Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2008

Dalton Hwy and Trans-Alaska pipeline, photo by Ken Irving

by

Sveta Berezovskaya, Jeff Derry, Douglas Kane, Rob Gieck, Michael Lilly, and Dan White

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Kuparuk Foothills Hydrology Project
Report No. INE/WERC 08.14

Water and Environmental Research Center

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

Conversion Factors

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

UNITS

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

Vertical Datum:

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

Horizontal Datum:

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

Abbreviations, Acronyms, and Symbols

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

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Snow Survey Data for the Kuparuk Foothills Hydrology Study: Spring 2008

1. INTRODUCTION

This report follows 2006 and 2007 snow survey data reports (Kane et al, 2006, Berezovskaya et al., 2007) and discusses snow conditions that were observed during 2008 end-of-winter snow surveys in the study area of the Kuparuk River basin. Field studies primarily focused on maximum snow water equivalent (SWE) accumulation during the 2007 - 2008 winter and the subsequent snow melt period. Field activities started at the end of April because the snowpack at that point in time reflects all precipitation falling during the period from October to April (less sublimation), with usually no winter melt occurring on the Alaska's Arctic Slope (AAS) (Benson et al., 1986). Deficiencies in determining 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.

Assessment of maximum snow accumulation is critical input to snow hydrology studies. Seasonal snowpack constitutes winter detention storage for precipitation, induces considerable differences in surface energy balance and impacts the amount of soil desiccation that occurs within the organic layer overlying permafrost (Kane et al., 1978). Snowmelt is also a major hydrological event each year. Peak discharge is highest for many rivers on the North Slope, particularly for the basins of the Sagavanirktok, Colville and Kuparuk Rivers, during the snowmelt period. These rivers drain a large area that extends from the Brooks Range through the Northern Foothills and across the coastal plain before discharging into the Arctic Ocean. Snow starts contributing to runoff in the southern Foothills in May 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 water equivalent observational data for the eastern part of the Alaskan Arctic. It summarizes 2008 data collection procedure, accuracy of observations, and their spatial distribution.

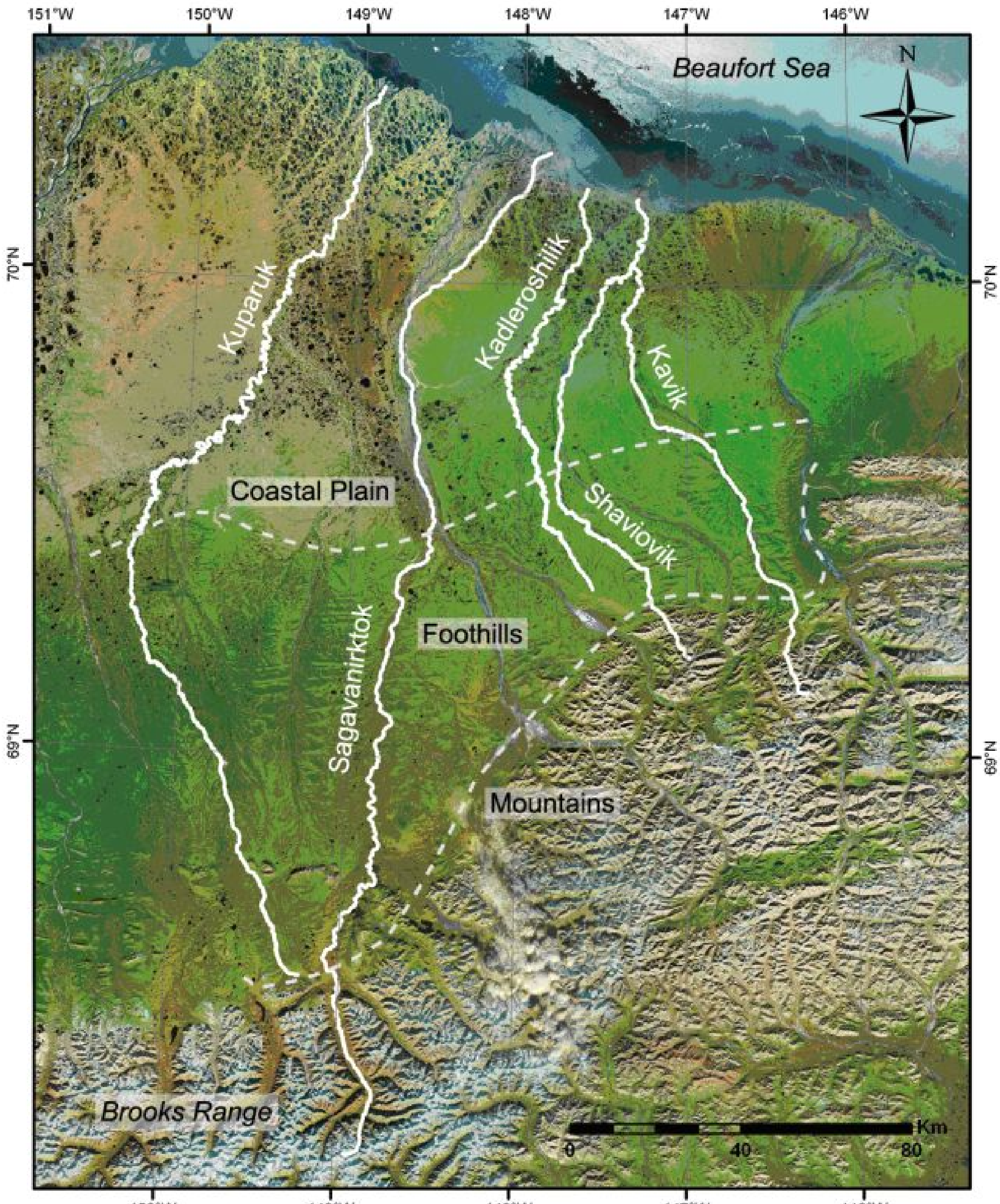

Figure 1. Geographical map of study area. Solid lines show major rivers; dashed lines represent approximate boundaries of the Coastal Plain, Foothills and Mountains regions.

2. STUDY AREA

The study domain covers an 80 by 230 km region of the AAS that is bounded by the Brooks Range on the south and the Arctic Ocean on the north and includes the Kuparuk River basin (8 140 km^2). The southern and northern boundaries of the domain are at 68° 28’ and 70° 30’ N latitude, respectively. The western and eastern boundaries of the domain are approximately at 150° 30’ and 148° 30’ W longitude, respectively. The total elevation range within the Kuparuk River basin is sea level to 1464 m (0 to 4800 ft). The topography is characterized by a flat northern portion, generally referred to as “*Coastal Plain*”, followed by gently rolling hills and valleys extending to the south (*“Foothills”*) and mountain ridges of the Brooks Range (*“Mountains”*) (Figure 1).

Sedge tussocks and mosses that cover much of northern Alaska are the dominant vegetation type. Occasional groupings of willows, approximately 40 cm high, occur in hillside water tracts and in the valley bottom. Riparian areas in the Foothills are covered with shrubs (up to 2 m tall) and even trees in some areas (maximum 8 to 10 m). The surface organic soils vary from live organic material at the surface to partially decomposed organic matter between 10 and 20 cm in depth. Silt, overlying a glacial till, makes up the mineral soil in the glaciated area (Kane et al, 1989). Overall, the topography and vegetation of the domain are representative of the AAS region.

3. SAMPLING METHODS

Snow surveys are made at designated stations throughout the domain to determine the depth, as well as vertically integrated density and water equivalent (Figure 2). Most of the sites, except for ablation measurements (see section 3.2), are visited once a year near the peak of snow accumulation, generally the last week of April. Our observations in the Foothills show that the onset of ablation is typically in May. The end of April is a good time to capture the end-of-winter SWE. Also, March, April and May are often the months of lowest precipitation and, therefore, there isn’t much accumulation between the surveys and ablation.

