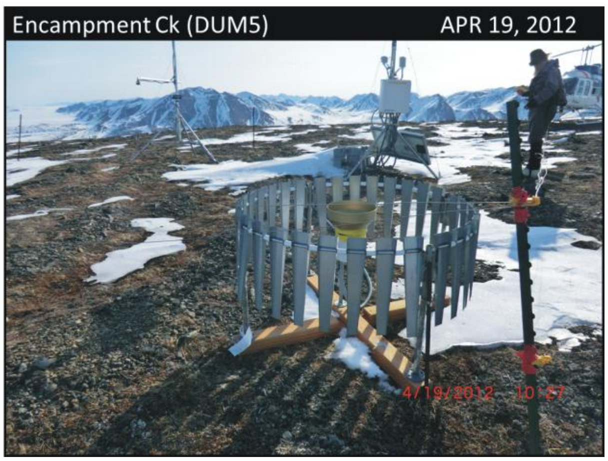
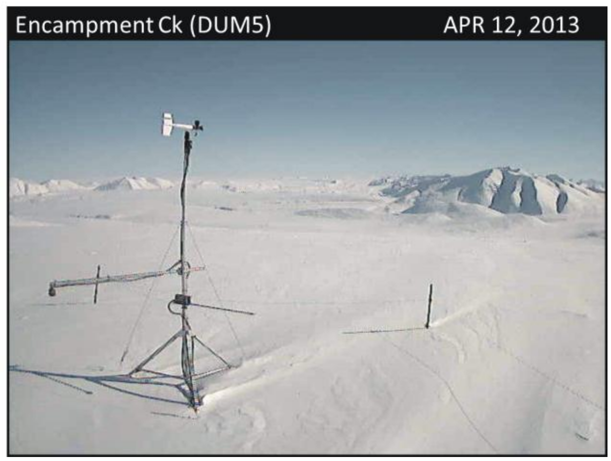
Snow Survey Results for the Central Alaskan Arctic, Arctic Circle to Arctic Ocean: Spring 2013





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

A report on research sponsored by the

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February 2014

Ambler and Umiat Hydrology Projects

Report Number INE/WERC 14.01

Water and Environmental Research Center

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Recommended Citation:

Stuefer, S.L., Homan, J.W., Kane, D.L., Gieck, R.E., and Youcha, E.K. 2014. Snow Survey Results for the Central Alaskan Arctic, Arctic Circle to Arctic Ocean. University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 14.01, Fairbanks, Alaska, 96 pp.

Fairbanks, Alaska

February 2014

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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. This work does not constitute a standard, specification, or regulation.

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UNITS, ABBREVIATIONS, AND SYMBOLS

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 "secondary" units has been provided in parentheses. Thus, for instance, snow density is reported in kilograms per cubic meter (kg m^{-3}), followed by the approximate value in slugs per cubic feet (slug ft^{-3}) in parentheses. Density of water at maximum density equals 1000 kg m^{-3} or 1.94 slug ft^{-3}.

Datum

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

Abbreviations, Acronyms, and Symbols

ADOT&PF	Alaska Department of Transportation and Public Facilities
AIDEA	Alaska Industrial Development and Export Authority
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
Put	Putuligayuk River
Sag	Sagavanirktok River
QA	quality assurance
QC	quality control
SWE	snow water equivalent
UAF	University of Alaska Fairbanks
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WERC	Water and Environmental Research Center
WGS84	World Geodetic System 1984

ACKNOWLEDGMENTS

This study was funded by grants ADN #2522174 (Ambler) and ADN #2522154 (Umiat), Alaska Department of Transportation and Public Facilities. Ken Irving, Joel Bailey, Bob Busey and many others from WERC/UAF participated in snow data collection. The contribution of Michael Lilly and Jeff Derry to earlier snow reports (2008, 2009, 2010) is greatly appreciated. Technical editor Grace Pedersen assisted with the formatting and proofreading of this report. UAF student Everett Megli worked on the formatting and processing of snow survey data and on the snow water equivalent corrections. Weather maps were provided by the National Oceanic and Atmospheric Administration (NOAA). U.S. National Park Service issued a permit for conducting snow survey in the Gates of the Arctic National Park & Preserve.

ABSTRACT

Many remote areas of Alaska lack meteorological data; this is especially true for solid precipitation. Researchers at the University of Alaska Fairbanks, Water and Environmental Research Center have been collecting end-of-winter snow cover observations (depth, density, snow water equivalent and ablation) since the year 2000. These observations do not document the total snowfall during the winter, but provide quantitative estimate of cold season precipitation on the ground at winter's end after sublimation and redistribution by wind. This report provides summary of snow cover data collected during cold season of 2012–2013. There are two main areas of study. One includes drainage areas of the western Sagavanirktok, Kuparuk, Itkillik, Anaktuvuk and Chandler Rivers located north of the continental divide in the Brooks Range. While the number of sites has varied each year, we visited 76 sites in April of 2013 on the North Slope of Alaska. Second study area was established in 2012 in the drainage areas of the Kogoluktuk, Mauneluk, Reed, Alatna, and Koyukuk Rivers south of the Brooks Range. Fifty seven new snow survey sites were visited south of the Brooks Range in April 2013. The cold season of 2012-2013 experienced heavy snowfalls (record amounts since 2000) north of the Brooks Range. This was the first year of data collection south of the Brooks Range, thus no comparison can be made. SWE averaged over entire study area was 13.1 cm in 2013, ranging from 1.2 cm to 35.2 cm. Generally, higher SWEs were found in the western portion of the study area. Ablation was later than normal in spring 2013. Ablation window extended from May 8, 2013 in the far south of the study area to middle June at higher elevations on the north side of the Brooks Range.

Snow Survey Results for the Central Alaskan Arctic, Arctic Circle to Arctic Ocean: Spring 2013

1. INTRODUCTION

This work was funded by the Alaska Department of Transportation and Public Facilities (ADOT&PF) to address environmental questions specifically related to the potential development of the Umiat and Ambler road corridors in northern Alaska. One of the main environmental questions pertains to the location and design of river crossings along the routes. This report is an assessment of water quantity in the seasonal snowpack of northern Alaska and the contribution of this snowpack to high flows in streams during snowmelt. This work is needed because of the lack of observational data that provide a foundation for flood frequency and risk analysis at river crossings. Snow survey data collected for the Ambler and Umiat hydrological projects are presented in this report. A summary of all hydrological data for the Umiat project and an analysis are provided in the main report (Kane et al., 2014).

Snow accumulation during the winter and following snowmelt period plays an important role in the hydrology of rivers flowing south and north that emanate from the Brooks Range. While peak flows sometimes occur during summer storms, snowmelt ensures high flows in these rivers every May–June. The seasonal snowpack constitutes winter storage of precipitation, introduces considerable differences in surface energy balance, and affects the amount of soil desiccation that occurs within the organic layer overlying the deeper mineral soils and the permafrost (Kane et al., 1978). For many river basins in northern Alaska, particularly the larger basins like the Colville or Kuparuk, 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. In the northern Brooks Range, snowmelt contributes to runoff beginning in May, and melting is usually complete within a month. Based on one year of data from the southern Brooks Range watersheds, timing of snowmelt is similar to that observed in the northern foothills. Note that May 2013 was unusually cold in northern and interior Alaska, and this contributed to late snowmelt in the study areas north and south of the Brooks Range.

To obtain accurate estimates of snow water equivalent (SWE), we measure snow in two ways that complement each other. First, continuous snow depth data are collected at each weather station. This data provides temporal snow variability over the entire winter period at one particular point under the snow depth sensor. Due to extremely high snowpack heterogeneity, knowledge of the spatial distribution of snow is required for understanding the watershed scale hydrologic response to snowmelt. To evaluate SWE at the watershed scale, we undertake a spring snow survey and collect snow depth and SWE across the watersheds at numerous, widely dispersed locations.

Discussed in this report are the snow conditions observed during the 2013 end-of-winter snow surveys in the watersheds north and south of the Brooks Range. Snow data were collected for the following watersheds north of the Brooks Range: Chandler, Anaktuvuk, Itkillik, Putuligayuk, Kuparuk, and western Sagavanirktok. Snow data were also collected for watersheds south of the Brooks Range, including the Koyukuk, Alatna, Reed, and Kogoluktuk, along with a few additional locations along the proposed road corridor. Snowpack field studies focused primarily on the maximum SWE accumulation of the 2012–2013 winter and on subsequent ablation. Field activities started in April because, by then, the snowpack reflects nearly the maximum precipitation that has fallen minus sublimation (Benson et al., 1986). Because of difficulties in quantifying snow precipitation and sublimation, measurements of snow accumulated on the ground provide the most reliable observational component of the net winter water budget for use in hydrologic studies.

2. STUDY AREA

The study domain covers a 400 km by 450 km region of northern Alaska that is bound by the Arctic Ocean to the north and the Arctic Circle to the south (Figure 1). The southern and northern boundaries of the domain are at 66°40′N and 70°15′N latitude, respectively. The western and eastern boundaries of the domain extend from 156°30′W to 148°00′W longitude, respectively. Elevation within the study area ranges from sea level to 2733 m (0 to 8966 ft). Rivers north of the Brooks Range divide such as Colville, Kuparuk, Putuligayuk (Put), and Sagavanirktok (Sag) contribute runoff to the Beaufort Sea and the Arctic Ocean. The Chandler, Anaktuvuk, and Itkillik Rivers flow first into the Colville River. Rivers south of the Brooks Range divide contribute freshwater to the Bering Sea and the Pacific Ocean via the Kobuk and Yukon Rivers. The Alatna first flows into the Koyukuk, which flows into the Yukon, while the Reed, Mauneluk, and Kogoluktuk flow into the Kobuk River.

Throughout the winter period, snow accumulation is affected by the local vegetation type and more specifically by its height. Trees and high-growing shrubs can protect snow from wind redistribution and/or can catch snow during wind transport. While along exposed ridges and in treeless Arctic and high alpine environments, snow can be transported by wind for long distances and partially lost to sublimation during this transport.

The region north of the Brooks Range is treeless (a few riparian areas have small trees) with occasional groupings of willows approximately 1 m (3 ft) high that occur in hillside water tracts and in valley bottoms. Tree line is located just south of the Brooks Range divide. Watersheds south of the Brooks Range have some cover of Black Spruce and Quaking Aspen, marking the northern limit of those trees (http://en.wikipedia.org/wiki/Brooks_Range). Generally, the organic soils vary from live material at the surface to partially decomposed matter between 10 and 20 cm (4–8 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.

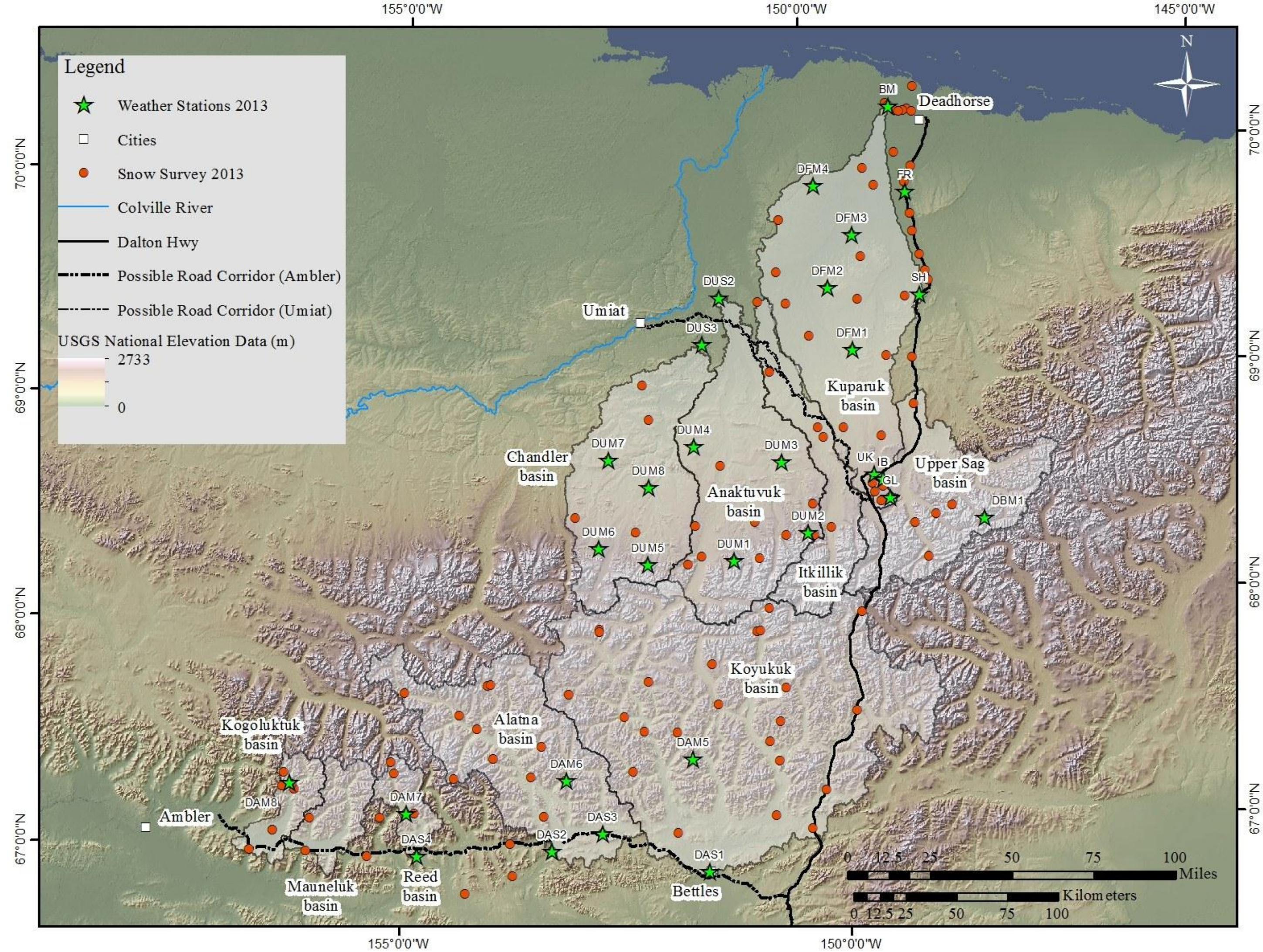


Figure 1. Geographical map of study area showing weather stations (which double as snow survey sites) and snow survey sites visited in April 2013. Plotted watershed boundaries above hydrologic observation stations were derived from the USGS national elevation data.

3. SAMPLING METHODS

Snow surveys are made at designated locations throughout the domain to determine snow depth, as well as vertically integrated density and SWE. Except when making ablation measurements (see Section 3.2), most of the sites are visited just once a year near the peak of snow accumulation, generally the last week of April for the region north of the Brooks Range and the first week of April for the region south of the Brooks Range. Our observations, from datasets collected north and south of the Brooks Range, show the onset of ablation is typically in late April or May. So, April is a good time to capture end-of-winter SWE. March, April, and May are often the months of lowest monthly precipitation, and usually little accumulation occurs between the end-of-winter snow surveys and the onset of ablation, although there are exceptions like 2013.

In addition to snow surveys, snow depths are collected throughout the winter at meteorological stations that are equipped with automated ultrasonic snow depth sensors (SR50 or SR50A). 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* (Rovansek et al. 1993). The snowpack in Alaska is extremely heterogeneous, with snow depth being more variable than density (Benson and Sturm, 1993). When double sampling, many more snow depths can be made in the same amount of time as a single SWE measurement. Typically, double sampling yields 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 a 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 method ensures that the complete snow column was sampled. The vegetation plug is removed, and the snow is either collected in Ziploc bags for weighing later in the laboratory or weighed directly in the field. Five snow cores are used to estimate the average snow density.

We use a constant 50 m length 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 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 (Berezovskaya et al., 2007b, available at http://ine.uaf.edu/werc/ projects/foothills/reports.html), we have summarized long-term snow ablation observations (Table 1) that have been conducted continuously since 1985 from earlier projects funded by the Department of Energy and the National Science Foundation, Office of Polar Programs. The data are presented in Appendix B.

Table 1. Summary of snow ablation sites from roughly north to south. The latitude and longitude of each site can be found in Appendix A.

North of Brooks Range		
Site Name	**Period of Record**	**Comments**
West Dock	1999 to 2009	150 m east of West Dock–GC1 Road, approximately 1 mile south of West Dock weather station.
Betty Pingo	1993 to 2012	Survey near USDA NRCS precipitation gauge.
Franklin Bluffs	1988 to 2012	Surveyed near weather station 1988 to 1998 (with some missing years), snow site moved west 700 m along access road 1999 to 2010.
Anaktuvuk	2011	10 m north (downstream) of Anaktuvuk weather station.
Lower Itkillik	2013	Left bank, 10 m north (downstream) of Lower Itkillik weather station.
Sagwon Hill	1988 to 2012	Adjacent to the Sagwon weather station.
Chandler	2011	Helicopter landing area near Chandler River weather station on bluff above the river.
Happy Valley	1999 to 2012	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.
Upper Itkillik	2011, 2013	Right bank on lower terrace, 200 m north of Upper Itkillik weather station.
Upper Kuparuk	1999 to 2013	Adjacent to the Upper Kuparuk weather station.
Imnavait	1985 to 2009 2012-2013	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 2013 (with a two year break in record during 2010 and 2011).
Galbraith	2010	West of Galbraith Airport, adjacent to gravel pit access road.
Atigun Pass	2010	30 m north of USDA NRCS precipitation gauge.
South of Brooks Range		
Alatna	2013	Adjacent to the Alatna weather station.
S Fork Bedrock	2013	Adjacent to the S Fork Bedrock weather station.
Reed	2013	Adjacent to the Reed weather station.

3.2.1 Observations from 1985 to 2012

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 frequently windy conditions, cores were placed in bags in the field and weighed indoors, using the Adirondack mechanical scale and, after 1999, digital scales. Following the method of 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), five to twenty snow cores were taken, along with fifty snow depths.

The number of observational sites has changed over time (Table 1) mostly due to the pattern of research funding. 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 northwest of the meteorological tower. The Franklin Bluffs sampling site was located adjacent to the weather station (1 km east of the Dalton Highway) from 1986 through 1998. In 1999, the snow survey and ablation observation site was moved west approximately 300 m off the Dalton Highway. The Betty Pingo site on the Prudhoe Bay Oil Field was established in 1992. This snow survey site was located near the U.S. Department of Agriculture (USDA) National Resources Conservation Service (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 surveys and ablation observation sites were added in 1999. Snow surveys at Upper Kuparuk were made just east of the meteorological tower. The Happy Valley survey site was located 500m west of the Dalton Highway across from the Happy Valley Camp, and the West Dock surveys were made 500 m south of the Oxbow Road and West Dock Road intersection. Three snow ablation observation sites—Oil Spill Hill, Galbraith, and Atigun Pass—were monitored only one year, in 2010. The Oil Spill Hill survey was conducted 500 m west of the Dalton Highway Oil Spill Hill pullout, the Galbraith site was 500 m west of the Galbraith Lake Airport, and the Atigun Pass survey was just north of the USDA NRCS Wyoming snow guage atop

Atigun Pass on the Dalton Highway. In 2011, ablation observation sites were established just north of the Anaktuvuk, Chandler, and Lower Itkillik weather stations.

Imnavait Creek basin (IB) differs from other basins 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 four 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.

A majority of the past snow ablation measurements were supported by the WERC/UAF project "Long-term measurements in the Kuparuk River Watershed," funded by the National Science Foundation (NSF). After spring 2010, support from this NSF project was no longer available, which resulted in a reduction of snow survey and ablation observation sites (Table 1). Three new ablation observation sites (Upper Itkillik, Anaktuvuk, and Chandler) were added in 2011, and one in 2013 (Lower Itkillik) as part of the Umiat project, while three additional sites (Alatna, S Fork Bedrock, and Reed) were added in 2013 as part of the Ambler project.

3.2.2 Observations from 2013

Ablation was measured at two long-term observational sites (Imnavait and Upper Kuparuk), two sites that are part of the Umiat Road corridor project (Lower and Upper Itkillik), and three new sites established for the Ambler Road corridor project (Alatna, S Fork Bedrock, and Reed). These sites were visited frequently in May and June (see Appendix B) to capture the net volumetric decrease in SWE. Sometimes gaps occur during the ablation measurements, indicating that either site access was limited due to weather or that the field crew was busy measuring streamflow during breakup at other sites. As our standard protocol, we took five snow density and fifty 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

During the 2012–2013 winter, automated snow depth measurements were recorded at fifteen meteorological stations north of the Brooks Range divide and at eight new meteorological stations south of the Brooks Range (Table 2). We also used depth measurements from one USDA NRCS SNOTEL site. The snow depth sensor used was a Campbell Scientific Sonic Ranger SR50 or SR50(A). The only difference between the SR50 and SR50(A) is the housing that encases 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 the sensitivity of the SR50(A) is designed for measuring distance to a snow surface.

The method used for determining snow depth with the SR50 is subtraction. When no snow is 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 22° from the bottom of the sensor. The program for the SR50 records measurements at one-minute intervals and reports hourly averages.

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

	Site Name	General Location
North of Brooks Range		
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, Valley Bottom
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, Valley Bottom
South of Brooks Range		
1	Bettles (DAS1)	Koyukuk River, Valley Bottom
2	Alatna (DAS2)	Alatna River, Valley Bottom
3	S Fork Bedrock (DAS3)	Atatna River, Valley Bottom
4	Reed (DAS4)	Reed River, Valley Bottom
5	Wild (DAM5)	Koyukuk River, Brooks Range
6	Upper Iniakuk (DAM6)	Alatna River, Brooks Range
7	Upper Reed (DAM7)	Reed River, Brooks Range
8	Upper Kogoluktuk (DAM8)	Kogoluktuk River, Brooks Range
9	Coldfoot (NRCS)	Koyukuk River, Forested Brooks Range

4. ACCURACY OF OBSERVATIONS

This section reports on 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 snow density measurements with the Adirondack or with snow pit estimates 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 mineral soils, snow depth is often overestimated (Stuefer et al., 2013). While measuring, the probe can easily penetrate low-density organic material, so this additional depth often is incorporated inadvertently into the snow depth measurement (Figure 2a). 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 (Figure 2b).

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

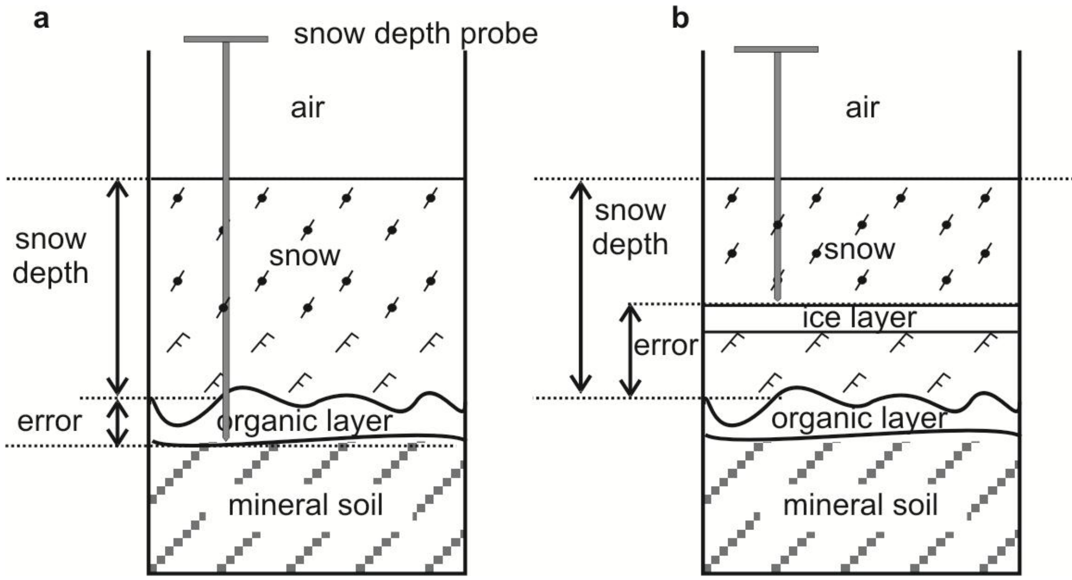


Figure 2. Schematic diagram of the snow depth measurements and possible errors associated with over- and underestimation of snow depth (Stuefer et al., 2013).

4.2 Snow Depth Sensors

Snow depth sensors track changes in snow depth very well. The manufacturer's stated accuracy is ±1 cm or 0.4% of the distance to snow surface from sensor, whichever is greater (Campbell, 2008). Local air temperature is measured to correct for errors in distance measurements. The mounting height of a sensor can also influence the quality of data recorded, with too high of a mounting height resulting in noisy data, and too low of a mounting height resulting in the potential for snow depths to reach or bury the sensor. Our sensors are generally mounted at a height of 1.5 m. Inaccuracies can result from the difficulty of establishing a zero point, which is caused by tussocks/uneven ground, vegetation growth, neglecting periodic maintenance requirements (replacement of sensor transducer), high wind, falling snow, low-density snow, blowing snow, and a change in sensor height due to ground heave.

Sonic snow depth records in this report were adjusted manually to account for field observations and erroneous data points. Brief periods of high winds, heavy snow, and/or blowing snow can cause the instrument to report inaccurate data. These brief periods of spurious data are excluded from the records. At the beginning and end of seasonal transition periods, there can be erroneous data as a result of underlying vegetation and uneven ground. During installation of sonic sensors and during subsequent station visits without snow on the ground, the ground surface under the snow sensors was trimmed of vegetation and leveled if possible. This practice 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 for QA/QC purposes. Our field procedures during site visits were as follows:

- During all site visits:
  - Inspect sensor and supporting structure for proper leveling and structural soundness.
  - Inspect sensor for corrosion; replace if necessary.
  - Measure the distance from the sensor to the ground.
- When clear of snow:
  - Trim vegetation under sensor and attempt to level ground.
- When snow covered:
  - Inspect for ice and frost on sensor.
  - Measure snow depth directly under the sensor.
  - Measure distance from sensor to snow surface.
  - Conduct snow survey near the sensor.

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 (Figure 1). Snow water equivalent is measured at elevations from 5 m to 1481 m (16.4 ft to 4859 ft); SWE changes with elevation in an irregular manner, as shown in Figure 3A. Heterogeneity in SWE results from snow redistribution by wind, causing shallow snowpack on top of the ridges and deep snow accumulation in depressions, in valley bottoms, and on leeward hillsides. Figure 3A shows how the range of SWE variability increases with elevation. Snow water equivalent varies from 2 to 18 cm at elevations less than 200 m; this range increases from 2 to 35 cm at higher elevations.

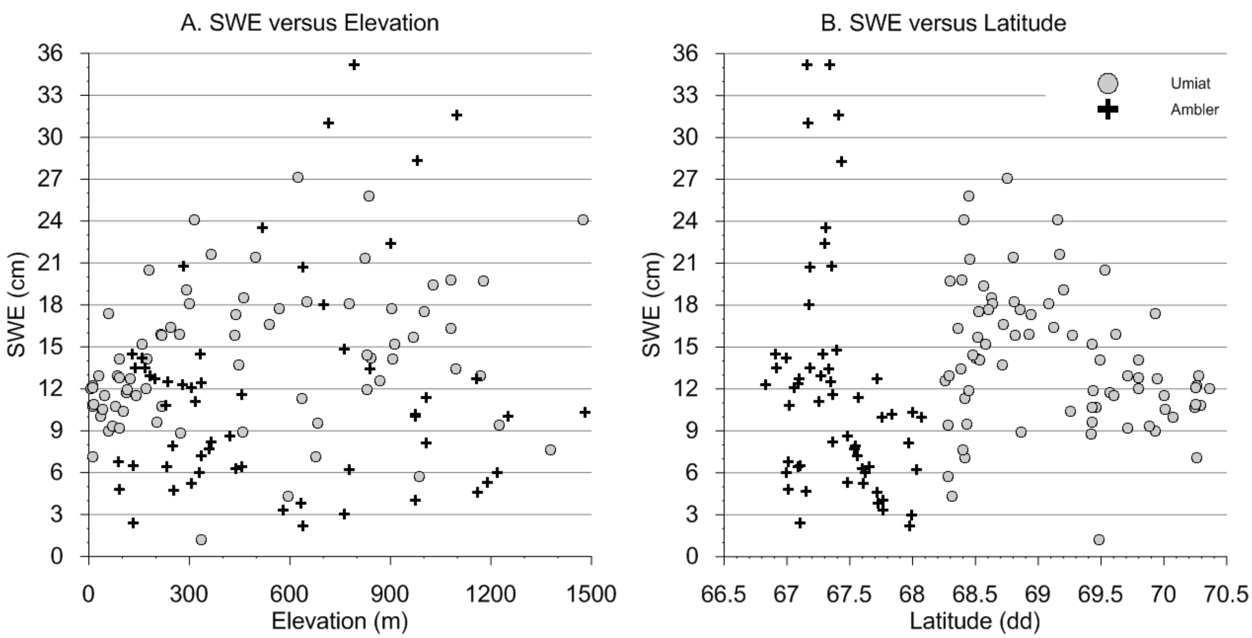


Figure 3. End-of-winter adjusted SWE (cm) south and north of the Brooks Range in spring 2013. Left panel (A) shows SWE variations with elevation. Right panel (B) shows variability in SWE with latitude.

Snow survey sites north of the Brooks Range were classified based on topography: the flat northern portion (generally referred to as *Coastal Plain*), gently rolling hills and valleys (*Foothills*), and mountain ridges (*Mountains*). In past reports, we observed that the regional end-of-winter SWE and snow depth of the Foothills and Coastal Plain are generally higher than end-of-winter SWE and snow depth in the Mountains. The average snow density of the Coastal Plain is generally higher than average snow density measured in the Foothills and Mountains. In 2013, average SWE was observed on the Coastal Plain, and above-average SWE was observed in the

Foothills. The Mountains had large SWE variability from shallow to deep snow, as shown in Figure 3B.

South of the Brooks Range, the regional classification of snow sites was not applied because of the more complex vegetation that affects snow distribution, together with the topography and wind. Figure 3B shows large SWE variability (from 2 cm to 35 cm) south of the Brooks Range for 2013. The highest SWEs (28, 31, 35 cm) were measured in the western watersheds of Alatna and Reed (Figure 4 and Figure 5).

The green dots on Figure 4 represent SWE that is close to average across the entire study area (approximately ±0.5 standard deviation). Yellow and orange dots indicate relatively low SWE, whereas dark blue and light blue show SWE that is above average. A visual interpretation of Figure 4 indicates relatively low SWE in the Koyukuk River watershed, as well as increases in SWE from east to west on the southern side of the Brooks Range. An exception to the increasing trend of SWE from east to west is in the low lying Ambler Flats region in the west, an open, mostly treeless area, where snow is blown away or redistributed during wind events.

Overall, 133 sites were visited in 2013. This number includes 76 sites located north of the Brooks Range (Umiat project) and 57 sites located south of the Brooks Range (Ambler project).

