in the fall of 2010, due to the ending of the Bullen project (funded by Alaska Department of Natural Resources) in July 2010. Only one station from the Bullen project (DBM1, Accomplishment Creek) remains in the Sagavanirktok basin. Four stations (DFM1-4) remain in the Kuparuk basin as part of the former Kuparuk Foothills (ADOT&PF study). As part of the Umiat Corridor Project (ADOT&PF), five new stations (DUM5-DUM8 and DUS3) were installed in the Chandler basin during the fall of 2010, bringing the 2010-2011 station count to fifteen (Figure 1 and) for the 2010-2011 winter.

The results of the SR50 snow depth sensors are presented in Figures 4-18. Most stations reported good quality SR50 snow depth data during the winter of 2010-2011 with only a few station malfunctions. The SR50 at the White Hills (DFM2) station was damaged by a bear and was non-functional until it was repaired on April 25th, 2011 after which time the station resumed collecting snow depth data. No SR50 snow depth data was recorded at the Chandler (DUS3) station until a dead battery was replaced on May 18th, 2011. A late season power problem occurred at Accomplishment Creek (DBM1), after which the station stopped recording data, however most of the winter season snow depth data was already collected.

The advantage of snow sensor information is its high temporal resolution which can capture the timing and magnitude of solid precipitation and wind blowing events. Records show that the snow accumulation began in mid to late September, 2010 (Figures 4-18). The Mountain stations (Accomplishment Creek, Encampment Creek, Itikmalakpak, Upper May Creek, and White Lake) show a large variation in snow depths. Accomplishment Creek snow depths almost doubled from the previous year and had the highest recorded snow depths during the 2010-2011 winter. Out of the 15 stations with SR50 sensors in the Anaktuvuk, Chandler, Kuparuk, and Sagavanirktok basins, four of the five stations located in the Mountain region had the lowest overall snow depths for 2010-2011 winter. Upper May Creek and Itikmalakpak had an average snow depth reduction of more than 200% from the previous year (16.9 cm to 4.3 cm and 42.4 cm to 16 cm, respectively).

Following initial snow accumulation, the stations in the Foothills region (Anaktuvuk, Hatbox Mesa, Nanushuk, Siksikpuk, South White Hills, Tuluga and White Hills) and Coastal Plain region (North White Hills and Northwest Kuparuk) recorded gradual accumulation as the season progressed. The snow depths were variable, but overall average snow depth was greater in the 2010-2011 winter as compared to the previous winter.

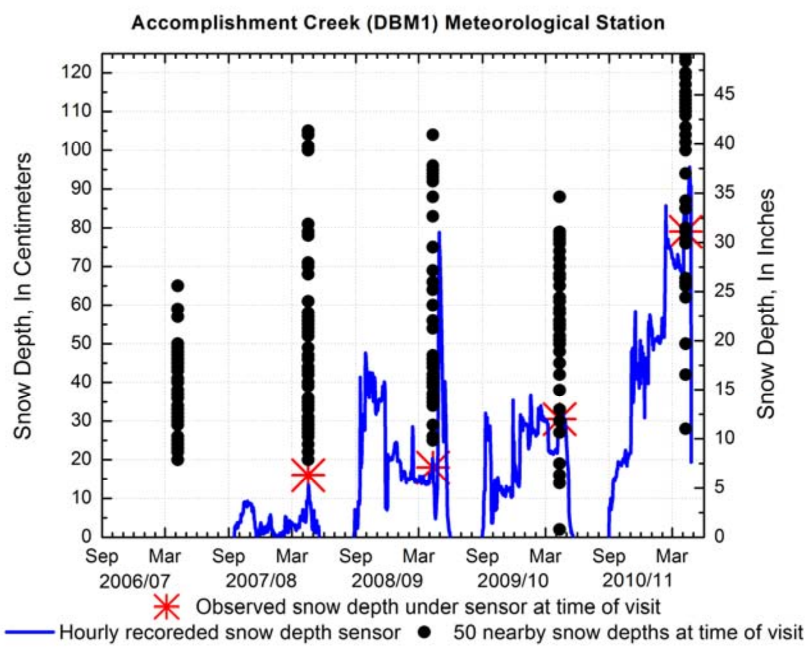

Figure 4. Accomplishment Creek meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2006-2011.

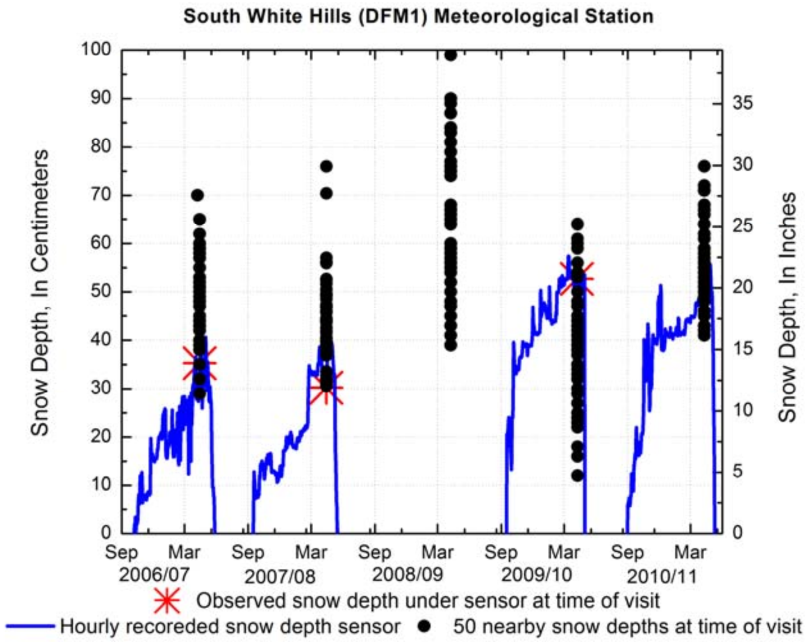

Figure 5. South White Hills meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2006-2011..

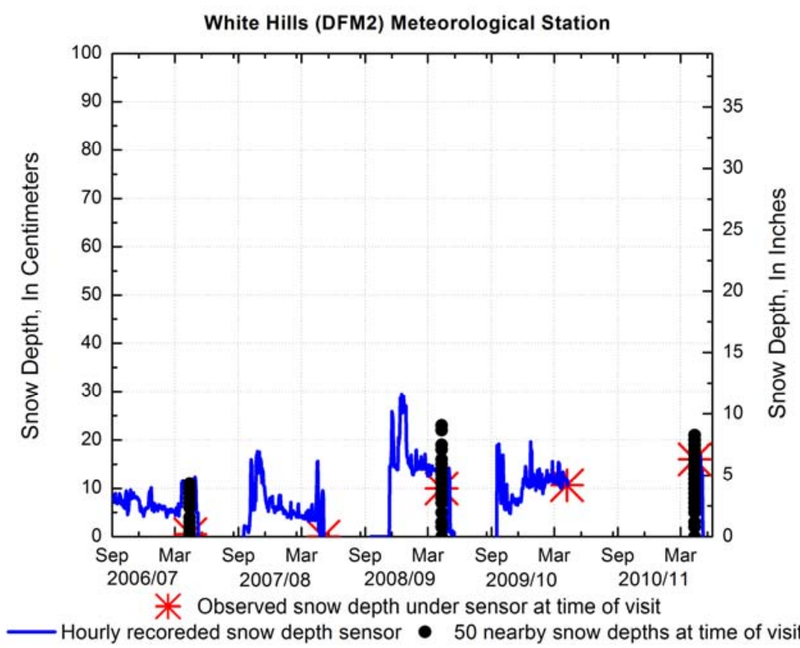

Figure 6. White Hills meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2006-2011.

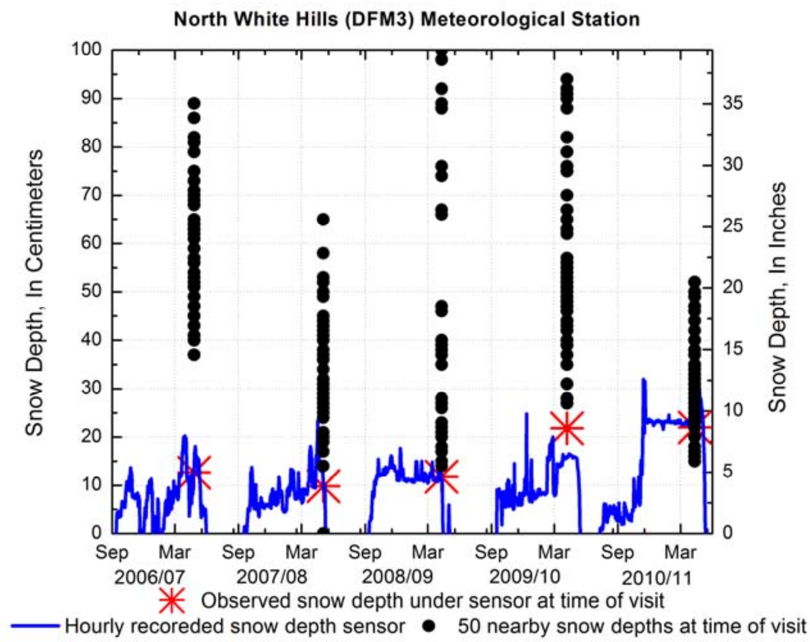

Figure 7. North White Hills meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2006-2011.