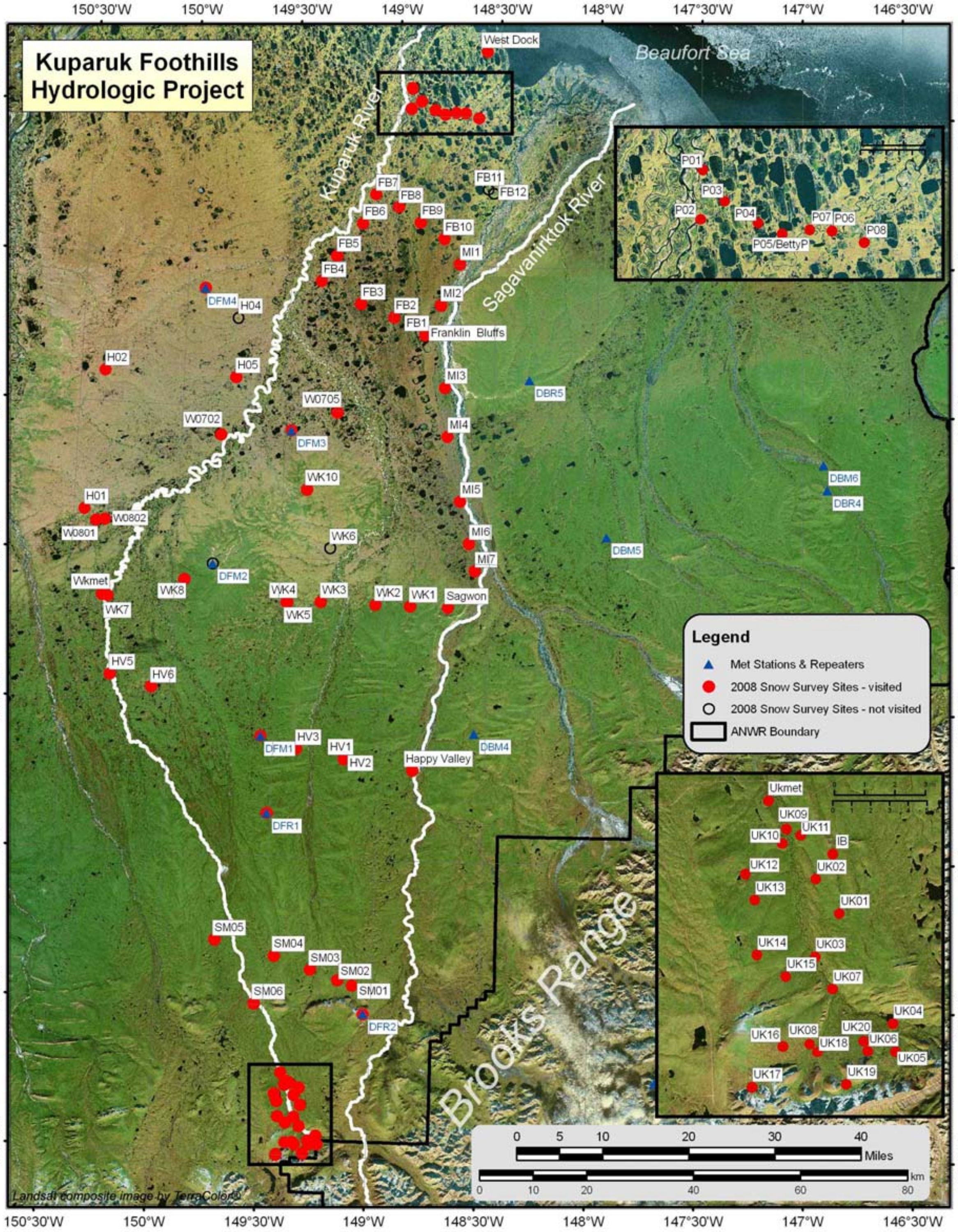

Figure 2. Location map of 2008 snow survey sites and meteorological stations in the vicinity of the Kuparuk River basin with detailed information for the Upper Kuparuk (inset).

In addition to snow surveys, snow depths are collected continuously throughout the winter at meteorological stations, which are equipped with 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 by collecting snow cores only. Rovansek et al. (1993) showed that double sampling provides improved SWE estimates and recommended sampling 12 to 15 snow depths for each snow core. However, this optimal ratio of snow depths to water equivalent appeared to vary greatly (from 1 to 23), depending on weather and snow conditions. Currently, we use an optimal ratio of 10; that is, 50 depths accompany five 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 it has a larger diameter than many other types of snow tubes and thus provides a larger sample for 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 the snow depth is recorded. The tube is then driven further into the organic layer and tipped sideways, retaining a vegetation plug that ensures the complete snow column was sampled. The vegetation plug is then removed and the snow is collected to be weighed later in the laboratory. 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 summarized long-term snowmelt observations, which have been conducted continuously since 1985 to 2007 (Table 1) from previously funded National Science Foundation, Office of Polar Programs projects.

Table 1. Summary of snow ablation sites.

Site Name	Period of Record	Comments
Betty Pingo	1993 to 2008	Surveyed near NRCS Wyoming gauge
Franklin Bluffs	1988 to 2008	Surveyed near Met site 1988 to 1998 (with some missing years), snow site moved west 700 meters along access road 1999 to 2008.
Happy Valley	1999 to 2008	Survey site 150 meters west of Dalton Highway from Happy Valley Airfield.
Imnavait Basin	1985 to 2008	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 2008.
Sagwon Hill	1988 to 2008	Adjacent to the Sagwon Meteorological Site
West Dock	1999 to 2008	150 meters east of West Dock - GC1 Road approximately one mile south of West Dock Meteorological Site.

Upper Kuparuk	1999 to 2008	Adjacent to the Upper Kuparuk Meteorological Site

3.2.1 Observation from 1985 to 2007

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 snow water equivalents were 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 difficulties weighing samples in frequent high wind conditions, cores were often placed in zip-lock bags in the field and weighed indoors out of the wind using the Adirondack mechanical scale and after 1999, digital scales were used. Following Rovansek et al. (1993), the double sampling technique was adopted in 1996 and continues to be used through today (section 3.1). During the transition period (1993-1995), 5 to 20 snow cores were taken along with fifty snow depths. Snow depths have been measured using a variety of devices such as: Adirondack snow tube, avalanche probes, T-handled graduated probes, MagnaProbe, as well as ski poles and rods with added graduated scales.

A number of observational sites have also changed over time (Table 1). In 1985, snow water equivalent 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 meters 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 meters 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.

Imnavait Creek basin (IB) differs from others in that it has the longest period of recorded and detailed observations. Several sites were sampled across the basin to capture basin average snow water equivalent. From 1985 through 1997 the Imnavait Basin snow water equivalent was determined from a transect made across the basin, perpendicular to the stream channel. At this time snow ablation was tracked only at the west facing slope adjacent to 4 runoff plots (Hinzman, 1990). In 1989, 2 additional sites were added, one in the valley bottom and one on the east facing slope of the basin. To provide consistent identification of sites, the transect was aligned with 7612800 northing (NAD27, UTM6) since 1999.

3.2.2 Observations from 2008

During the 2008 snowmelt season, SWE observations were taken at the Upper Kuparuk station (UKmet), Happy Valley (HV), Sagwon Hill (SH), Franklin Bluffs (FR), Betty Pingo (Betty), West Dock (WD) and at the six sites across the Imnavait basin (IB1-IB6). Sites are visited daily or every other day to capture the net volumetric decrease in SWE. We take the 5 snow densities and 50 snow depths at each site. The only difference from the end-of-winter snow survey is that the snow depth course has an assigned location, because of numerous repeated measurements.

3.3 Snow-Depth Sensors

Each of the four meteorological stations - DFM1, DFM2, DFM3, DFM4 - located in the Kuparuk Foothills Project is equipped with one of two kinds of snow-depth sensors, the Campbell Scientific Sonic Ranger 50 (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 take 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.

The method for measuring snow depth with the SR50(A) 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-depth of 10 inches under the sensor.

The ultrasonic pulse has a measurement cone width of 22º from the bottom of the sensor. The SR50(A) 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 reported dataset can be used properly.

4.1 Snow Water Equivalent

Snow density and SWE are estimated using snow core sampling. Woo et al. (1997) showed that a larger tube diameter increases the accuracy of density determination; he 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 is difficult to quantify. 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 is often inadvertently incorporated 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, as well as depending on the snow and soil conditions at each site.

Whereas snow depths show a systematic overestimation error, snow core densities tend to be close to, or to underestimate, true value. The difficulty in SWE accuracy interpretations is that actual, accurate SWE is unknown. Comparing different sampling methods, Berezovskaya and

Kane (2007) concluded that SWE of the tundra snow estimated with double sampling technique has error of ± 10 %.

4.2 Snow-Depth Sensors

While end-of-winter snow surveys provide areal average snow depth accounting for spatial snowpack heterogeneity, the SR50(A) measures snow depth directly under the sensor during the entire winter. Snow sensor data used in conjunction with snow survey data can enhance and expand the information gained with each sampling method.

Diligent field practices are essential for accurate measurements. After the sensor is installed and subsequently every time the station is visited, the distance from the bottom of the sensor to five points (four distances at 22° angles around sensor, and one directly underneath) on the ground are measured. When snow is on the ground, five depth measurements and the distance from the sensor to the snow surface are obtained. This information is crucial for post-processing data correction.