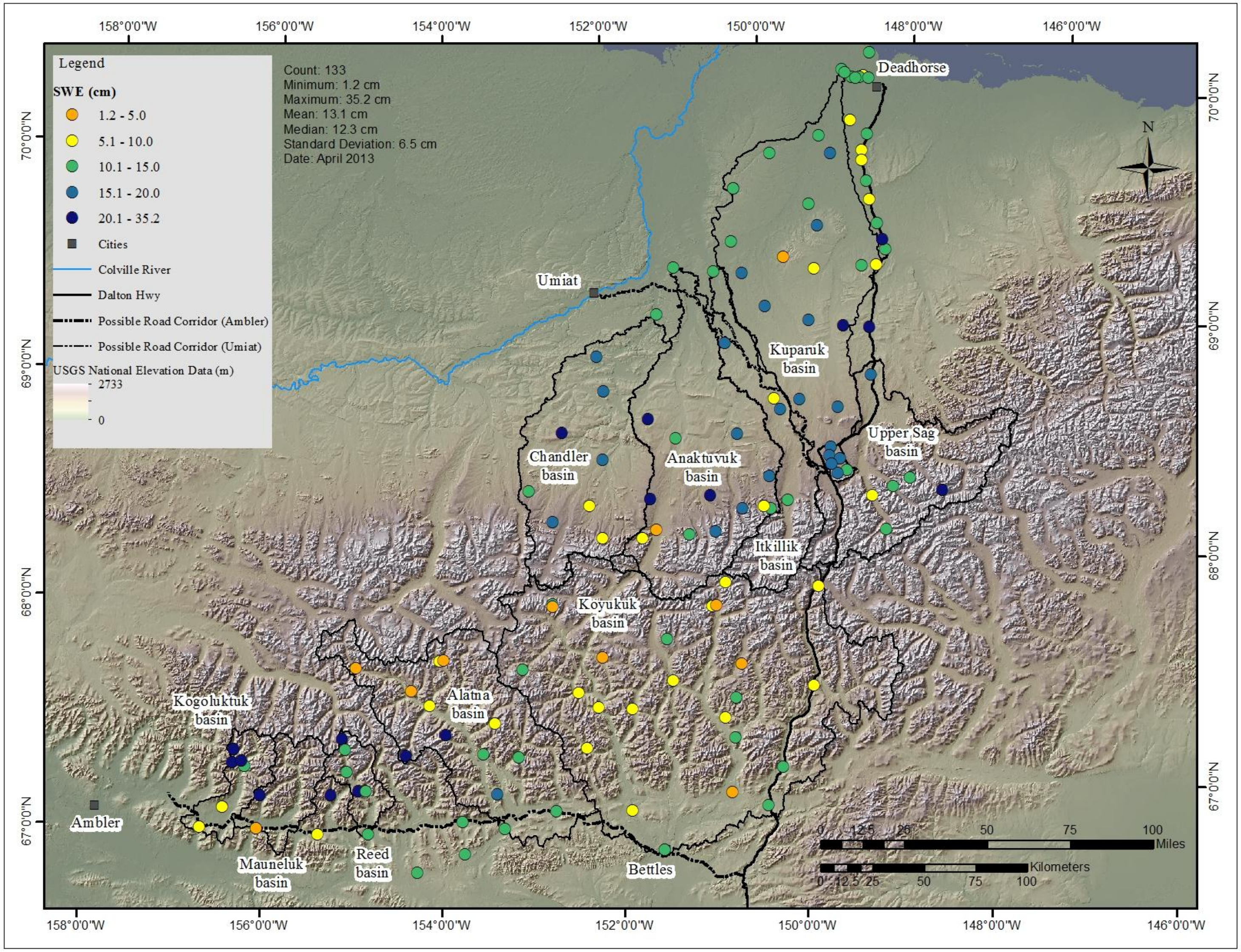


Figure 4. End-of-winter adjusted SWE (cm) in spring 2013. Each point represents the average from 50 snow depths and 5 snow densities.

6. SNOW SURVEY DATA AT WATERSHED SCALE

This section summarizes the snow data at watershed scale. The number of visited snow survey sites at each watershed varies from year to year, because weather conditions do not always allow access to all the stations by helicopter. In addition, research funding varies from year to year. A complete list of snow survey sites and collected data are presented at the end of this report for 2013 (Appendix A). End-of-winter SWE data were adjusted for the snowfall events that occurred at the majority of the Ambler and Umiat snow survey sites after the snow surveys were completed in April, but before ablation. For more details on SWE adjustment, please see section 9 on "Corrections to end-of-winter SWE".

Snow water equivalent distribution for each watershed is summarized using a box and whisker plot shown in Figure 5.

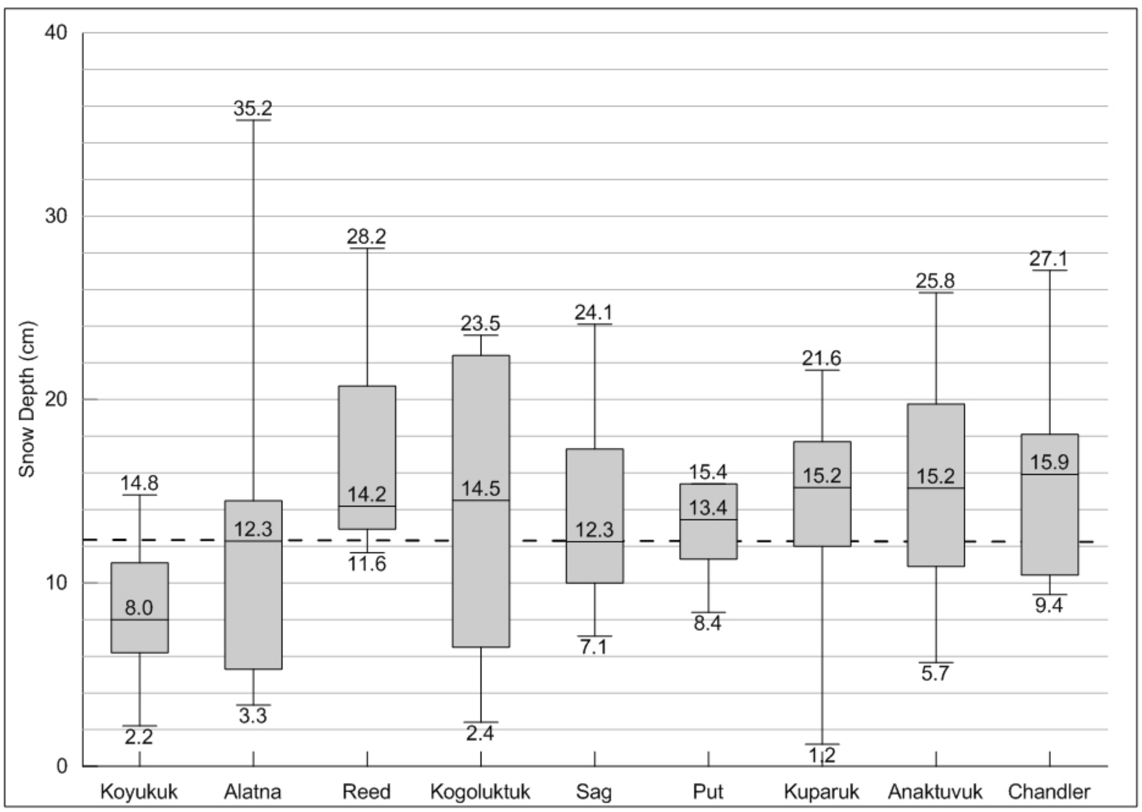


Figure 5. Box and whisker plot of adjusted SWE, April 2013 (median is printed in each box; 25 and 75 quantiles represent upper and lower boundary of the box; maximum and minimum snow depth is shown by whisker). The dashed line represents the median from all data = 12.3 cm. Average SWE (n = 133) is 13.1 cm.

This figure provides a visual interpretation of the symmetry, variability, presence of outliers, and central tendency in the data (median). The median corresponds to the middle SWE obtained from the data that were arranged from lowest value to highest value (probability of occurrence is 0.5), which can differ from the average SWE presented in Table 3. By comparing variability in SWE from different watersheds plotted side-by-side, it can be seen that the Koyukuk River and Putuligayuk River watersheds have the lowest SWE variability and the Alatna River watershed has the highest SWE variability.

Sample mean or average SWEs, are shown in Table 3. Median (Figure 5) and mean SWEs are fairly close to each other for most of the watersheds. SWE measurements in the Reed watershed are positively skewed (also small sample $n = 6$), suggesting that the median (SWE = 14.2 cm) is a better measure of central tendency than the sample mean (SWE = 16.9 cm).

Snow survey sites south of the Brooks Range (the Koyukuk, Alatna, Reed, and Kogoluktuk River watersheds) were established in spring 2013, so no comparison with previous years can be provided. For other watersheds, presented in Table 3, SWE in 2013 is significantly higher than SWE in 2012. For more details on interannual variability, please see the section on "Long-term snow observations" later in this section.

Table 3. Basin average adjusted snow water equivalent (SWE) for 2013.

Basin	**Number of sites**	**2013**		**Percent of last year**
		SWE (cm)	**Std. Dev. (cm)**	**%**
Chandler	9	15.5	5.6	138
Anaktuvuk	14	15.5	5.8	185
Kuparuk	24	14.6	3.8	133
Sagavanirktok	16	13.2	5.5	125
Putuligayuk	8	10.7	1.8	111
Koyukuk	24	8.2	3.4	No data
Alatna	16	12.8	8.9	No data
Reed	6	16.9	6.4	No data
Kogoluktuk	7	13.9	8.7	No data

Since SWE is a product of snow depth and snow density, the next two pages are maps of their spatial distribution. Snow depth and snow density were not adjusted for the additional snow accumulation that occurred after the snow survey. For more details on SWE corrections, please see section on "SWE corrections" later in this report. Figure 6 shows the end-of-winter snow depths, while Figure 7 presents the densities. Most sites with deep snowpacks have high SWEs, but that is not always the case (Table 3, Table 4). Coastal Plain Putuligayuk Basin snow cover is exposed to frequent high wind events and often has densities higher than the regional average (Figure 7). Snow survey sites with deep snowpacks also report higher snow density (ALAT2, ALAT3, REED2, and CHA4 in Appendix A3).

Table 4. Basin average measured (not adjusted) snow depth for 2013.

Basin	**Number of sites**	**2013**		**Percent of last year**
		Snow Depth (cm)	**Std. Dev. (cm)**	**%**
Chandler	8	57.2	18.1	122
Anaktuvuk	14	52.7	24.4	161
Kuparuk	24	46.3	14.7	111
Sagavanirktok	16	32.3	6.4	80
Putuligayuk	8	43.3	15.7	120
Koyukuk	24	39.3	16.2	No data
Alatna	16	52.7	27.3	No data
Reed	6	65.8	17.6	No data
Kogoluktuk	7	47.0	20.8	No data

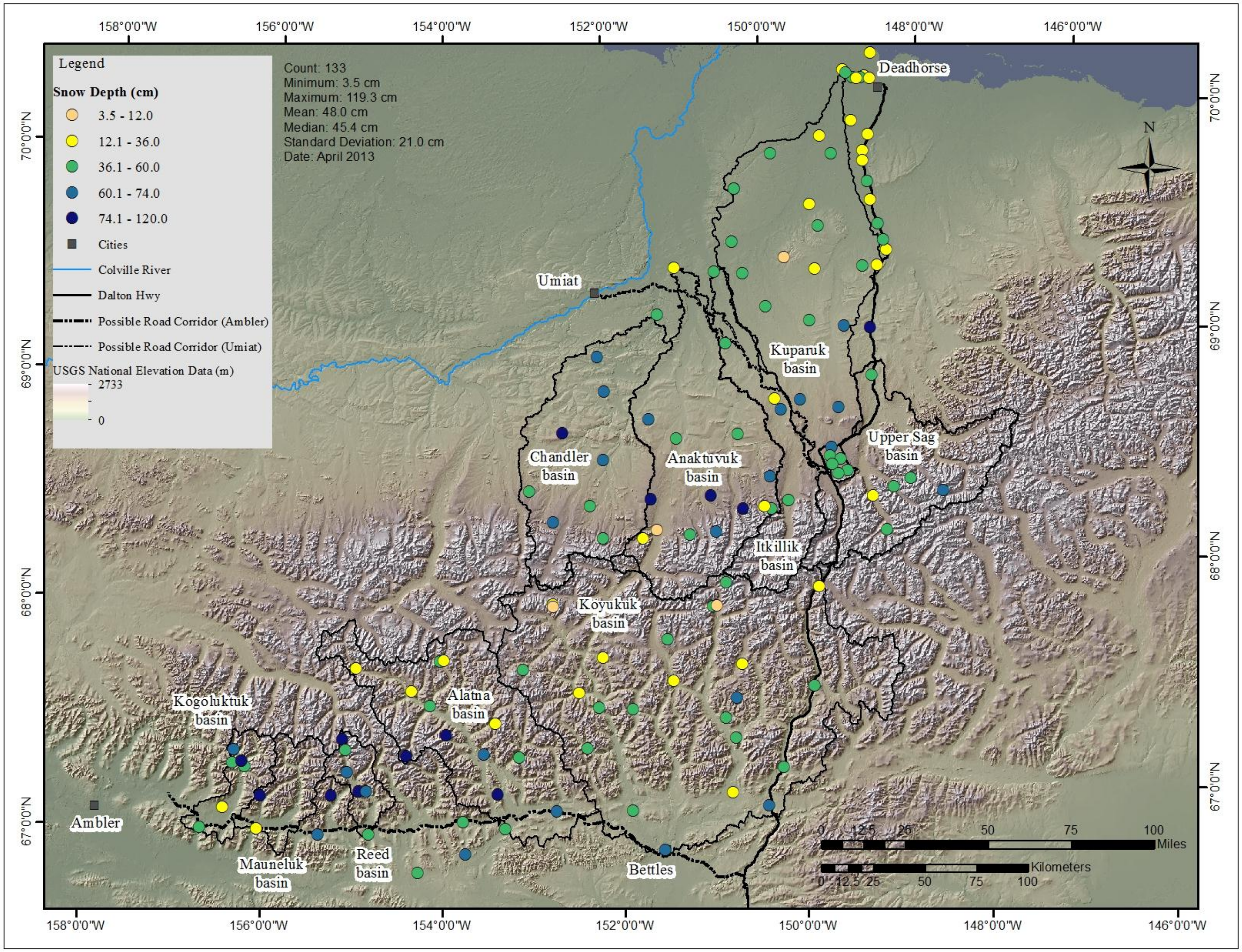


Figure 6. End-of-winter snow depth (cm) in spring 2013. Each point represents the average from 50 snow depths.

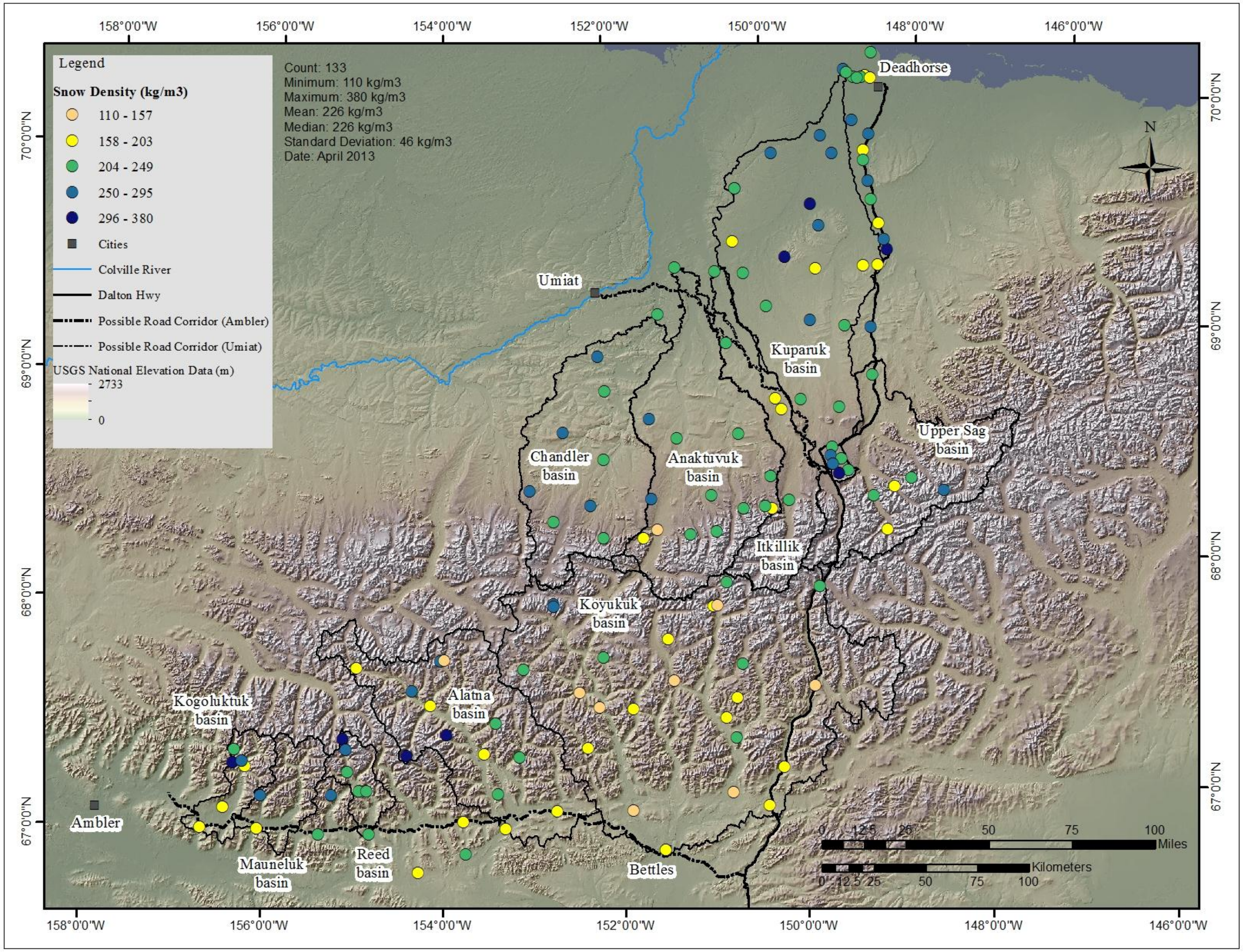


Figure 7. End-of-winter snow density (kg/m^3) in spring 2013. Each point represents the average from 5 measurements.

Long-term snow observations

Repeated SWE observations of such a large domain are rarely available in the Arctic (Stuefer et al., 2013). Snow sites with repeated observations from 2000 to 2013 are indicated by yellow dots on Figure 8. These long-term snow survey sites were used to determine regional SWE variations from year to year. SWE data from the short-term sites located in the Chandler River, Anaktuvuk River and Itkillik River watersheds are not included in the discussion that follows.

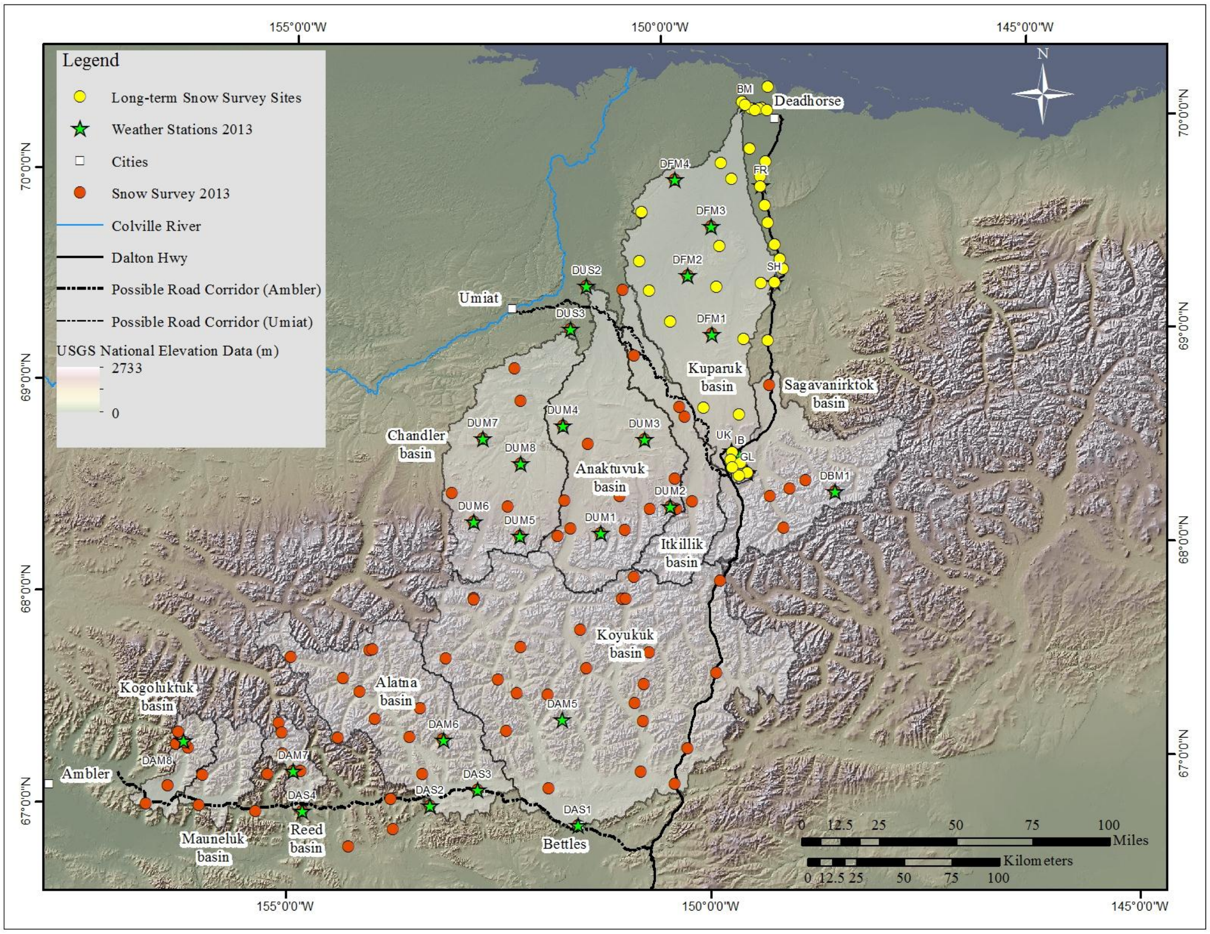


Figure 8. The long-term snow survey sites visited in April 2013 are indicated by yellow dots. Plotted watershed boundaries above hydrologic observation stations were derived from the USGS national elevation data.

The average end-of-winter SWE (13.7 cm, 5.4 in.) north of the Brooks Range in 2013 accounts for 130% of the 14-year average SWE, and is slightly higher than the previous maximum SWE in 2011 (13.2 cm, 5.2 in.) The 2013 end-of-winter SWE for the Foothills and Coastal Plain are higher than average and represent 133% and 113%, respectively, of the 14-year average SWE. The Foothills had the highest 14-year SWE average (15.9 cm, 6.3 in.) in 2013 (Table 5). In 2010, the number of long-term observational sites in the Kuparuk River basin decreased by 50%. Only one long-term snow survey site was visited in the Mountains in 2010 and 2011. Previous measurements indicated that SWE in the Mountains region was lower than in the Foothills and Coastal Plain regions. This database has become long enough that we can start to analyze variability from year to year (Table 5). The highest snow accumulations were observed in recent years—2009, 2011, and 2013—whereas 2001, 2006, and 2008 were relatively low snow years.

Table 5. Maximum, minimum, and average snow water equivalent in the Coastal Plain, Foothills, and Mountains of the Kuparuk, Sagavanirktok, and Putuliagyuk regions from long-term measurements (2000–2013, *n* = 14). The statistics below do not include short-term (less than 6 years of data) snow survey sites.

Region	**2013**		**Maximum**		**Minimum**		**Average**	
	cm	**in.**	**cm (yr)**	**in.**	**cm (yr)**	**in.**	**cm**	**in.**
Mountains	-	-	14.7 (2003)	5.8	3.5 (2008)	1.4	8.1	3.1
Foothills	15.9	6.3	15.9 (2013)	6.3	8.9 (2006)	3.5	12.0	4.7
Coastal Plain	11.6	4.5	13.4 (2009)	5.3	8.4 (2001)	3.3	10.2	4.0
Average	13.7	5.4	13.7 (2013)*	5.4	7.3 (2008)	2.9	10.5	4.1

* *The average is affected by discontinuing observations at the higher elevation in the Kuparuk River watershed (Mountains) in 2009. We do collect data in the mountains west and east of the Kuparuk River, but the records do not go back to 2000 and, therefore, are not represented in Table 5.*

The longest snow survey record (since the 1970s) on the Alaska North Slope has been maintained by the USDA NRCS, based on few snow survey sites established along the Dalton Highway. Our snow survey dataset covers a shorter period of time (2000–2013), but has much larger and more detailed spatial coverage.

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 the SR50 sensor.

7.1 North of the Brooks Range Divide

During the 2012–2013 winter, SR50 measurements were recorded at fifteen meteorological stations north of the Brooks Range divide (Table 6, Figure 9–Figure 23). The stations are a composite of several projects and encompass Alaska’s Central Arctic Slope. One station from the Bullen project (DBM1, Accomplishment Creek, founded by Alaska Department of Natural Resources) remains in the Sagavanirktok basin, four stations (DFM1–DFM4) remain in the Kuparuk basin as part of the Kuparuk Foothills (ADOT&PF) study, and ten stations (DUM1–DUM8 and DUS2–DUS3) are in the Itkillik, Anaktuvuk, and Chandler basins as part of the Umiat corridor project (ADOT&PF). In 2013, the snow survey depths were quite variable, and averages were slightly larger in 2013 compared with 2012 (Table 7) and 2011 (Table 8). Table 9 compares the average snow survey depths for 2011–2013 and lists the percent differences from the maximum averages. Nine of the fifteen stations recorded maximum snow depths during 2013, with most of the remaining six stations having snow depths not far from being the three-year maximum. Figure 24, Figure 25, and Figure 26 visually compare the annual spatial variability of snow cover at the end of the snow-accumulation period for three meteorological stations during 2012 and 2013. The visual comparison clearly illustrates that the annual variability can be extreme.

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 of the snow depth sensor. For example, the SR50 sensor at North White Hills (DFM3) station (Figure 12) consistently records a lower SR50 snow depth than the fifty observed depths collected near the station during end-of-winter snow surveys. The SR50 sensor at Northwest Kuparuk (DFM4)

Table 6. 2013 snow depth information from 15 meteorological stations and co-located snow surveys north of the Brooks Range.

Meteorological Station	Snow Survey Depth Range (cm)	Snow Survey Depth Ave. (cm)	Observed Depth Under SR50 (cm)	SR50 Reported Depth at Time of Observed Depth (cm)	Differerence Between Observed and SR50 Reported Depth (cm)
Accomplishment Creek (DBM1)	30-100	66	64	63	1
South White Hills (DFM1)	32-73	56	76	75	1
White Hills (DFM2)	0-19	4	NA	NA	NA
North White Hills (DFM3)	10-64	34	36	33	3
Northwest Kuparuk (DFM4)	17-69	38	47	NA	NA
Itikmalakpak (DUM1)	7-101	44	77	76	2
Upper May Creek (DUM2)	12-43	22	30	27	3
Nanushuk (DUM3)	37-71	57	51	46	5
Tuluga (DUM4)	56-84	69	54	51	3
Encampment Creek (DUM5)	12-60	38	17	37	-20
White Lake (DUM6)	17-114	67	62	60	2
Hatbox Mesa (DUM7)	62-117	87	94	93	1
Siksikpuk (DUM8)	52-85	70	57	73	-16
Anaktuvuk (DUS2)	20-58	33	40	38	2
Chandler (DUS3)	22-53	37	65	65	0

Table 7. 2012 snow depth information from 15 meteorological stations and co-located snow surveys north of the Brooks Range.

Meteorological Station	Snow Survey Depth Range (cm)	Snow Survey Depth Ave. (cm)	Observed Depth Under SR50 (cm)	SR50 Reported Depth at Time of Observed Depth (cm)	Differerence Between Observed and SR50 Reported Depth (cm)
Accomplishment Creek (DBM1)	35-67	26	8	7	1
South White Hills (DFM1)	27-70	49	49	43	6
White Hills (DFM2)	NA	NA	0	NA	NA
North White Hills (DFM3)	28-56	33	23	8	15
Northwest Kuparuk (DFM4)	0-84	53	52	44	8
Itikmalakpak (DUM1)	23-57	46	38	39	-1
Upper May Creek (DUM2)	18-59	4	3	1	2
Nanushuk (DUM3)	0-79	38	26	24	2
Tuluga (DUM4)	3-72	40	48	50	-2
Encampment Creek (DUM5)	26-63	3	0	0	0
White Lake (DUM6)	15-44	30	23	20	3
Hatbox Mesa (DUM7)	32-59	75	68	69	-1
Siksikpuk (DUM8)	0-94	51	72	67	5
Anaktuvuk (DUS2)	29-63	36	34	24	10
Chandler (DUS3)	NA	NA	NA	NA	NA

Table 8. 2011 snow depth information from 15 meteorological stations and co-located snow surveys north of the Brooks Range.

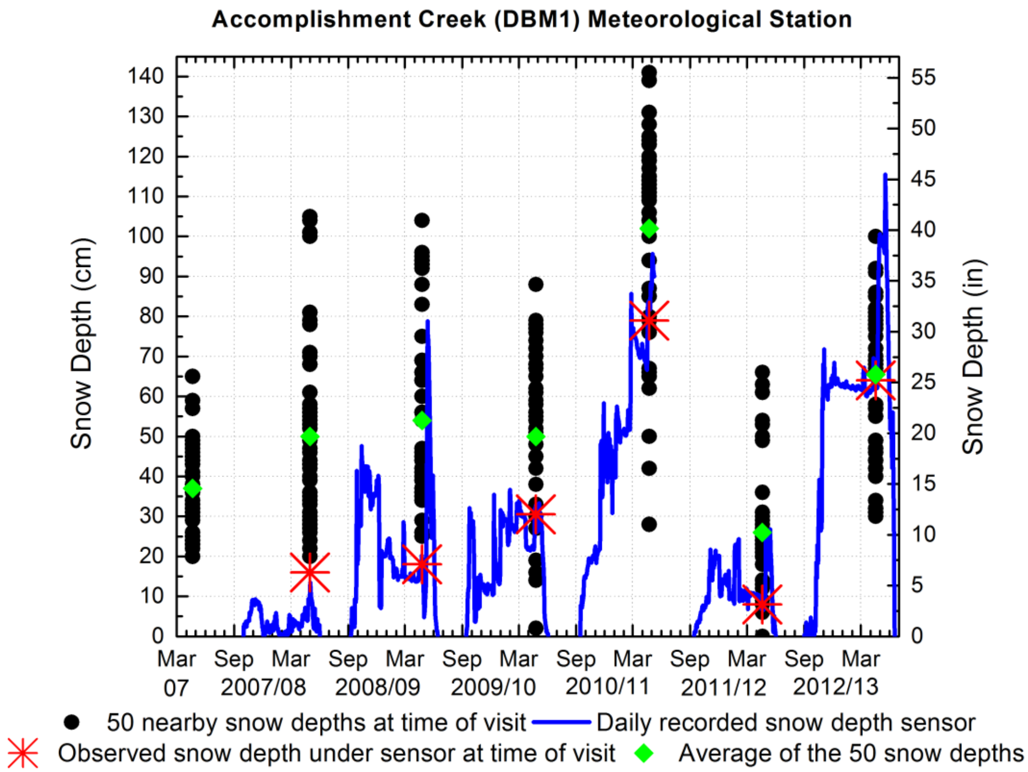
Meteorological Station	Snow Survey Depth Range (cm)	Snow Survey Depth Ave. (cm)	Observed Depth Under SR50 (cm)	SR50 Reported Depth at Time of Observed Depth (cm)	Differerence Between Observed and SR50 Reported Depth (cm)
Accomplishment Creek (DBM1)	28-141	102	79	82	-3
South White Hills (DFM1)	41-76	55	NA	50	NA
White Hills (DFM2)	0-21	12	16	16	0
North White Hills (DFM3)	15-52	31	22	26	-4
Northwest Kuparuk (DFM4)	28-79	52	61	61	0
Itikmalakpak (DUM1)	16-51	27	18	16	2
Upper May Creek (DUM2)	1-15	6	5	4	1
Nanushuk (DUM3)	5-66	33	17	15	2
Tuluga (DUM4)	11-87	54	54	54	0
Encampment Creek (DUM5)	0-37	12	1	NA	NA
White Lake (DUM6)	10-45	23	27	25	2
Hatbox Mesa (DUM7)	38-64	53	85	84	1
Siksikpuk (DUM8)	31-87	61	77	77	0
Anaktuvuk (DUS2)	21-51	37	37	40	-3
Chandler (DUS3)	35-70	56	48	NA	NA

Table 9. Snow survey depth averages for 2011–2013 and percent differences from the maximum averages for each site north of the Brooks Range.

	2011		2012		2013	
Meteorological Station	Snow Survey Depth Ave. (cm)		Snow Survey Depth Ave. (cm)		Snow Survey Depth Ave. (cm)	
Accomplishment Creek (DBM1)	102	-	26	-75%	66	-36%
South White Hills (DFM1)	55	-2%	49	-14%	56	-
White Hills (DFM2)	12	-	NA	NA	4	-71%
North White Hills (DFM3)	31	-11%	33	-3%	34	-
Northwest Kuparuk (DFM4)	52	-3%	53	-	38	-28%
Itikmalakpak (DUM1)	27	-42%	46	-	44	-4%
Upper May Creek (DUM2)	6	-71%	4	-83%	22	-
Nanushuk (DUM3)	33	-42%	38	-33%	57	-
Tuluga (DUM4)	54	-23%	40	-43%	69	-
Encampment Creek (DUM5)	12	-68%	3	-92%	38	-
White Lake (DUM6)	23	-65%	30	-55%	67	-
Hatbox Mesa (DUM7)	53	-39%	75	-14%	87	-
Siksikpuk (DUM8)	61	-14%	51	-28%	70	-
Anaktuvuk (DUS2)	37	-	36	-4%	33	-12%
Chandler (DUS3)	56	-	NA	NA	37	-33%
Average	41		37		48	

station (Figure 13) records close to average snow depth (compared with the 50 observed depths measured near the station) each winter, with the exception of lower snow depth in winter 2006–2007 and higher snow depth in winter 2007–2008. This example illustrates the challenges associated with siting the sensor and using SR50 snow depth data for quantitative analysis.