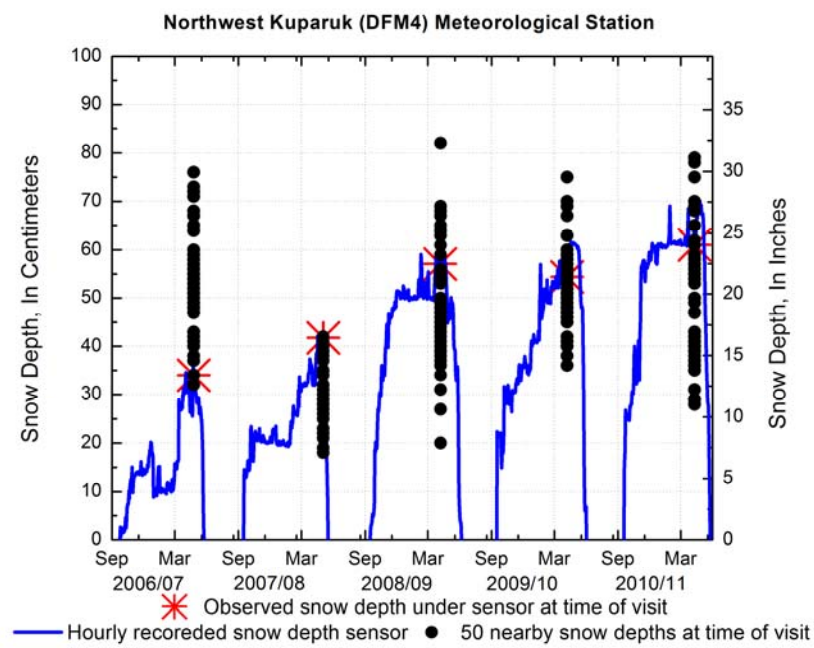

Figure 8. Northwest Kuparuk meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2006-2011.

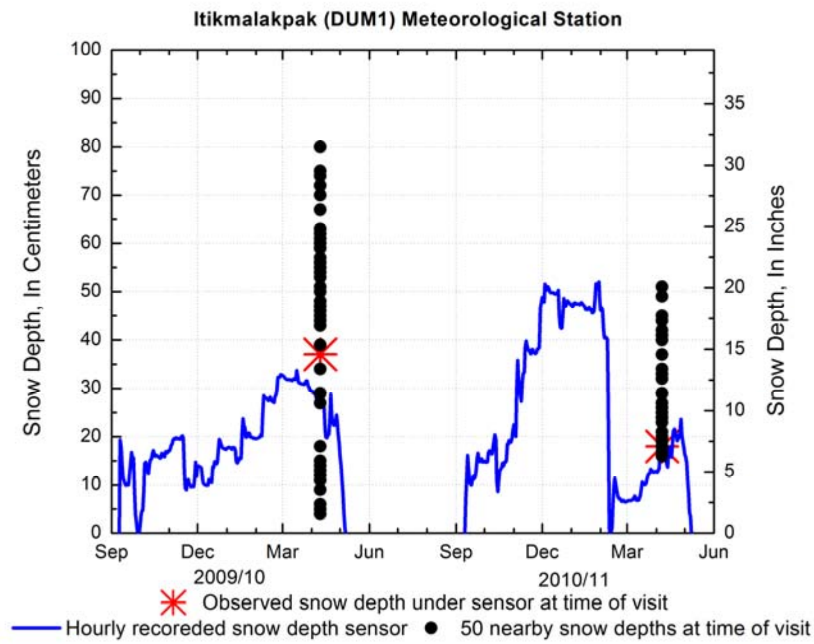

Figure 9. Itikmalakpak meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2009-2011.

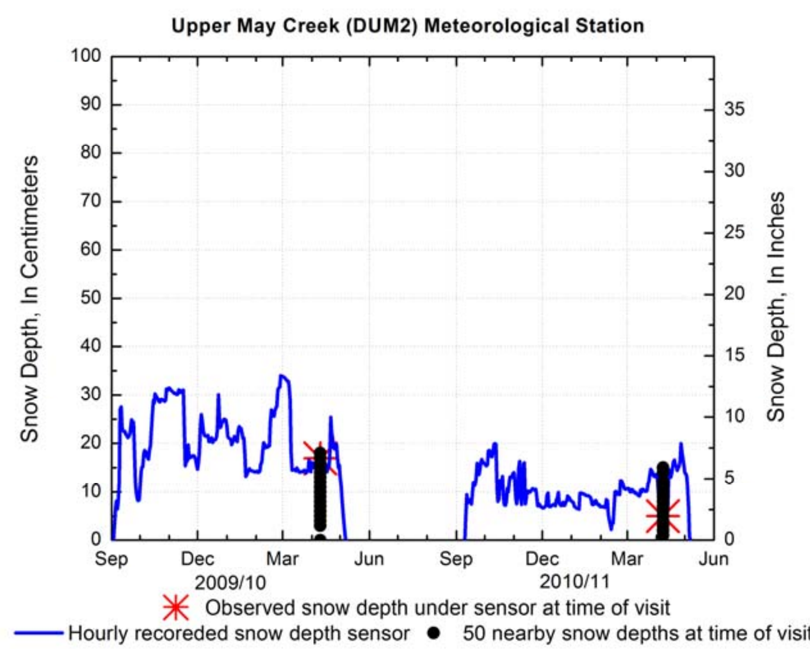

Figure 10. Upper May Creek meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2009-2011..

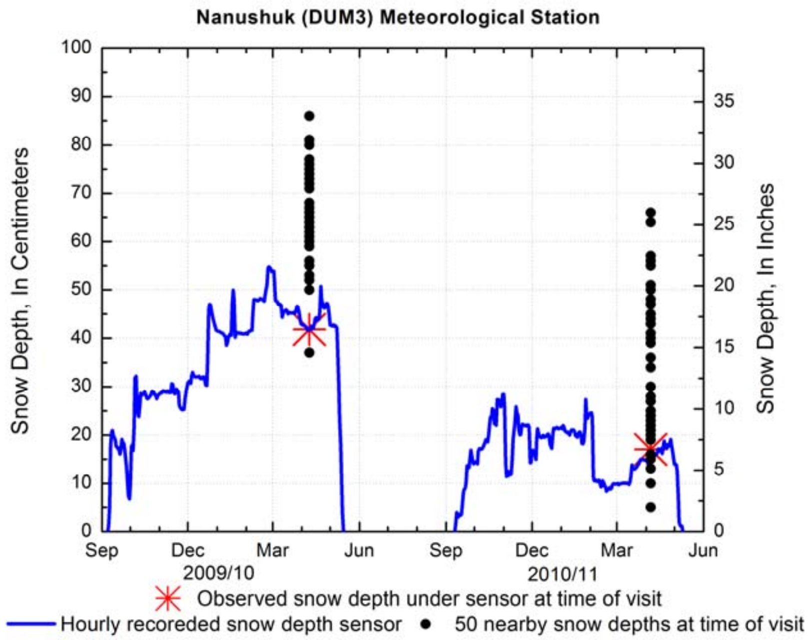

Figure 11. Nanushuk meteorological hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2009-2011.