Post-processing adjustments to data may vary according to the error tolerance and goals of the investigation, for this project QA/QC procedures are outlined below:

- Establish a baseline value that represents no snow on the ground.
- Manually review data (graphically), and replace erroneous values with the average from the first and last data value that is deemed reasonable.
- Adjust data to fit observed values in the field.
- Smooth the data and omit smaller, sporadic, data values. If the difference between a data point and the prior data point is greater than 1.5 cm, and/or if the difference between a data point and the following data point is greater than 1.5 cm, then replace the data point with the average of the prior 5 hours and following 5 hours data values. A 10-hour average helped smooth out blowing snow events and cold periods that may have altered readings.
- As to avoid an abrupt transition during accumulation and/or ablation periods, incrementally adjust data over a period of days.

High frequency, small amplitude, noise is inherent in ultrasonic snow-depth sensors and can be an impediment to accurate snow accumulation measurements (Brazenec, 2005). For example, since the speed of sound in air is affected by the temperature of the air it is traveling in, an air temperature measurement is required to correct distance readings. Inaccuracies can be caused by poor calibration and/or neglecting periodic maintenance requirements. Physically related errors include wind and/or blowing snow creating spurious data readings, difficulty in establishing a zero point due to tussocks, low shrubs, grass, etc., and changes in sensor height due to ground heave and wildlife curiosities.

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. Snow water equivalents are measured at elevations from sea level to 3674 ft (0 to 1,120 m) in the Kuparuk River basin (Appendix A1-A3).

There are two distinctly different snow regimes across the Kuparuk basin, uplands and coastal plain (Liston and Sturm, 2002). To determine regional SWE, snow sites are classified as the Coastal Plain and uplands, the latter is separated into Foothills and Mountains. The coastal sites are the sites located below an elevation isoline of 500 ft (152 m) and those above are referred to as uplands sites. Uplands snow sites are, in turn, separated into foothills and mountains based on elevation and surrounding topography (Appendix A1-A3). Elevation alone is not always representative for this purpose, because most of the snow survey sites in the mountains are located in the valley bottoms where helicopter can safely access the site.

We also list the lake sites that are visited for the purpose of chemistry data collection (*e.g.* Chambers et. al., 2006). Snow surveys are always conducted on the lake surface, because the lake snow is thinner, denser, harder, and has less snow water equivalent than snow on surrounding tundra (Sturm and Liston, 2003). If time allows, snow surveys are also taken on the surrounding tundra. Lake snow data collection is not applied for the long-term SWE analysis since different lakes are visited every year. However, lake snow parameters (depth, density, distribution and thermal properties) are critical input to the physical models to account appropriately for ice thickness and heat losses (Sturm and Liston, 2003). Snow survey measurements were taken on the lake surface of 4 lakes in 2008 (Appendix A3 and Appendix B3).

Overall, 113 sites were visited in 2008. This number includes 84 sites within the frame of the Foothills project (80 snow survey sites and 4 lake sites) and 29 sites within the Bullen Point project (26 snow survey sites and 3 lake sites). Eight of the Foothills project sites are located in the Mountains, 42 sites are in the Foothills and 30 sites are on the Coastal Plain.

6. SNOW SURVEY DATA

The average of Coastal Plain snow density (0.415 slug ft^{-3}, 214 kg m^{-3}) is less than Foothills density (0.455 slug ft^{-3} / 235 kg m^{-3}) and Mountains density (0.480 slug ft^{-3}, 248 kg m^{-3}) (Appendix B1-B3).

The average Coastal Plain SWE is (3.6 in, 9.1 cm), and snow depth is (14.5 in, 36.9 cm). The Foothills average SWE is (3.7 in, 9.4 cm), and snow depth average is (15.3 in, 38.9 cm). The Mountains average SWE (1.4 in, 3.5 cm) and snow depths average is (6.3 in, 16.1 cm) and is generally lower than those at the Coastal Plain and Foothills. Figure 3 and Figure 4 show the snow depth and SWE at each snow survey site in the AAS. Overall, average end-of-winter SWE tends to be the highest in the Foothills (3.7 in, 9.4 cm) and lowest in the Mountains (1.4 in, 3.5 cm) (Figures 3 and 4, Table 2).

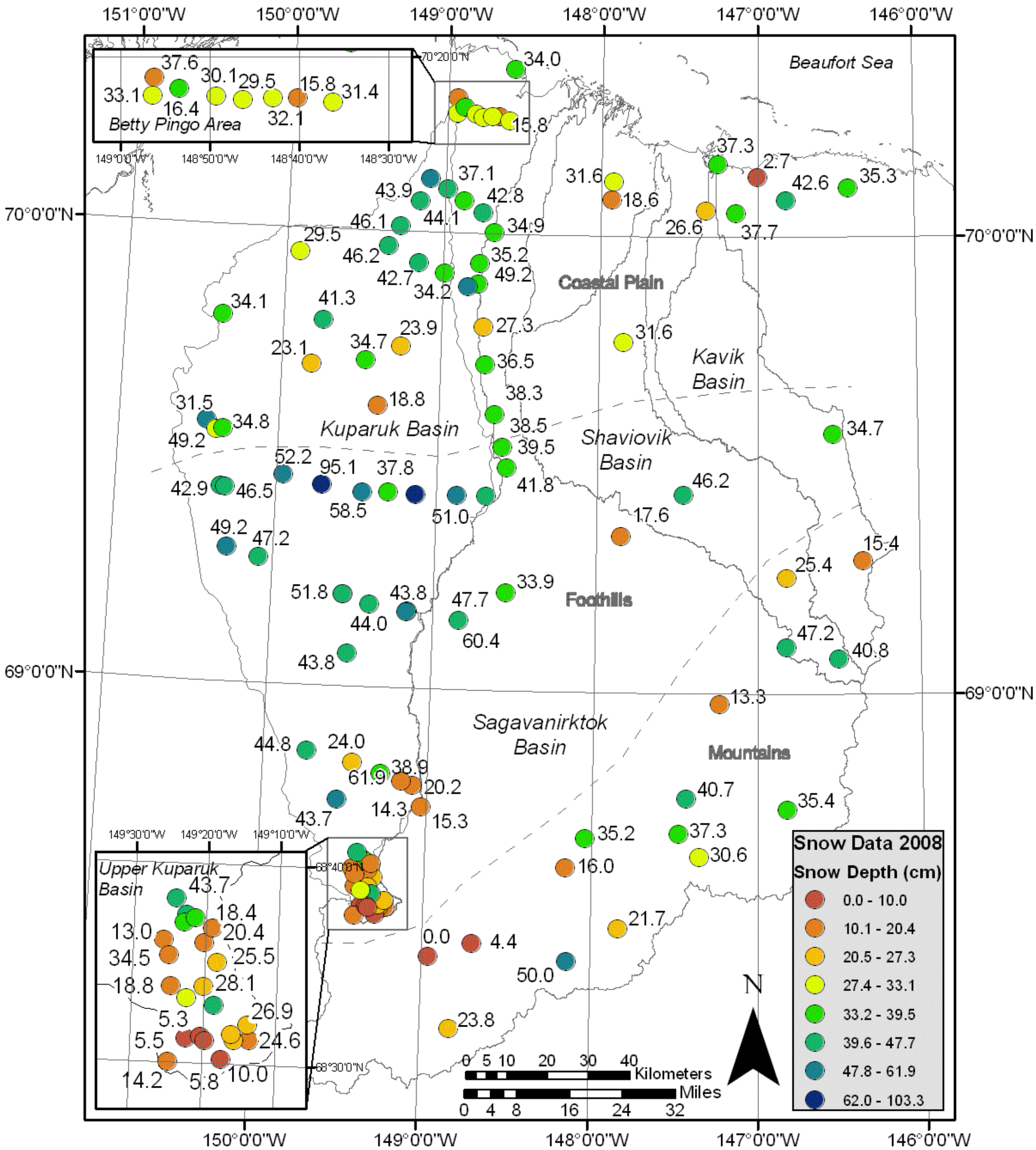

Figure 3. End of winter snow depth (cm) collected from snow survey sites at the North Slope of Alaska in spring 2008. The colored circles represent the snow depth class that minimizes the sum of squared difference from the mean within the class. Dashed lines indicate the approximate boundary between the Mountains, Foothills, and Coastal Plains regions.