The results of the SR50 snow depth sensors are presented in Figure 9–Figure 23. Most stations reported good-quality SR50 snow depth data during the winter of 2012–2013, with only a few station malfunctions. The SR50 at the White Hills (DFM2) station (Figure 12) was inoperable through the entire winter period because of station logger malfunctioning. This site, in particular, has had a variety of problems the last few years including damage from bear and strong winds, as well as sensor obstruction from frosting. In fall 2012, the entire Tuluga (DUM4) meteorological station (Figure 17) was not operational due to a bear having disconnected the power supply cables from the battery box, shutting down the logger for the winter. The cables were reconnected while acquiring spring snow surveys, and the SR50 was active thereafter.



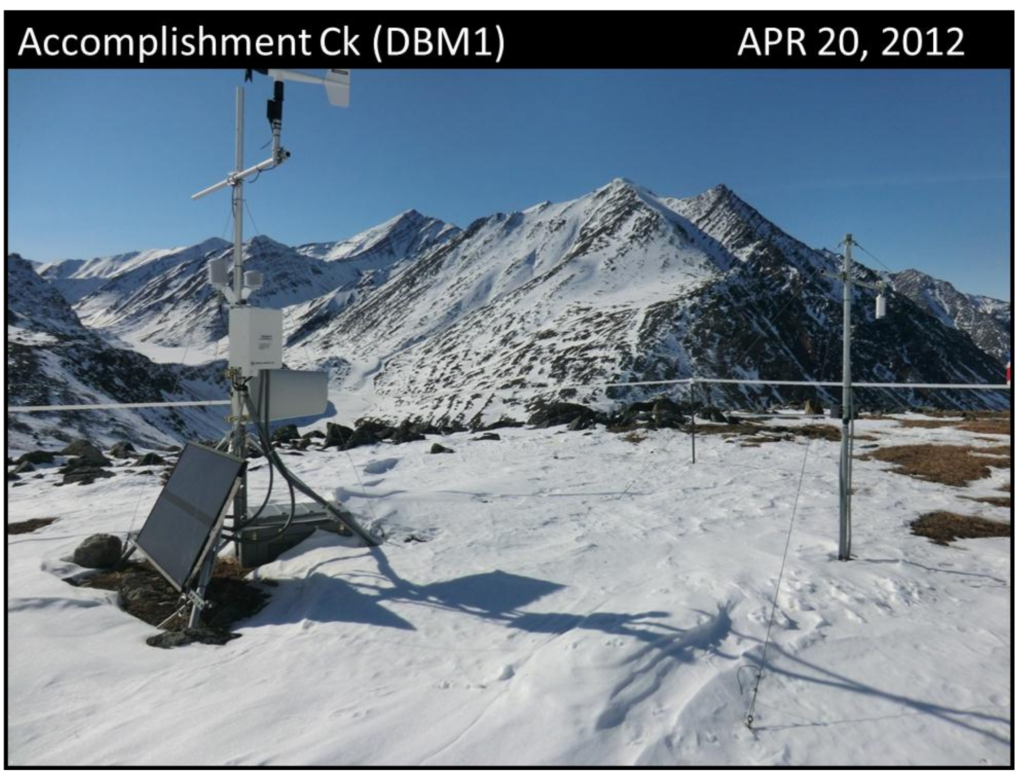
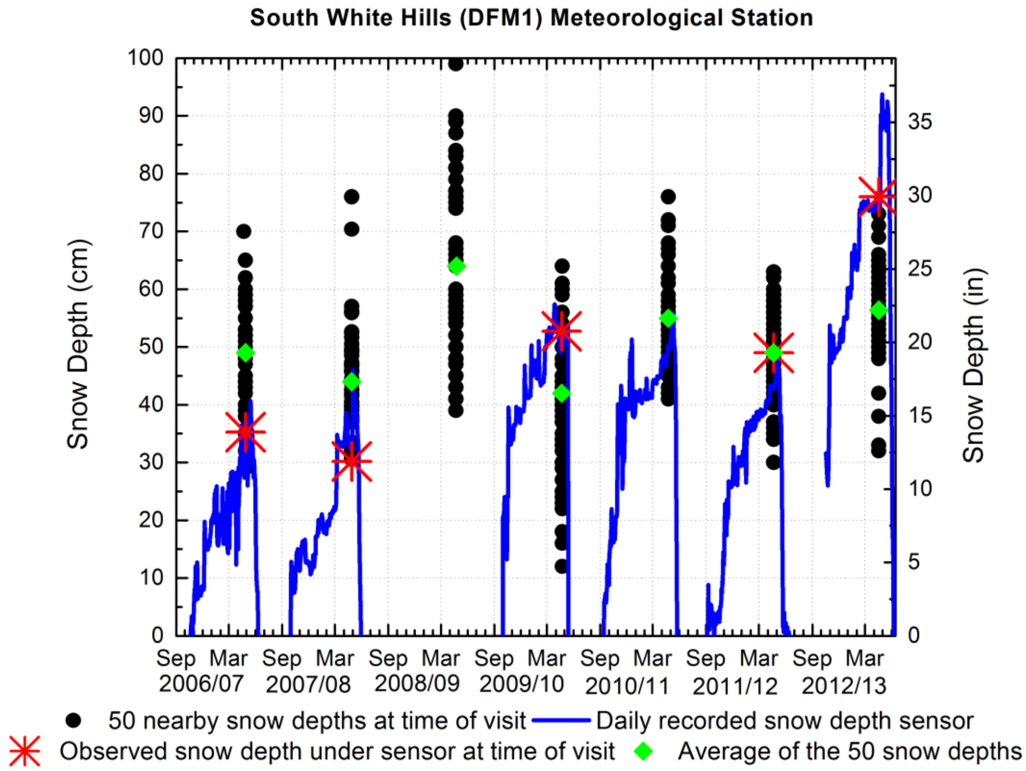


Figure 9. Accomplishment Creek (DBM1) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2006–2013.



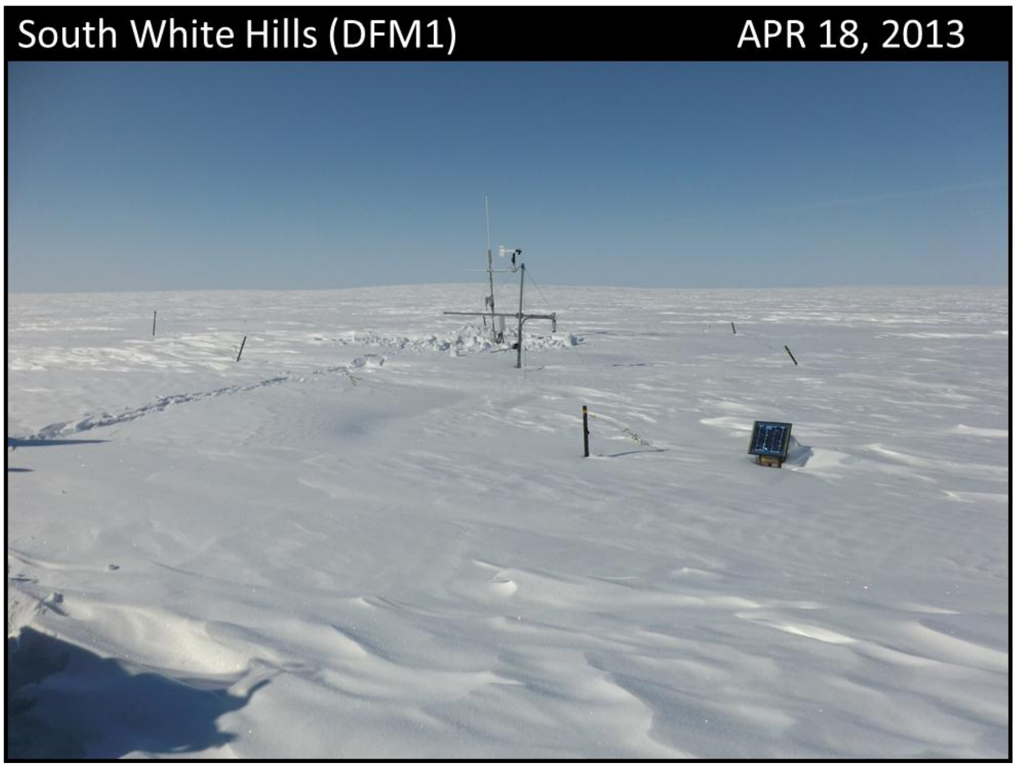
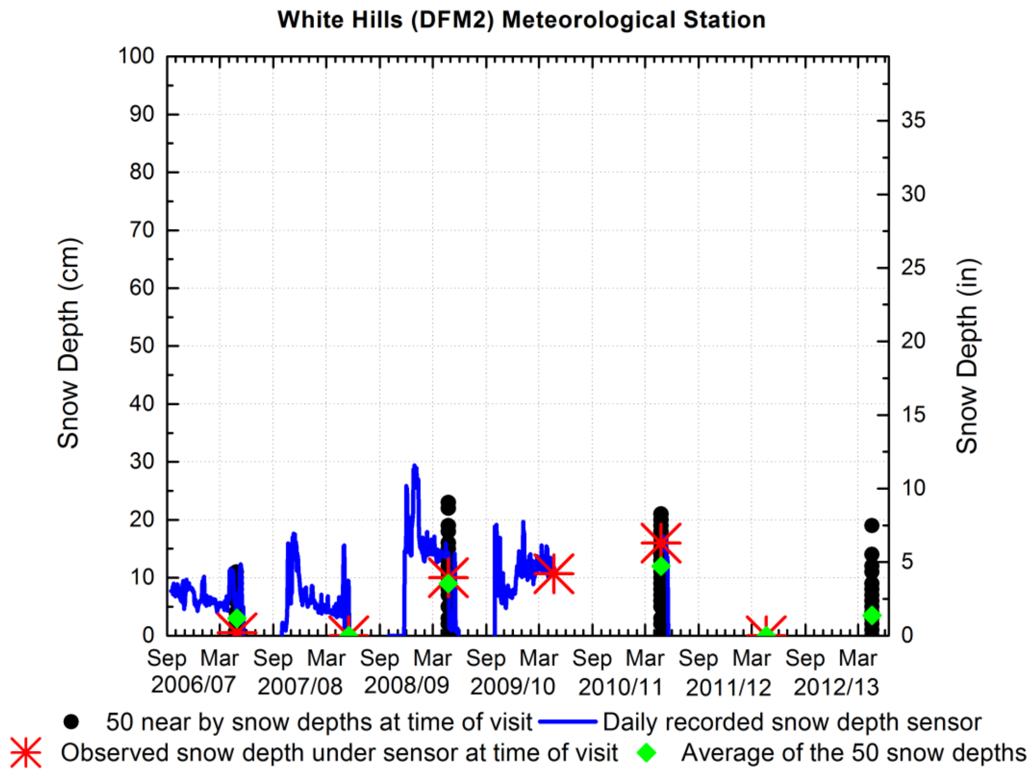


Figure 10. South White Hills (DFM1) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2006–2013.



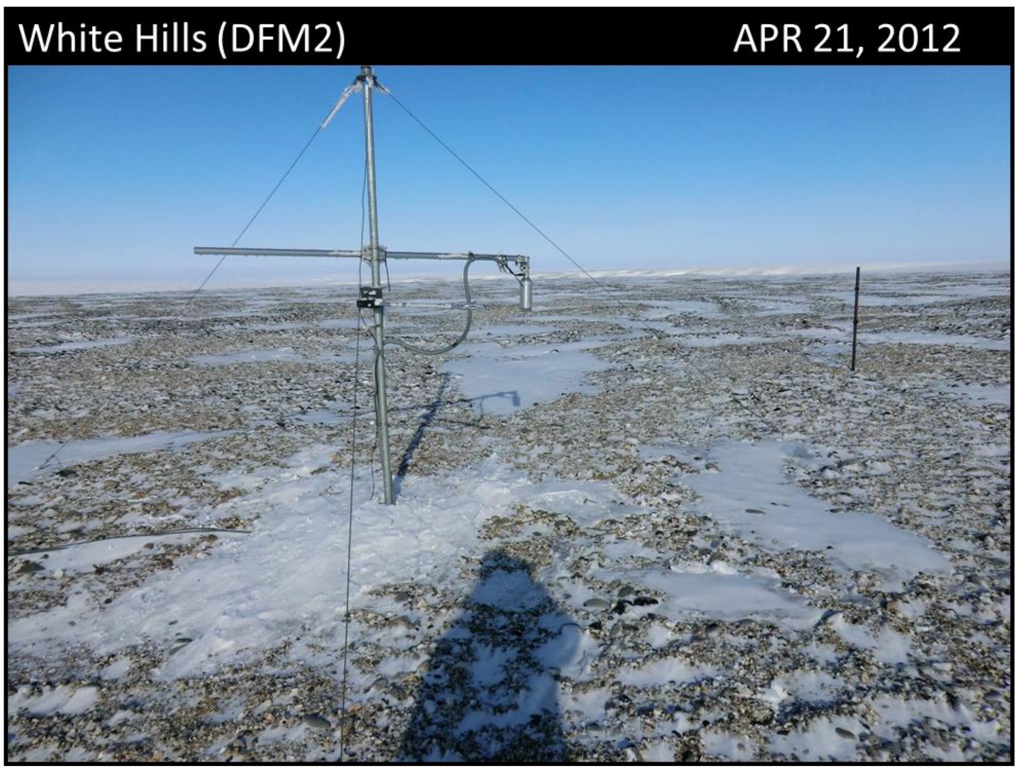


Figure 11. White Hills (DFM2) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2006–2013.

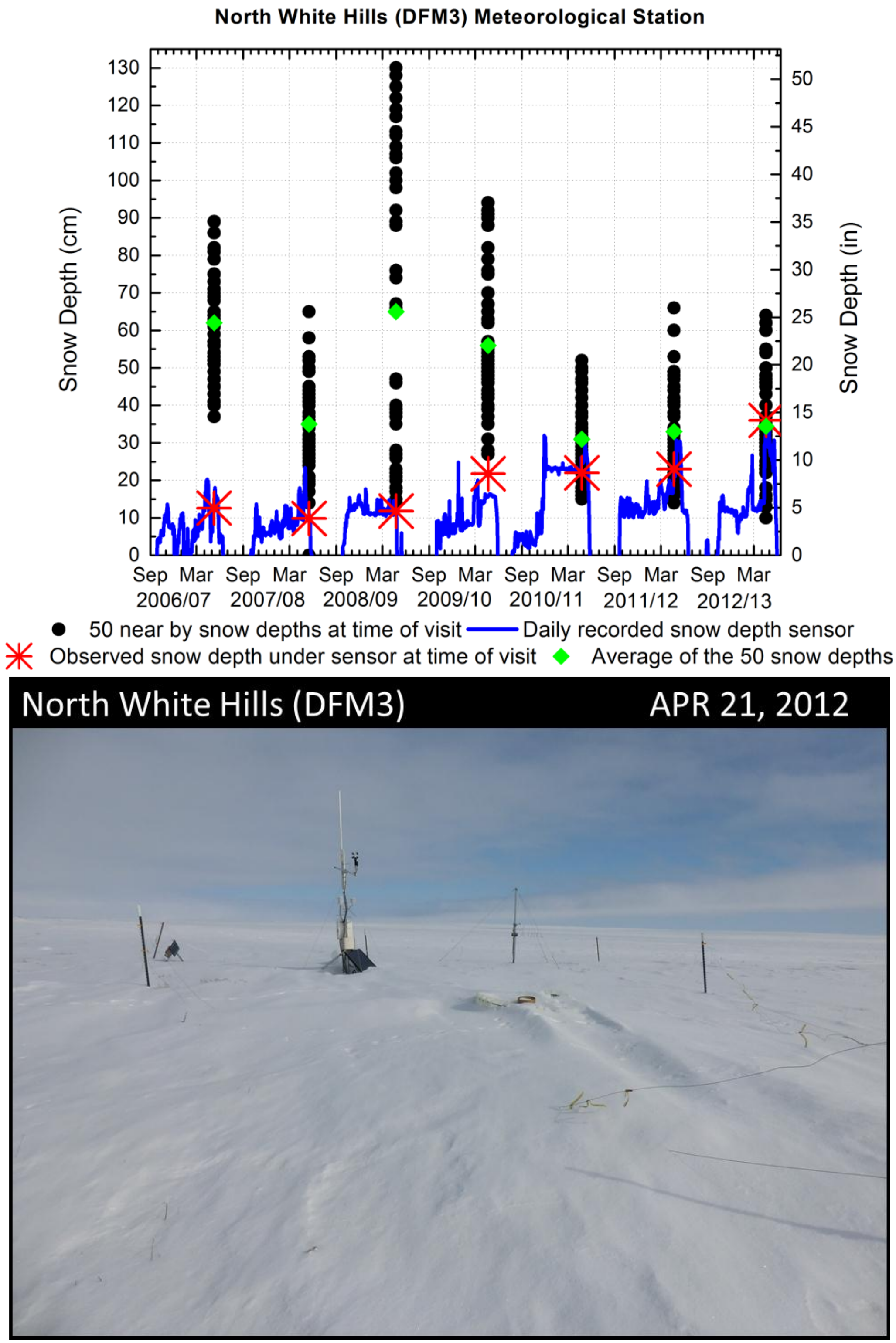
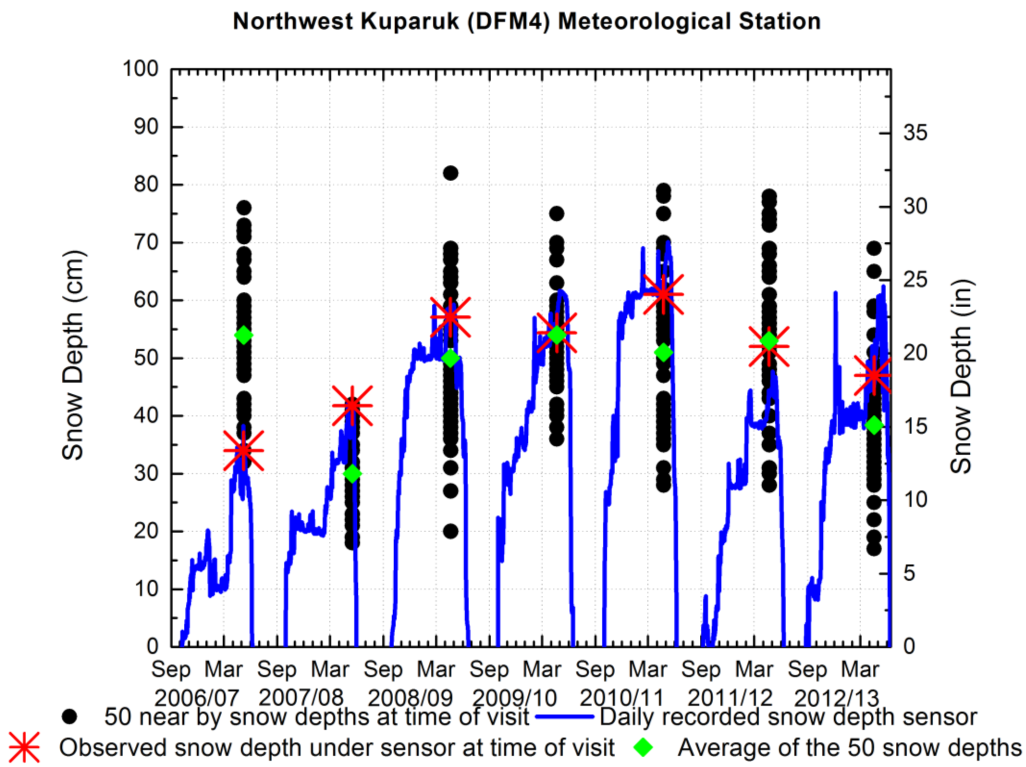


Figure 12. North White Hills (DFM3) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2006–2013.



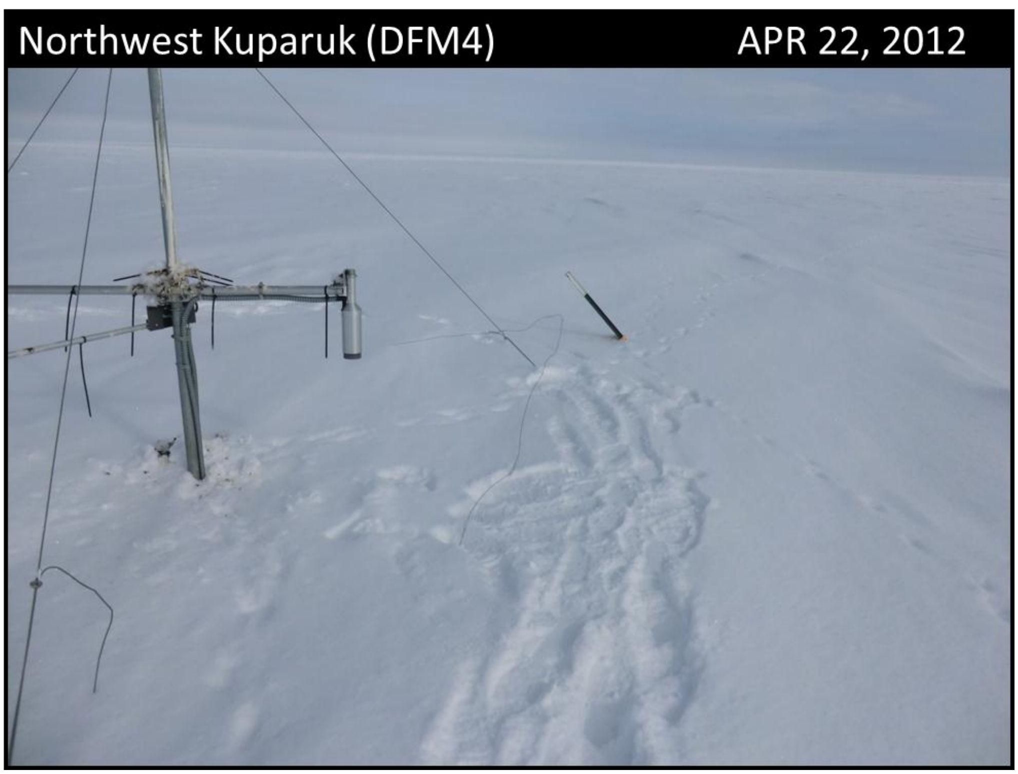


Figure 13. Northwest Kuparuk (DFM4) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2006–2013.

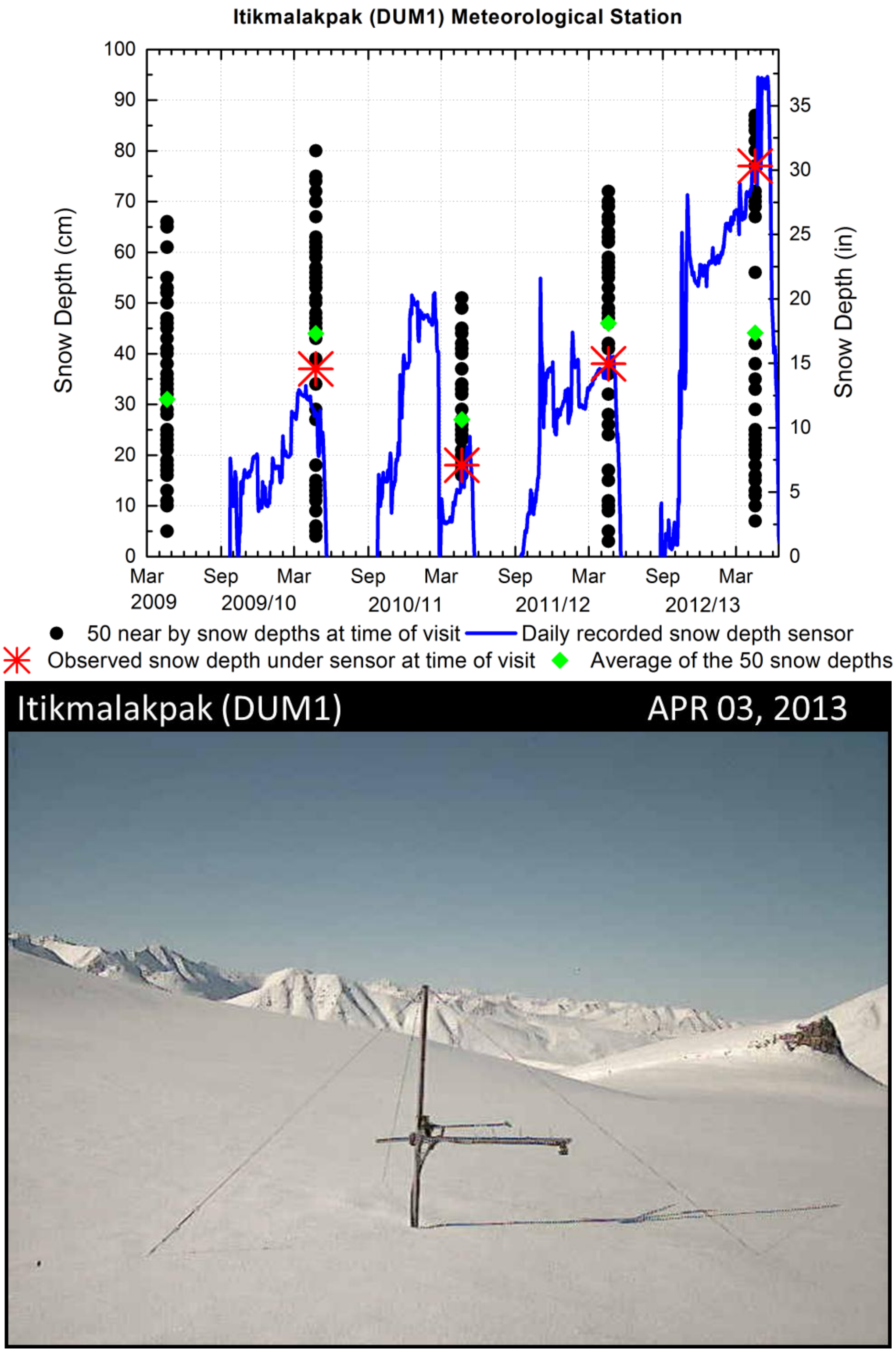
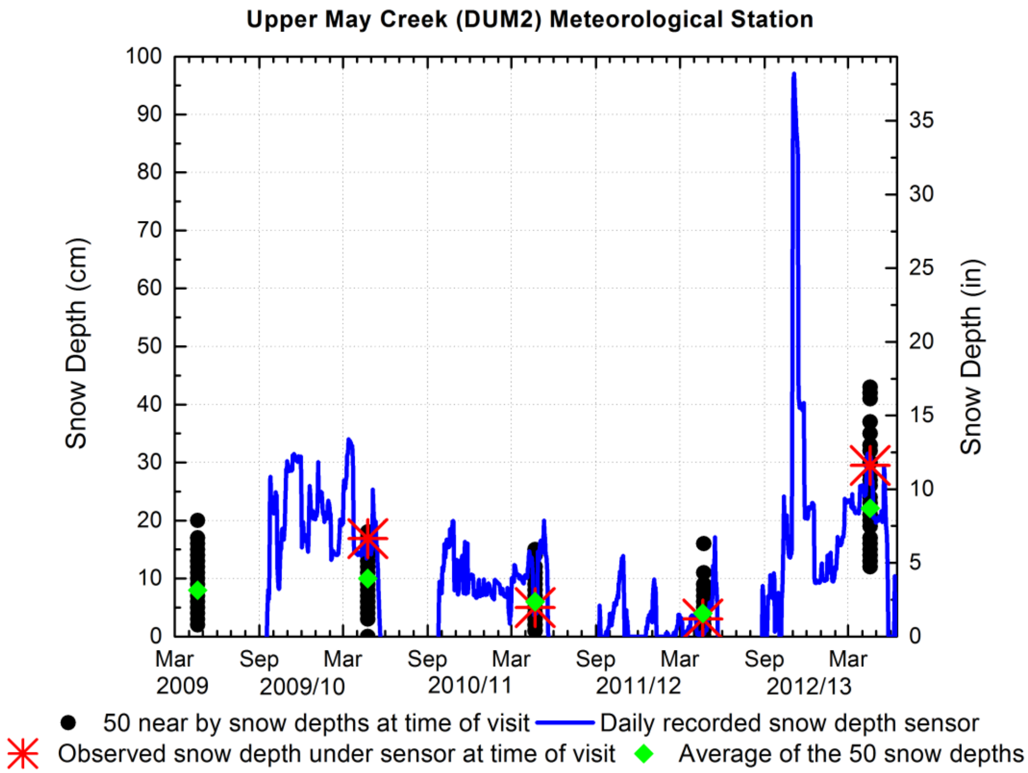


Figure 14. Itikmalakpak (DUM1) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2009–2013.



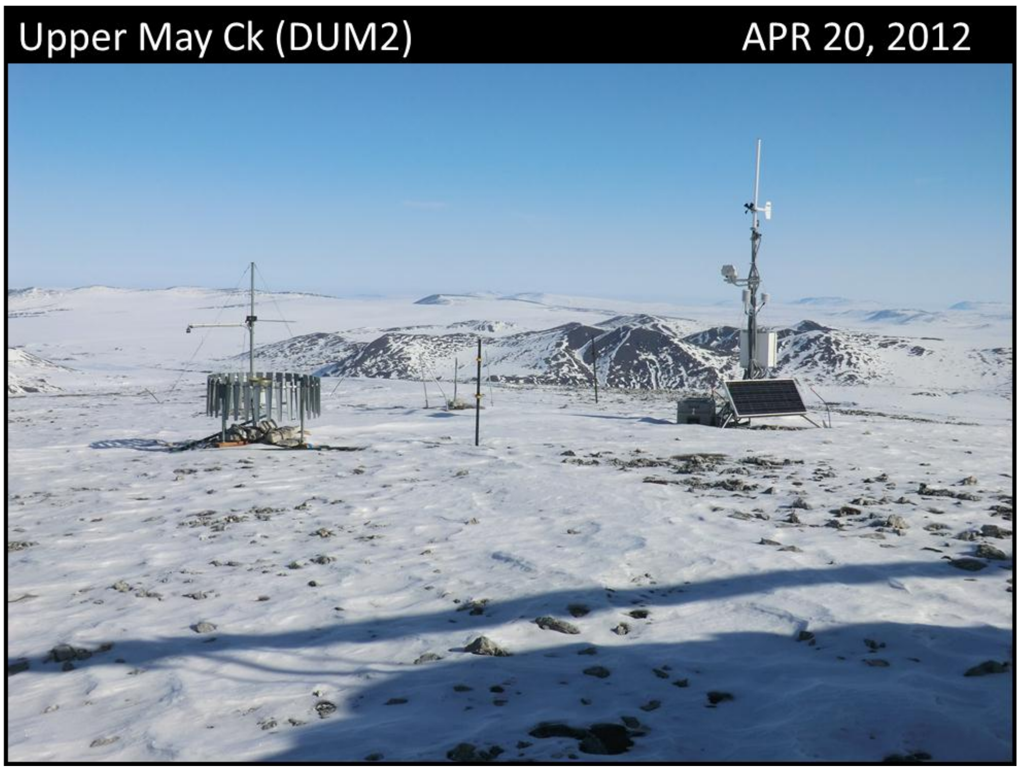


Figure 15. Upper May Creek (DUM2) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2009–2013.