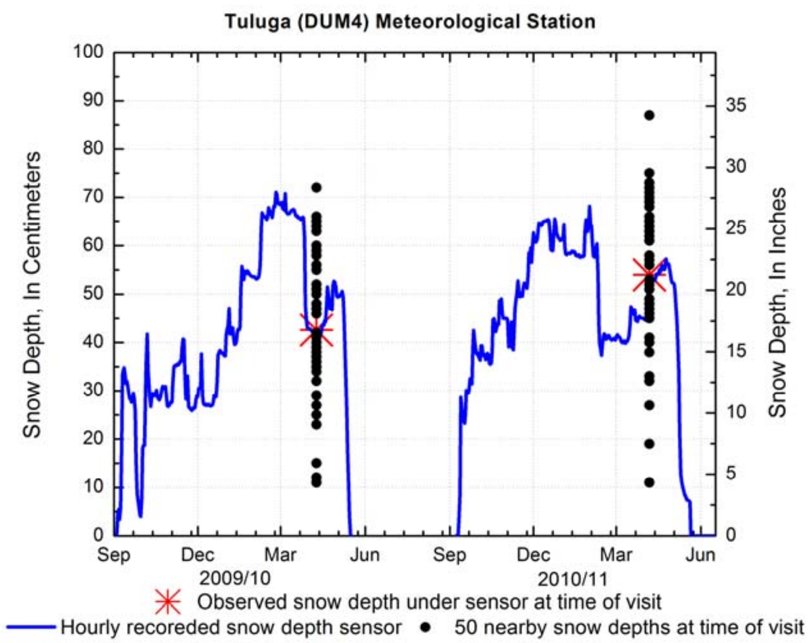

Figure 12. Tuluga meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2009-2011.

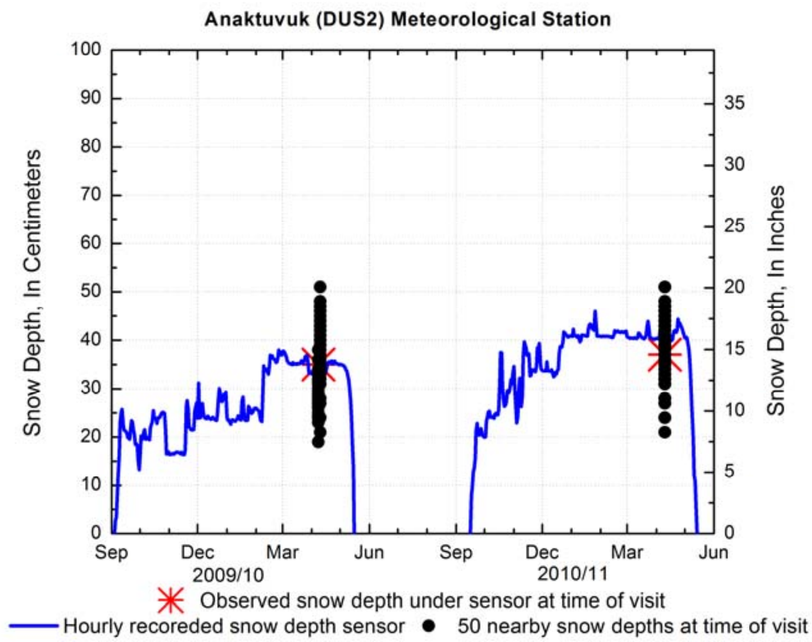

Figure 13. Anaktuvuk meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2009-2011.

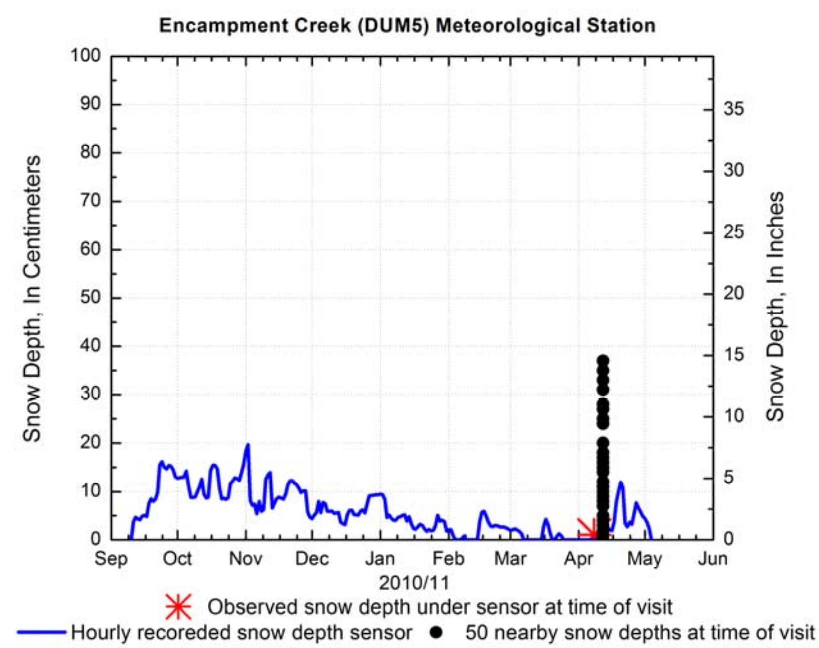

Figure 14. Encampment Creek meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2010-2011.

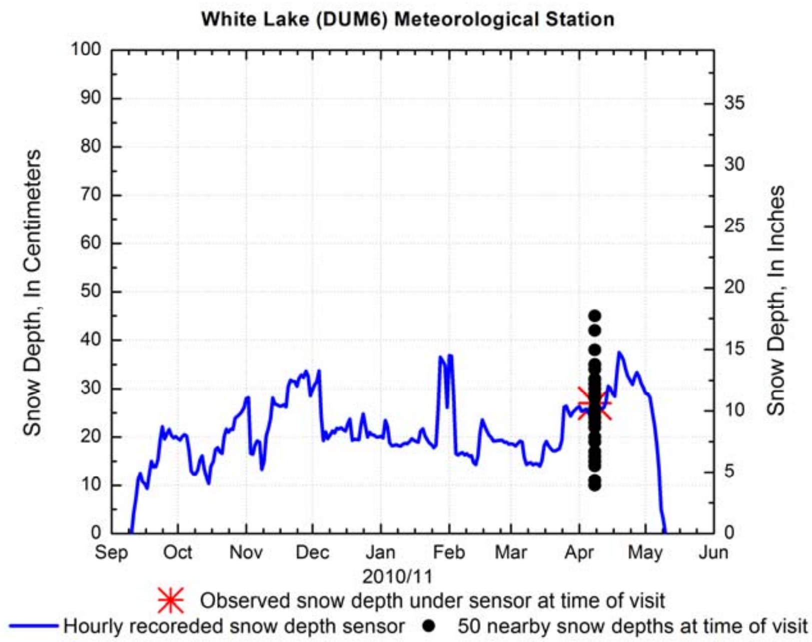

Figure 15. White Lake meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2010-2011.

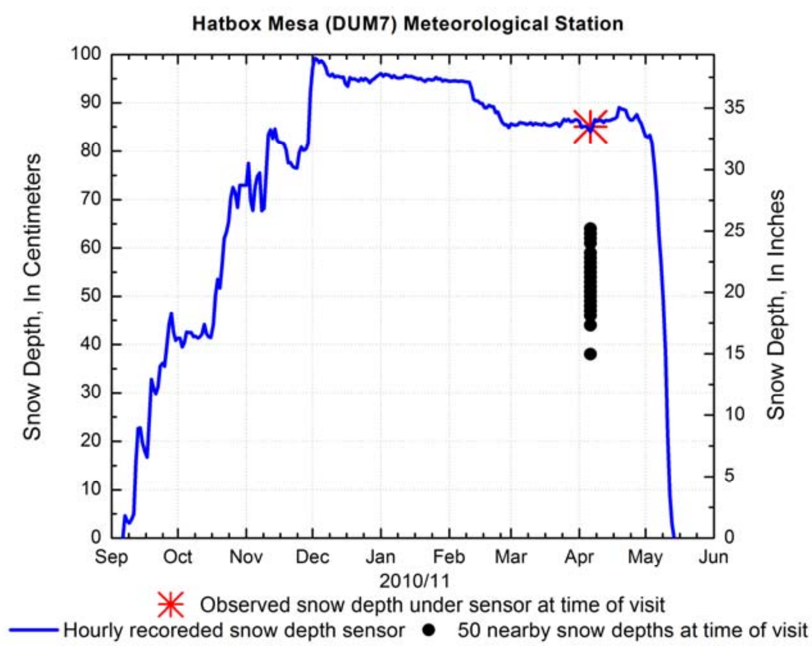

Figure 16. Hatbox Mesa meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2010-2011.