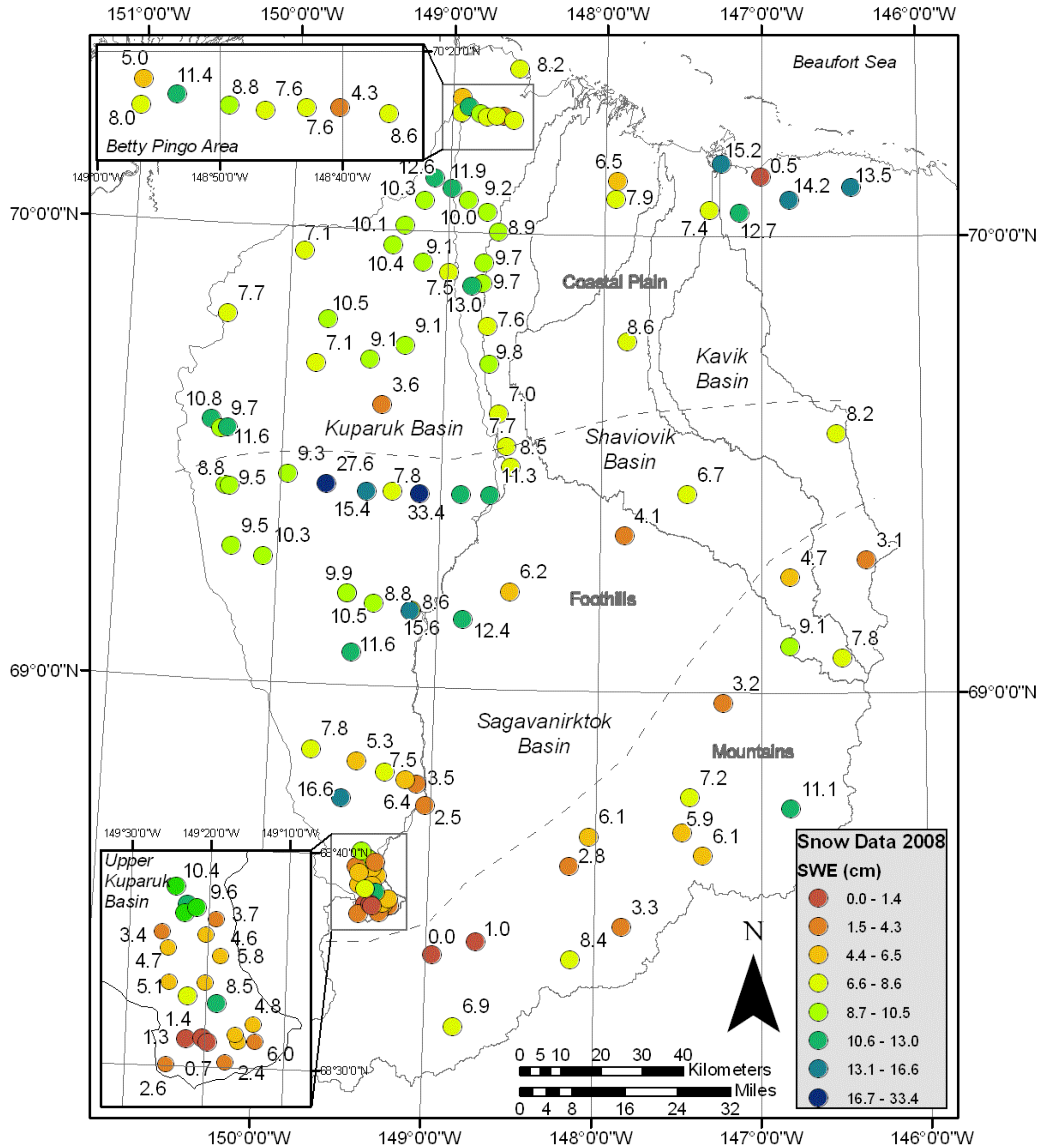

Figure 4. End of winter snow water equivalent (cm) collected from snow survey sites at the North Slope of Alaska in spring 2008. The colored circles represent the snow water equivalent class that minimizes the sum of squared difference from the mean within the class. Dashed lines indicate the approximate boundary between the Mountains, Foothills, and Coastal Plains regions.

Table 2. The Kuparuk River snow water equivalent: 2000-2008.

YEAR	Mountains			Foothills			Coastal Plain			Kuparuk basin		
	SWE		Number of sites	SWE		Number of sites	SWE		Number of sites	SWE		Number of sites
	cm	in		cm	in		cm	in		cm	in	
2000	9.3	3.7	2	12.3	4.8	36	9.9	3.9	20	10.5	4.1	58
2001	8.3	3.3	3	11.8	4.6	36	8.4	3.3	36	9.5	3.7	75
2002	6.6	2.6	2	11.0	4.3	32	9.4	3.7	34	9	3.5	68
2003	14.7	5.8	3	12.2	4.8	36	11.2	4.4	32	12.7	5.0	71
2004	8.8	3.5	3	11.3	4.4	28	9.2	3.6	14	9.8	3.9	45
2005	11.6	4.6	1	11.4	4.5	33	8.9	3.5	26	10.6	4.2	60
2006[1]	6.7	2.6	7	8.9	3.5	39	9.3	3.7	41	8.3	3.3	87
2007[1]	6.3	2.5	7	11.5	4.5	43	9.0	3.5	32	8.9	3.5	84
2008	3.5	1.4	8	9.4	3.7	42	9.1	3.6	30	7.3	2.9	80
Average	8.4	3.3		11.1	4.3		9.4	3.7		9.6	3.8	

The Mountains and Foothills have less end-of-winter SWE in 2008 compared to the previous years (55% and 81% of the 2006 and 2007 SWE). The Coastal Plain has a similar SWE in 2007, 102% of the 2006 and 2007 end-of-winter SWE (Table 3). The Foothills have the highest 9-year SWE average (11.1 cm) versus 8.4 cm for the Mountains and 9.4 cm for the Coastal Plain. This database is starting to be long enough that we can start to get an understanding of variability from year-to-year (Table 3).

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[1] Note the 2007 and 2006 Coastal Plain and Basin averages are slightly different from those reported in Kane et al., 2006 and Berezovskaya et al., 2007. This table contains averages only from 'long-term' snow survey sites, i.e. lake snow survey sites are excluded from 2006 and 2007 averages.

Table 3. Maximum, minimum, and average snow water equivalent in the Coastal Plain, Foothills, and Mountainous regions of the Kuparuk River Basin (2000-2008, n=9).

Region	Maximum	Minimum	Average
	cm (year)	cm (year)	cm
Mountains	14.7 (2003)	3.5 (2008)	8.4
Foothills	12.3 (2000)	8.9 (2006)	11.1
Coastal Plain	11.2 (2003)	8.4 (2001)	9.4
The Kuparuk River basin	12.7 (2003)	7.3 (2008)	9.6

Table 4. 2008 snow water equivalent analysis.

Region	Number of sites	SWE		Percent of last year	Percent of average 2000-2008
		cm	in		
Mountains	8	3.5	1.4	55	not defined *
Foothills	42	9.4	3.7	81	84
Coastal Plain	30	9.1	3.6	102	97
The Kuparuk River basin	80	7.3	3.6	82	76

* not enough data

Long-term snow surveys on the AAS have been maintained by the US Department of Agriculture (USDA) since the 1970s. The USDA Natural Resources Conservation Service (NRCS) reports that the Arctic Coast SWE in 2008 (average from 2 snow courses) accounts for 65% of the long-term average SWE and the Dalton highway has received 60% of the long-term average SWE (McClure R., 2008).

Our dataset covers a relatively short period of time (2000-2008) compared to the NRCS, but has a much larger spatial extent. The number of sites in specific regions in general has increased in time (Table 2). End-of-winter SWE over the Kuparuk river watershed in 2008 accounts for 76 % of the 9-year average SWE (Table 4). Foothills and Coastal Plain end-of-winter SWE in 2008 represent 84 % and 97 % respectively of the 9-year average SWE (Table 4).

7. SONIC SNOW DEPTH DATA

All four meteorological stations in the Kuparuk River Basin reported continuous, good quality sensor snow depth from the accumulation and ablation season (Figure 5-7). The White Hills (DFM2) sensor data is not shown because there was no snow reported at the site this year. This station is located on top of a ridge, where snow is eroded due to persistent strong winds.

Sonic snow-depth records at the other three stations are adjusted to account for field observations and anomalous data points (Section 3.3). Transition periods, particulary the transition from fall to winter, are difficult periods to assertain accurate snow depths. For instance, the South White Hills and Northwest Kuparuk stations (DFM1 and DFM4) reported sensor snow depths that agreed very well with measured snow depths when sites were visited on May 17 (Figure 5, Figure 7). Yet, data indicated a snow depth of 10 cm (3.9 in) the first of October when there was no snow on the ground. This is likely due to the vegetation at these sites – grass and tundra can create a false surface which the ultrasonic sensor measures. Typically, however, snow is quickly captured by the vegetation and accumulates to the top of the vegetation height during the first snow events of the season. Data is corrected for these erronous readings during the beginning of the season when reporting in real-time.