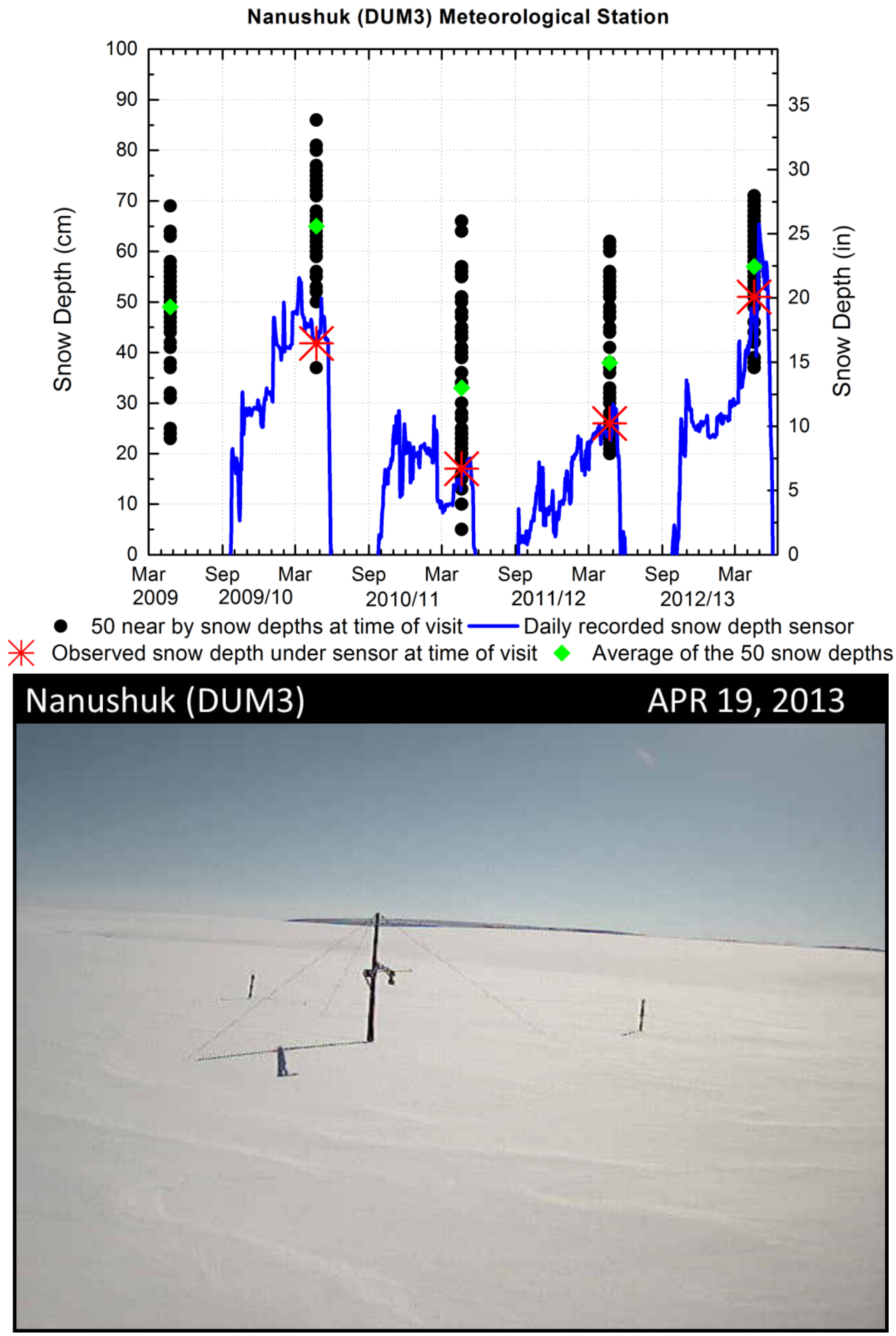


Figure 16. Nanushuk (DUM3) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2009–2013.

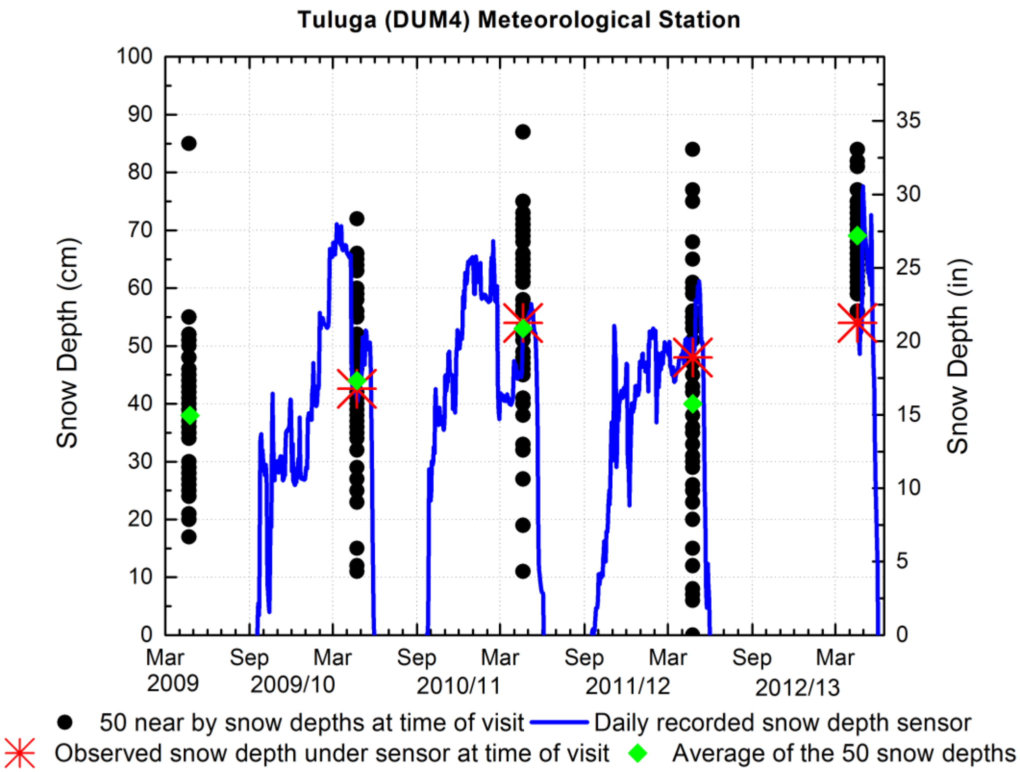


Figure 17. Tuluga (DUM4) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2009–2013.

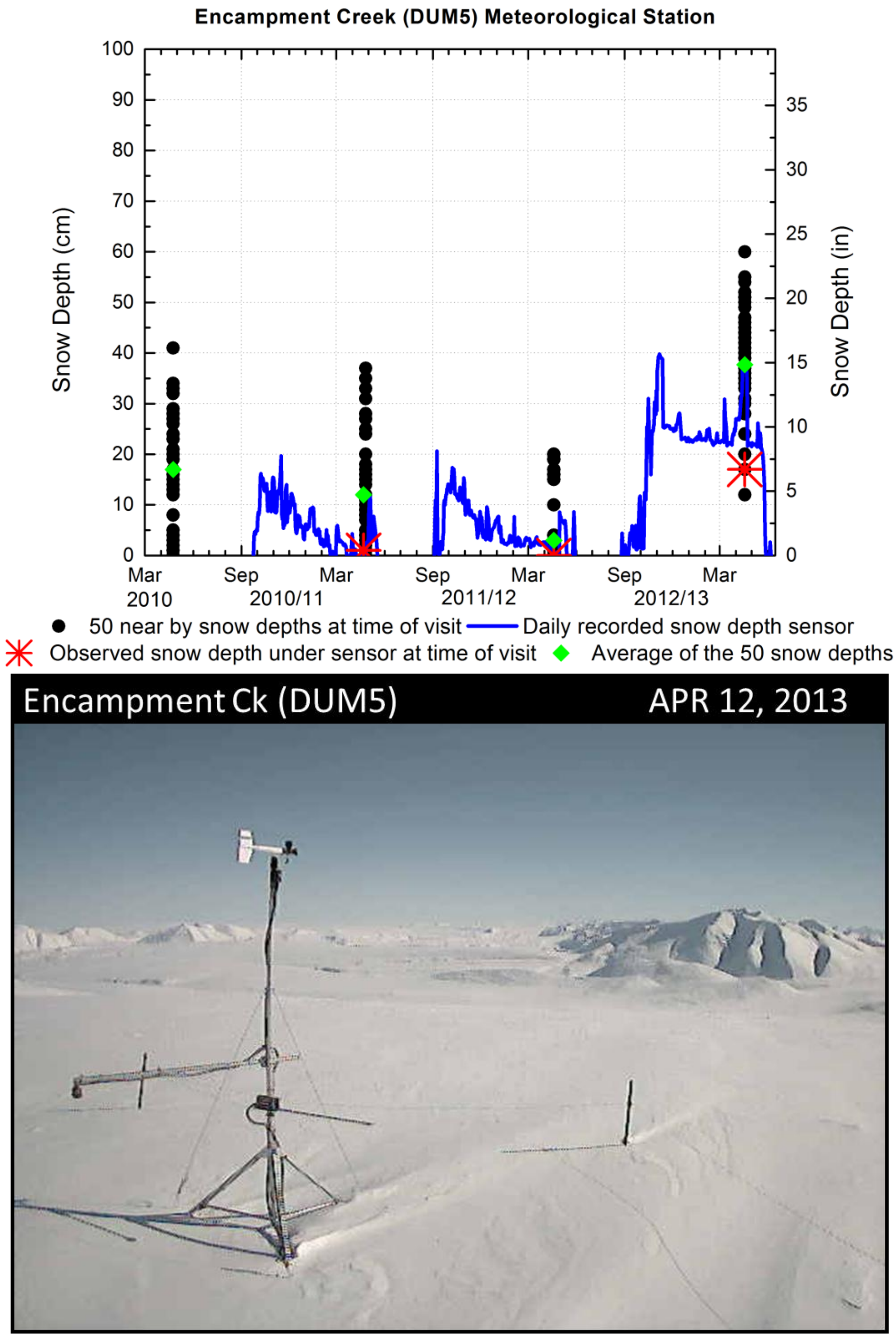
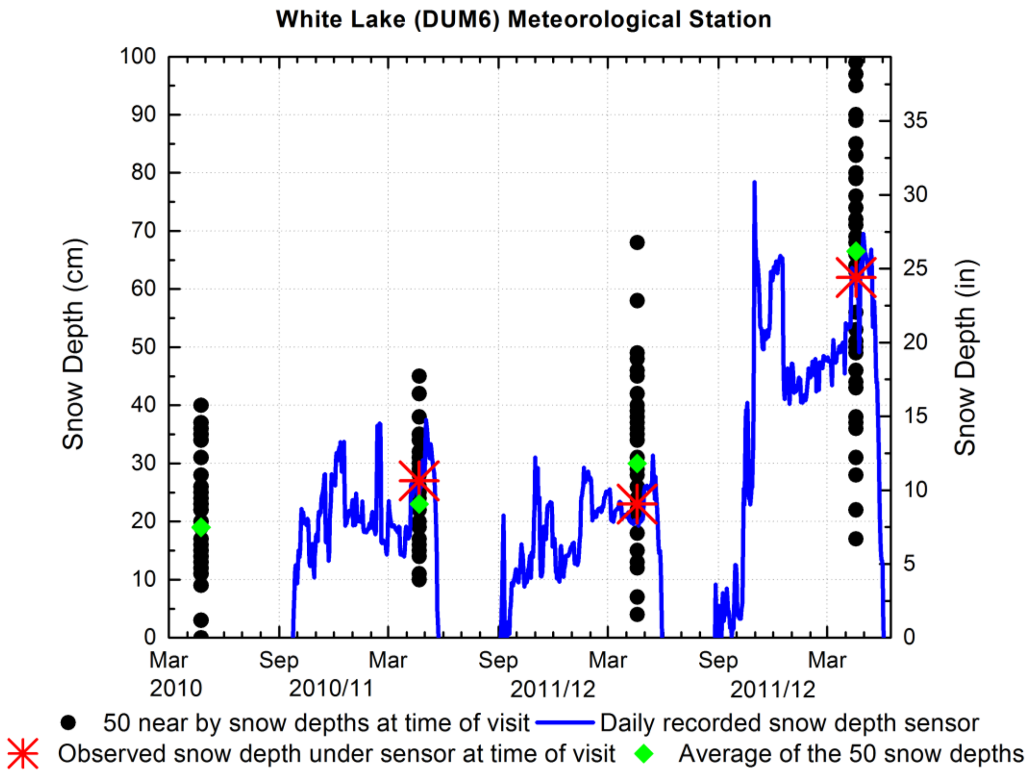


Figure 18. Encampment Creek (DUM5) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2010–2013.



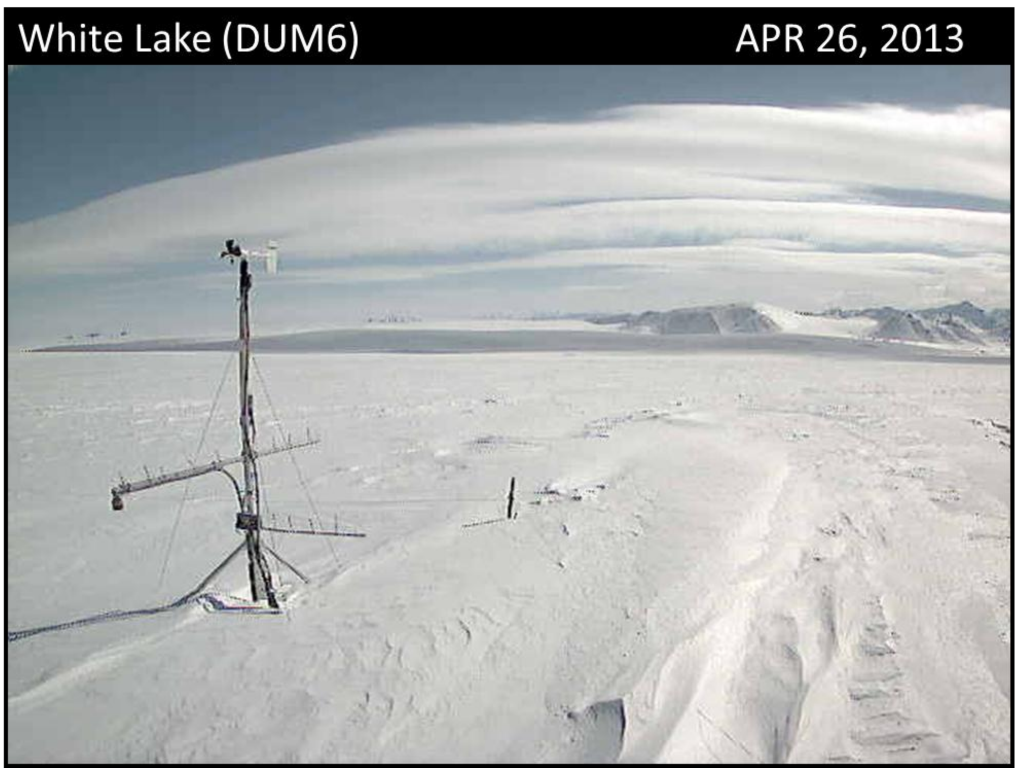


Figure 19. White Lake (DUM6) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2010–2013.

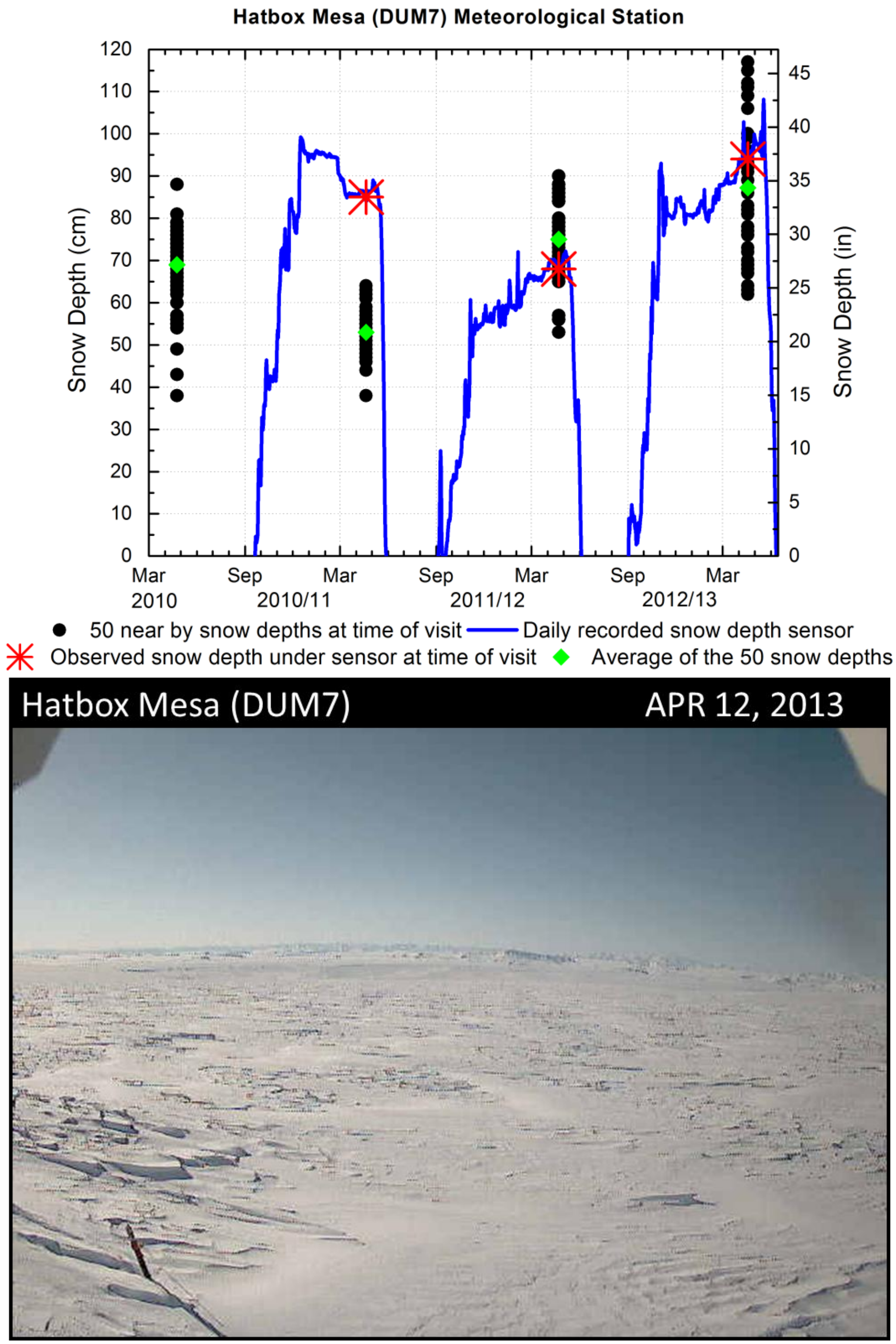
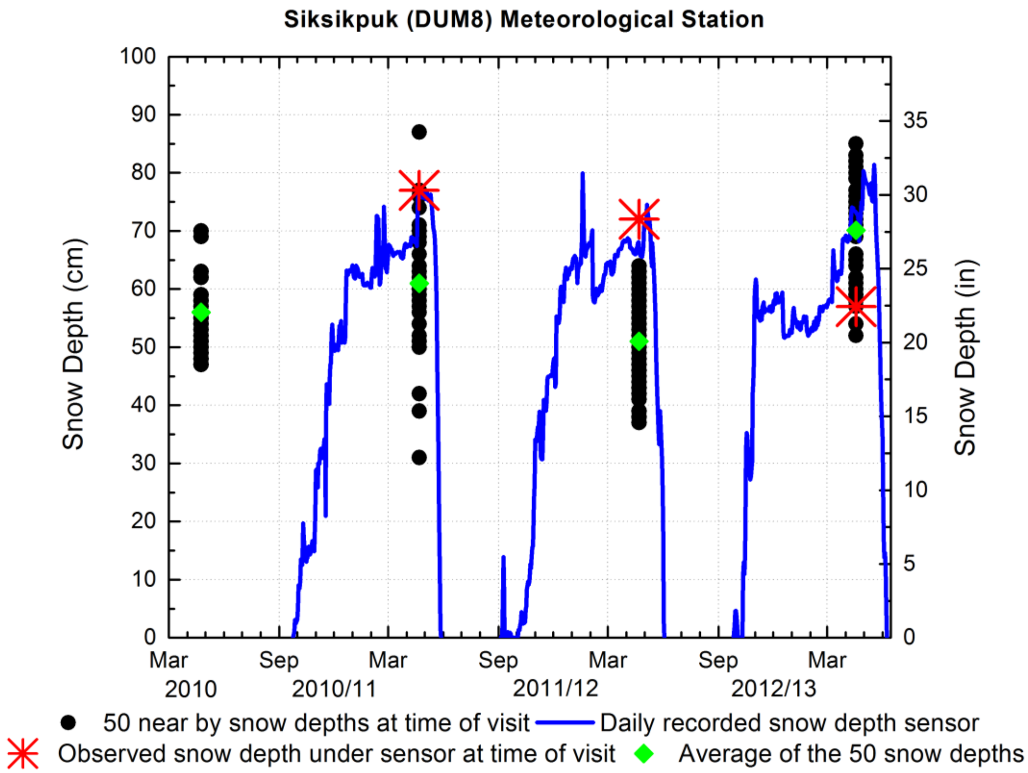


Figure 20. Hatbox Mesa (DUM7) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2010–2013.



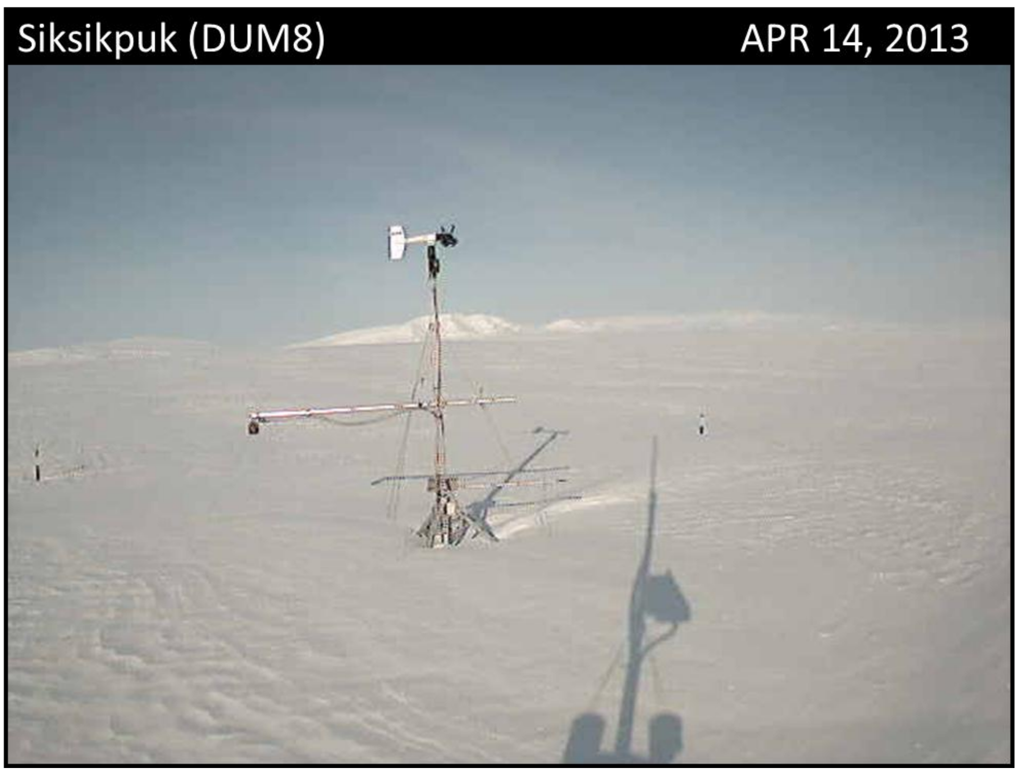


Figure 21. Siksikpuk (DUM8) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2010–2013.

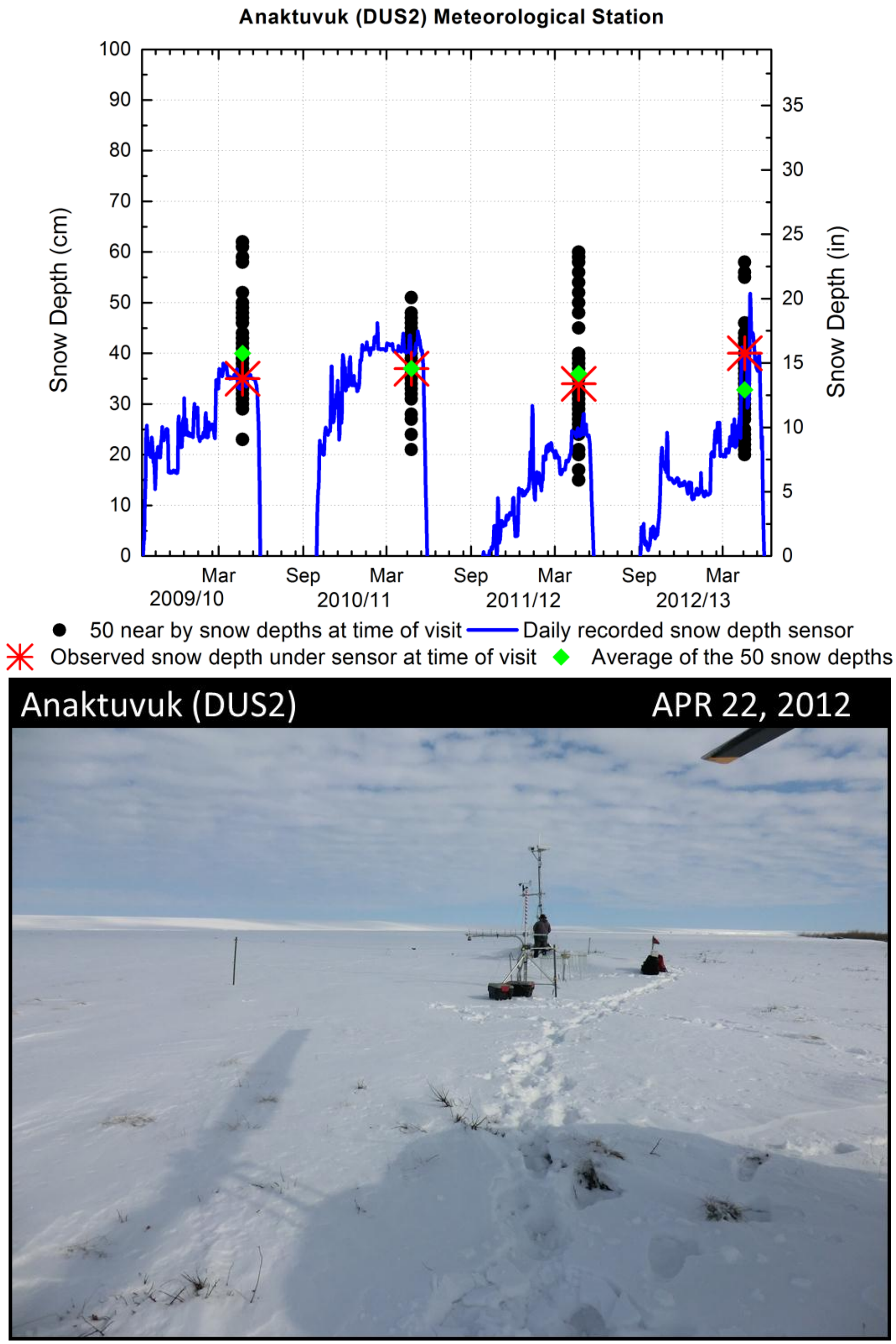


Figure 22. Anaktuvuk (DUS2) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2009–2013.

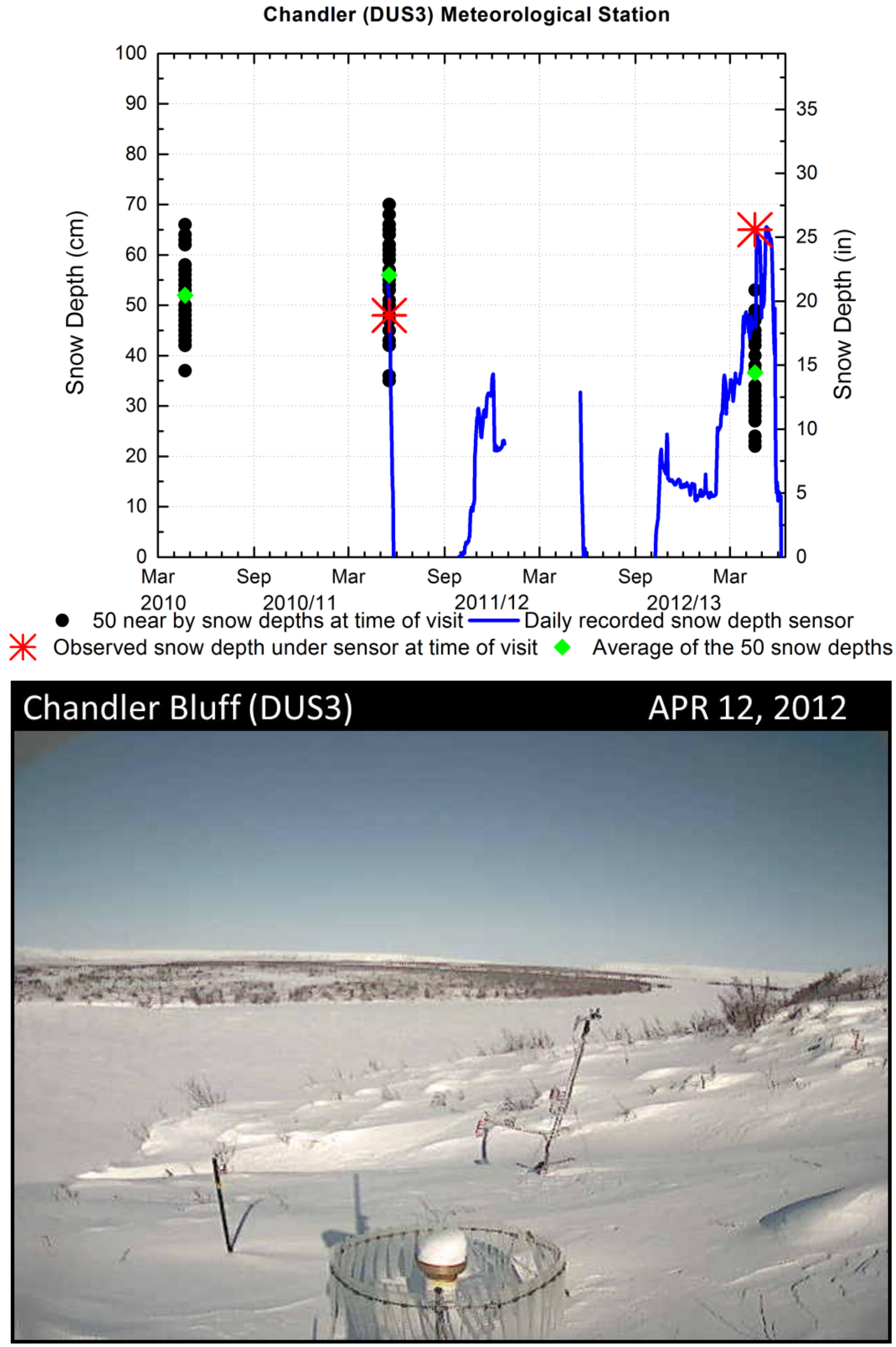


Figure 23. Chandler Bluff (DUS3) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor and average of 50 depths, 2010–2013.