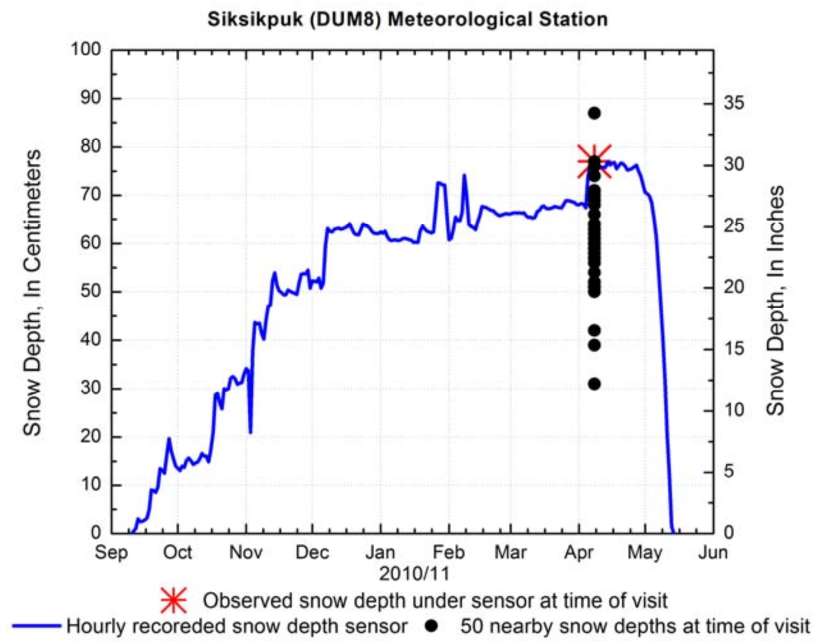

Figure 17. Siksikpuk meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2010-2011.

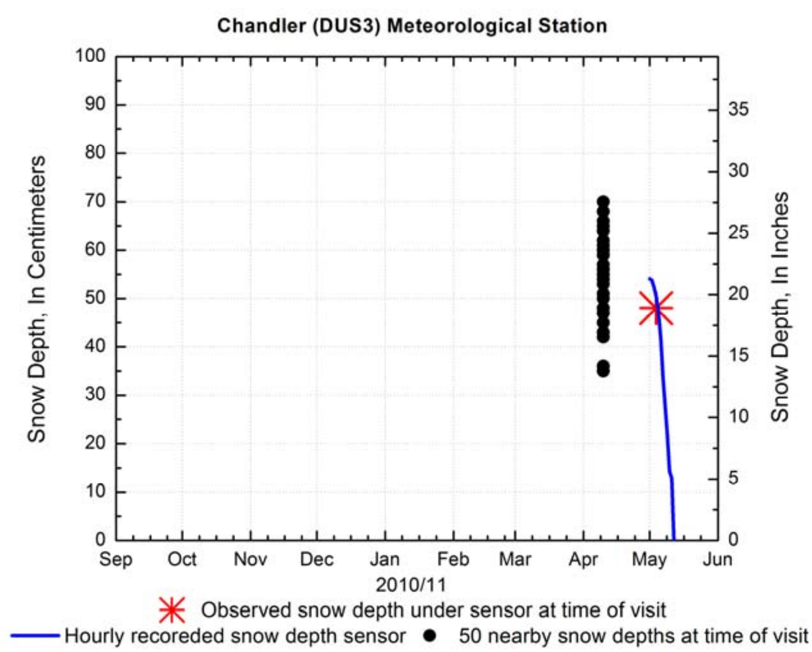

Figure 18. Chandler Bluff meteorological station hourly recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, and 50 snow survey depths measured near sensor, 2010-2011.

On February 23, 2011 there was a major wind event that is visible in most of the continuous snow depth measurements. An increase in air temperature from -20 degrees C to 0 degrees C was also observed. The strong winds significantly redistributed the snow and completely removed the snowpack from some locations (e.g. Encampment Creek and Itikmalakpak). Figure 19 and Figure 20 show the web camera, windspeed, and snow depth at the high elevation Itikmalakapak station in the Anaktuvuk basin. There was a decrease of 40 cm in snow depth in two days according to the SR50 snow depth sensor and camera images. At Encampment Creek station in the upper Chandler basin the average hourly windspeed was measured up to 35 m/s (78 mph), with a maximum windspeed of 49 m/s (109 mph). Evidence of this wind event was also visible at the Imnavait Creek snow fence, where the snow depth increased at the fence at least 1.8 m. Although most of the stations located in the Mountain region had decreases in snow depth during the wind event, local redistribution was observed at Accomplishment Creek, where the snow depth increased by 30 cm. This means that the Accomplishment Creek site is located in an area where snow is deposited during snow redistribution by wind (i.e. snow drift), whereas other sites with decreased snow depth (Encampment Creek) are located in the snow erosion areas.

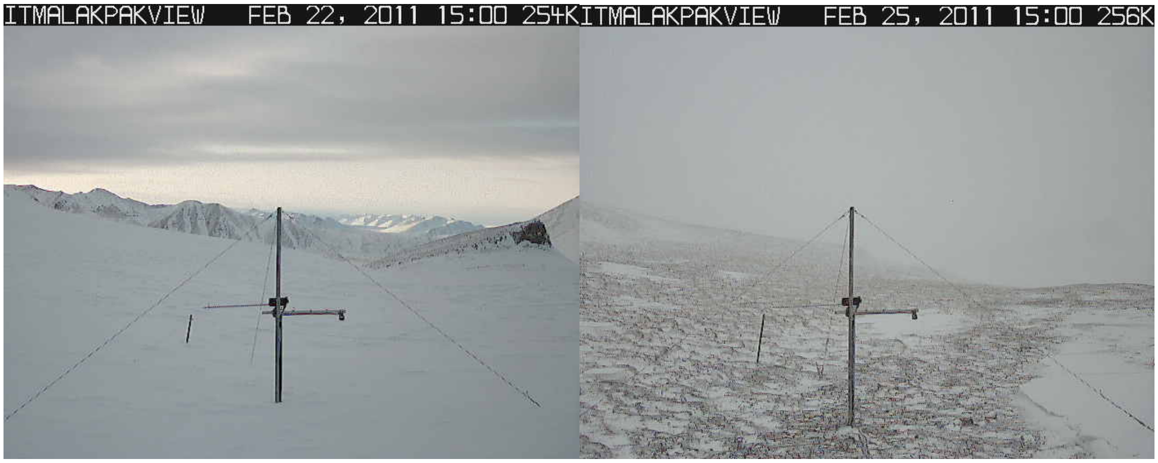

Figure 19. Webcam images at Itikmalakpak station shows a decrease in snow depth during the February 23 wind event.

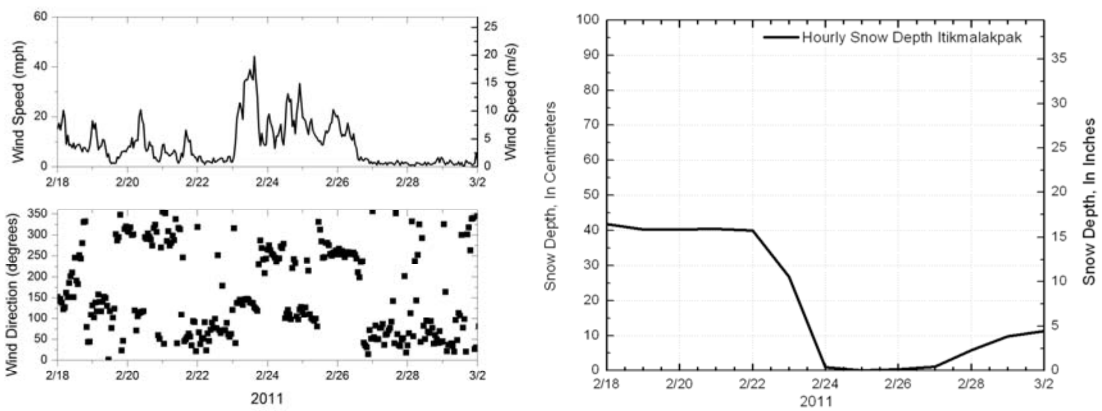

Figure 20. Wind speed, direction, and snow depth recorded at Itikmalakpak before and after the February 23, 2011 event.

8. ABLATION DATA

Historical ablation data were collected at five sites (Upper Kuparuk, Happy Valley, Sagwon Hills, Franklin Bluffs and Betty Pingo) (see Section 3.2 for details). In addition to historical sites, three new sites were monitored in the Foothills (Anaktuvuk, Chandler and Itkillik). The data is summarized in Appendix B.

The ablation window varies greatly from year to year, depending on meteorological conditions such as radiation and air temperature along with snowpack depth. Most of the sites report onset of snowmelt around May 17th, 2011. The entire snowpack melted within 8 days at the Sagwon and Itkillik locations, and within 10-12 days at all other sites (Figure 21). Southern sites, i.e. Itkillik, Anaktuvuk, Chandler, Upper Kuparuk, reported compete snowmelt by May 26-27, 2011. Northern sites, i.e. Betty Pingo and Franklin Bluffs, reported complete snowmelt few days later by May 30, 2011. The snow at the Happy Valley site (located along Dalton Hwy between Upper Kuparuk and Sagwon) was the last one to melt, because it had very deep snowpack (38 cm of SWE, 124 cm of snow depth). This area generally has high snow accumulation due to the local topography and vegetation.