Since snow-depth sensor measurements are made at a point, knowledge of the representativeness of sensor data with the surrounding area is useful. Snow depths from snow surveys conducted near the stations show snow depth variability within 30 cm to 76 cm (11.8 in to 29.9 in) for the South White Hills, 0 cm to 65 cm (0 cm to 25.6 in) for the North White Hills, and 18 cm to 42 cm (7.1 in to 16.5 in) for the Northwest Kuparuk station (Figure 5, Figure 6, Figure 7). For North White Hills and South White Hills, sensor readings reflect the lowest depths measured from the snow surveys (Figure 5 and Figure 6). The opposite is true for the Northwest Kuparuk site where snow survey depths range from 18 cm to 42 cm (7.1 in to 16.5 in) while sensor values reported 41 cm (16.1 in) (Figure 7). For South White Hills and North White Hills stations, sensor data is in the 0.08 and 0.01 quantile respectively (the percentage of data that falls below the given sensor value compared to the 50 snow survey depths). For Northwest Kuparuk, sensor data is in the 1.00 quantile. These comparisons are informative when making inferences about the surrounding area when inspecting data in real-time throughout the season.

The advantage of snow sensor information is its high temporal resolution, which can capture the timing and magnitude of snow events. Records show that snow accumulation began approximately in the middle of October at all of the Kuparuk meteorological sites. The beginning of the snow season was largely uneventful from October to January with snow depth slowly increasing or remaining relatively constant. South White Hills and Northwest Kuparuk report an event the first week of March that deposited 10 -15 cm (3.9 – 5.9 in) of snow. All stations show similar responses to snow events the month of April with accumulation occurring the second and last week of the month. The maximum snow depth during the winter is in the range between approximately 44 cm to 50 cm (17.3 in to 18 in) at the South White Hills and Northwest Kuparuk stations on May 1st, 2008. The maximum depth for the North White Hills station was recorded at 25 cm (10 in) also on May 1st, 2008.

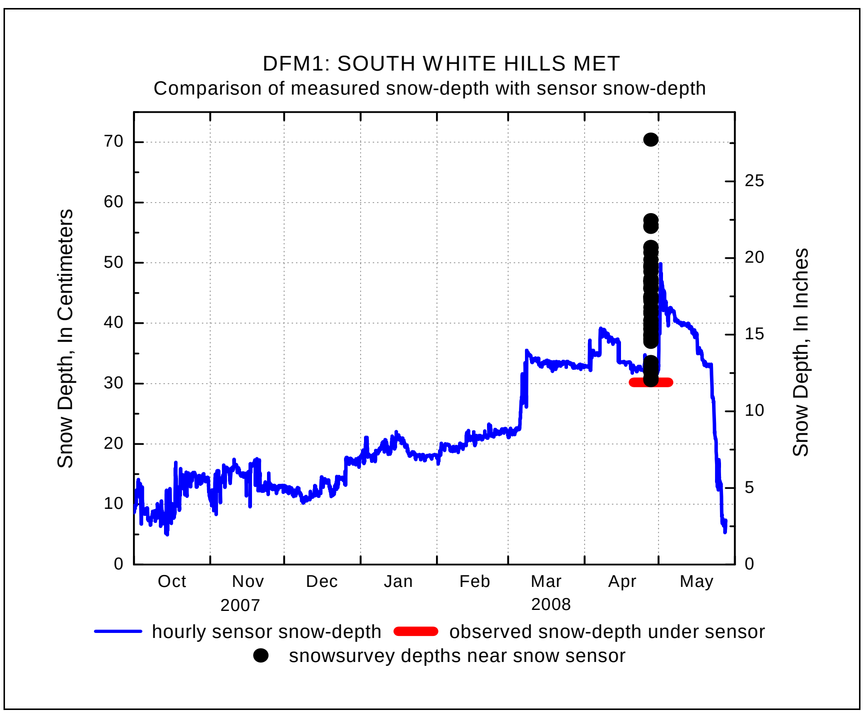

Figure 5. Hourly SR50 sensor snow depths measured over the winter, observed snow depth under the sensor, and snow survey depths measured near sensor at the South White Hills meteorological station.

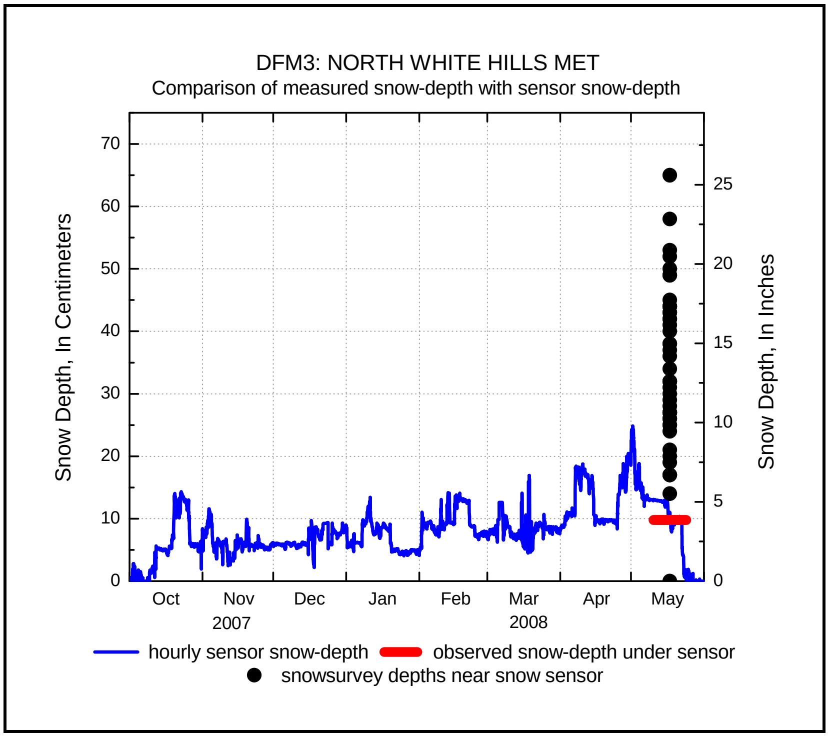

Figure 6. Hourly SR50 sensor snow depths measured over the winter, observed snow depth under the sensor, and snow survey depths measured near sensor at the North White Hills meteorological station.

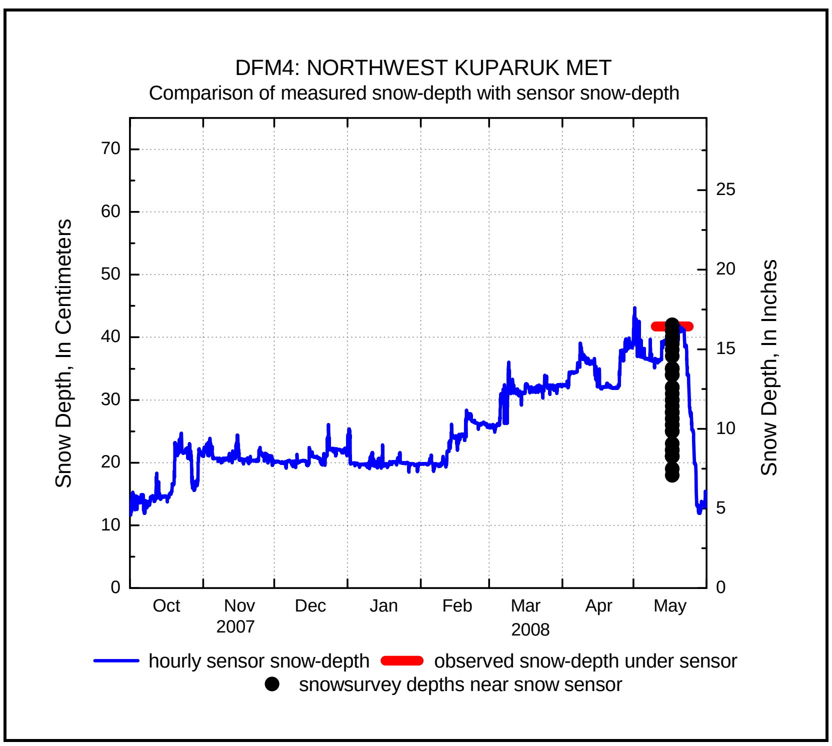

Figure 7. Hourly SR50 sensor snow depths measured over the winter, observed snow depth under the sensor, and snow survey depths measured near sensor at the Northwest Kuparuk meteorological station.

8. ABLATION DATA

Historical ablation data are reported in Appendix C. The ablation window varies greatly depending on meteorological conditions and snowpack depth. The start of spring snowmelt usually occurs in the southern Foothills first (Imnavait Basin, Upper Kuparuk sites), and a week or two later snow starts melting on the Coastal Plain (Franklin Bluffs, Betty Pingo and West Dock). Onset of ablation in 2008 varied from May 15th at the Imnavait Basin and Upper Kuparuk sites to May 21st – May 25th at northern sites, with an average of 6 days to complete the melt (Figure 6). Snowpacks across the entire Kuparuk River basin melted within three weeks from May 15th to May 30th, 2008.