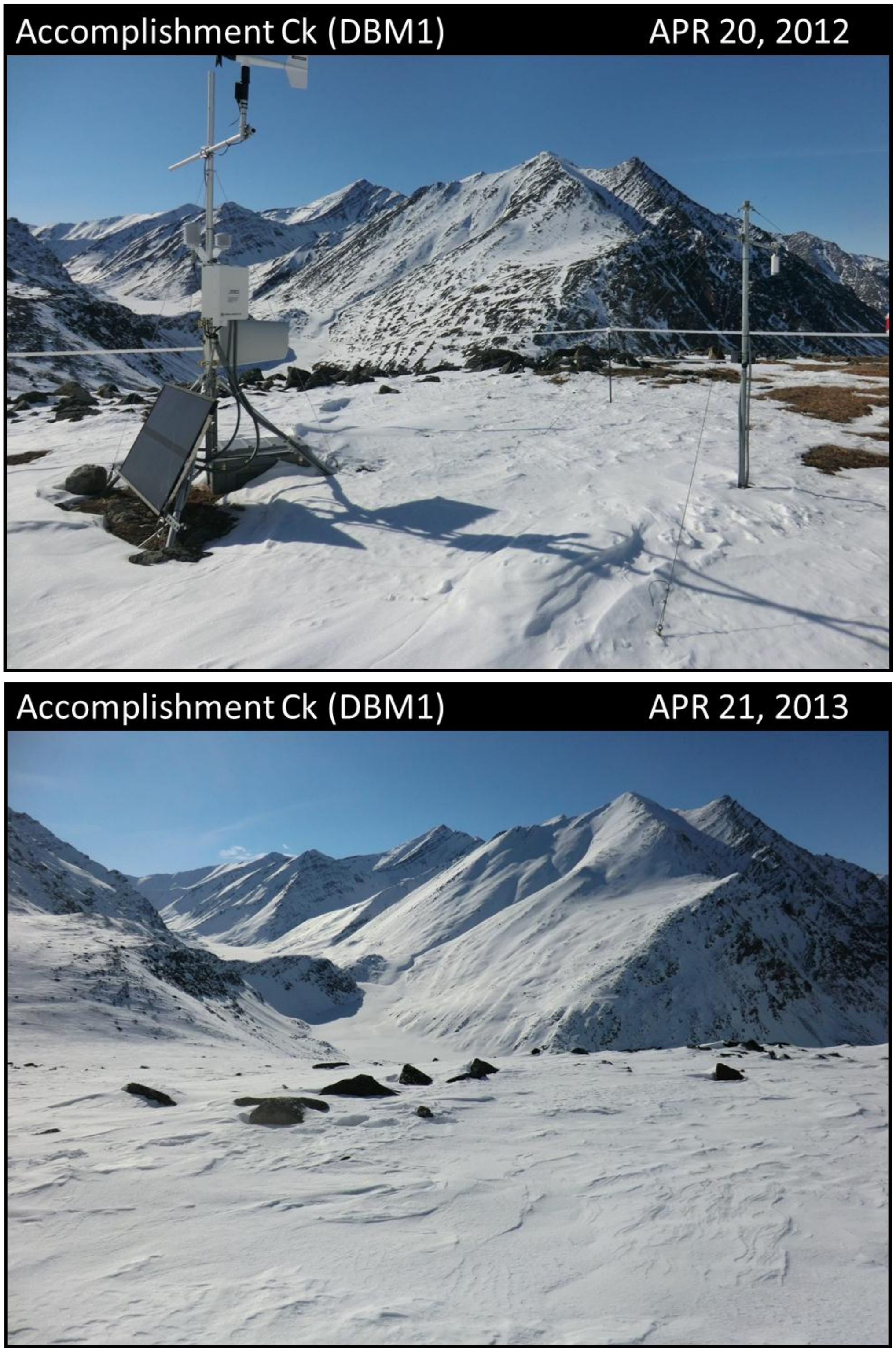


Figure 24. Accomplishment Creek (DBM1) meteorological station photo comparison illustrating temporal and spatial variability of snow cover during subsequent springs.

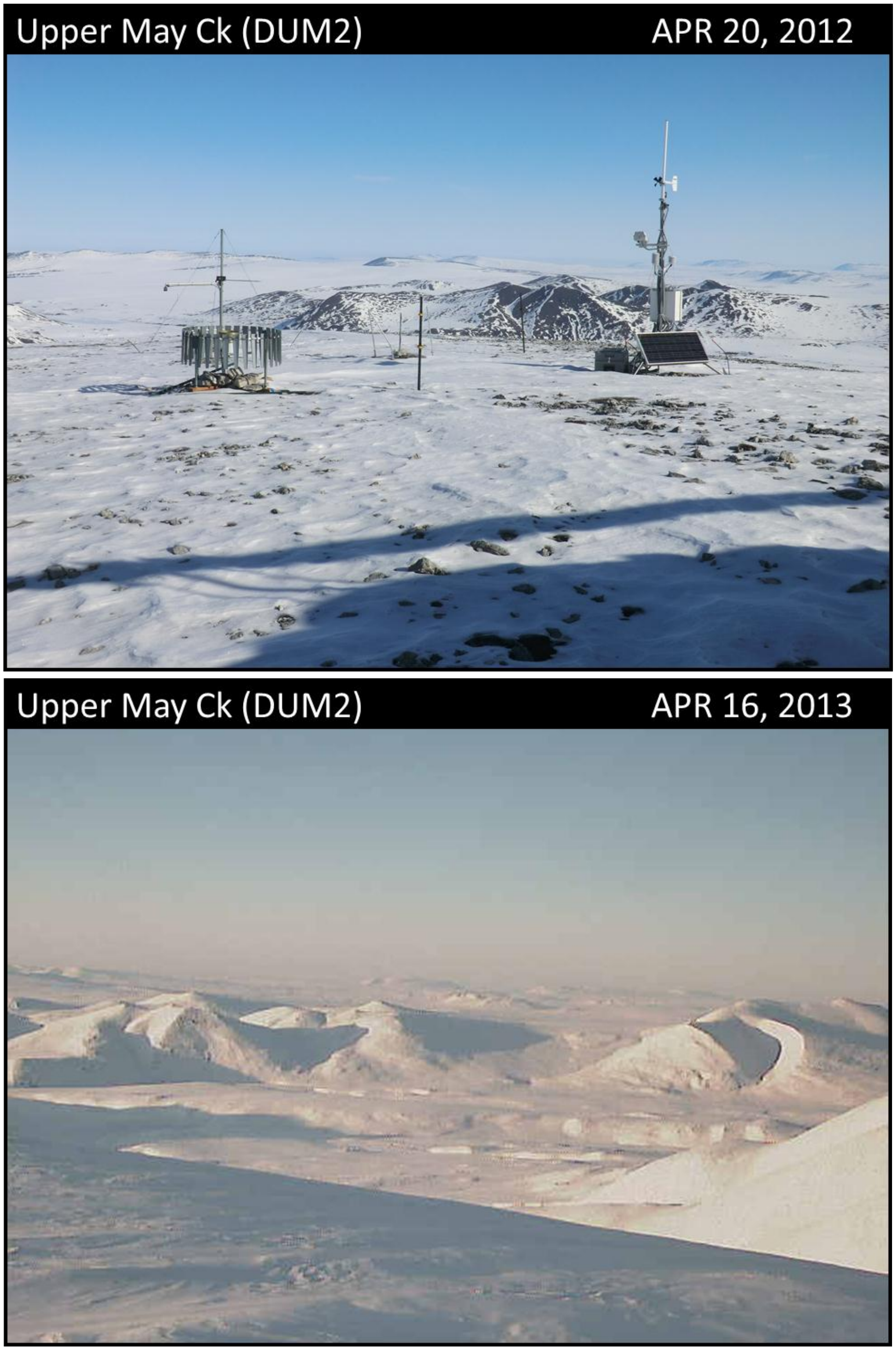
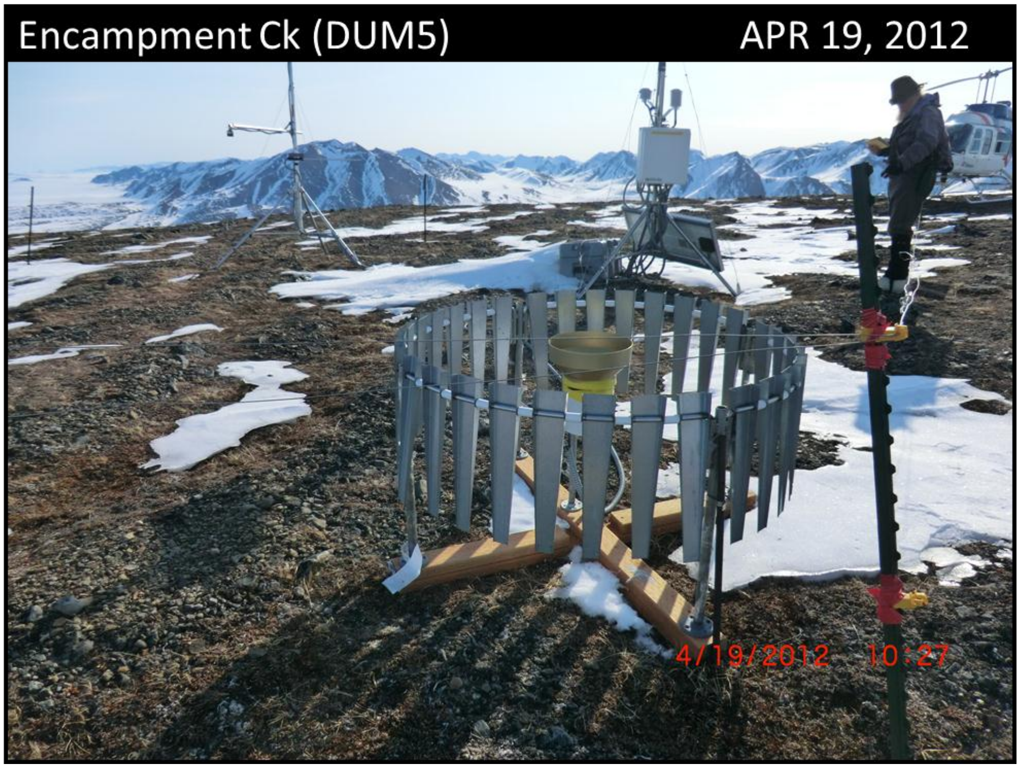


Figure 25. Upper May Creek (DUM2) meteorological station photo comparison illustrating temporal and spatial variability of snow cover during subsequent springs.



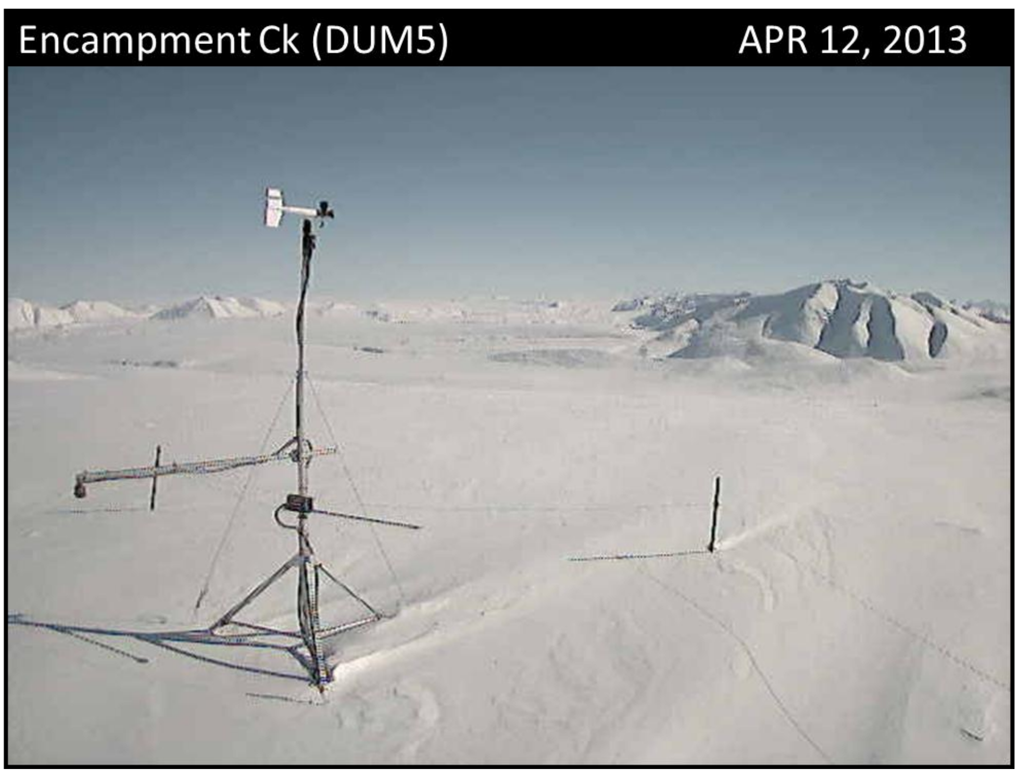


Figure 26. Encampment Creek (DUM5) meteorological station photo comparison illustrating temporal and spatial variability of snow cover during subsequent springs.

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. Daily average SR50 snow depth data at each station during the 2012–2013 winter are shown in Figure 27. This figure is used to identify periods of snow accumulation and redistribution during snowstorms and wind events.

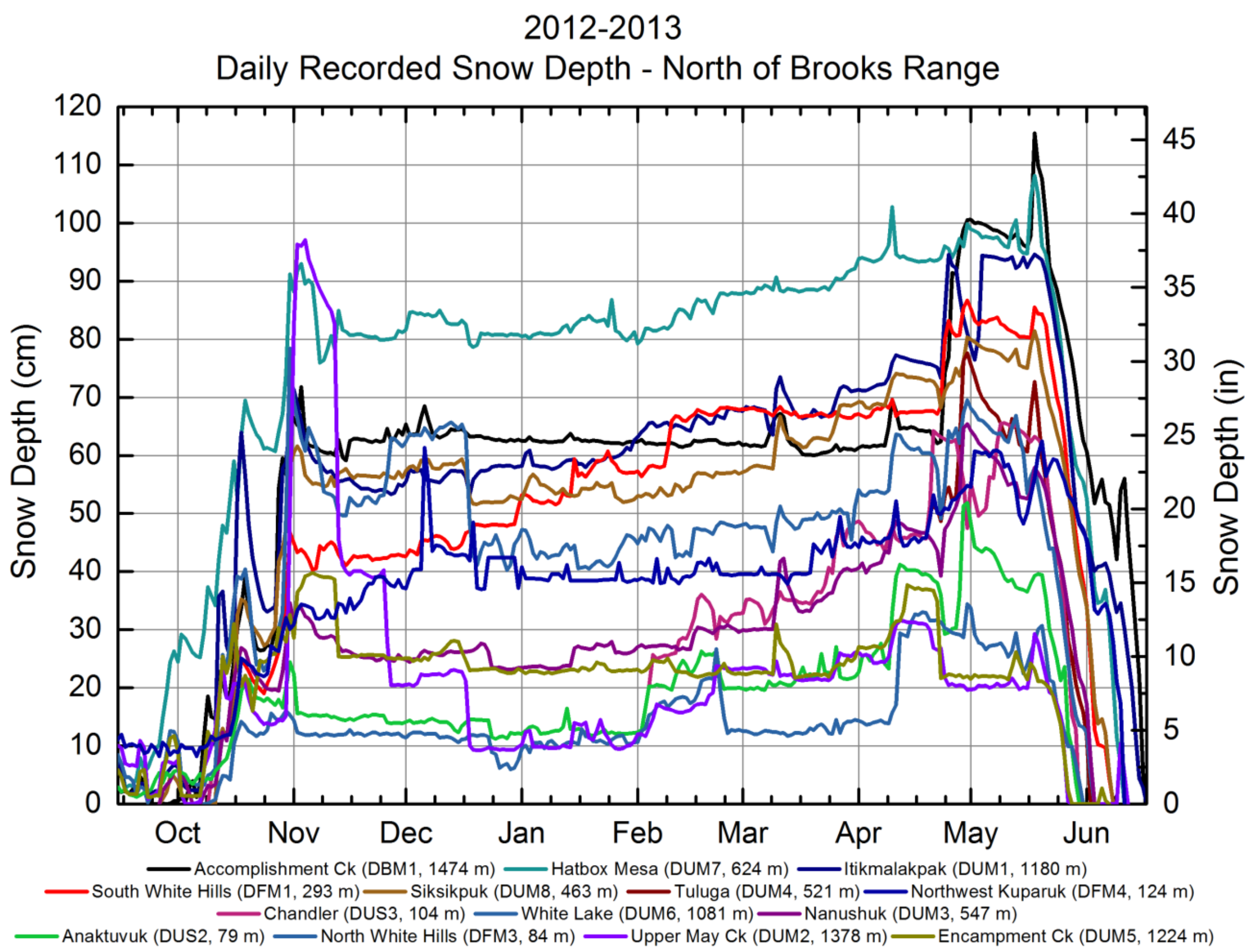


Figure 27. SR50 daily (hourly averaged) snow depths at the fifteen meteorological stations north of the Brooks Range during the 2012–2013 winter period. Station names, IDs and elevations (in meters) are listed in the legend below the graph.

Records show that snow accumulation north of the Brooks Range mostly began in early September 2012, but this varied slightly depending on station location (Figure 9–Figure 23 and Figure 27). Following initial snow accumulation, a storm during mid-October was responsible for most of the winter's precipitation (see Section 8 (Figure 40) "Surface weather analysis" for more details). During the remainder of the winter, many small (<5 cm) snow events occurred, but overall, very little snow accumulated and most sites actually had a reduction in snow depth as a result of wind erosion and compaction. It was not until late spring that most sites received another large snowfall.

Most of the Mountains stations (Encampment Creek, Upper May Creek, and White Lake) show the largest variation in snow depths due to lateral snow transport by wind in this treeless area. Note that the above general descriptions of snow accumulation do not hold true for all station locations. South White Hills (DFM1), for example, accumulates snow gradually throughout the entire winter. Another example of spatial variability amongst stations is the event that took place on November 26–27, 2012, when Upper May Creek (DUM2) experienced significant wind erosion, White Lake (DUM6) accumulated snow, and very little snow depth change was observed at any of the other locations.

A review of events in the SR50 snow depth record for 2012–2013 (Figure 27), 2011–2012 (Figure 28), and 2010–2011 (Figure 29) winter periods indicates that the process of snow deposition and erosion is complex, controlled by wind speed and other factors. We examined a few of the larger and spatially widespread winter storm events and found that most stations are subject to both snow accumulation and wind-generated loss. A few stations are in snow erosional areas (such as the Mountains stations, Upper May Creek and Encampment Creek, along with the high-elevation White Hills station). These stations record very little snow most of the year, because any accumulation of snow is blown away during frequent high wind-speed events. The SR50 snow depth record of the more protected stations in the Mountains region (like Accomplishment Creek and Itikmalakpak Creek) indicates high amounts of snow accumulation, but still suggests snow loss during high wind-speed events. A larger amount of snow accumulates by the end of winter at the Hatbox Mesa and Siksikpuk stations, located in the Foothills region of the Chandler basin, with little loss to erosion. Stations located on the Coastal Plain tend to have less overall variability in snow depth over the winter period and gradual accumulation throughout the season.

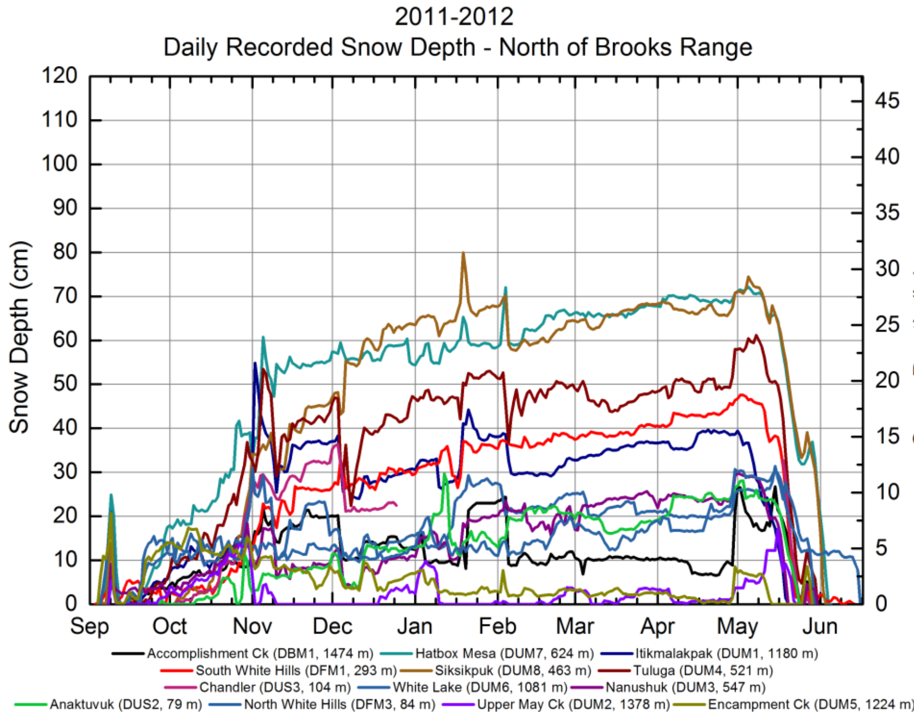


Figure 28. SR50 daily (hourly averaged) snow depths at the fifteen meteorological stations north of the Brooks Range during the 2011–2012 winter period. Station names, IDs and elevations (in meters) are listed in the legend below the graph.

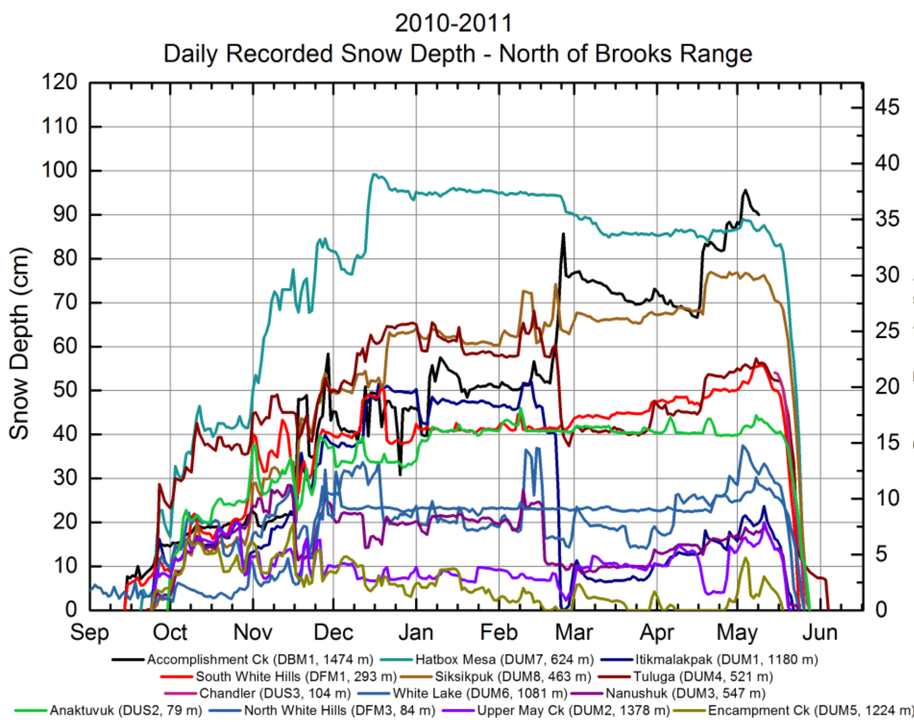


Figure 29. SR50 daily (hourly averaged) snow depths at the fifteen meteorological stations north of the Brooks Range during the 2010–2011 winter period. Station names, IDs, and elevations (in meters) are listed in the legend below the graph.

7.2 South of the Brooks Range Divide

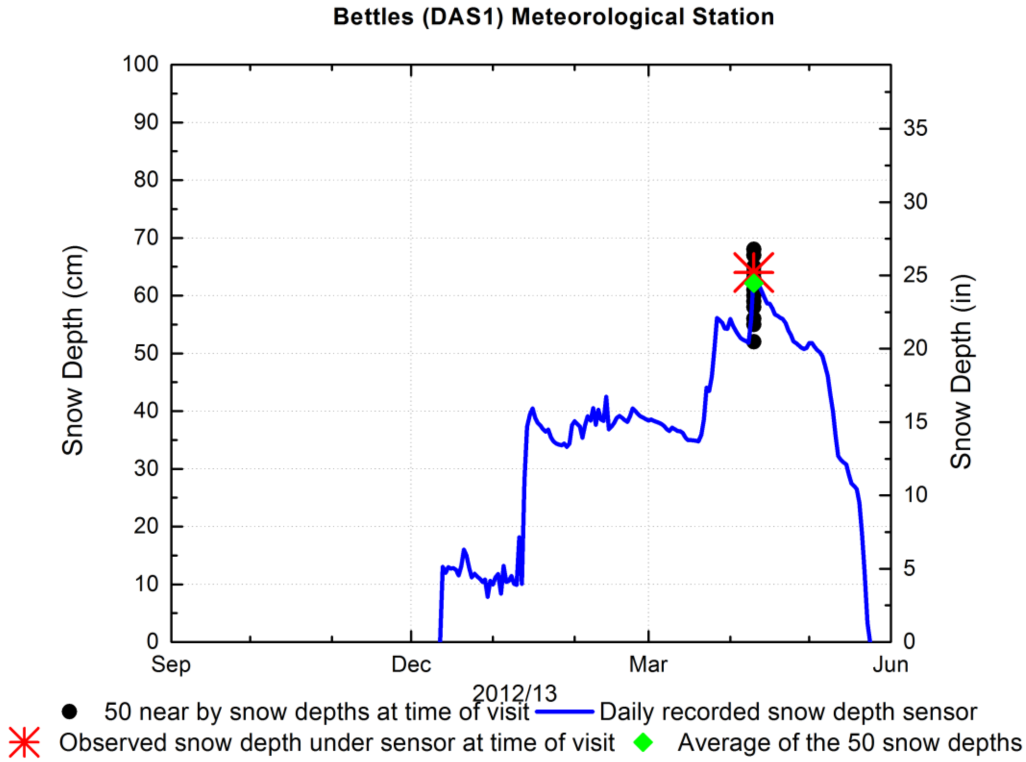
South of the Brooks Range, eight meteorological stations (DAS1–DAS4 and DAM5–DAM8) were installed during summer 2012. The stations were originally established under the Ambler corridor project (ADOT&PF), but are now maintained under a project funded by the Alaska Industrial Development and Export Authority (AIDEA). Also, data from one USDA NRCS SNOTEL site are also reported here (Coldfoot). So, during the winter of 2012–2013, SR50 measurements were recorded at nine meteorological stations south of the Brooks Range divide (Table 10, Figure 30–Figure 38).

Table 10. Snow depth information for 2013 from meteorological stations and co-located snow surveys south of the Brooks Range. NA represents no measurement.

Meteorological Station	Snow Survey Depth Range (cm)	Snow Survey Depth Ave. (cm)	Observed Depth Under SR50 (cm)	SR50 Reported Depth at Time of Observed Depth (cm)	Differerence Between Observed and SR50 Reported Depth (cm)
Bettles (DAS1)	52-68	62	64	56	8
Alatna (DAS2)	31-69	51	51	49	2
S Fork Bedrock (DAS3)	54-82	65	NA	40	NA
Reed (DAS4)	50-73	57	34	37	-3
Wild (DAM5)	NA	NA	NA	40	NA
Upper Iniakuk (DAM6)	12-92	56	NA	33	NA
Upper Reed (DAM7)	76-93	84	62	57	5
Upper Kogoluktuk (DAM8)	60-89	47	77	79	-2
Coldfoot March(NRCS)	27-47	38	NA	31	NA
Coldfoot April (NRCS)	43-70	59	NA	48	NA

The initiation of snow accumulation south of the Brooks Range varied greatly depending on elevation and proximity to the mountains. The four mountain sites (DAM5–DAM8) started receiving snow during mid-September, while the four lower elevation river stations (DAS1–DAS4 and Coldfoot) did not receive significant snow accumulation until mid-December (Figure 30–Figure 38 and Figure 39). Regardless of elevation, all stations south of the Brooks Range (except Wild) received the most snow during one large storm event that took place in mid-January, 2013 (see Section 8 (Figure 41) "Surface weather analysis" for more details). A second storm during early April, 2013 delivered significant amounts of snow also, but not across the entire south of the Brooks Range study area as happened with the mid-January storm. This second storm, however, precipitated greater quantities of snow at lower elevations (Bettles, Alatna, and Coldfoot). For the remainder of the winter, relatively little fluctuation in snow depths occurred.

All stations south of the Brooks Range reported good-quality SR50 snow depth data. Variability is evident, however, in terms of how well the automated snow depths represent local snow courses. Most of the snow course data (fifty observed depths collected near the station during end-of-winter snow surveys) had tightly grouped snow depths, illustrating somewhat homogeneous snowpacks. Upper Iniakuk (DAM6) was the only station with greatly varying snow depths and, consequently, a heterogeneous snowpack (Figure 35). Roughly half of the snow courses (Bettles, Alatna, Upper Kogoluktuk, and Coldfoot) had averages that closely matched the automated snow depth measurements (Figure 30, Figure 31, Figure 37, and Figure 38). The snow courses at S Fork Bedrock Creek (DAS3), Reed River (DAS4), and Upper Reed (DAM7) stations all had averages well above the SR50 snow depth measurements (Figure 32, Figure 33, and Figure 36). In summary, snow courses at four stations had strong correlations with the SR50 measurements and the remaining four snow courses were significantly above the automated measurements. Because of weather, no end-ofpwinter observations were made at Wild (DAM5) (Figure 34) This information exemplifies the challenges associated with siting the sensor and using SR50 snow depth data for quantitative analysis.



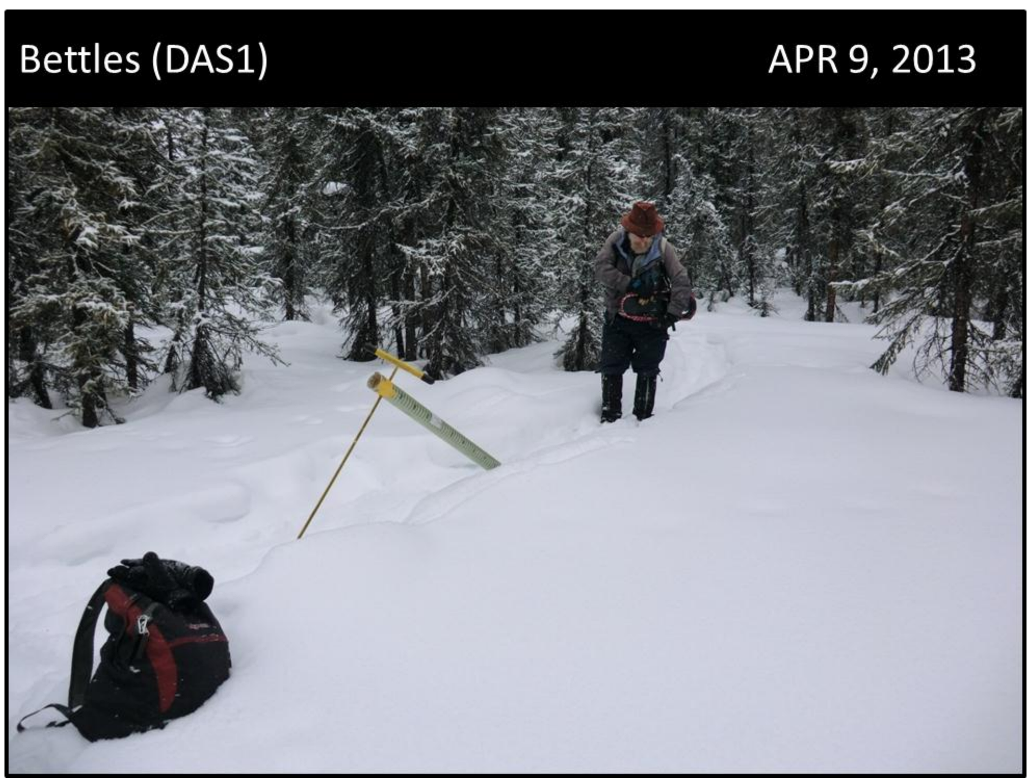


Figure 30. Bettles (DAS1) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.