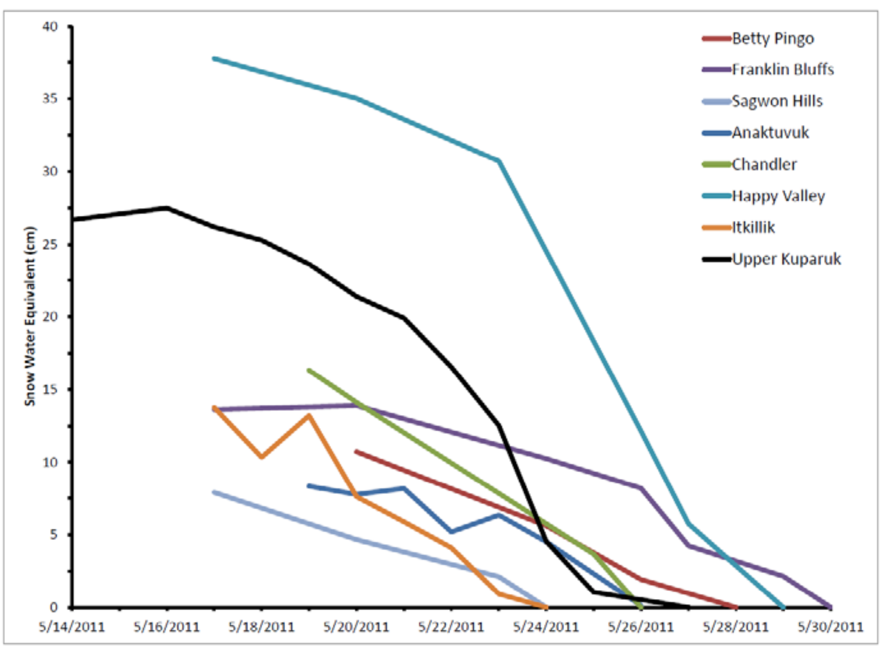

Figure 21. Ablation curves for selected sites in the Central Alaskan Arctic.

9. SUMMARY

This report describes snow depth, snow water equivalent, and snow density data collected in April–May 2011 in the Central Alaskan Arctic. Snow surveys were conducted in the watersheds of the Kuparuk, Anaktuvuk, Chandler, Itkillik and Sagavanirktok Rivers. As of 2011, the Kuparuk River watershed has 12 years of repeated end-of-winter snow survey data. The Sagavanirktok, Kadleroshilik, Shaviovik and Kavik River basins had 5 years of repeated snow surveys data, from 2006 to 2010. The Anaktuvuk and Itkillik River basins have 3 years of repeated snow survey data, 2009, 2010 and 2011. Snow survey observations in the Chandler River basin were initiated in 2010. Overall, 77 sites were visited in 2011. This number includes 16 sites located in the Mountains, 40 sites in the Foothills, and 21 sites on the Coastal Plain.

The end-of-winter SWE observed in 2011 accounts for 106% of the 12-year average SWE in the Kuparuk watershed. The 2011 end-of-winter SWEs for the Foothills and Coastal Plain are higher than average and represent 116% and 128%, respectively, of the 12-year average SWEs. This is the second highest SWE in the record. Both the Foothills and Coastal Plain had the highest 12-year SWE average (15.4 and 13.4 cm, 6.1 and 5.3 in.) in 2009 (Table 4).

10. REFERENCES

Benson, C.S., W. Harrison, J. Gosink, L. Mayo and D. Trabant 1986. The role of glacierized basins in Alaskan Hydrology, pp. 471–483, in Kane, D.L. (Ed.), Symposium: Cold Regions Hydrology: American Water Resources Assoc.

Benson, C. S. and M. Sturm 1993. Structure and wind transport of seasonal snow on the Arctic Slope of Alaska. Annals of Glaciol., 18, 261–267.

Berezovskaya, S. and D.L. Kane 2007. Strategies for measuring snow water equivalent for hydrological applications: Part 1, accuracy of measurements. Proceedings of 16th Northern Research Basin Symposium, Petrozavodsk, Russia, Aug 27–Sep 2.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Geick, R.E., Lilly, M.R., and White, D.M. 2007a. Snow survey data for the Sagavanirktok River / Bullen Point Hydrology Study: Spring 2007. July 2007, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 07.18, Fairbanks, Alaska, 17 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Geick, R.E., Lilly, M.R., and White, D.M. 2007b. Snow survey data for the Kuparuk Foothills Hydrology Study: Spring 2007. July 2007, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 07.17, Fairbanks, Alaska, 21 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., Lilly, M.R., and White, D.M. 2008a. Snow survey data for the Kuparuk Foothills Hydrology Study: Spring 2008. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 08.14, Fairbanks, Alaska, 40 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Lilly, M.R., and White, D.M. 2008b. Snow survey data for the Sagavanirktok River / Bullen Point Hydrology Study: Spring 2008. June 2008, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 08.15, Fairbanks, Alaska, 30 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., and Lilly, M.R. 2009. Snow Survey Data for the Central North Slope Watersheds: Spring 2009. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 09.01, Fairbanks, Alaska, 45 pp.

Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., and Lilly, M.R. 2010. Snow Survey Data for the Central North Slope Watersheds: Spring 2010. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 10.01, Fairbanks, Alaska, 45 pp.
Berezovskaya, S.L., Derry, J.E., Kane, D.L., Gieck, R.E., and Lilly, M.R. 2010. Snow Survey Data for the Central North Slope Watersheds: Spring 2010. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 10.01, Fairbanks, Alaska, 45 pp.

Brazenec, W.A 2005. Evaluation of ultrasonic snow-depth sensors for Automated Surface Observing Systems (ASOS). M.S. thesis, Colorado State University, 66 pp.

Campbell 2008. SR50A Sonic Ranger Sensor, Campbell Scientific, Inc. Revised June 8, 2008.

Hinzman, L.D 1990. The interdependence of the thermal and hydrologic processes of an arctic watershed and their response to climatic change. Ph.D. thesis, University of Alaska Fairbanks, 403 pp.

Kane, D.L., J.N. Luthin and G.S. Taylor 1978. Heat and mass transfer in cold regions soils. IWR-65, Institute of Water Resources, University of Alaska Fairbanks.

Kane, D.L., L.D. Hinzman, C.S. Benson and K.R. Everett 1989. Hydrology of Imnavait Creek, an arctic watershed. Holarctic Ecology, 12, 262–269.

Kane, D.L., S. Berezovskaya, K. Irving, R. Busey, R. Gieck, M. Chambers, A.J. Blackburn, and M.R. Lilly 2006. Snow survey data for the Kuparuk Foothills Hydrology Study: Spring 2006. July 2006, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 06-06, Fairbanks, Alaska, 11 pp.

McClure, R., J. Montesi and D. Kenney 2009. Alaska Snow Survey Report, Natural Resources Conservation Service, Anchorage, Alaska, May 1.

Rovansek, R.J., D.L. Kane and L.D. Hinzman 1993. Improving estimates of snowpack water equivalent using double sampling. Proceedings of the 61st Western Snow Conference, 157–163.

Woo, M-K 1997. A guide for ground based measurement of the arctic snow cover. Canadian Snow Data CD, Meteorological Service of Canada, Downsview, Ontario, 30 pp.

APPENDIX A. 2011 SNOW SURVEY DATA

Appendix A1. Snow water equivalent, snow depth and snow density in the Mountains.

N	ID	ELEV	LAT	LON	SWE		Snow Depth		Snow Density		Survey
		m	dd	dd	cm	in	cm	in	kg m-3	slug ft-3	Date
1	SAG1	678	68.4150	-148.9600	3.2	1.3	14.6	5.7	216	0.419	4/23/2011
2	SAG2	868	68.2597	-148.8256	26.9	10.6	89.3	35.2	301	0.584	4/23/2011
3	SAG3	830	68.4462	-148.7042	13.6	5.4	49.1	19.3	277	0.537	4/23/2011
4	DBM1	1474	68.4116	-148.1365	25.7	10.1	102.4	40.3	251	0.487	4/23/2011
5	UK15	951	68.5540	-149.3730	18.0	7.1	70.4	27.7	256	0.497	4/22/2011
6	MTN1	1096	68.3852	-150.1521	3.8	1.5	14.0	5.5	272	0.528	4/24/2011
7	MTN3	1080	68.3917	-150.4843	4.2	1.7	19.9	7.8	211	0.409	4/21/2011
8	MTN4	1179	68.2972	-150.8125	12.7	5.0	60.6	23.9	209	0.405	4/21/2011
9	MTN6	986	68.2814	-151.6606	3.3	1.3	13.4	5.3	249	0.483	4/22/2011
10	ANA2	595	68.3158	-151.4967	2.3	0.9	11.0	4.3	210	0.407	4/22/2011
11	CHA1	1224	68.2865	-152.1318	2.9	1.1	12.2	4.8	234	0.454	4/26/2011
12	CHA2	1081	68.3629	-152.7067	5.5	2.2	23.1	9.1	240	0.466	4/22/2011
13	ITK2	635	68.4170	-149.9472	8.8	3.5	33.6	13.2	262	0.508	4/25/2011
14	Galbraith	831	68.4780	-148.5030	13.7	5.4	58.0	22.8	237	0.460	4/23/2011
15	MTN5-Itikm	1168	68.2901	-151.1150	5.4	2.1	26.5	10.4	256	0.497	4/21/2011
16	MTN2-May	1378	68.3985	-150.2277	2.3	0.9	6.4	2.5	203	0.394	4/22/2011

Appendix A2. Snow water equivalent, snow depth and snow density in the Foothills.