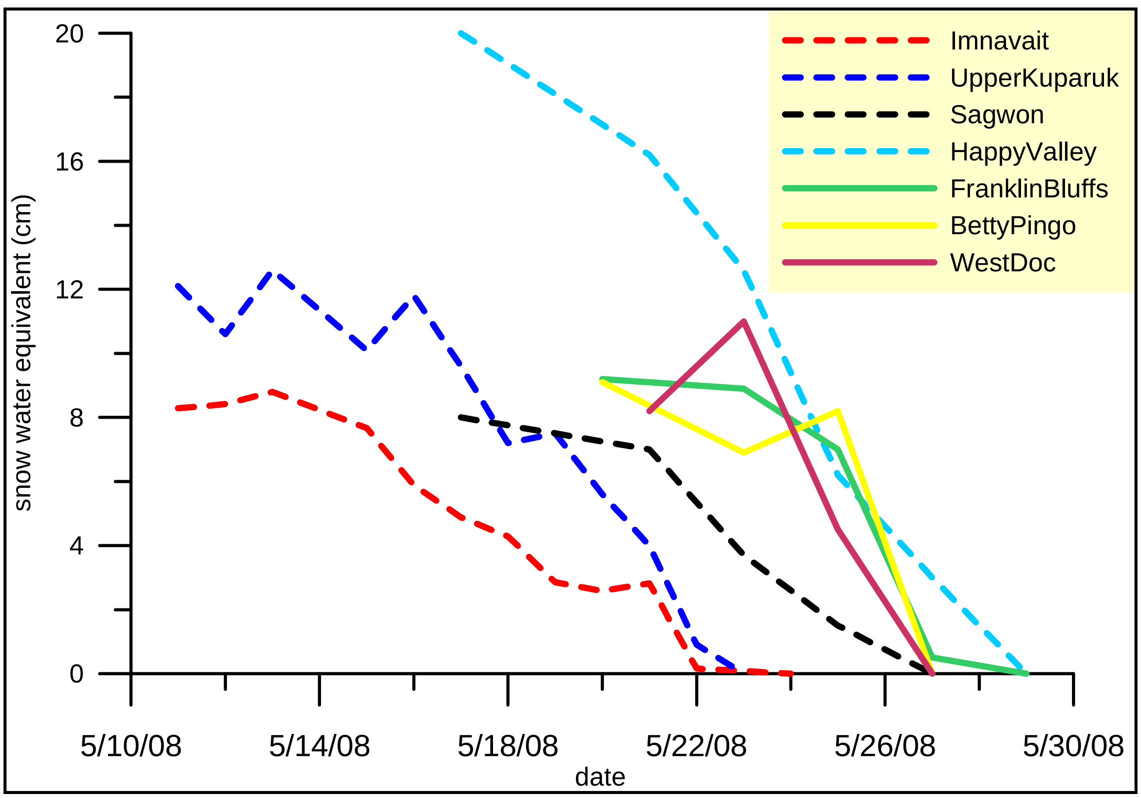

Figure 8. Net volumetric decrease in SWE. Snow ablation curves at the Foothills are shown as dashed lines and on the Coastal Plain as solid lines.

The Imnavait Basin ablation curve differs in that it is an average of six sites across the basin. Within a few days of sustained melt the entire watershed becomes a patchwork of snow covered and bare tundra. The west-facing slope (~80% of catchment) melts off sooner than the rest of the watershed, because it retains less snow and has more direct solar radiation in the afternoon when air temperatures are highest (Hinzman et al., 1996). In contrast, the east-facing slope has deeper snowpack and receives its maximum irradiance in the morning while convective heat transfer is smaller. Ten days were required to complete ablation in the Imnavait watershed.

9. SUMMARY

Observed end-of-winter 2008 Kuparuk basin SWE is less than the 9-year average (76 %). This is caused by low Foothills and Mountains SWE, whereas the Coastal Plain has an average SWE close to the 9-year average (97%). Snowpacks across the entire Kuparuk River basin melted within three weeks from May 15th to May 30th, 2008.

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LIST OF APPENDICES

APPENDIX A. LIST OF THE SNOW SURVEY SITES IN 2007

Appendix A1. Elevation and coordinates of the sites located in the Mountains

№	ID	ELEV (m)	LAT decimal degree	LON decimal degree
1	UK05	1021	68.5200	-149.227
2	UK06	1050	68.5199	-149.262
3	UK14	1027	68.5638	-149.411
4	UK16	1045	68.5207	-149.373
5	UK17	1109	68.5007	-149.411
6	UK19	1115	68.5037	-149.289
7	UK20	1024	68.5247	-149.269
8	DFR2	1177	68.7408	-149.033

Appendix A2. Elevation and coordinates of the sites located in the Foothills

№	ID	ELEV (m)	LAT decimal degree	LON decimal degree
1	UK01	912	68.5849	-149.306
2	UK02	834	68.6010	-149.338
3	UK03	827	68.5639	-149.335
4	UK04	908	68.5335	-149.231
5	UK07	848	68.5489	-149.311
6	UK08	968	68.5222	-149.338
7	UK09	763	68.6241	-149.379
8	UK10	801	68.6173	-149.384
9	UK11	796	68.6215	-149.360
10	UK12	904	68.6022	-149.430
11	UK13	937	68.5899	-149.416
12	UK15	951	68.5540	-149.373
13	UK18	981	68.5187	-149.328
14	Ukmet	778	68.6374	-149.404
15	IB	897	68.6134	-149.318
16	SM01	732	68.7879	-149.087
17	SM02	680	68.7956	-149.158
18	SM03	651	68.8122	-149.284
19	SM04	612	68.8336	-149.456
20	SM05	568	68.8565	-149.733
21	SM06	609	68.7521	-149.539
22	Happy Valley	314	69.1519	-148.839
23	HV1	365	69.1682	-149.155
24	HV2	353	69.1667	-149.162
25	HV3	386	69.1816	-149.390
26	HV4	308	69.2007	-149.558
27	HV5	179	69.2937	-150.284
28	HV6	218	69.2756	-150.087
29	Wkmet	159	69.4259	-150.342
30	WK1	218	69.4265	-148.872
31	WK2	226	69.4278	-149.038
32	WK3	174	69.4291	-149.298
33	WK4	203	69.4269	-149.461
34	WK5	197	69.4269	-149.457
35	WK8	173	69.4576	-149.953
36	WK10	214	69.6173	-149.384
37	Sagwon	275	69.4262	-148.691
38	H02	172	69.8020	-150.384
39	MI6		69.5344	-148.599
40	MI7		69.4887	-148.568
41	DFR1	508	69.0726	-149.515
42	DFM1	293	69.2007	-149.558

Appendix A3. Elevation and coordinates of the sites located on the Coastal Plain (A) and Lake Sites (B).

Table A. Coastal Plain.

№	ID	ELEV (m)	LAT decimal degree	LON decimal degree
1	West Dock	5	70.3602	-148.570
2	Franklin Bluffs	71	69.8886	-148.775
3	FB1	71	69.8828	-148.839
4	FB2	64	69.9108	-148.992
5	FB3	58	69.9316	-149.156
6	FB4	52	69.9676	-149.351
7	FB5	42	70.0113	-149.283
8	FB6	38	70.0667	-149.160
9	FB7	32	70.1160	-149.101
10	FB8	34	70.0960	-148.987
11	FB9	34	70.0710	-148.878
12	FB10	40	70.0451	-148.758
13	P01	12	70.2955	-148.937
14	P02	15	70.2614	-148.940
15	P03/BettyP	11	70.2744	-148.891
16	P04	12	70.2601	-148.821
17	P05	15	70.2532	-148.772
18	P06	12	70.2562	-148.670
19	P07	12	70.2566	-148.716
20	P08	12	70.2486	-148.604
21	MI1	48	70.0032	-148.679
22	MI2	60	69.9336	-148.768
23	MI3	90	69.7950	-148.736
24	MI4	90	69.7130	-148.716
25	MI5	140	69.6050	-148.649
26	H01	113	69.5687	-150.448
27	H05	90	69.8000	-149.750
28	WK7	137	69.4243	-150.315
29	DFM3	84	69.7149	-149.470
30	DFM4	124	69.9475	-149.917

Table B. Lake sites[1].

№	ID	ELEV (m)	LAT decimal degree	LON decimal degree
1	W0702		-149.8088	69.703
2	W0705		-149.2518	69.748
3	W0801		-150.3887	69.550
4	W0802		-150.3456	69.552

[1] Lake sites are separated because most of them do not represent repeated yearly measurements.