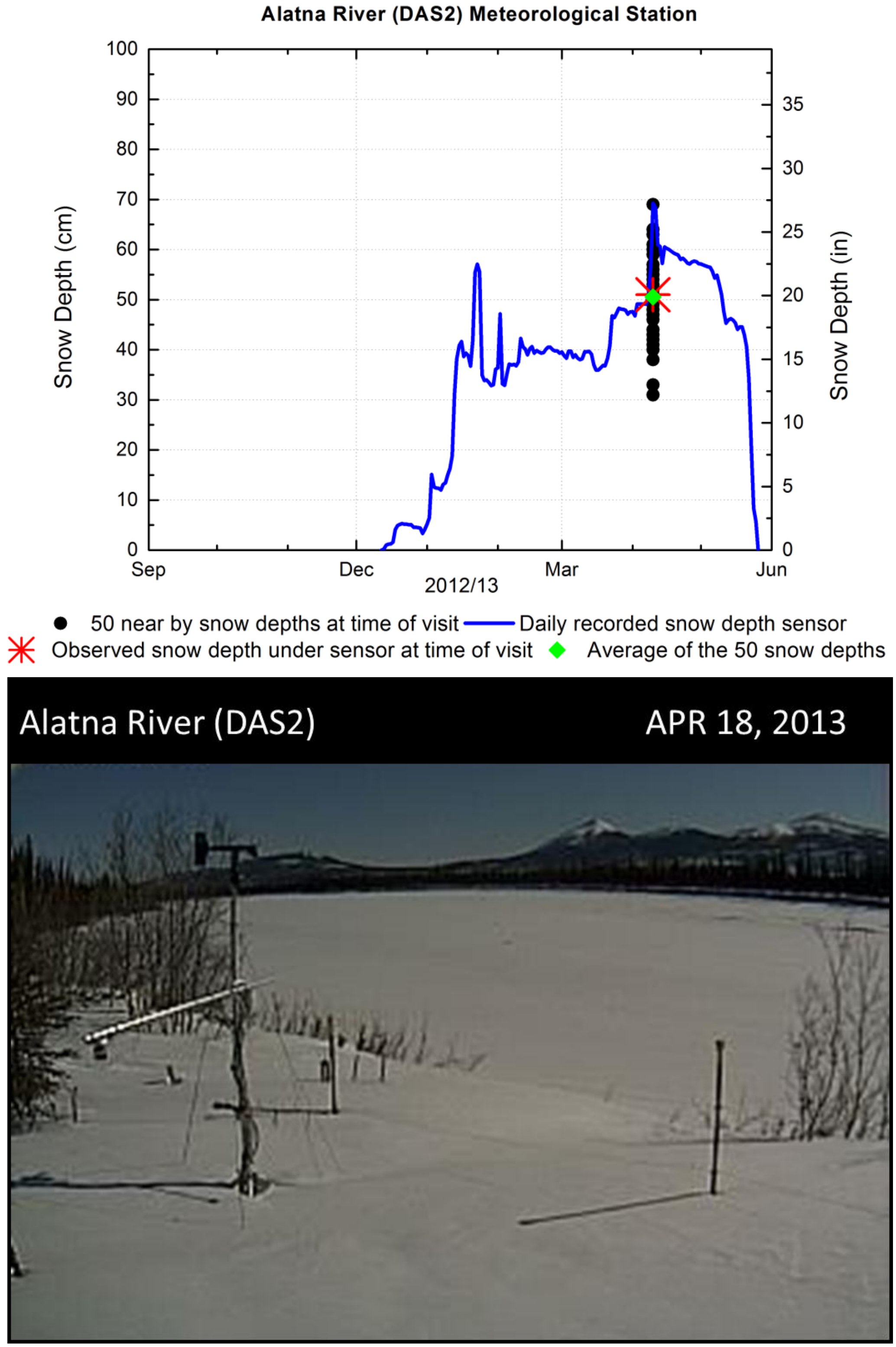
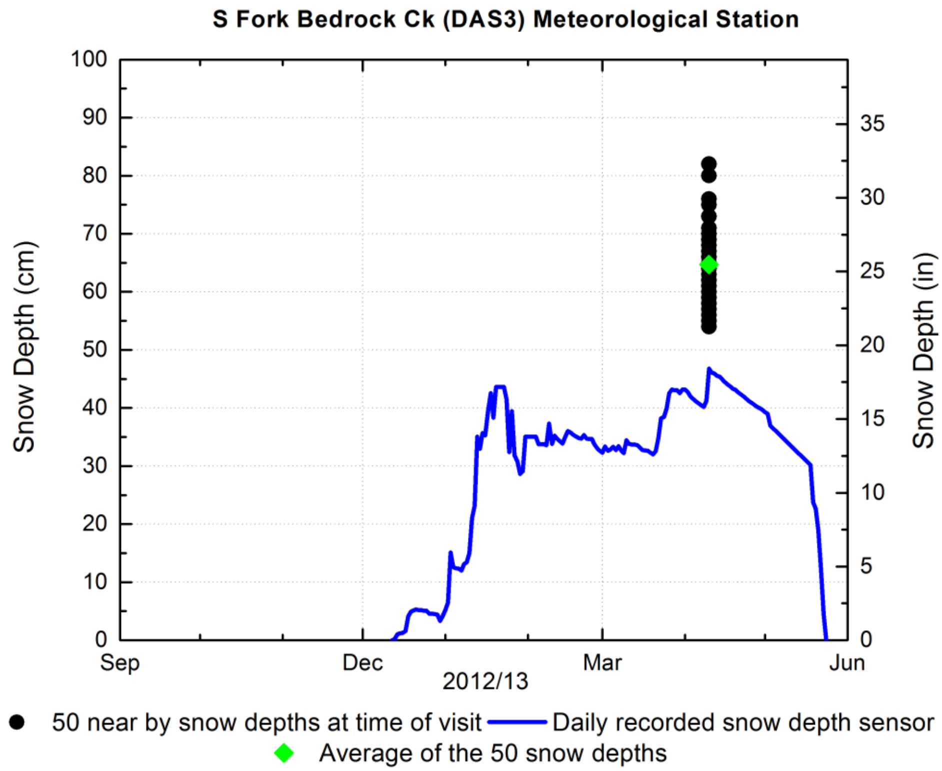


Figure 31. Alatna River (DAS2) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.



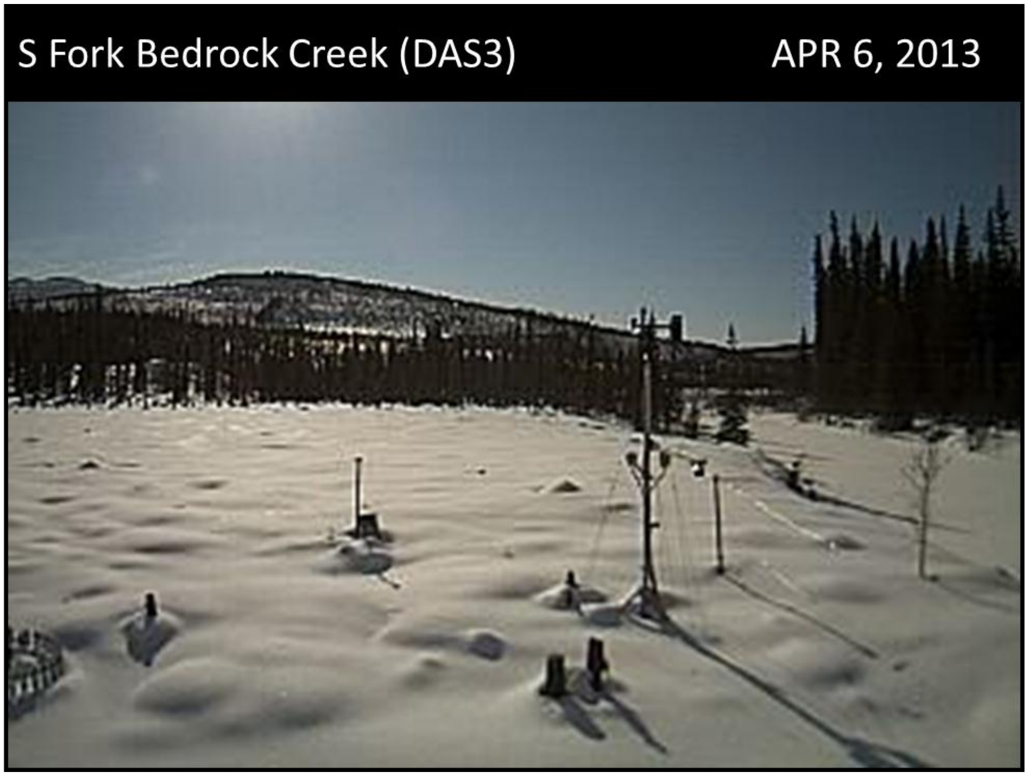


Figure 32. S Fork Bedrock Creek (DAS3) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.

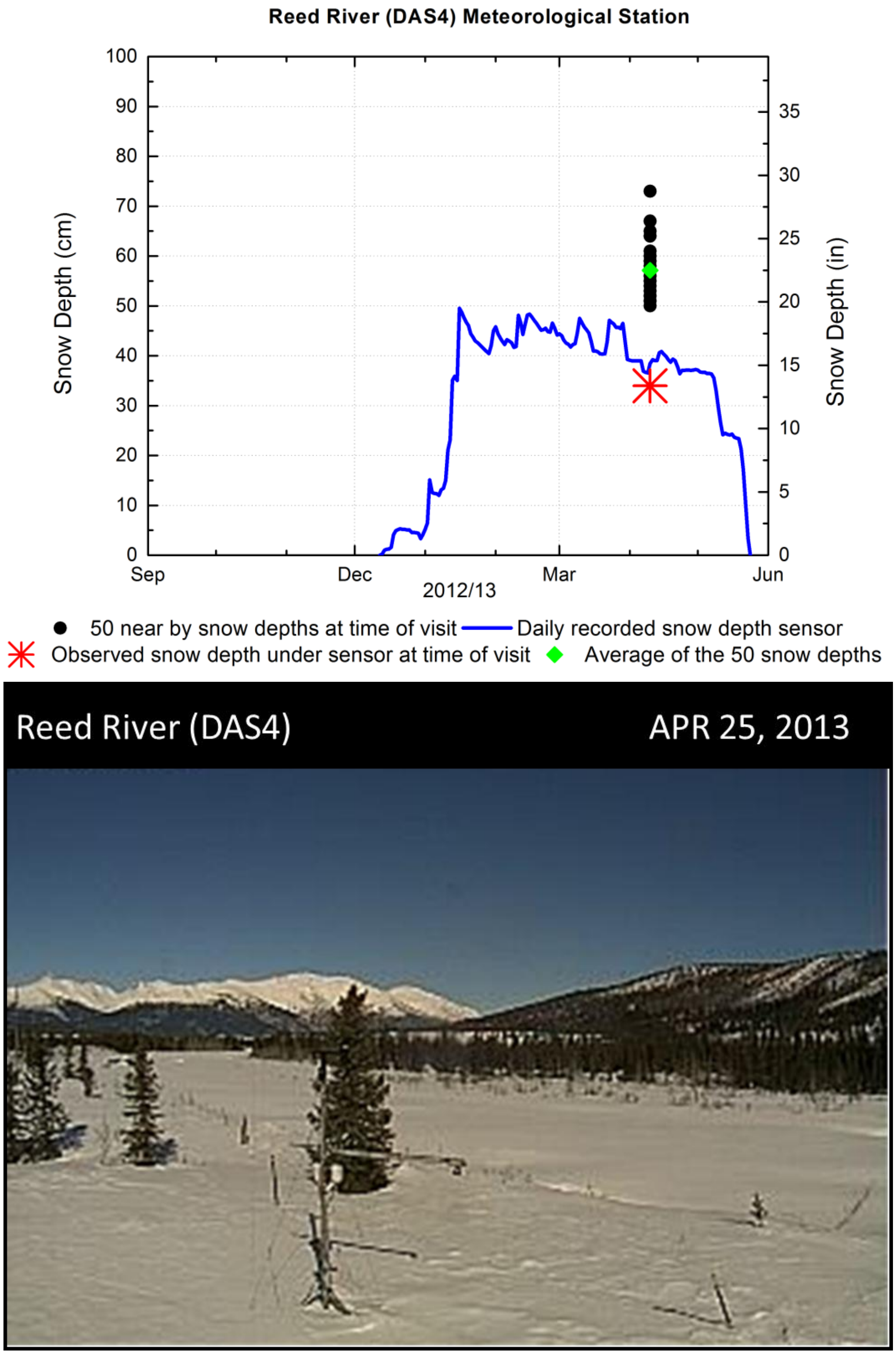
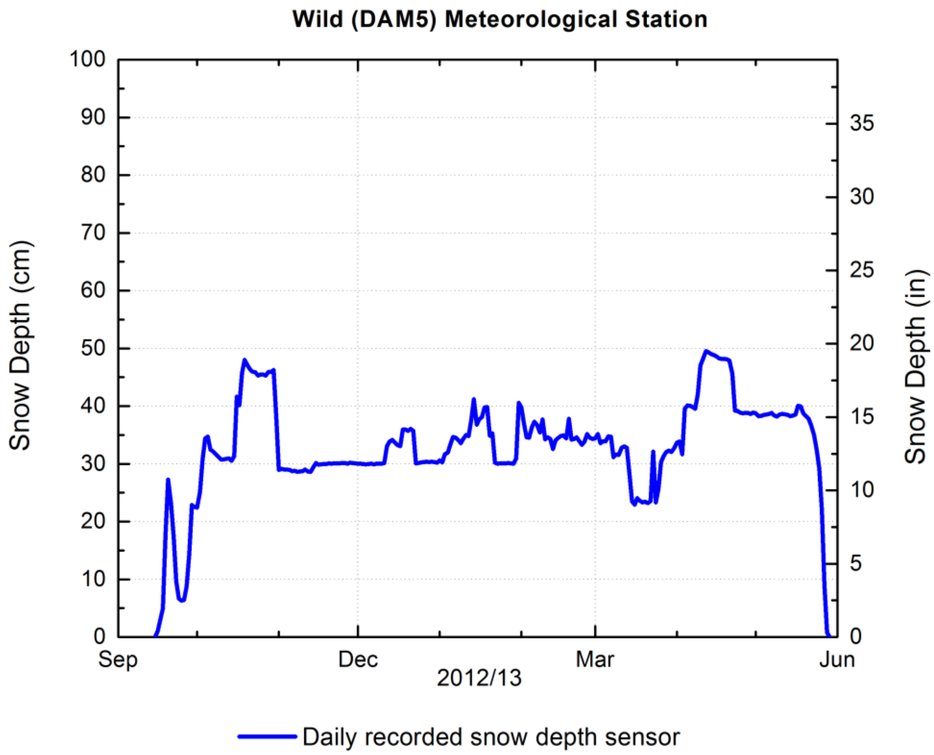


Figure 33. Reed River (DAS4) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.



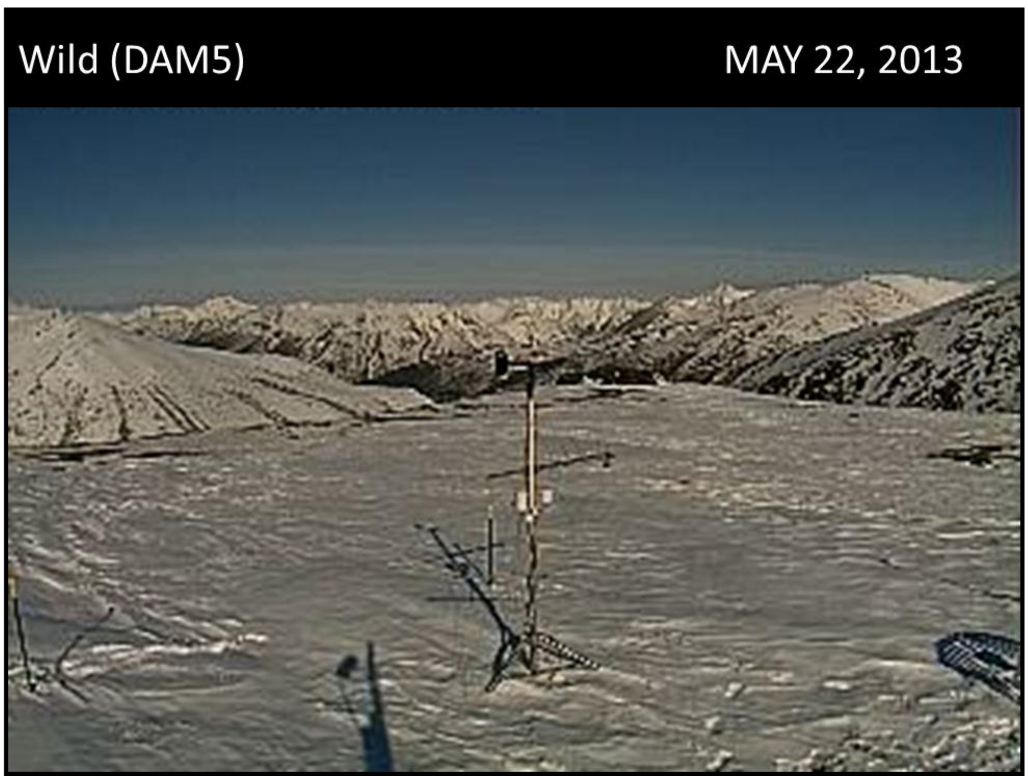
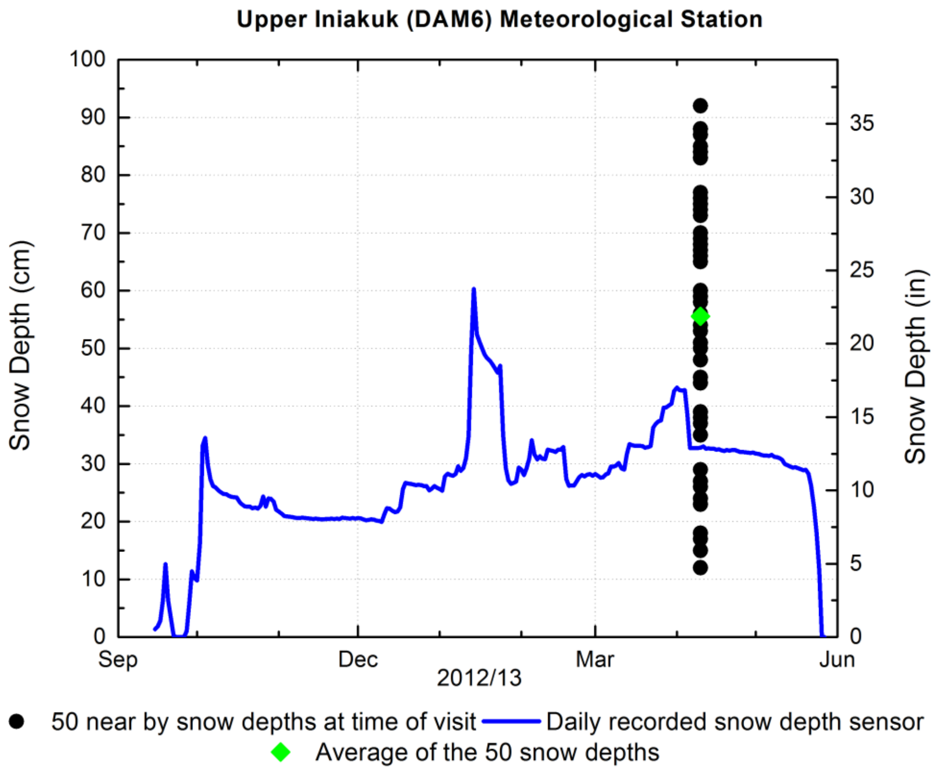


Figure 34. Wild (DAM5) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, 2012–2013.



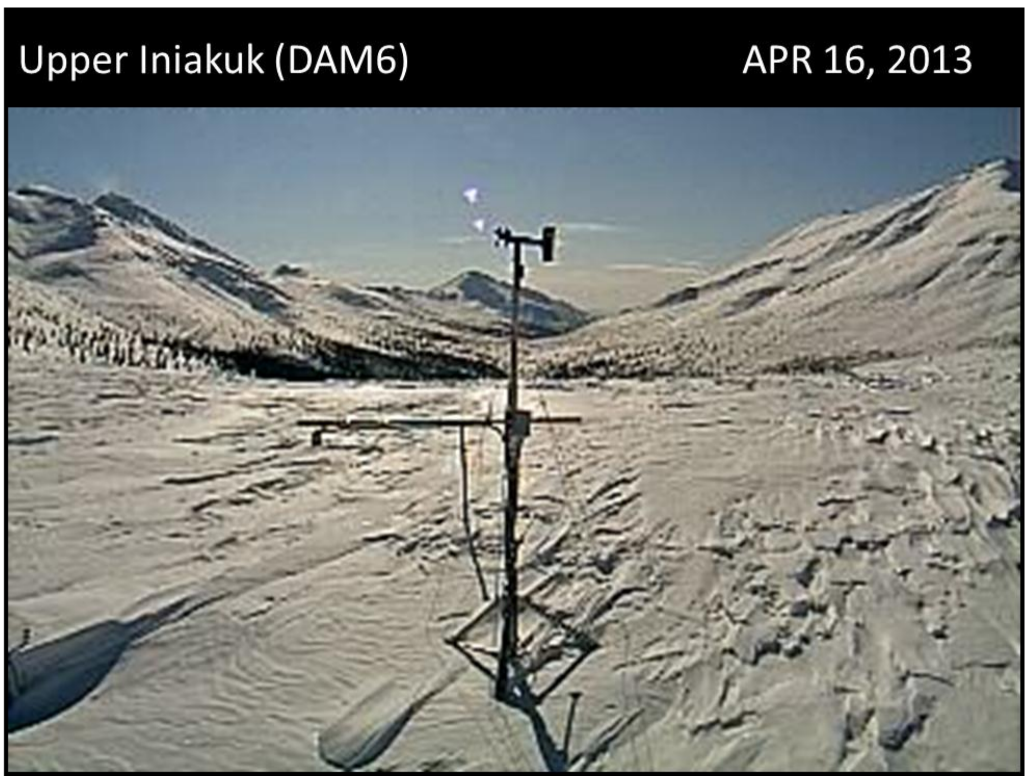


Figure 35. Upper Iniakuk (DAM6) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.

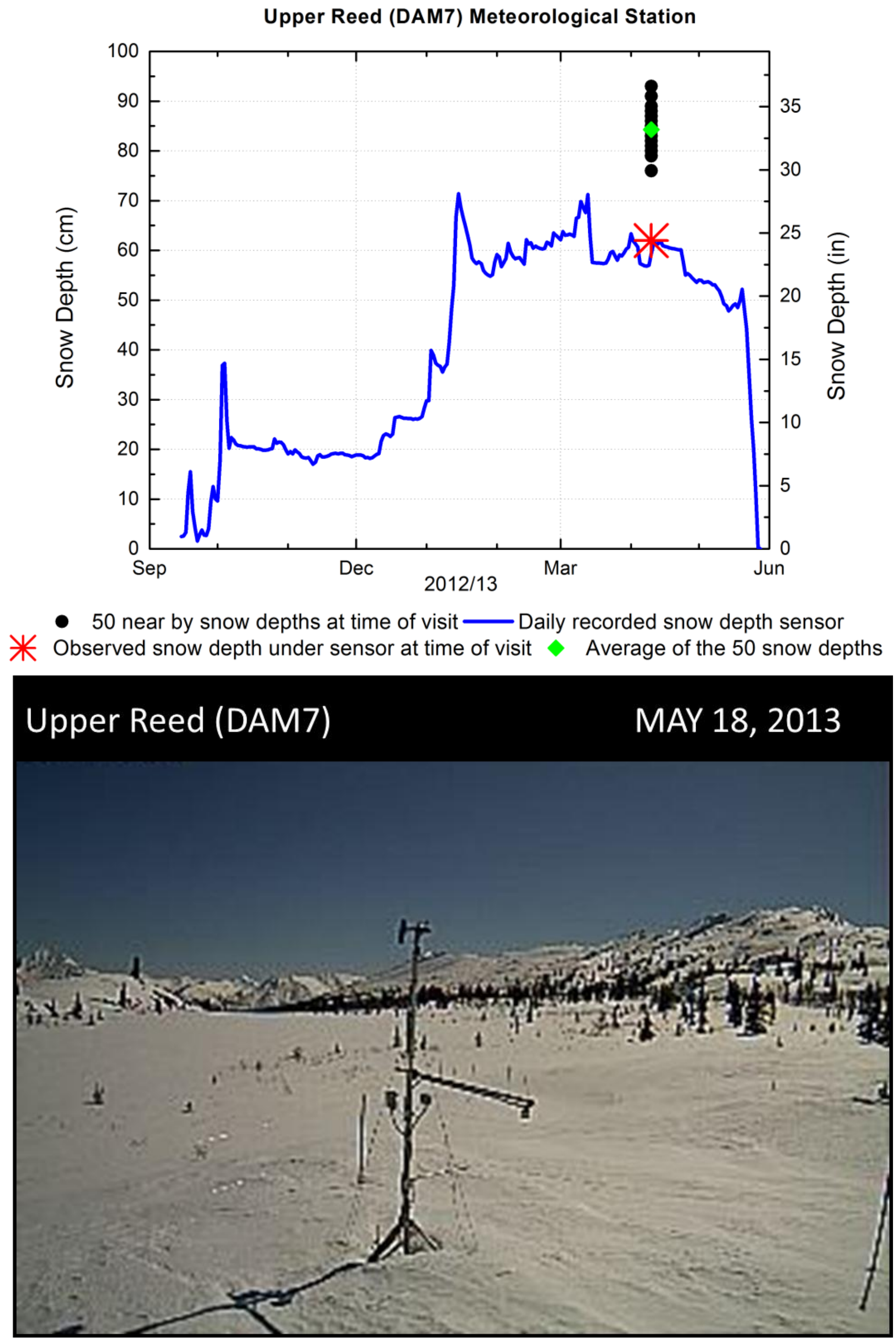


Figure 36. Upper Reed (DAM7) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.

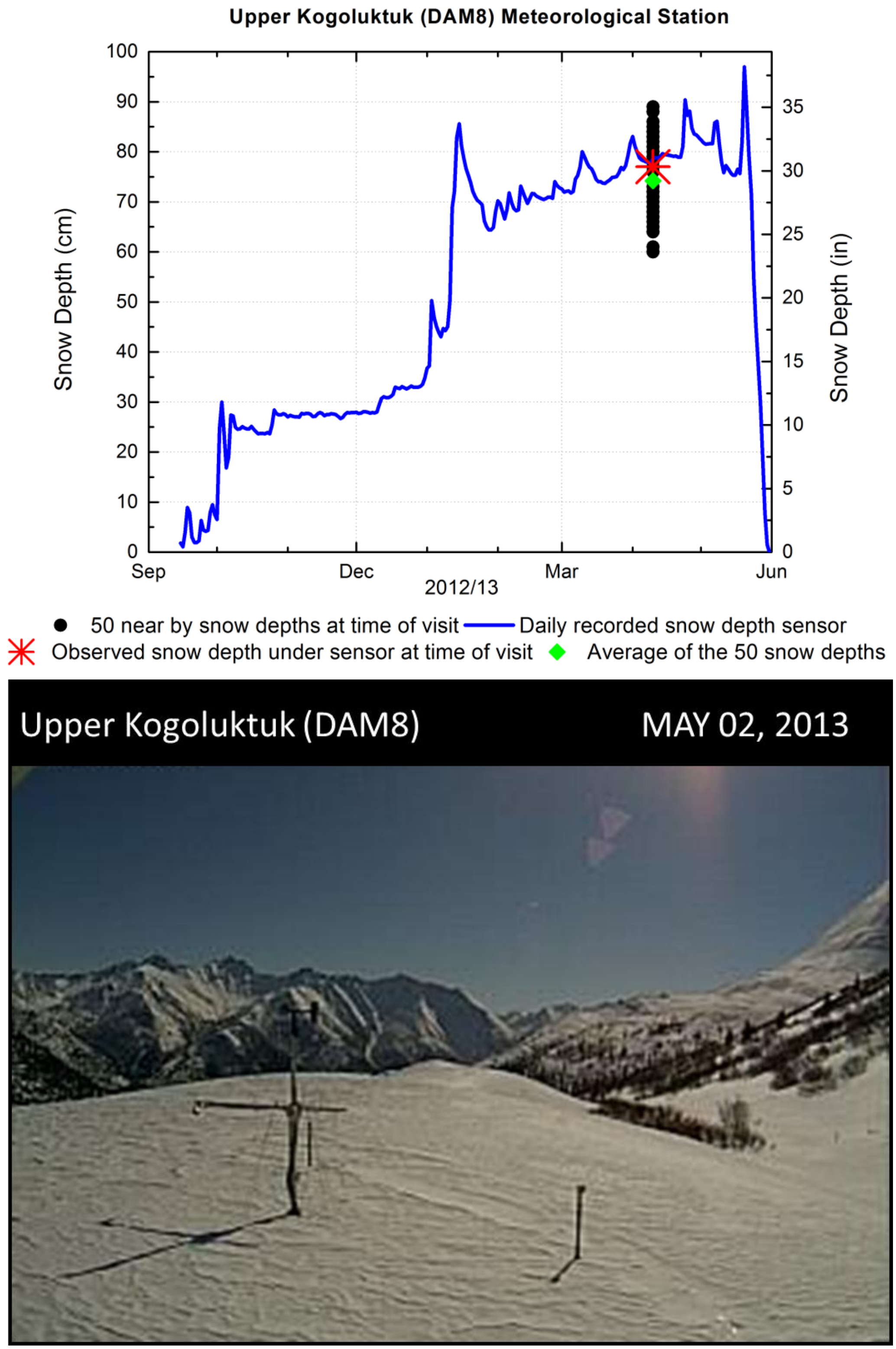


Figure 37. Upper Kogoluktuk (DAM8) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, observed snow depth under the sensor at time of visit, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.

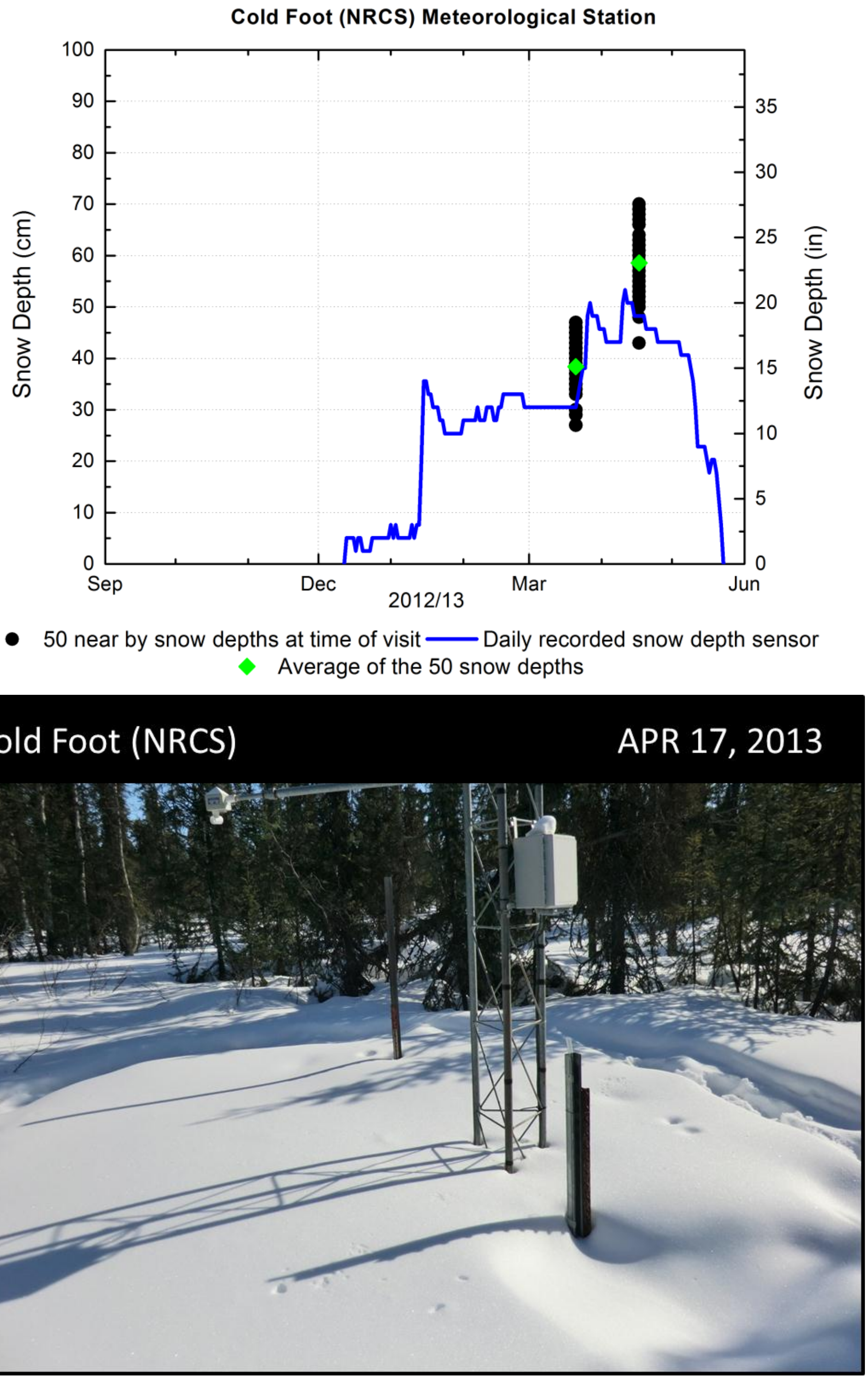


Figure 38. Coldfoot (NRCS) meteorological station daily (hourly averaged) recorded SR50 sensor snow depths, 50 snow survey depths measured near sensor, and average of 50 depths, 2012–2013.