N	ID	ELEV	LAT	LON	SWE		Snow Depth		Snow Density		Survey
		m	dd	dd	cm	in	cm	in	kg m-3	slug ft-3	Date
1	UK01-EH	912	68.5849	-149.3063	16.9	6.7	61.8	24.3	274	0.532	4/23/2011
2	UK04-GCL	908	68.5335	-149.2310	2.8	1.1	11.7	4.6	243	0.471	4/22/2011
3	UK08-UH	968	68.5222	-149.3380	4.3	1.7	18.1	7.1	237	0.460	4/23/2011
4	UK12-NH	904	68.6021	-149.4305	5.2	2.0	23.9	9.4	218	0.423	4/23/2011
5	Ukmet	778	68.6374	-149.4039	27.4	10.8	92.0	36.2	298	0.578	4/23/2011
6	OilSpill	440	68.9424	-148.8660	11.8	4.6	48.6	19.1	242	0.469	4/20/2011
7	Happy Valley	314	69.1519	-148.8389	38.0	15.0	124.1	48.9	306	0.594	4/20/2011
8	HV1	365	69.1682	-149.1548	19.1	7.5	79.9	31.5	239	0.464	4/24/2011
9	WK1	218	69.4265	-148.8722	13.9	5.5	63.1	24.8	220	0.427	4/24/2011
10	WK4	203	69.4269	-149.4609	10.8	4.3	48.7	19.2	221	0.429	4/24/2011
11	WK10	214	69.6173	-149.3839	12.3	4.8	51.5	20.3	240	0.466	4/25/2011
12	Sagwon	275	69.4247	-148.6950	8.6	3.4	44.0	17.3	197	0.382	4/20/2011
13	MI6	179	69.7772	-148.5990	17.4	6.9	62.8	24.7	276	0.535	4/22/2011
14	MI7	175	69.4887	-148.5678	15.5	6.1	57.2	22.5	271	0.526	4/20/2011
15	DFM1	293	69.2034	-149.5611	10.9	4.3	55.2	21.7	198	0.384	4/24/2011
16	DFM2	337	69.4865	-149.8214	2.7	1.1	12.5	4.9	216	0.419	4/25/2011
17	DFM3	84	69.7149	-149.4705	6.6	2.6	30.6	12.0	217	0.421	4/25/2011
18	SM03	651	68.8122	-149.2838	16.4	6.5	58.9	23.2	278	0.539	4/25/2011
19	SM06	609	68.7521	-149.5393	21.8	8.6	83.6	32.9	261	0.506	4/25/2011
20	ITK1	436	68.8196	-149.9762	8.7	3.4	42.6	16.8	205	0.398	4/22/2011
21	HV6	218	69.2748	-150.0869	6.5	2.6	31.6	12.4	205	0.398	4/25/2011
22	Wkmet	159	69.4259	-150.3417	12.7	5.0	58.9	23.2	216	0.419	4/12/2011
23	HO1	113	69.5687	-150.4478	15.7	6.2	59.8	23.5	263	0.510	4/12/2011
24	DUS2-Anak	79	69.4645	-151.1690	8.3	3.3	37.4	14.7	220	0.427	4/24/2011
25	GUN4-Tul	497	68.8041	-151.5460	13.1	5.2	53.5	21.1	244	0.473	4/20/2011
26	GUN2-Nan	540	68.7207	-150.5030	8.3	3.3	32.9	13.0	250	0.485	4/20/2011
27	DUS3-Cha	104	69.2604	-151.3964	11.3	4.4	55.6	21.9	203	0.394	4/24/2011
28	GUN3	447	68.7142	-151.2321	7.3	2.9	36.8	14.5	200	0.388	4/20/2011
29	CHA3	843	68.4990	-152.9805	4.4	1.7	21.9	8.6	200	0.388	4/22/2011
30	CHA4	624	68.7543	-152.5730	9.8	3.9	53.4	21.0	183	0.355	4/20/2011
31	CHA5	300	69.0840	-152.1394	14.9	5.9	59.0	23.2	252	0.489	4/23/2011
32	CHA6	463	68.6301	-152.1022	13.2	5.2	60.6	23.9	219	0.425	4/22/2011
33	CHA7	683	68.4301	-152.2715	6.8	2.7	44.6	17.6	153	0.297	4/22/2011
34	CHA8	271	68.9303	-152.0723	14.9	5.9	57.9	22.8	220	0.427	4/23/2011
35	TLK1	1000	68.5269	-150.1483	10.9	4.3	50.9	20.0	214	0.415	4/22/2011
36	TLK2	824	68.4587	-150.8559	11.7	4.6	55.2	21.7	212	0.411	4/21/2011
37	TLK3	868	68.4440	-151.5462	4.0	1.6	21.5	8.5	187	0.363	4/22/2011
38	TLK4	835	68.4503	-151.5571	16.3	6.4	55.8	22.0	293	0.568	4/22/2011
39	SWB1	243	69.1231	-150.5891	10.8	4.3	50.9	20.0	212	0.411	4/23/2011
40	SWB2	226	69.1218	-151.2492	21.3	8.4	85.9	33.8	248	0.481	4/23/2011

Appendix A3. Snow water equivalent, snow depth and snow density on the Coastal Plain.

N	ID	ELEV	LAT	LON	SWE		Snow Depth		Snow Density		Survey
		m	dd	dd	cm	in	cm	in	kg m-3	slug ft-3	Date
1	West Dock	5	70.3602	-148.5697	10.1	4.0	35.0	13.8	290	0.563	4/21/2011
2	Franklin Bluffs	71	69.8886	-148.7747	12.1	4.8	43.7	17.2	277	0.537	4/16/2011
3	FB3	58	69.9316	-149.1563	17.0	6.7	60.2	23.7	282	0.547	4/25/2011
4	FB5	42	70.0113	-149.2829	10.0	3.9	43.0	16.9	232	0.450	4/25/2011
5	FB7	32	70.1160	-149.1010	20.3	8.0	63.9	25.2	318	0.617	4/25/2011
6	FB9	34	70.0710	-148.8780	19.7	7.8	59.3	23.3	333	0.646	4/25/2011
7	P01	12	70.2955	-148.9373	5.7	2.2	19.5	7.7	292	0.566	4/21/2011
8	P02	15	70.2614	-148.9396	9.5	3.7	40.3	15.9	235	0.456	4/21/2011
9	P03-Betty	30	70.2806	-148.8961	10.6	4.2	39.5	15.6	268	0.520	4/21/2011
10	P04	12	70.2601	-148.8211	12.3	4.8	41.3	16.3	298	0.578	4/21/2011
11	P05	15	70.2532	-148.7716	11.8	4.6	41.7	16.4	282	0.547	4/21/2011
12	P06	12	70.2604	-148.6715	6.2	2.4	24.1	9.5	257	0.499	4/21/2011
13	P07	12	70.2566	-148.7160	11.2	4.4	44.8	17.6	250	0.485	4/21/2011
14	P08	12	70.2486	-148.6041	13.7	5.4	47.5	18.7	289	0.561	4/21/2011
15	MI1	48	70.0032	-148.6792	16.1	6.3	51.2	20.2	315	0.611	4/20/2011
16	MI2	60	69.9336	-148.7677	15.2	6.0	48.0	18.9	316	0.613	4/20/2011
17	MI3	90	69.7950	-148.7361	10.7	4.2	36.8	14.5	290	0.563	4/20/2011
18	MI4	90	69.7130	-148.7165	19.3	7.6	68.4	26.9	282	0.547	4/20/2011
19	MI5	140	69.6050	-148.6487	12.8	5.0	55.1	21.7	232	0.450	4/20/2011
20	H02	172	69.8020	-150.3838	13.5	5.3	45.8	18.0	296	0.574	4/24/2011
21	DFM4	124	69.9475	-149.9169	12.7	5.0	51.5	20.3	247	0.479	4/24/2011

APPENDIX B. HISTORICAL ABLATION DATA

Appendix B1. Snow water equivalent (cm) in the Imnavait Creek basin (basin average).