APPENDIX B. AVERAGE SNOW DENSITY, SNOW DEPTH AND SNOW WATER EQUIVALENT

Appendix B1. Summary for the sites located in the Mountains

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	$slug/ft^3$
1	UK05	3.2	1.3	18.4	7.2	175	0.340
2	UK06	5.1	2.0	21.8	8.6	233	0.452
3	UK14	4.7	1.9	18.8	7.4	253	0.491
4	UK16	1.3	0.5	5.8	2.3	219	0.425
5	UK17	2.6	1.0	14.2	5.6	183	0.355
6	UK19	2.4	0.9	10.0	3.9	243	0.471
7	UK20	6.0	2.4	24.6	9.7	242	0.469
8	DFR2	2.5	1.0	15.3	6.0	162	0.314
	Average	**3.5**	**1.4**	**16.1**	**6.3**	**213.8**	**0.4**

Appendix B2. Summary for the sites located in the Foothills.

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	slug/ft^3
1	UK01	5.8	2.3	25.5	10.0	227	0.440
2	UK02	5.8	2.3	19.4	7.6	298	0.578
3	UK04	5.1	2.0	21.2	8.3	239	0.464
4	UK03	4.8	1.9	26.9	10.6	180	0.349
5	UK07	11.9	4.7	40.5	15.9	293	0.568
6	UK08	1.4	0.6	5.5	2.2	262	0.508
7	UK09	10.7	4.2	46.9	18.5	228	0.442
8	UK10	10.1	4.0	34.5	13.6	294	0.570
9	UK11	9.6	3.8	37.5	14.8	255	0.495
10	UK12	3.4	1.3	13.0	5.1	262	0.508
11	UK13	4.6	1.8	20.4	8.0	224	0.435
12	UK15	8.5	3.3	28.1	11.1	304	0.590
13	UK18	0.7	0.3	5.3	2.1	138	0.268
14	Ukmet	10.4	4.1	43.7	17.2	237	0.460
15	SM01	3.7	1.5	18.4	7.2	200	0.388
16	SM02	3.5	1.4	14.3	5.6	244	0.473
17	SM03	6.4	2.5	20.2	8.0	317	0.615
18	SM04	7.5	3.0	38.9	15.3	193	0.374
19	SM05	5.3	2.1	24.0	9.4	219	0.425
20	SM06	7.8	3.1	44.8	17.6	174	0.338
21	Happy Valley	16.6	6.5	61.9	24.4	269	0.522
22	HV1	12.4	4.9	47.7	18.8	261	0.506
23	HV2	8.6	3.4	42.7	16.8	201	0.390
24	HV3	15.6	6.1	60.4	23.8	258	0.501
25	HV4	10.5	4.1	43.8	17.2	240	0.466
26	HV5	9.9	3.9	51.8	20.4	190	0.369
27	HV6	9.5	3.7	49.2	19.4	192	0.372
28	Wkmet	10.3	4.1	47.2	18.6	218	0.423
29	WK1	8.8	3.5	42.9	16.9	204	0.396
30	WK2	10.8	4.3	51.0	20.1	212	0.411
31	WK3	27.6	10.9	95.1	37.4	291	0.565
32	WK4	7.8	3.1	37.8	14.9	207	0.402
33	WK5	33.4	13.1	103.3	40.7	323	0.627
34	WK8	15.4	6.1	58.5	23.0	263	0.510
35	WK10	9.3	3.7	52.2	20.6	177	0.343
36	Sagwon	3.6	1.4	18.8	7.4	189	0.367
37	H02	11.3	4.4	41.8	16.5	271	0.526
38	IB	7.7	3.0	34.1	13.4	223	0.433
39	MI6	7.7	3.0	38.5	15.2	200	0.388
40	MI7	8.5	3.3	39.5	15.6	215	0.417
41	*DFR1*	11.6	4.6	43.8	17.2	265	0.514
42	*DFM1*	8.8	3.5	44.0	17.3	200	0.388
	Average	**9.4**	**3.7**	**38.9**	**15.3**	**235**	**0.455**

Appendix B3. Summary for the sites located on the Coastal Plain (A) and Lake Sites (B).

Table A. Coastal Plain.

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	$slug/ft^3$
1	West Dock	8.2	3.2	34.0	13.4	241	0.468
2	Franklin Bluffs	9.7	3.8	37.7	14.8	189	0.367
3	FB1	13.0	5.1	49.2	19.4	260	0.504
4	FB2	7.5	3.0	34.2	13.5	220	0.427
5	FB3	9.1	3.6	42.7	16.8	210	0.407
6	FB4	10.1	4.0	46.1	18.1	220	0.427
7	FB5	10.4	4.1	46.2	18.2	220	0.427
8	FB6	10.3	4.1	43.9	17.3	230	0.446
9	FB7	12.6	5.0	50.3	19.8	250	0.485
10	FB8	11.9	4.7	44.1	17.4	270	0.524
11	FB9	9.2	3.6	37.1	14.6	250	0.485
12	FB10	10.0	3.9	42.8	16.9	230	0.446
13	P01	5.0	2.0	16.4	6.5	303	0.588
14	P02	8.0	3.1	33.1	13.0	243	0.471
15	P03/BettyP	11.4	4.5	37.6	14.8	303	0.588
16	P04	8.8	3.5	30.1	11.9	291	0.565
17	P05	7.6	3.0	29.5	11.6	258	0.501
18	P06	4.3	1.7	15.8	6.2	271	0.526
19	P07	7.6	3.0	32.1	12.6	238	0.462
20	P08	8.6	3.4	31.4	12.4	274	0.532
21	MI1	8.9	3.5	34.9	13.7	253	0.491
22	MI2	9.7	3.8	35.2	13.9	277	0.537
23	MI3	7.6	3.0	27.3	10.7	277	0.537
24	MI4	9.8	3.9	36.5	14.4	267	0.518
25	MI5	7.0	2.8	38.3	15.1	183	0.355
26	H01	11.6	4.6	49.2	19.4	236	0.458
27	H05	10.5	4.1	41.3	16.3	255	0.495
28	WK7	9.5	3.7	46.5	18.3	205	0.398
29	*DFM3*	9.1	3.6	34.7	13.7	262	0.508
30	*DFM4*	7.1	2.8	29.5	11.6	241	0.468
	Average	**9.1**	**3.6**	**36.9**	**14.5**	**248**	**0.480**

Table B. Lake sites[2].

№	ID	SWE		SNOW DEPTH		SNOW DENSITY	
		cm	in	cm	in	kg/m^3	$slug/ft^3$
1	W0702	7.1	2.8	23.1	9.1	308	0.598
2	W0705	9.1	3.6	23.9	9.4	383	0.743
3	W0801	9.7	3.8	31.5	12.4	311	0.603
4	W0802	10.8	4.3	34.8	13.7	311	0.603
	Average	**9.2**	**3.6**	**28.3**	**11.2**	**328.3**	**0.637**

[2] Lake sites are separated because most of them do not represent repeated yearly measurements.

APPENDIX C. HISTORICAL ABLATION DATA

Appendix C1. Snow water equivalent (cm) in the Imnavait Creek basin (basin average).

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120											14													
121																								
122										8														
123				7.5																				
124							8.2																	
125																								
126										4.6	6.8													
127																					12			
128	10.6									1.7	5.3													
129	10.3		10	6.9		9.9	1.1												15.7	12.0				
130	9.7		8.8	5.1			0.3			1.3	1.3								14.4					
131	7.9		8.6	4.8			0.2												14.9					
132			7.6	1.9		7.8	0.14												14.3				11.3	8.3
133	8.1		7.4	0.4		6.9	0.12		10.1				12.5		6.9				14.4		5.7	9.6		8.4
134	7.5		7.5	0.0		6.5	0.06			0.1			10.5		5.7				14.4	9.3	4.5			8.8
135				0.0		4.9	0						11.0	9.5	5.1		13	12.4	15.1	8.2	3.3	6.8	12.4	
136			7.7			3.6				0	0		7.3	8.7	3.9			12.2	15.1	7.8	1.4		11.0	7.7
137			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
138	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
139	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
140	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
141	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
142	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
143	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
144	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
145	1.8				9.3							6.6	0.7			8.0	14	0.0	17.1		0.2		3.0	0.0
146	0.9				8.6			14.6				4.8	0.4			7.5	13		17.3		0.1		1.8	
147	0.6	11.4			7.6			13.9				2.6	2.5			7.3	12		15.1		0.0		0.9	
148	0.3	11.2			4.5			13.9					2.2			6.4	12		15.3				0.2	
149	0.1	10.2			2.0			14.1				1.6	2.2			3.9	12		14.5				0.0	
150	0.0	10.2			0.0			13.7				0.4	0.8			0.2	9.6		12.8					
151		8.9						13.0					0.6			0.01	4.6		11.4					
152		7.4						10.8				0.0	0.0			0.0	6.0		11.7					
153		5.1						9.7									5.9		7.2					
154		4.1						8.8									3.1		3.6					
155		2.3						7.5									2.2		0.4					
156		0.3						5.8									0.8		0.0					
157		0.0						5.1									0.2							
158								5.2									0.0							
159								4.0																
160								2.7																
161								1.0																
162								0.0																
163																								