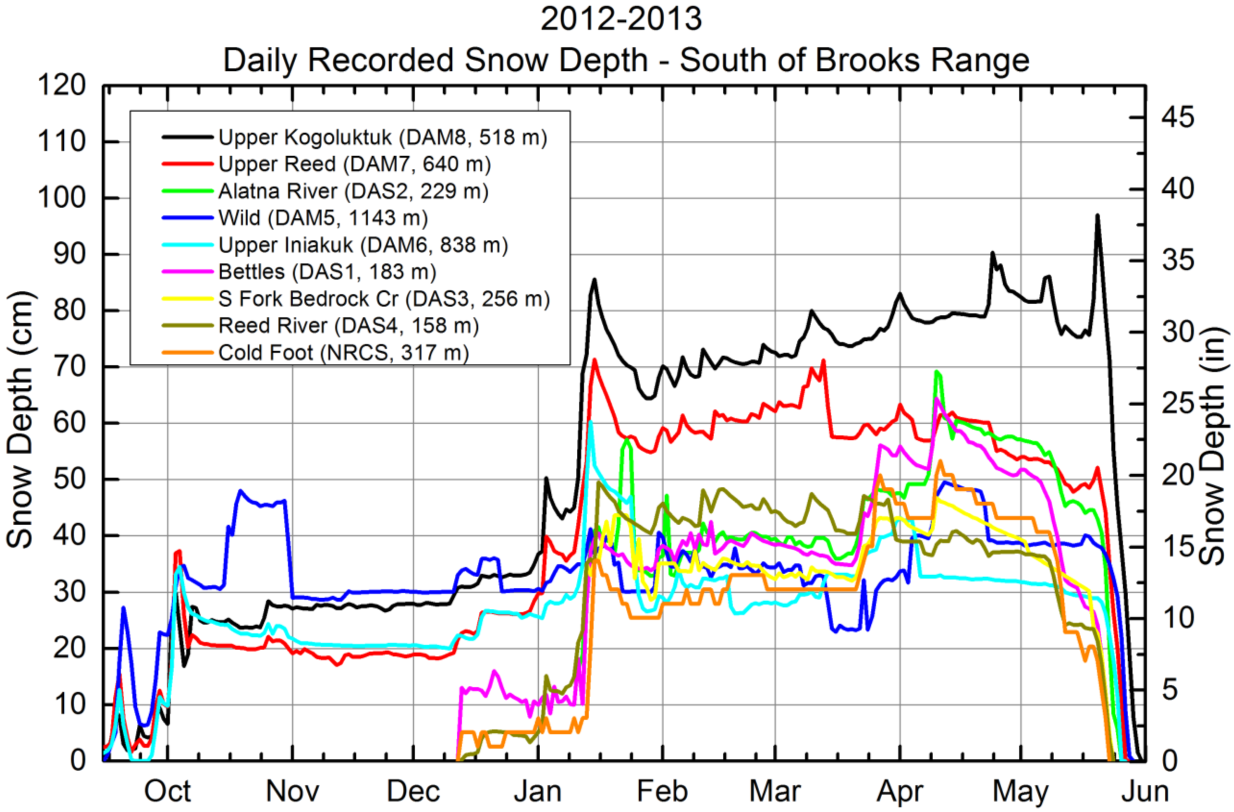


Figure 39. SR50 daily (hourly averaged) snow depths at the nine meteorological stations south of the Brook Range during the 2012–2013 winter period. Station names, IDs, and elevations (in meters) are listed in the legend.

8. SURFACE WEATHER ANALYSIS

For a significant precipitation event on the North Slope a low pressure system needs to reach the area without crossing any of the significant east-west mountain ranges. Following is one possible scenario for significant precipitation on the North Slope. Figure 40 shows the development of a fall storm (October 2012) that generated widespread heavy snowfall on the North Slope of Alaska. In panel A, a ridge of high pressure was located over the North Slope and wind flow was from the southeast creating a generally dry weather pattern. A strong low pressure system was approaching from the southwest over Bering Sea. As this system moved north into the Arctic Ocean (Panel B), it pushed a warm moist air mass around the west end of the Brooks Range to the North Slope and Beaufort Sea. Due to the warm temperatures, any precipitation this storm generated south of the Brooks Range as it moved north fell as rain, except at high elevations (i.e. Wild Station (1143m), Figure 39). This weather system stalled with a stationary front running from the Chukchi Sea across to the Beaufort Sea just off the Alaskan coast. In Panel C, a secondary low pressure system developed to the northeast along the stationary front forming a cold front. This new system pushed a cold arctic air mass southeastward toward the Brooks Range and generated a heavy snow event across the North Slope of Alaska. A majority of the weather stations north of the Brooks Range recorded an increase in snow depth during second week of October, 2012 (Figure 27). Panel D shows the redevelopment of a high pressure ridge over northern Alaska ending the snow event.

Figure 41 shows the development of an early winter storm that generated a large snowfall on the southern slopes of the Brooks Range in January, 2013. In panel A, high pressure and an easterly wind flow dominated the northern interior and the North Slope of Alaska resulting in cold dry conditions. Panel B shows a strengthening storm in the Bering Sea that pushed warm moist air into the northern interior of Alaska initiating heavy snowfall along the southern slopes of the Brooks Range. The storm continued to intensify as shown in Panel C. This strong southwesterly flow of air from the Bering Sea produced widespread snowfall in the northern interior of Alaska. As this air mass pushed over the Brooks Range, orographic effects caused heavy snowfall to occur over the southern slopes of the Brooks Range. All weather stations south of the Brooks Range recorded a large increase in snow depth in mid-January, 2013 (Figure 39). Down slope winds north of the Brooks Range produced little or no snowfall. In Panel D, the storm moved into Canada leaving only a weak trough of low pressure ending the snow storm.

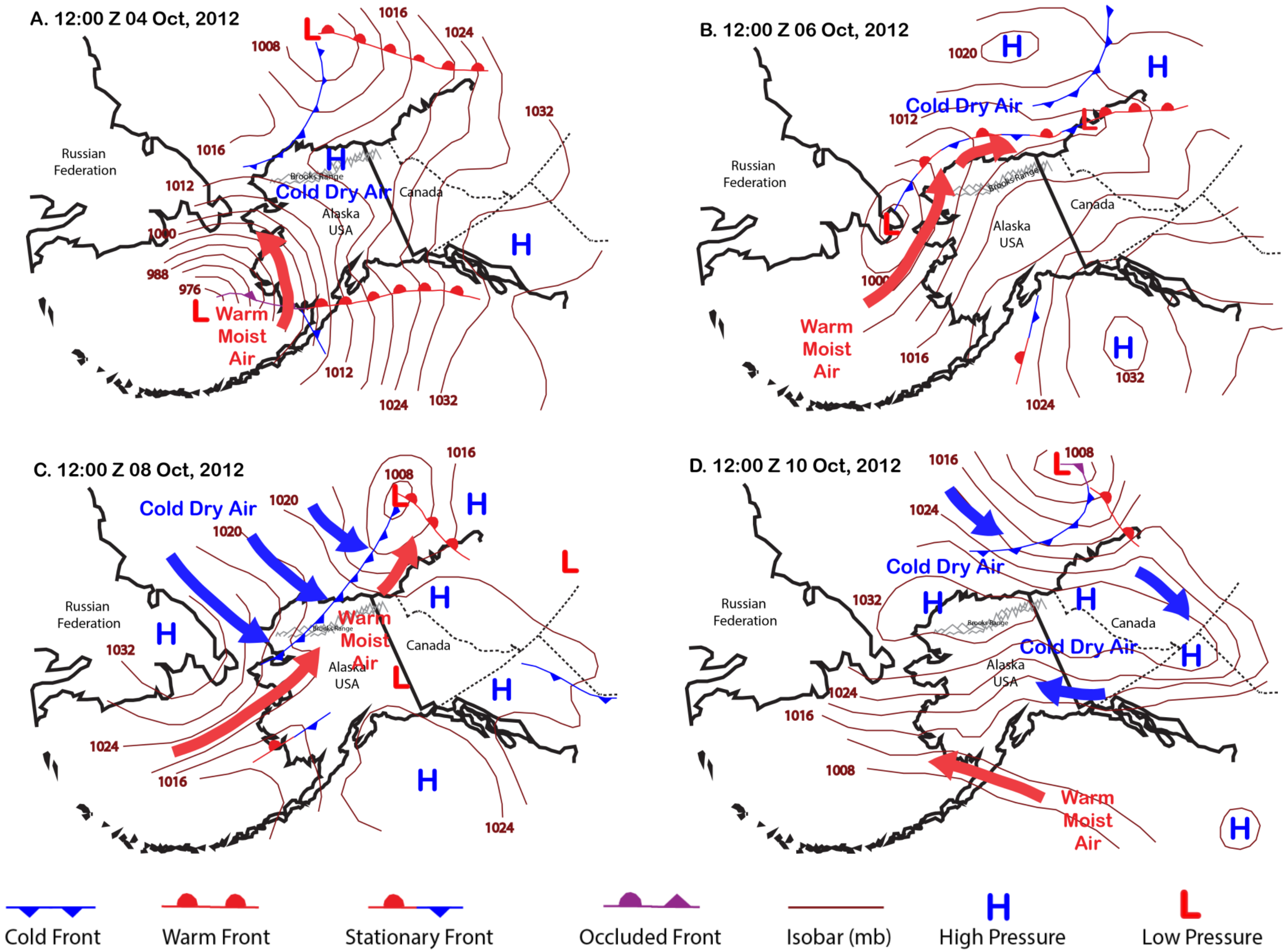


Figure 40. Archived NOAA Surface Weather Analysis of a winter storm that produced significant snowfall on the North Slope of Alaska (NOAA, 2013).

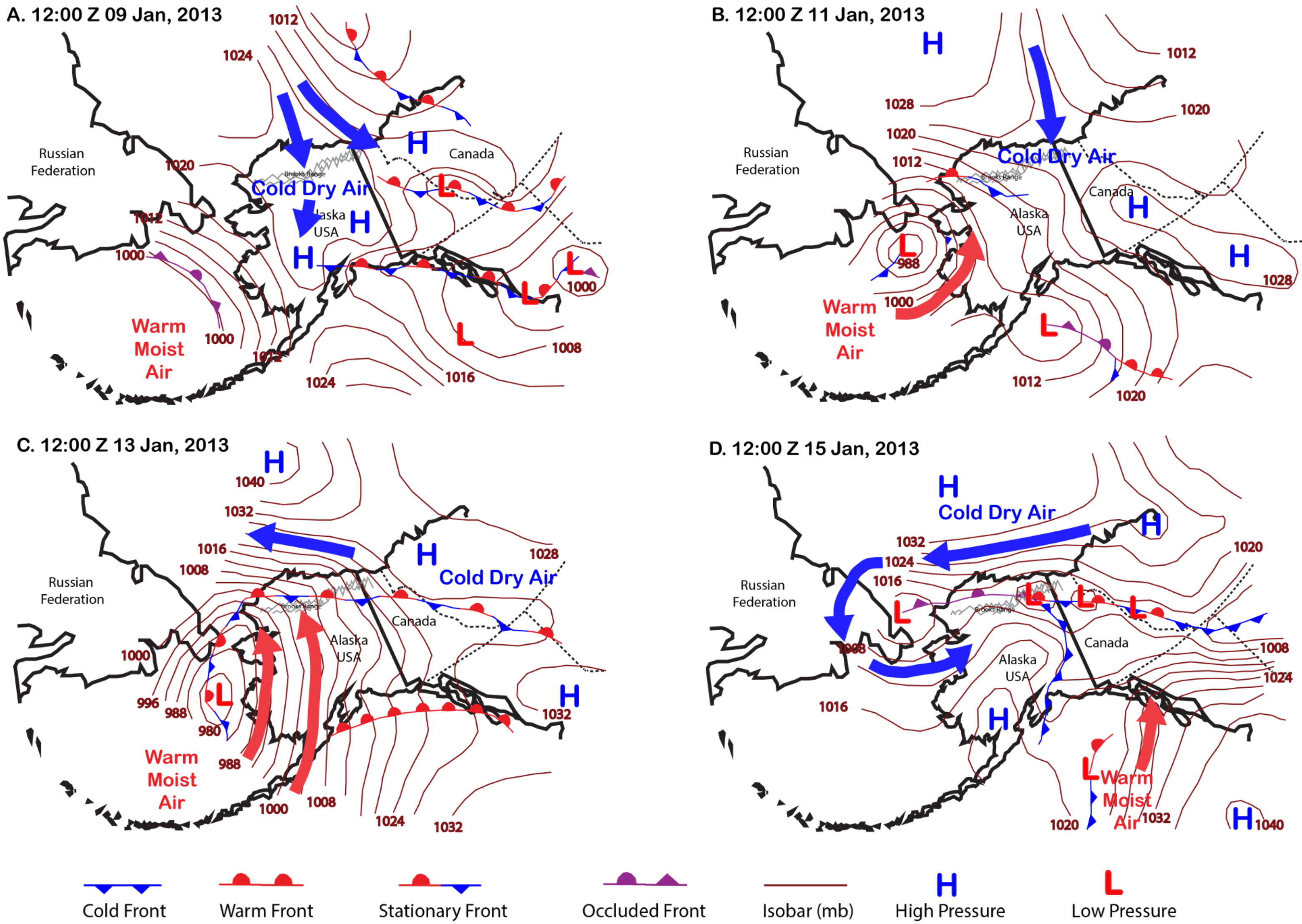


Figure 41. Archived NOAA Surface Weather Analysis of a winter storm that produced significant snowfall in the northern interior of Alaska (NOAA, 2013).

9. SWE CORRECTIONS

Spring of 2013 was unusual in that the cold temperatures over northern and interior Alaska extended long into May, resulting in a late river breakup—one of the latest breakups in the 97-year-long breakup record of the Tanana River at the town of Nenana. This extended cold period caused additional snow accumulation. Following the end-of-winter snow surveys in April, snowfall events occurred at the majority of the Ambler and Umiat snow survey sites, resulting in an end-of-winter SWE increase. We used snow depth data from SR50 sensors, additional snow surveys, and USDA NRCS data to account for additional SWE. Appendix A1 and Appendix A3 reports the original snow survey data for north and south of the Brooks Range, respectively, while the corrected end-of-winter SWE is reported in Appendix A2 and Appendix A4 for north and south of the Brooks Range, respectively.

The general approach used for SWE adjustment was:

1. to locate weather stations that reported an increase in snow depth,
2. to analyze individual snowfall events and estimate the snowfall from change in snow depth at the SR50,
3. to convert the change in snow depth to SWE, assuming that density of freshly fallen snow is 100 kg/m^3, and
4. to apply the SWE adjustment to the snow survey sites.

Snow survey sites were grouped and assigned to a representative meteorological station based on geographical proximity. The end-of-winter SWE for all survey sites within a group was given the same correction as the representative station.

9.1 Snow Depth Increase in the Umiat Study Area

The 2013 Umiat end-of-winter snow surveys were conducted between April 18 and April 24. Thirteen meteorological stations within the Umiat study area between the Brooks Range and the coastal plain received significant snow accumulation after April 24.

In the Mountains, snow accumulation events occurred on April 24 and May 17. In the Foothills, stations recorded an increase in snow depth on April 23–29 and May 17. On the Coastal Plain, stations recorded significant snowfall on April 28–May 2, and May 18. SWE adjustment and resulting final SWE for the Ambler study area is summarized in Appendix A2.

9.2 Snow Depth Increase in the Ambler Study Area

Most of the 2013 Ambler end-of-winter snow surveys were conducted between April 3 and April 9. Two snowfall events occurred after that on April 9–10 and May 20, 2013. To adjust for the increase in snow depth due to these snowfalls, we used data recorded at the nine meteorological stations and observations made by the snow survey team on April 9, 2013, while finishing the end-of-winter snow surveys. SWE adjustment and resulting final SWE for the Ambler study area are summarized in Appendix A4.

10. ABLATION DATA

Snow ablation is the term used to describe snowmelt or net decrease in SWE. Many northern watersheds retain winter precipitation for seven to eight months a year, with minor losses in SWE. Ablation occurs in that short period when winter precipitation is released to the hydrologic cycle. To capture ablation, snow surveys are conducted frequently (daily or every other couple days) during snowmelt. All of the long-term ablation observation sites are located along the Dalton Highway for logistical reasons, while some shorter measurement duration sites are more remote. Appendix B provides ablation measurements for all observational sites north and south of the Brooks Range.

Average annual precipitation in the Umiat study areas ranges from 170 mm on the Coastal Plain to almost 400 mm at higher elevations of the Brooks Range. The end-of-winter SWE (used as a proxy for the winter precipitation) constitutes roughly 40% to 50% of annual precipitation north of the Brooks Range. The percentage of winter precipitation in the Ambler study area is slightly less at approximately 25%. This amount of water becomes available to the streamflow network during the ablation window (Figure 42, Figure 43). This ablation window varies from year to year, depending on atmospheric circulation, solar radiation, air temperature, and depth of the snowpack, etc. Due to record cold temperatures across the state in May 2013, snowmelt was postponed by one to two weeks.

Most of the weather site south of the Brooks Range divid reported the onset of snowmelt around May 18–20, 2013. Several weather stations indicated the onset of snowmelt earlier, around May 8, 2013. Those stations were located at low elevations south of the Brooks Range (Bettles, S Fork Bedrock, Reed, and Coldfoot). Snow also disappeared the earliest at these locations, by May 24, 2013. Snow melted by June 1, 2013, at all weather stations south of the Brooks Range.

North of the Brooks Range, the ablation window occurred from May 18 to June 17, 2013. Three stations with deep snow (greater than 90 cm) recorded snow disappearance between June 11 and June 17, 2013. Two of those stations (Accomplishment Creek and Itikmalakpak) are located at higher elevations (1474 m and 1180 m); the third station (Hatbox Mesa) is located at 624 m. Two other sites at high elevation with relatively shallow snow (Upper May Creek and Encampment

Creek) indicated snow disappearance by May 28, 2013, almost three weeks earlier. Most of the weather stations north of the Brooks Range reported snow-free conditions by June 8, 2013.

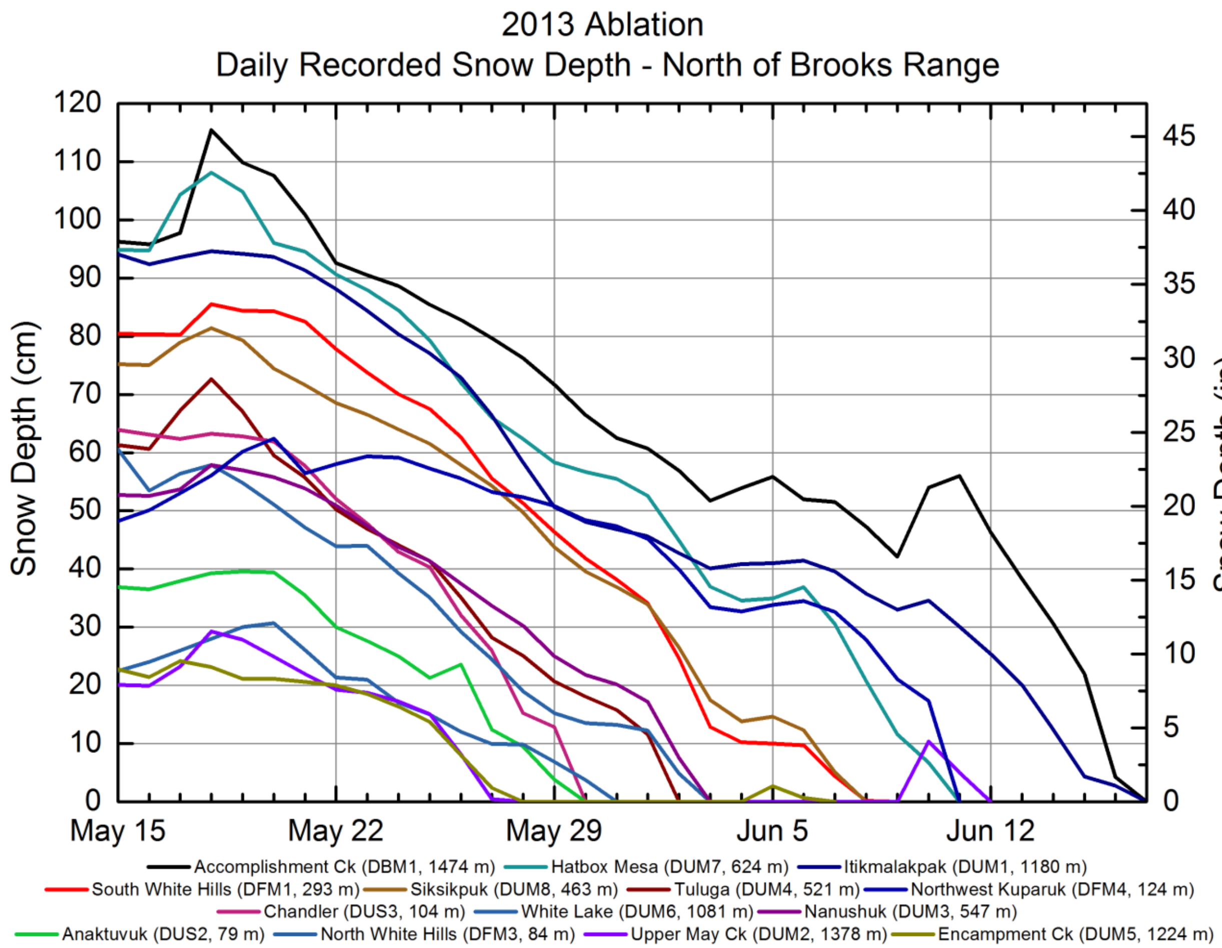


Figure 42. SR50 daily (hourly averaged) snow depths at the fifteen meteorological stations north of the Brooks Range during the 2013 ablation period. Station elevations (in meters) are listed in the legend.

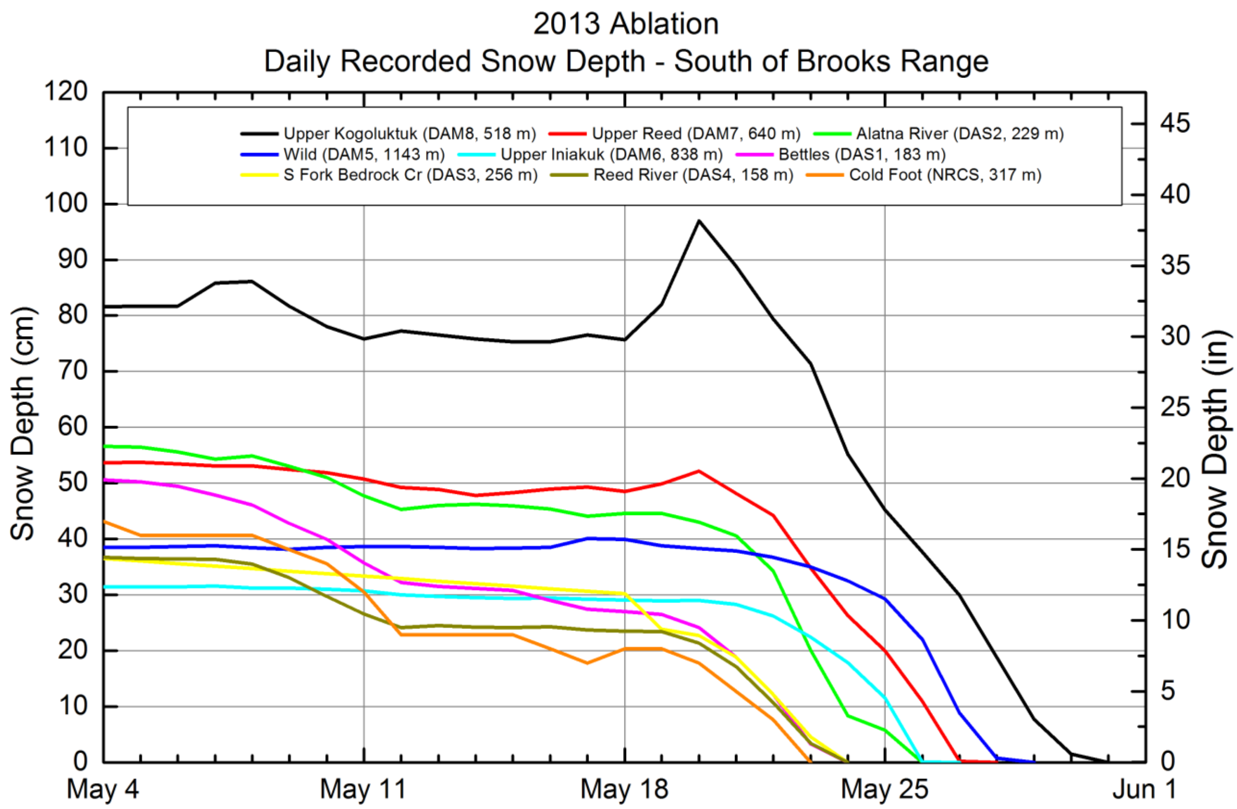


Figure 43. SR50 daily (hourly averaged) snow depths at the fifteen meteorological stations on the south side of Brooks Range during the 2013 ablation period. Station elevations (in meters) are listed in the legend.

11. SUMMARY

This report describes the snow depth, snow water equivalent (SWE), snow density, and ablation data collected during the winter of 2012 - 2013 in Alaska's Central Arctic, from the Arctic Circle to the Arctic Ocean. These data are used to quantitatively represent winter precipitation (less sublimation) in the region where winter precipitation data are not available. Once combined with snowmelt discharge data, this snow dataset provides a foundation for the modeling of flood frequency and risk analysis at river crossings. Conventional flood frequency analysis (Bulletin 17B, 1982) cannot be easily performed for most of the river crossings along the proposed road corridors because of the limited availability of annual peak streamflow data.

Snow surveys in 2013 were conducted in the watersheds of the Kuparuk, Putuligayuk, Anaktuvuk, Chandler, Itkillik, and western Sagavanirktok Rivers for the Umiat project. Snow data collected south of the Brooks Range were located in the Koyukuk, Alatna, Reed, Mauneluk and Kogoluktuk watersheds. Overall, 133 sites were visited in 2013. This number includes 76 sites located north of the Brooks Range (Umiat project) and 57 sites located south of the Brooks Range (Ambler project). As of 2013, the Kuparuk River watershed has 14 years of repeated end-of-winter snow survey data. The Anaktuvuk and Itkillik River basins have 5 years of repeated snow survey data, 2009–2013. Snow survey observations in the Chandler River basin were initiated in 2010. Snow survey observation in the watersheds south of the Brooks Range divide started in 2013.

Generally, SWE is higher in the western reaches of the study area and most of the SWE accumulates prior to February, both north and south of the Brooks Range. The end-of-winter SWE observed in 2013 accounted for 130% of the 14-year average SWE in the Kuparuk watershed. This was the highest SWE in our record. Shorter records from the Anaktuvuk, Itkillik, and Chandler River watersheds showed similar results; that is, end-of-winter SWE was higher than average. Snowmelt started as early as May 8, 2013, at the southern weather stations located at low elevations (Bettles, S Fork Bedrock, Reed, etc.). Most of the stations indicated the onset of ablation around May 18, 2013 (later than usual). Snow mostly disappeared by June 8, 2013, with two weather stations reporting a snow-free date as late as June 17, 2013.

Discharge measurements at major rivers were conducted during snowmelt. Further information on the stream response to snowmelt is presented in a hydrological report (Kane et al., 2014).

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APPENDIX A. SNOW SURVEY DATA

Appendix A provides lists of snow survey sites with coordinates, elevation, snow water equivalent, average snow depth (from 50 measurements), and average snow density (from 5 measurements). For more information, see Section 3 – Sampling Methods.

Appendix A1. Measured snow survey data for the Umiat Study Area, April 18-24, 2013.

N	Survey Date	ID	ELEV m	LAT dd	LON dd	SWE cm	SWE in	Snow Depth cm	Snow Depth in	Snow Density kg/m^3	Snow Density slug/ft^3	Basin
1	04/22/13	DUS2-Anak	79	69.4645	-151.1690	7.8	3.1	32.8	12.9	238	0.461	Anaktuvuk
2	04/21/13	MTN6	986	68.2814	-151.6606	4.4	1.7	21.8	8.6	202	0.392	Anaktuvuk
3	04/21/13	MTN3	1080	68.3917	-150.4843	17.1	6.7	79.0	31.1	216	0.420	Anaktuvuk
4	04/20/13	GUN3	447	68.7142	-151.2321	10.6	4.2	46.0	18.1	230	0.447	Anaktuvuk
5	04/20/13	GUN4-Tul	497	68.8041	-151.5460	18.3	7.2	69.1	27.2	265	0.514	Anaktuvuk
6	04/20/13	GUN2-Nan	540	68.7207	-150.5030	13.1	5.2	57.0	22.4	230	0.446	Anaktuvuk
7	04/21/13	TLK2	824	68.4587	-150.8559	17.8	7.0	85.8	33.8	207	0.402	Anaktuvuk
8	04/21/13	TLK4	835	68.4503	-151.5571	22.7	8.9	82.9	32.6	274	0.531	Anaktuvuk
9	04/21/13	TLK1	1000	68.5269	-150.1483	14.0	5.5	60.8	23.9	230	0.447	Anaktuvuk
10	04/21/13	ANA2	595	68.3158	-151.4967	1.5	0.6	9.6	3.8	156	0.303	Anaktuvuk
11	04/21/13	MTN1	1096	68.3852	-150.1521	10.7	4.2	52.8	20.8	203	0.393	Anaktuvuk
12	04/21/13	MTN5-Itikm	1168	68.2901	-151.1150	10.1	4.0	44.1	17.4	229	0.444	Anaktuvuk
13	04/21/13	MTN4	1179	68.2972	-150.8125	16.9	6.7	73.8	29.1	229	0.444	Anaktuvuk
14	04/21/13	MTN2-May	1378	68.3985	-150.2277	4.9	1.9	22.1	8.7	222	0.430	Anaktuvuk
Average						12.1	4.8	52.7	20.7	224	0.434	
1	04/19/13	CHA8	271	68.9303	-152.0723	12.8	5.0	60.3	23.7	212	0.412	Chandler
2	04/19/13	CHA5	300	69.0840	-152.1394	18.1	7.1	70.9	27.9	255	0.495	Chandler
3	04/19/13	CHA6-Sik	463	68.6301	-152.1022	16.8	6.6	70.1	27.6	240	0.465	Chandler
4	04/19/13	CHA4-Hat	624	68.7543	-152.5730	25.2	9.9	87.2	34.3	289	0.561	Chandler
5	04/19/13	CHA7	683	68.4301	-152.2715	9.5	3.7	37.4	14.7	254	0.493	Chandler
6	04/19/13	CHA3	843	68.4990	-152.9805	14.2	5.6	48.1	18.9	295	0.573	Chandler
7	04/19/13	CHA2-Whi	1081	68.3629	-152.7067	16.3	6.4	66.5	26.2	245	0.476	Chandler
8	04/19/13	CHA1-Enc	1224	68.2865	-152.1318	8.1	3.2	37.7	14.8	215	0.417	Chandler
9	04/20/13	DUS3-Chandle	105	69.2604	-151.3964	7.5	3.0	36.6	14.4	205	0.398	Chandler
Average						14.3	5.6	57.2	22.5	246	0.476	
1	04/22/13	ITK1	436	68.8196	-149.9762	12.3	4.8	67.6	26.6	182	0.353	Itkillik
2	04/21/13	ITK2	635	68.4170	-149.9472	8.6	3.4	39.8	15.7	216	0.419	Itkillik
3	04/18/13	SWB1	243	69.1233	-150.5890	12.9	5.1	58.7	23.1	220	0.426	Itkillik
4	04/24/13	DUS1-U.Itk	458	68.8665	-150.0400	5.1	5.6	31.1	25.9	164	0.318	Itkillik
5	04/20/13	DUS4-L.Itkillik	115	69.4386	-150.6879	9.0	3.5	39.1	15.4	230	0.447	Itkillik
Average						9.6	4.5	47.3	21.3	202	0.393	
1	04/20/13	WestDock	5	70.3602	-148.5697	8.4	3.3	34.0	13.4	247	0.479	Kuparuk
2	04/22/13	FB05	42	70.0113	-149.2829	8.4	3.3	33.0	13.0	255	0.494	Kuparuk
3	04/22/13	FB03	58	69.9316	-149.1563	15.3	6.0	51.8	20.4	295	0.573	Kuparuk
4	04/18/13	DFM3-NWH	84	69.7149	-149.4705	10.4	4.1	34.4	13.5	302	0.587	Kuparuk
5	04/18/18	H05	90	69.8000	150.3838	10.3	4.1	38.5	15.2	268	0.519	Kuparuk
6	04/18/13	H01	113	69.5687	-150.4478	8.8	3.5	44.9	17.7	196	0.380	Kuparuk
7	04/18/13	DFM4-NWKup	124	69.9475	-149.9169	10.7	4.2	38.4	15.1	279	0.541	Kuparuk
8	04/18/13	H02	172	69.8020	-150.3838	10.0	3.9	41.2	16.2	243	0.471	Kuparuk
9	04/22/13	WKmet	159	69.4259	-150.3417	12.3	4.8	53.9	21.2	228	0.443	Kuparuk
10	04/18/13	WK10	214	69.6173	-149.3839	13.4	5.3	49.9	19.6	269	0.521	Kuparuk
11	04/22/13	HV6	218	69.2748	-150.0869	11.7	4.6	50.6	19.9	231	0.449	Kuparuk
12	04/22/13	WK01	218	69.4265	-148.8722	7.1	2.8	41.6	16.4	171	0.331	Kuparuk
13	04/21/13	Sagwon	275	69.4247	-148.6950	5.2	2.0	26.6	10.5	195	0.379	Kuparuk
14	04/18/13	DFM1	293	69.2034	-149.5611	15.0	5.9	56.4	22.2	266	0.516	Kuparuk
15	04/22/13	DFM2	337	69.4865	-149.8214	1.2	0.5	3.5	1.4	343	0.665	Kuparuk
16	04/18/12	HV1	365	69.1682	-149.1548	17.5	6.9	71.3	28.1	245	0.476	Kuparuk

Appendix A1 continued.