Month and Day	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09
30-Apr											14														
1-May																									
2-May										8															
3-May				7.5																					
4-May							8.2																		
5-May																									
6-May										4.6	6.8														
7-May																					12				
8-May	10.6									1.7	5.3														
9-May	10.3		10	6.9		9.9	1.1												15.7	12.0					
10-May	9.7		8.8	5.1			0.3			1.3	1.3								14.4						
11-May	7.9		8.6	4.8			0.2												14.9						
12-May			7.6	1.9		7.8	0.14												14.3				11.3	8.3	
13-May	8.1		7.4	0.4		6.9	0.12		10.1				12.5		6.9				14.4		5.7	9.6		8.4	
14-May	7.5		7.5	0.0		6.5	0.06			0.1			10.5		5.7				14.4	9.3	4.5			8.8	
15-May				0.0		4.9	0						11.0	9.5	5.1		13	12.4	15.1	8.2	3.3	6.8	12.4		
16-May			7.7			3.6				0	0		7.3	8.7	3.9			12.2	15.1	7.8	1.4		11.0	7.7	
17-May			7.5		13	1.8			5.8			10.1	5.8	6.5	3.6			12.6	15.4	6.0	2.1	4.0	11.3	5.9	
18-May	8.0		6.9			1.1			0.7				5.3	6.2	3.2		13	12.1	14.8	4.3		3.4	11.1	4.9	16.9
19-May	7.3		5.2		12.3	0.4			0.1				4.5	4.2	2.2	11.2	14	11.2	15.2	2.0	1.8	2.9	10.4	4.3	17.4
20-May	6.9		3.9		12.0	0.02			0.0			10.2	3.7	1.5	1.1	10.7		11.1	15.4	2.1	2.1	1.3		2.9	16.1
21-May	6.2		2.6		12.0	0.0							2.8	1.5	0.6	10.2	14	9.3	18.5	1.8	1.0	0.3	9.5	2.6	15.4
22-May	6.2		1		11.4								2.2	0.1	0.4	9.2		7.0	18.4	1.1	0.9	0.5	9.4	2.8	15.0
23-May	5.7		0.2		10.7							10.2	1.9	0.0		9.5	14	5.4	16.4	0.2	0.8	0.1	6.7	0.2	12.9
24-May	4.4		0.0		10.5			15.3				9.0	1.4			9.3		0.5	15.3	0.0	0.4	0.0	5.0	0.1	12.8
25-May	1.8				9.3							6.6	0.7			8.0	14	0.0	17.1		0.2		3.0	0.0	10.0
26-May	0.9				8.6			14.6				4.8	0.4			7.5	13		17.3		0.1		1.8		11.1
27-May	0.6	11.4			7.6			13.9				2.6	2.5			7.3	12		15.1		0.0		0.9		12.4
28-May	0.3	11.2			4.5			13.9					2.2			6.4	12		15.3				0.2		13.4
29-May	0.1	10.2			2.0			14.1				1.6	2.2			3.9	12		14.5				0.0		12.6
30-May	0.0	10.2			0.0			13.7				0.4	0.8			0.2	9.6		12.8						12.4
31-May		8.9						13.0					0.6			0.01	4.6		11.4						10.8
1-Jun		7.4						10.8				0.0	0.0			0.0	6.0		11.7						9.4
2-Jun		5.1						9.7									5.9		7.2						6.6
3-Jun		4.1						8.8									3.1		3.6						2.3
4-Jun		2.3						7.5									2.2		0.4						0.0
5-Jun		0.3						5.8									0.8		0.0						
6-Jun		0.0						5.1									0.2								
7-Jun								5.2									0.0								
8-Jun								4.0																	
9-Jun								2.7																	
10-Jun								1.0																	
11-Jun								0.0																	

Note: Data collection discontinued after June, 2009.

Appendix B2. Snow water equivalent (cm) at the Upper Kuparuk (UK) site

Month and Day	99	00	01	02	03	04	05	06	07	08	09	10	11
30-Apr		15		10	14	18	18		12				27.4
1-May													
2-May													
3-May													
4-May													
5-May													
6-May													
7-May													
8-May													
9-May					17.4								
10-May					17.0								
11-May					15.3		13.0						
12-May					12.3		11.5			12.1			
13-May	4.7							12.4		10.6			
14-May	3.6			12.9		16.4	6.0			12.6			26.7
15-May	1.7		17	12.5	18.3	17.0	13.2					14.5	27.5
16-May	1.2			15.3	17.4			8.0	14.2	10.1		14.8	26.2
17-May	1.0						9.1	7.8		11.8		12.6	25.3
18-May	0.0			15.2	18.1	11.5		6.4	13.0	9.6		12.7	23.6
19-May			14		18.7	9.8	7.2	4.5	13	7.2		11.0	21.4
20-May		20.5	16			7.7	8.1	1.8		7.5	23.8	12.1	19.9
21-May				12.6		9.2	5.5	0.0	11.8	5.6	20.3	13.9	16.6
22-May			17				0.3			4.0	16.7	10.0	12.5
23-May				5.8		5.9			8.0	0.9		9.4	4.5
24-May			17		17.6				5.4	0.0	12.4	7.0	1.1
25-May				0	17.9	1.1					9.2	3.2	0
26-May			18		17.3	0.5			3.1		10.4	0.5	
27-May			15						0.0				
28-May			13		15.2						9.2		
29-May			15								6.2		
30-May			13.3		13.1								
31-May		17.2	10.1								7.8		
1-Jun			13.7		12.3								
2-Jun		17	9.7		10.6						7.2		
3-Jun					7.9								
4-Jun		17	0										
5-Jun		16											
6-Jun		9.8											
7-Jun		4.8											
8-Jun		1.3											
9-Jun		0											
10-Jun													
11-Jun													
12-Jun													

Appendix B3. Snow water equivalent (cm) at the Happy Valley (HV) site.

Month and Day	99	00	01	02	03	04	05	06	07	08	09	10	11
30-Apr			14	15	13	23	24		7.3		41		40
1-May													
2-May													
3-May													
4-May													
5-May													
6-May													
7-May													
8-May													
9-May													
10-May					16.4								
11-May													
12-May													
13-May								22.0					
14-May				13.1									
15-May							28.3					14.4	
16-May				12.5									
17-May									8.1				37.8
18-May				9.6						20.0		14.9	
19-May		15.3				17.4		22.0					
20-May	7.4		19	6.7			30.0					12.8	35.0
21-May					17.7	14.9					27.4		
22-May	10			0.8				14.1	7.8	16.2		14.9	
23-May				0.0	11.1	14.7	28.6						30.7
24-May								13		12.6	21.0	11.1	
25-May					20.2	8.2			6.9				
26-May			14				26.7	8.2		6.2	15.6	6.6	12.1
27-May													5.8
28-May					11.0		21	7	6.3	3.0		0.2	
29-May						0					17.5		0
30-May		16.0					19	4.2	5.8	0			
31-May					24.3								
1-Jun			11.7				13	0	4.7		15.6		
2-Jun		13			4.4								
3-Jun			9.2				10		1.7				
4-Jun		12											
5-Jun			4.1				4.3		0				
6-Jun		11											
7-Jun			0										
8-Jun		2.3											
9-Jun													
10-Jun		0											
11-Jun													
12-Jun											0		

Appendix B4. Snow water equivalent (cm) at the Sagwon (SH) site.