Appendix C2. Snow water equivalent (cm) at the Upper Kuparuk (UK) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120																15		10	14	18	18		12	
121																								
122																								
123																								
124																								
125																								
126																								
127																								
128																								
129																			17.4					
130																			17.0					
131																			15.3		13.0			
132																			12.3		11.5			12.1
133															4.7							12.4		10.6
134															3.6			12.9		16.4	6.0			12.6
135															1.7		17	12.5	18.3	17.0	13.2			
136															1.2			15.3	17.4			8.0	14.2	10.1
137															1.0						9.1	7.8		11.8
138															0.0			15.2	18.1	11.5		6.4	13.0	9.6
139																	14		18.7	9.8	7.2	4.5	13	7.2
140																20.5	16			7.7	8.1	1.8		7.5
141																		12.6		9.2	5.5	0.0	11.8	5.6
142																	17				0.3			4.0
143																		5.8		5.9			8.0	0.9
144																	17		17.6				5.4	0.0
145																		0	17.9	1.1				
146																	18		17.3	0.5			3.1	
147																	15						0.0	
148																	13		15.2					
149																	15							
150																	13.3		13.1					
151																17.2	10.1							
152																	13.7		12.3					
153																17	9.7		10.6					
154																			7.9					
155																17	0							
156																16								
157																9.8								
158																4.8								
159																1.3								
160																0								
161																								
162																								
163																								

Appendix C3. Snow water equivalent (cm) at the Happy Valley (HV) site.

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120																	14	15	13	23	24		7.3	
121																								
122																								
123																								
124																								
125																								
126																								
127																								
128																								
129																								
130																			16.4					
131																								
132																								
133																						22.0		
134																		13.1						
135																					28.3			
136																		12.5						
137																							8.1	
138																		9.6						20.0
139																15.3				17.4		22.0		
140															7.4		19	6.7			30.0			
141																			17.7	14.9				
142															10			0.8				14.1	7.8	16.2
143																		0.0	11.1	14.7	28.6			
144																						13		12.6
145																			20.2	8.2			6.9	
146																	14				26.7	8.2		6.2
147																								
148																			11.0		21	7	6.3	3.0
149																				0				
150																16.0					19	4.2	5.8	0
151																			24.3					
152																	11.7				13	0	4.7	
153																13			4.4					
154																	9.2				10		1.7	
155																12								
156																	4.1				4.3		0	
157																11								
158																	0							
159																2.3								
160																								
161																0								
162																								
163																								

Appendix C4. Snow water equivalent (cm) at the Sagwon (SH) site.

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120				8.1	9.1	4.4	6.0		5.6			8.3	12			10	6.4	10	8.1	11	5.5		7.5	
121																								
122																								
123																								
124																								
125																								
126																								
127							1.7																	
128						2.0																		
129				5.4																				
130																								
131																								
132																								
133				3.9			1.7															6.0		
134																		7.9						
135			5.2													7.9					3.6			
136																		7.7						
137				3.9												7.7							7.3	
138				4.4														3.3						8.0
139												0.4				3.3				8.2		0.0		
140						1.1								1.7	5.8		8.1	0.0			4.3			
141				3.9												0.0			8.4	4.8				
142															7.7								7.2	7.0
143																			10.2	4.9	3.4			
144				3.8									1.1		4.1									3.7
145					5.9				2.3											2.8			7.1	
146				3.7													6.6				2.9			1.5
147																								
148				3.7															9.2		2.2		7.1	0.0
149																				2.8				8.0
150				2.6																	0.3		6.3	
151																			2.0					
152				2.4													5.7			2.3	0		4.7	
153																								
154				1.8													1.8			1.3			0	
155																								
156				1.7													0.5			0.5				
157																	0.0							
158																				0				
159																								
160																								
161																								
162																								
163																								

Appendix C5. Snow water equivalent (cm) at the Franklin Bluffs (FR) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120				9.3		4.7	11.3		12.7					6.5		10		8.5	12		12	10	6.6	
121																								
122																								
123																								
124										6.1														
125																								
126											7.0													
127																								
128						5.6																		
129				2.7																				
130																			10.2					
131																								
132																								
133																								
134							10.7											8.3						
135			8.5																		12.0			
136								8.0										6.5						
137																			15.6				8.7	
138																		4.7	17.6					
139												6.9							19.5			8.1		
140														7.1		14.5	13	3.3	19.1	9.1	11.5			
141							10.9	6.7											12.5					9.2
142				5.4										9.1				1.0	12.3		12.8	5.5	8.4	
143																		0.0						
144							8.6							8.2					10.0			1.8		8.9
145					22.3				14					9.6					9.2	2.9			7.8	
146				4.9										9.1							12.3	0		7.0
147							8.6							8					11.4					
148				4.0										8.6					9.4		11		6.5	0.5
149													22.9	7.8						2.9				
150				3.4										6.9					7.3		8		6.3	0
151							2.8							6.7		14.7			14.6					
152				1.6										4.7			13.4			2.3	6		5.8	
153														2.9					2.6					
154				0.8										1.9			9.6			1.3	2.7		1.9	
155														1.4		14			0.5					
156				0.7										0.7			7.7			0.4	0.4		0	
157					7.7									0			5.5		0	0.4				
158				0												9.2	4.5			0	0			
159																8.2	3.5							
160																3.5	2							
161																2	0							
162																1.2								
163																0.3								

Appendix C6. Snow water equivalent (cm) at the Betty Pingo (BP) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120																						12		
121																								
122																								
123																								
124																								
125																								
126											6.6													
127																								
128																								
129											7.6													
130											7.1													
131											6.3													
132											6.0													
133											6.0							9					9.3	
134											5.9													
135											5.8				9.9									
136																		8.9						
137										7.3			12.8					8.3	10.9					
138													12.7					6.3	10.0		7.0			
139												4.7	12.9					5.4	11.5	8.1				
140										7.2		4.4	13.3					4.5	12.7		9.5			
141										6.8		4.6	13.2		9.3	12.8	8.3	4.5	12.6					9.1
142												4.3	12.6		8.5			2.7	12.7					
143										4.2		2.8	11.8					0.6	11.3					
144									10	3		1.9	11.3		9.2			0.0	9.5	2.7		6.3	8.2	6.9
145									10	1.8	5.8	1.4	13.0		7.5									5.0
146									12	0.9	5.1	1.8	12.3		8.1				11.1		10.8	2.6	8.8	3
147									12	0.6	4.1	0.7	13.3		8.5				11.8					3.2
148									11	0.8	3.7	0.4			7				11.8			0	9.2	1.0
149									5.5	0.4	3				7.2				11.5	2.6				0.5
150									3.8	0.1	2.1				7				9.8		5.5		7	0.3
151										0	1.3				6.8				10.1	2.6	4.4			0
152									0		0				5.7	14.9	8.8		8.9		4.2			
153											0				5.7				7.1	1.9			6.4	
154															4.5		4.1		6.5	1.3	3			
155															3.4				1.9	1.1	2.4		3.1	
156													9.7		2.9		3.4		0.0	0.6	1.1			
157													6.6		2.6	8.4	2			0	0.2		0	
158													4.2			6.7	1.2							
159													3.4			6.2	0.9							
160													1.4			3.8	0.7							
161													0.9			1.7	0							
162																0.3								
163																0.0								

Appendix C7. Snow water equivalent (cm) at the West Dock (WD) site

Day of Year	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
120																6.5	5.7	7.3	18	7	6.3		5.8	
121																								
122																								
123																								
124																								
125																								
126																								
127																								
128																								
129																								
130																								
131																								
132																								
133																		7.7					6.5	
134																								
135																					3.7	8.8		
136																		7.6						
137																		7.7	7.3					
138																		6.5	9.4			7.3		
139																		4.8						
140																		4.3	14.6	8.2	4.9			
141															10.6		6.3	4.3	11.2					
142															8.9			3.1	9.3					8.2
143																		1.0						
144															12			0.0	11.2					11.0
145															9.6					2				
146															11				9.2		3.8		6.2	4.5
147															11				7.3			4		
148															11				8.9				6.0	0.0
149															9.1				6.6			0		
150															11				10.3	2.4	3.3		8.3	
151															8.9	6.2					2			
152															8		6.3		14.1	2.4	1			
153															6.8				5.7				7.1	
154															7.6		4.2		4.9	1	0.6			
155															5.6				4.0	1	0.2		4.3	
156															4.7	7.2	2.8			0.8				
157															4.7	6.8	1.7		0.4	0.4			0	
158															3.4	5.4	0.9							
159															2.8	3.4	0.4							
160															3.3	1.6	0.4							
161															1.6	0.7	0.2							
162															0.5	0.6	0							
163															0	0								