Month and Day	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
30-Apr		8.1	9.1	4.4	6.0		5.6			8.3	12			10	6.4	10	8.1	11	5.5		7.5		4.3		8.6
1-May																									
2-May																									
3-May																									
4-May																									
5-May																									
6-May																									
7-May					1.7																				
8-May				2.0																					
9-May		5.4																							
10-May																									
11-May																									
12-May																									
13-May		3.9			1.7															6.0					
14-May																7.9									
15-May	5.2													7.9					3.6					5.1	
16-May																7.7									
17-May		3.9												7.7							7.3				7.9
18-May		4.4														3.3						8.0		5.9	
19-May										0.4				3.3				8.2		0.0					
20-May				1.1								1.7	5.8		8.1	0.0			4.3					5.8	4.7
21-May		3.9												0.0			8.4	4.8					0		
22-May													7.7								7.2	7.0		5.3	
23-May																	10.2	4.9	3.4						2.1
24-May		3.8									1.1		4.1									3.7		4.2	0
25-May			5.9				2.3											2.8			7.1				
26-May		3.7													6.6				2.9			1.5		1.1	
27-May																									
28-May		3.7															9.2		2.2		7.1	0.0			
29-May																		2.8				8.0			
30-May		2.6																	0.3		6.3				
31-May																	2.0								
1-Jun		2.4													5.7			2.3	0		4.7				
2-Jun																									
3-Jun		1.8													1.8			1.3			0				
4-Jun																									
5-Jun		1.7													0.5			0.5							
6-Jun															0.0										
7-Jun																		0							
8-Jun																									
9-Jun																									
10-Jun																									
11-Jun																									
12-Jun																									

Appendix B5. Snow water equivalent (cm) at the Franklin Bluffs (FR) site

Month and Day	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
30-Apr		9.3		4.7	11.3		12.7					6.5		10		8.5	12		12	10	6.6				12.1
1-May																									
2-May																									
3-May																									
4-May								6.1																	
5-May																									
6-May									7.0																
7-May																									
8-May				5.6																					
9-May		2.7																							
10-May																	10.2								
11-May																									
12-May																									
13-May																									
14-May					10.7											8.3									
15-May	8.5																		12.0						
16-May						8.0										6.5									
17-May																	15.6				8.7				13.6
18-May																4.7	17.6								
19-May										6.9							19.5			8.1					
20-May												7.1		14.5	13	3.3	19.1	9.1	11.5						13.9
21-May					10.9	6.7											12.5					9.2	9.1		
22-May		5.4										9.1				1.0	12.3		12.8	5.5	8.4				
23-May																0.0									
24-May					8.6							8.2					10.0			1.8		8.9	4.8		10.2
25-May			22.3				14					9.6					9.2	2.9			7.8				
26-May		4.9										9.1							12.3	0		7.0	0.0		8.2
27-May					8.6							8					11.4								4.2
28-May		4.0										8.6					9.4		11		6.5	0.5			
29-May											22.9	7.8						2.9							2.2
30-May		3.4										6.9					7.3		8		6.3	0		9.2	0.0
31-May					2.8							6.7		14.7			14.6							5.8	
1-Jun		1.6										4.7			13.4			2.3	6		5.8			5.5	
2-Jun												2.9					2.6							4.1	
3-Jun		0.8										1.9			9.6			1.3	2.7		1.9			3.9	
4-Jun												1.4		14			0.5							2.1	
5-Jun		0.7										0.7			7.7			0.4	0.4		0			0	
6-Jun			7.7									0			5.5		0	0.4							
7-Jun		0												9.2	4.5			0	0						
8-Jun														8.2	3.5										
9-Jun														3.5	2										
10-Jun														2	0										
11-Jun														1.2											
12-Jun														0.3											

Appendix B6. Snow water equivalent (cm) at the Betty Pingo (BP) site

Month and Day	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
30-Apr														12			8.0		10.6
1-May																			
2-May																			
3-May																			
4-May																			
5-May																			
6-May			6.6																
7-May																			
8-May																			
9-May			7.6																
10-May			7.1																
11-May			6.3																
12-May			6.0																
13-May			6.0							9					9.3				
14-May			5.9																
15-May			5.8				9.9												
16-May										8.9									
17-May		7.3			12.8					8.3	10.9								
18-May					12.7					6.3	10.0		7.0						
19-May				4.7	12.9					5.4	11.5	8.1							
20-May		7.2		4.4	13.3					4.5	12.7		9.5						10.7
21-May		6.8		4.6	13.2		9.3	12.8	8.3	4.5	12.6					9.1	4.2		
22-May				4.3	12.6		8.5			2.7	12.7								
23-May		4.2		2.8	11.8					0.6	11.3								
24-May	10	3		1.9	11.3		9.2			0.0	9.5	2.7		6.3	8.2	6.9	1.4		5.6
25-May	10	1.8	5.8	1.4	13.0		7.5									5.0			
26-May	12	0.9	5.1	1.8	12.3		8.1				11.1		10.8	2.6	8.8	3	0		1.9
27-May	12	0.6	4.1	0.7	13.3		8.5				11.8					3.2			
28-May	11	0.8	3.7	0.4			7				11.8			0	9.2	1.0			0
29-May	5.5	0.4	3				7.2				11.5	2.6				0.5			
30-May	3.8	0.1	2.1				7				9.8		5.5		7	0.3			
31-May		0	1.3				6.8				10.1	2.6	4.4			0			
1-Jun	0		0				5.7	14.9	8.8		8.9		4.2						
2-Jun			0				5.7				7.1	1.9			6.4				
3-Jun							4.5		4.1		6.5	1.3	3						
4-Jun							3.4				1.9	1.1	2.4		3.1				
5-Jun					9.7		2.9		3.4		0.0	0.6	1.1						
6-Jun					6.6		2.6	8.4	2			0	0.2		0				
7-Jun					4.2			6.7	1.2										
8-Jun					3.4			6.2	0.9										
9-Jun					1.4			3.8	0.7										
10-Jun					0.9			1.7	0										
11-Jun								0.3											
12-Jun								0.0											

Appendix B7. Snow water equivalent (cm) at the West Dock (WD) site

Month and Day	99	00	01	02	03	04	05	06	07	08	09
30-Apr		6.5	5.7	7.3	18	7	6.3		5.8		10.0
1-May											
2-May											
3-May											
4-May											
5-May											
6-May											
7-May											
8-May											
9-May											
10-May											
11-May											
12-May											
13-May				7.7					6.5		
14-May											
15-May							3.7	8.8			
16-May				7.6							
17-May				7.7	7.3						
18-May				6.5	9.4			7.3			
19-May				4.8							
20-May				4.3	14.6	8.2	4.9				
21-May	10.6		6.3	4.3	11.2						9.7
22-May	8.9			3.1	9.3					8.2	
23-May				1.0							
24-May	12			0.0	11.2					11.0	8.7
25-May	9.6					2					
26-May	11				9.2		3.8		6.2	4.5	4.5
27-May	11				7.3			4			
28-May	11				8.9				6.0	0.0	
29-May	9.1				6.6			0			3.9
30-May	11				10.3	2.4	3.3		8.3		
31-May	8.9	6.2					2				0.0
1-Jun	8		6.3		14.1	2.4	1				
2-Jun	6.8				5.7				7.1		
3-Jun	7.6		4.2		4.9	1	0.6				
4-Jun	5.6				4.0	1	0.2		4.3		
5-Jun	4.7	7.2	2.8			0.8					
6-Jun	4.7	6.8	1.7		0.4	0.4			0		
7-Jun	3.4	5.4	0.9								
8-Jun	2.8	3.4	0.4								
9-Jun	3.3	1.6	0.4								
10-Jun	1.6	0.7	0.2								
11-Jun	0.5	0.6	0								
12-Jun	0	0									

Appendix B8. 2010 Snow water equivalent (cm) at the Atigun, Galbraith Lake and Oilspill hill sites.

Day-Month 2010	Atigan Pass	Galbraith Lake	Oil Spill Hill
30-Apr			
1-May			
2-May			
3-May			
4-May			
5-May			
6-May			
7-May			
8-May			
9-May			
10-May			
11-May			
12-May			
13-May			
14-May			
15-May	19.2	2.2	2.2
16-May	20.2	0.8	0.8
17-May		0.1	0.1
18-May	18.6		
19-May	19.1		
20-May			
21-May	16.3		
22-May			
23-May	11.4		
24-May			
25-May	8.9		
26-May			
27-May	7.7		
28-May	5.8		
29-May			
30-May			
31-May			
1-Jun			
2-Jun			
3-Jun			
4-Jun			
5-Jun			
6-Jun			
7-Jun			
8-Jun			

Appendix B9. 2011 Snow water equivalent (cm) at the Anaktuvuk River, Chandler River, Itkillik River met sites.

Day-Month 2011	Anaktuvuk River	Chandler River	Itkillik River
30-Apr	8.3	11.3	
1-May			
2-May			
3-May			
4-May			
5-May			
6-May			
7-May			
8-May			
9-May			
10-May			
11-May			
12-May			
13-May			
14-May		11.9	
15-May			11.9
16-May		13.8	
17-May		10.3	13.8
18-May		13.2	10.3
19-May	8.3	7.6	13.2
20-May	7.8	5.9	7.6
21-May	8.2	4.1	5.9
22-May	5.2	.9	4.1
23-May	6.4	0	.9
24-May	5.4		0
25-May			
26-May	.1		
27-May			
28-May			
29-May			
30-May			
31-May			
1-Jun			
2-Jun			
3-Jun			
4-Jun			
5-Jun			
6-Jun			
7-Jun			
8-Jun			