N	Survey Date	ID	ELEV m	LAT dd	LON dd	SWE cm	SWE in	Snow Depth cm	Snow Depth in	Snow Density kg/m^3	Snow Density slug/ft^3	Basin
17	04/22/13	SM05	568	68.8565	-149.7332	14.2	5.6	64.4	25.4	220	0.428	Kuparuk
18	04/22/13	SM03	651	68.8122	-149.2838	14.7	5.8	65.0	25.6	226	0.439	Kuparuk
19	04/22/13	UKmet	778	68.6374	-149.4039	14.3	5.6	65.7	25.9	218	0.422	Kuparuk
20	04/22/13	UK12-NH	904	68.6021	-149.4305	13.9	5.5	48.8	19.2	285	0.553	Kuparuk
21	04/22/13	UK04-GCL	908	68.5335	-149.2310	10.3	4.1	46.8	18.4	220	0.427	Kuparuk
22	04/22/13	UK01-EH	912	68.5849	-149.3063	11.4	4.5	50.8	20.0	224	0.435	Kuparuk
23	04/23/13	UK08-UH	968	68.5222	-149.3380	11.9	4.7	40.1	15.8	297	0.576	Kuparuk
24	04/23/13	UK14-WH	1027	68.5638	-149.4108	15.6	6.1	59.4	23.4	263	0.509	Kuparuk
Average						11.3	4.5	46.3	18.2	249	0.484	
1	04/20/13	P01	12	70.2955	-148.9373	7.2	2.8	26.4	10.4	273	0.529	Putuligayuk
2	04/20/13	P04	12	70.2601	-148.8211	8.6	3.4	39.0	15.4	221	0.428	Putuligayuk
3	04/20/13	P06	12	70.2604	-148.6715	3.5	1.4	21.3	8.4	164	0.319	Putuligayuk
4	04/20/13	P07	12	70.2566	-148.7160	8.5	3.3	36.1	14.2	235	0.457	Putuligayuk
5	04/20/13	P08	12	70.2486	-148.6041	7.1	2.8	35.2	13.9	202	0.391	Putuligayuk
6	04/20/13	P05	15	70.2532	-148.7716	7.3	2.9	33.1	13.0	221	0.428	Putuligayuk
7	04/20/13	P03-Betty	30	70.2806	-148.8961	9.3	3.7	39.0	15.4	238	0.463	Putuligayuk
8	04/22/13	WK04	203	69.4269	-149.4609	5.5	2.2	28.6	11.3	192	0.373	Putuligayuk
Average						7.1	2.8	32.3	12.8	218	0.423	
1	04/22/13	FB09	34	70.0710	-148.8780	7.9	3.1	27.0	10.6	293	0.568	Sagavanirktok
2	04/19/13	MI1	48	70.0032	-148.6792	8.3	3.3	30.9	12.2	269	0.521	Sagavanirktok
3	04/19/13	MI2	60	69.9336	-148.7677	5.8	2.3	29.6	11.7	196	0.380	Sagavanirktok
4	04/22/13	FranklinBluffs	71	69.8886	-148.7747	7.2	2.8	32.4	12.8	222	0.431	Sagavanirktok
5	04/19/13	MI3	90	69.7950	-148.7361	10.9	4.3	39.1	15.4	279	0.541	Sagavanirktok
6	04/19/13	MI4	90	69.7130	-148.7165	6.0	2.4	24.1	9.5	249	0.483	Sagavanirktok
7	04/19/13	MI5	140	69.6050	-148.6487	7.9	3.1	39.3	15.5	201	0.390	Sagavanirktok
8	04/19/13	MI7	175	69.4887	-148.5678	10.5	4.1	34.8	13.7	302	0.585	Sagavanirktok
9	04/19/13	MI6	179	69.5344	-148.5990	16.9	6.7	59.9	23.6	282	0.547	Sagavanirktok
10	04/18/12	HappyValley	314	69.1519	-148.8389	20.0	7.9	77.8	30.6	257	0.499	Sagavanirktok
11	04/18/12	OilSpill	440	68.9424	-148.8660	13.2	5.2	56.8	22.4	232	0.451	Sagavanirktok
12	04/21/13	SAG1	678	68.4150	-148.9600	5.8	2.3	28.3	11.1	205	0.398	Sagavanirktok
13	04/21/13	SAG3	830	68.4462	-148.7042	9.2	3.6	45.4	17.9	203	0.393	Sagavanirktok
14	04/21/13	Galbraith	831	68.4780	-148.5030	11.7	4.6	52.8	20.8	222	0.430	Sagavanirktok
15	04/21/13	SAG2	868	68.2597	-148.8256	9.9	3.9	48.8	19.2	203	0.394	Sagavanirktok
16	04/21/13	DBM1-AccCr	1474	68.4116	-148.1365	16.6	6.5	65.5	25.8	253	0.492	Sagavanirktok
Average						10.5	4.1	43.3	17.0	242	0.469	

Appendix A2. Adjustment of the snow water equivalent for the Umiat Study Area, spring 2013.

N	ID	ELEV m	LAT	LON	SWE		SWE	Final SWE		Basin
			dd	dd	cm	in	Adjustment	cm	in	
1	DUS2-Anak	79	69.4645	-151.1690	7.8	3.1	2.9	10.7	4.2	Anaktuvuk
2	MTN6	986	68.2814	-151.6606	4.4	1.7	1.3	5.7	2.2	Anaktuvuk
3	MTN3	1080	68.3917	-150.4843	17.1	6.7	2.7	19.8	7.8	Anaktuvuk
4	GUN3	447	68.7142	-151.2321	10.6	4.2	3.1	13.7	5.4	Anaktuvuk
5	GUN4-Tul	497	68.8041	-151.5460	18.3	7.2	3.1	21.4	8.4	Anaktuvuk
6	GUN2-Nan	540	68.7207	-150.5030	13.1	5.2	3.5	16.6	6.5	Anaktuvuk
7	TLK2	824	68.4587	-150.8559	17.8	7.0	3.5	21.3	8.4	Anaktuvuk
8	TLK4	835	68.4503	-151.5571	22.7	8.9	3.1	25.8	10.2	Anaktuvuk
9	TLK1	1000	68.5269	-150.1483	14.0	5.5	3.5	17.5	6.9	Anaktuvuk
10	ANA2	595	68.3158	-151.4967	1.5	0.6	9.4	10.9	4.3	Anaktuvuk
11	MTN1	1096	68.3852	-150.1521	10.7	4.2	2.7	13.4	5.3	Anaktuvuk
12	MTN5-Itikm	1168	68.2901	-151.1150	10.1	4.0	2.8	12.9	5.1	Anaktuvuk
13	MTN4	1179	68.2972	-150.8125	16.9	6.7	2.8	19.7	7.8	Anaktuvuk
14	MTN2-May	1378	68.3985	-150.2277	4.9	1.9	2.7	7.6	3.0	Anaktuvuk
Average					12.1	4.8	3.4	15.5	6.1	
1	CHA8	271	68.9303	-152.0723	12.8	5.0	3.1	15.9	6.3	Chandler
2	CHA5	300	69.0840	-152.1394	18.1	7.1	0.0	18.1	7.1	Chandler
3	CHA6-Sik	463	68.6301	-152.1022	16.8	6.6	1.7	18.5	7.3	Chandler
4	CHA4-Hat	624	68.7543	-152.5730	25.2	9.9	1.9	27.1	10.6	Chandler
5	CHA7	683	68.4301	-152.2715	9.5	3.7	0.0	9.5	3.7	Chandler
6	CHA3	843	68.4990	-152.9805	14.2	5.6	0.0	14.2	5.6	Chandler
7	CHA2-Whi	1081	68.3629	-152.7067	16.3	6.4	0.0	16.3	6.4	Chandler
8	CHA1-Enc	1224	68.2865	-152.1318	8.1	3.2	1.3	9.4	3.7	Chandler
9	DUS3-Chandler	105	69.2604	-151.3964	7.5	3.0	2.9	10.4	4.1	Chandler
Average					14.3	5.6	1.2	15.5	6.1	
1	ITK1	436	68.8196	-149.9762	12.3	4.8	3.5	15.8	6.2	Itkillik
2	ITK2	635	68.4170	-149.9472	8.6	3.4	0.0	8.6	3.4	Itkillik
3	SWB1	243	69.1233	-150.5890	12.9	5.1	3.5	16.4	6.5	Itkillik
4	DUS1-U.Itk	458	68.8665	-150.0400	5.1	5.6	3.8	8.9	3.5	Itkillik
5	DUS4-L.Itkillik	115	69.4386	-150.6879	9.0	3.5	2.9	11.9	4.7	Itkillik
Average					9.6	4.5	2.7	12.3	4.9	
1	WestDock	5	70.3602	-148.5697	8.4	3.3	3.5	11.9	4.7	Kuparuk
2	FB05	42	70.0113	-149.2829	8.4	3.3	2.1	10.5	4.1	Kuparuk
3	FB03	58	69.9316	-149.1563	15.3	6.0	2.1	17.4	6.8	Kuparuk
4	DFM3-NWH	84	69.7149	-149.4705	10.4	4.1	2.5	12.9	5.1	Kuparuk
5	H05	90	69.8000	150.3838	10.3	4.1	2.5	12.8	5.0	Kuparuk
6	H01	113	69.5687	-150.4478	8.8	3.5	2.9	11.7	4.6	Kuparuk
7	DFM4-NWKup	124	69.9475	-149.9169	10.7	4.2	2.0	12.7	5.0	Kuparuk
8	H02	172	69.8020	-150.3838	10.0	3.9	2.0	12.0	4.7	Kuparuk
9	WKmet	159	69.4259	-150.3417	12.3	4.8	2.9	15.2	6.0	Kuparuk
10	WK10	214	69.6173	-149.3839	13.4	5.3	2.5	15.9	6.2	Kuparuk
11	HV6	218	69.2748	-150.0869	11.7	4.6	4.1	15.8	6.2	Kuparuk
12	WK01	218	69.4265	-148.8722	7.1	2.8	3.6	10.7	4.2	Kuparuk
13	Sagwon	275	69.4247	-148.6950	5.2	2.0	3.6	8.8	3.4	Kuparuk
14	DFM1	293	69.2034	-149.5611	15.0	5.9	4.1	19.1	7.5	Kuparuk
15	DFM2	337	69.4865	-149.8214	1.2	0.5	4.1	5.3	2.1	Kuparuk
16	HV1	365	69.1682	-149.1548	17.5	6.9	4.1	21.6	8.5	Kuparuk

Appendix A2 continued.

N	ID	ELEV m	LAT dd	LON dd	SWE cm	SWE in	SWE Adjustment	Final SWE cm	Final SWE in	Basin
17	SM05	568	68.8565	-149.7332	14.2	5.6	3.5	17.7	7.0	Kuparuk
18	SM03	651	68.8122	-149.2838	14.7	5.8	3.5	18.2	7.2	Kuparuk
19	UKmet	778	68.6374	-149.4039	14.3	5.6	3.8	18.1	7.1	Kuparuk
20	UK12-NH	904	68.6021	-149.4305	13.9	5.5	3.8	17.7	7.0	Kuparuk
21	UK04-GCL	908	68.5335	-149.2310	10.3	4.1	3.8	14.1	5.6	Kuparuk
22	UK01-EH	912	68.5849	-149.3063	11.4	4.5	3.8	15.2	6.0	Kuparuk
23	UK08-UH	968	68.5222	-149.3380	11.9	4.7	3.8	15.7	6.2	Kuparuk
24	UK14-WH	1027	68.5638	-149.4108	15.6	6.1	3.8	19.4	7.6	Kuparuk
Average					11.3	4.5	3.3	14.6	5.7	
1	P01	12	70.2955	-148.9373	7.2	2.8	3.5	10.7	4.2	Putuligayuk
2	P04	12	70.2601	-148.8211	8.6	3.4	3.5	12.1	4.8	Putuligayuk
3	P06	12	70.2604	-148.6715	3.5	1.4	3.5	7.0	2.8	Putuligayuk
4	P07	12	70.2566	-148.7160	8.5	3.3	3.5	12.0	4.7	Putuligayuk
5	P08	12	70.2486	-148.6041	7.1	2.8	3.5	10.6	4.2	Putuligayuk
6	P05	15	70.2532	-148.7716	7.3	2.9	3.5	10.8	4.3	Putuligayuk
7	P03-Betty	30	70.2806	-148.8961	9.3	3.7	3.5	12.8	5.1	Putuligayuk
8	WK04	203	69.4269	-149.4609	5.5	2.2	4.1	9.6	3.8	Putuligayuk
Average					7.1	2.8	3.6	10.7	4.2	
1	FB09	34	70.0710	-148.8780	7.9	3.1	2.1	10.0	3.9	Sagavanirktok
2	MI1	48	70.0032	-148.6792	8.3	3.3	3.2	11.5	4.5	Sagavanirktok
3	MI2	60	69.9336	-148.7677	5.8	2.3	3.2	9.0	3.5	Sagavanirktok
4	FranklinBluffs	71	69.8886	-148.7747	7.2	2.8	2.1	9.3	3.7	Sagavanirktok
5	MI3	90	69.7950	-148.7361	10.9	4.3	3.2	14.1	5.5	Sagavanirktok
6	MI4	90	69.7130	-148.7165	6.0	2.4	3.2	9.2	3.6	Sagavanirktok
7	MI5	140	69.6050	-148.6487	7.9	3.1	3.6	11.5	4.5	Sagavanirktok
8	MI7	175	69.4887	-148.5678	10.5	4.1	3.6	14.1	5.5	Sagavanirktok
9	MI6	179	69.5344	-148.5990	16.9	6.7	3.6	20.5	8.1	Sagavanirktok
10	HappyValley	314	69.1519	-148.8389	20.0	7.9	4.1	24.1	9.5	Sagavanirktok
11	OilSpill	440	68.9424	-148.8660	13.2	5.2	4.1	17.3	6.8	Sagavanirktok
12	SAG1	678	68.4150	-148.9600	5.8	2.3	0.0	5.8	2.3	Sagavanirktok
13	SAG3	830	68.4462	-148.7042	9.2	3.6	0.0	9.2	3.6	Sagavanirktok
14	Galbraith	831	68.4780	-148.5030	11.7	4.6	0.0	11.7	4.6	Sagavanirktok
15	SAG2	868	68.2597	-148.8256	9.9	3.9	0.0	9.9	3.9	Sagavanirktok
16	DBM1-AccCr	1474	68.4116	-148.1365	16.6	6.5	7.5	24.1	9.5	Sagavanirktok
Average					10.5	4.1	2.7	13.2	5.2	

Appendix A3. Measured Snow Survey Data for the Ambler Study Area, April 3-9, 2013.

N	Survey Date	ID	ELEV m	LAT	LON	SWE		Snow Depth		Snow Density		Basin
				dd	dd	cm	in	cm	in	kg/m^3		
1	04/03/13	ALAT1	335	67.5623	-154.1389	6.8	2.7	43.5	17.1	160	0.310	Alatna
2	04/07/13	ALAT2	792	67.3433	-154.4033	34.8	13.7	109.1	43.0	320	0.621	Alatna
3	04/07/13	ALAT3	981	67.4330	-153.9595	28.3	11.1	92.9	36.6	300	0.582	Alatna
4	04/07/13	DAS2-ALATNA	229	67.0220	-153.3020	9.6	3.8	50.5	19.9	190	0.369	Alatna
5	04/08/13	ALAT9	701	67.1743	-153.3821	18.0	7.1	78.1	30.7	230	0.446	Alatna
6	04/07/13	ALAT10	235	67.3483	-153.5318	12.5	4.9	61.7	24.3	200	0.388	Alatna
7	04/08/13	DAM6-UPPER INI	838	67.3341	-153.1354	13.4	5.3	55.6	21.9	240	0.466	Alatna
8	04/07/13	ALAT_SOUTH01	332	66.9122	-153.7448	13.3	5.2	60.5	23.8	220	0.427	Alatna
9	04/07/13	S2	280	66.8330	-154.2696	11.7	4.6	57.7	22.7	200	0.388	Alatna
10	04/03/13	ALAT5 RAM CREE	1219	67.6245	-154.3458	4.4	1.8	16.0	6.3	270	0.679	Alatna
11	04/03/13	ALAT6	634	67.7230	-154.9814	3.4	1.3	20.9	8.2	160	0.310	Alatna
12	04/03/13	ALAT7	975	67.7575	-154.0215	9.6	3.8	36.8	14.5	260	0.504	Alatna
13	04/03/13	ALAT8	579	67.7616	-153.9825	2.9	1.1	18.8	7.4	150	0.291	Alatna
14	04/10/13	DAS3-SFORKBEDR	198	67.0953	-152.7240	12.7	5.0	64.7	25.5	196	0.380	Alatna
15	04/03/13	ALAT4	1189	67.4846	-153.4039	5.3	2.1	23.3	9.2	230	0.446	Alatna
Average						12.4	4.9	52.7	20.7	222	0.441	
1	04/04/13	KOGO2	900	67.2993	-156.3531	17.9	7.0	47.1	18.5	380	0.737	Kogoluktuk
2	04/04/13	KOGO3	282	67.3573	-156.3370	16.3	6.4	70.7	27.8	230	0.446	Kogoluktuk
3	04/04/13	KOGO4	129	67.2840	-156.2110	10.0	3.9	51.9	20.4	190	0.369	Kogoluktuk
4	04/04/13	DAM8-UPPER KO	518	67.3071	-156.2446	19.0	7.5	74.2	29.2	260	0.504	Koguluktuk
5	04/04/13	KOGO5TUNDRA	134	67.1021	-156.4432	1.8	0.7	15.7	6.2	110	0.213	Kogoluktuk
6	04/04/13	KOGO5TREES	134	67.1021	-156.4432	5.9	2.3	33.4	13.1	180	0.349	Kogoluktuk
7	04/04/13	KOGOCROSSING	87	67.0125	-156.6914	6.2	2.4	36.2	14.3	170	0.330	Kogoluktuk
Average						11.0	4.3	47.0	18.5	217	0.421	
1	04/06/13	REED2	1097	67.4125	-155.1232	27.8	12.5	88.5	34.8	314	0.679	Reed
2	04/06/13	REED1	457	67.3659	-155.0852	11.2	4.4	41.9	16.5	270	0.524	Reed
3	04/06/13	REED3	183	67.2676	-155.0656	12.5	4.9	60.1	23.7	210	0.407	Reed
4	04/06/13	DAM7-UPPER REE	640	67.1853	-154.9361	20.3	8.0	84.3	33.2	240	0.466	Reed
5	04/06/13	REED4	168	67.1872	-154.8484	12.9	5.1	63.0	24.8	210	0.407	Reed
6	04/07/13	DAS4_REED	158	66.9973	-154.8192	13.6	5.4	57.1	22.5	240	0.466	Reed
Average						16.4	6.71	65.8	25.9	247	0.491	
1	04/05/13	NFK5	1006	67.9724	-150.8868	7.4	2.9	37.7	14.8	200	0.388	Koyukuk
2	04/05/13	NFK9	640	67.9736	-150.8429	1.5	0.6	11.0	4.3	140	0.272	Koyukuk
3	04/05/13	NFK4	1250	68.0730	-150.7257	9.3	3.7	40.7	16.0	230	0.446	Koyukuk
4	04/05/13	NFK3	1006	67.5662	-150.6684	10.4	4.1	60.1	23.7	170	0.330	Koyukuk
5	04/05/13	NFK2	422	67.4806	-150.7973	7.6	3.0	43.4	17.1	170	0.330	Koyukuk
6	04/05/13	NFK6	762	67.3925	-150.7003	13.8	5.4	58.2	22.9	240	0.466	Koyukuk
7	04/08/13	NFK7	975	67.8351	-151.4221	8.8	3.5	51.0	20.1	170	0.330	Koyukuk
8	04/08/13	NFK8	457	67.6538	-151.3669	5.0	2.0	34.0	13.4	150	0.291	Koyukuk
9	04/05/13	NFK1	253	67.1522	-150.7640	3.7	1.5	26.1	10.3	140	0.272	Koyukuk
10	04/05/13	JOHN7	358	67.5357	-151.8476	2.5	2.5	39.3	15.5	160	0.310	Koyukuk
11	04/05/13	JOHN1	305	67.6114	-152.4497	5.2	2.0	34.5	13.6	150	0.291	Koyukuk
12	04/05/13	JOHN6	250	67.5444	-152.2218	6.5	2.6	42.6	16.8	150	0.291	Koyukuk
13	04/05/13	JOHN8	366	67.3676	-152.3676	6.8	2.7	40.4	15.9	170	0.330	Koyukuk

Appendix A3 continued.

N	Survey Date	ID	ELEV m	LAT dd	LON dd	SWE cm	SWE in	Snow Depth cm	Snow Depth in	Snow Density kg/m^3		Basin
14	04/05/13	JOHN9	233	67.0913	-151.8771	4.6	1.8	38.6	15.2	120	0.233	Koyukuk
15	04/08/13	JOHN3	1158	67.7159	-153.0833	12.7	5.0	54.6	21.5	230	0.446	Koyukuk
16	04/08/13	JOHN4	1481	68.0006	-152.7231	8.9	3.5	31.5	12.4	280	0.543	Koyukuk
17	04/08/13	JOHN5	762	67.9919	-152.7231	1.6	0.6	6.4	2.5	260	0.504	Koyukuk
18	04/08/13	JOHN2-PAM. LAK	975	67.7644	-152.1636	4.0	1.6	16.7	6.6	240	0.466	Koyukuk
19	04/09/13	DAS1-BTT-MET	137	66.9140	-151.5360	11.7	4.6	62.2	24.5	190	0.369	Koyukuk
20	04/05/13	CHIMNEY MTN	1161	67.7142	-150.5850	4.6	1.8	21.6	8.5	210	0.407	Koyukuk
21	04/17/13	SUKAPAK	439	67.5991	-149.7814	6.3	2.5	45.4	17.9	139	0.270	Koyukuk
22	04/17/13	COLDFOOT	317	67.2532	-150.1826	10.1	4.0	58.6	23.1	172	0.334	Koyukuk
23	04/17/13	JIM RIVER DOT	335	67.0871	-150.3660	11.4	4.5	64.6	25.4	177	0.343	Koyukuk
24	04/17/13	UPPER DEITRICH	777	68.0342	-149.6574	5.5	2.2	23.6	9.3	233	0.452	Koyukuk
Average						7.1	2.8	39.3	15.5	187	0.363	
1	04/04/13	MAUN2	792	67.1597	-156.0287	30.7	12.1	113.4	44.6	270	0.524	Mauneluk
2	04/06/13	MAUN1	91	67.0134	-156.0618	4.2	1.7	22.1	8.7	190	0.369	Mauneluk
3	04/06/13	BEAVER1	330	66.9939	-155.3787	5.4	2.1	64.2	25.3	210	0.407	Beaver
4	04/04/13	BEAVER2	715	67.1682	-155.2424	30.6	12.0	119.3	47.0	260	0.504	Beaver
5	04/07/13	KOB1	305	67.0552	-153.7673	10.9	4.3	54.8	21.6	200	0.388	Kobuk

Appendix A4. Adjustment of the snow water equivalent data for the Ambler Study Area, spring 2013.

N	ID	ELEV m	LAT dd	LON dd	SWE cm	SWE in	SWE Adjustm	Final SWE cm	Final SWE in	Basin
1	ALAT1	335	67.5623	-154.1389	6.8	2.7	0.4	7.2	2.9	Alatna
2	ALAT2	792	67.3433	-154.4033	34.8	13.7	0.4	35.2	13.9	Alatna
3	ALAT3	981	67.4330	-153.9595	28.3	11.1	0.0	28.3	11.1	Alatna
4	DAS2-ALATNA	229	67.0220	-153.3020	9.6	3.8	1.2	10.8	4.2	Alatna
5	ALAT9	701	67.1743	-153.3821	18.0	7.1	0.0	18.0	7.1	Alatna
6	ALAT10	235	67.3483	-153.5318	12.5	4.9	0.0	12.5	4.9	Alatna
7	DAM6-UPPER INI	838	67.3341	-153.1354	13.4	5.3	0.0	13.4	5.3	Alatna
8	ALAT_SOUTH01	332	66.9122	-153.7448	13.3	5.2	1.2	14.5	5.7	Alatna
9	S2	280	66.8330	-154.2696	11.7	4.6	0.6	12.3	4.8	Alatna
10	ALAT5 RAM CREEK	1219	67.6245	-154.3458	4.4	1.8	0.4	4.8	1.9	Alatna
11	ALAT6	634	67.7230	-154.9814	3.4	1.3	0.4	3.8	1.5	Alatna
12	ALAT7	975	67.7575	-154.0215	9.6	3.8	0.4	10.0	4.0	Alatna
13	ALAT8	579	67.7616	-153.9825	2.9	1.1	0.4	3.3	1.3	Alatna
14	DAS3-SFORKBEDROCK	198	67.0953	-152.7240	12.7	5.0	0.0	12.7	5.0	Alatna
15	ALAT4	1189	67.4846	-153.4039	5.3	2.1	0.0	5.3	2.1	Alatna
	Average				12.4	4.9	0.4	12.8	5.0	
1	KOGO2	900	67.2993	-156.3531	17.9	7.0	4.5	22.4	8.8	Kogoluktuk
2	KOGO3	282	67.3573	-156.3370	16.3	6.4	4.5	20.8	8.2	Kogoluktuk
3	KOGO4	129	67.2840	-156.2110	10.0	3.9	4.5	14.5	5.7	Kogoluktuk
4	DAM8-UPPER KOGO	518	67.3071	-156.2446	19.0	7.5	4.5	23.5	9.3	Koguluktuk
5	KOGO5TUNDRA	134	67.1021	-156.4432	1.8	0.7	0.6	2.4	0.9	Kogoluktuk
6	KOGO5TREES	134	67.1021	-156.4432	5.9	2.3	0.6	6.5	2.6	Kogoluktuk
7	KOGOCROSSING	87	67.0125	-156.6914	6.2	2.4	0.6	6.8	2.7	Kogoluktuk
	Average				11.0	4.3	2.8	13.9	5.5	
1	REED2	1097	67.4125	-155.1232	27.8	12.5	0.4	28.2	11.1	Reed
2	REED1	457	67.3659	-155.0852	11.2	4.4	0.4	11.6	4.6	Reed
3	REED3	183	67.2676	-155.0656	12.5	4.9	0.4	12.9	5.1	Reed
4	DAM7-UPPER REED	640	67.1853	-154.9361	20.3	8.0	0.4	20.7	8.2	Reed
5	REED4	168	67.1872	-154.8484	12.9	5.1	0.6	13.5	5.3	Reed
6	DAS4_REED	158	66.9973	-154.8192	13.6	5.4	0.6	14.2	5.6	Reed
	Average				16.4	6.71	0.5	16.9	6.6	
1	NFK5	1006	67.9724	-150.8868	7.4	2.9	0.7	8.1	3.2	Koyukuk
2	NFK9	640	67.9736	-150.8429	1.5	0.6	0.7	2.2	0.9	Koyukuk
3	NFK4	1250	68.0730	-150.7257	9.3	3.7	0.7	10.0	3.9	Koyukuk
4	NFK3	1006	67.5662	-150.6684	10.4	4.1	1.0	11.4	4.5	Koyukuk
5	NFK2	422	67.4806	-150.7973	7.6	3.0	1.0	8.6	3.4	Koyukuk
6	NFK6	762	67.3925	-150.7003	13.8	5.4	1.0	14.8	5.8	Koyukuk
7	NFK7	975	67.8351	-151.4221	8.8	3.5	1.4	10.2	4.0	Koyukuk
8	NFK8	457	67.6538	-151.3669	5.0	2.0	1.4	6.4	2.5	Koyukuk
9	NFK1	253	67.1522	-150.7640	3.7	1.5	1.0	4.7	1.9	Koyukuk
10	JOHN7	358	67.5357	-151.8476	6.3	2.5	1.4	7.7	3.0	Koyukuk
11	JOHN1	305	67.6114	-152.4497	5.2	2.0	0.0	5.2	2.0	Koyukuk
12	JOHN6	250	67.5444	-152.2218	6.5	2.6	1.4	7.9	3.1	Koyukuk
13	JOHN8	366	67.3676	-152.3676	6.8	2.7	1.4	8.2	3.2	Koyukuk

Appendix A4 continued.

N	ID	ELEV m	LAT dd	LON dd	SWE cm	SWE in	SWE Adjustm	Final SWE cm	Final SWE in	Basin
14	JOHN9	233	67.0913	-151.8771	4.6	1.8	1.8	6.4	2.5	Koyukuk
15	JOHN3	1158	67.7159	-153.0833	12.7	5.0	0.0	12.7	5.0	Koyukuk
16	JOHN4	1481	68.0006	-152.7231	8.9	3.5	1.4	10.3	4.0	Koyukuk
17	JOHN5	762	67.9919	-152.7231	1.6	0.6	1.4	3.0	1.2	Koyukuk
18	JOHN2-PAM. LAKE	975	67.7644	-152.1636	4.0	1.6	0.0	4.0	1.6	Koyukuk
19	DAS1-BTT-MET	137	66.9140	-151.5360	11.7	4.6	1.8	13.5	5.3	Koyukuk
20	CHIMNEY MTN	1161	67.7142	-150.5850	4.6	1.8	0.0	4.6	1.8	Koyukuk
21	SUKAPAK	439	67.5991	-149.7814	6.3	2.5	0.0	6.3	2.5	Koyukuk
22	COLDFOOT	317	67.2532	-150.1826	10.1	4.0	1.0	11.1	4.4	Koyukuk
23	JIM RIVER DOT	335	67.0871	-150.3660	11.4	4.5	1.0	12.4	4.9	Koyukuk
24	UPPER DEITRICH	777	68.0342	-149.6574	5.5	2.2	0.7	6.2	2.4	Koyukuk
	Average				7.2	2.8	0.9	8.2	3.2	
1	MAUN2	792	67.1597	-156.0287	30.7	12.1	4.5	35.2	12.1	Mauneluk
2	MAUN1	91	67.0134	-156.0618	4.2	1.7	0.6	4.8	1.7	Mauneluk
3	BEAVER1	330	66.9939	-155.3787	5.4	2.1	0.6	6.0	2.1	Beaver
4	BEAVER2	715	67.1682	-155.2424	30.6	12.0	0.4	31.0	12.0	Beaver
5	KOB1	305	67.0552	-153.7673	10.9	4.3	1.2	12.1	4.3	Kobuk

APPENDIX B. ABLATION DATA

Appendix B1a. Snow water equivalent (cm) in the Imnavait Creek basin 85-99 (basin average).

Month and Day	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99
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															
8-May	10.6									1.7	5.3				
9-May	10.3		10	6.9		9.9	1.1								
10-May	9.7		8.8	5.1			0.3			1.3	1.3				
11-May	7.9		8.6	4.8			0.2								
12-May			7.6	1.9		7.8	0.14								
13-May	8.1		7.4	0.4		6.9	0.12		10.1				12.5		6.9
14-May	7.5		7.5	0.0		6.5	0.06			0.1			10.5		5.7
15-May				0.0		4.9	0						11.0	9.5	5.1
16-May			7.7			3.6				0	0		7.3	8.7	3.9
17-May			7.5		13	1.8			5.8			10.1	5.8	6.5	3.6
18-May	8.0		6.9			1.1			0.7				5.3	6.2	3.2
19-May	7.3		5.2		12.3	0.4			0.1				4.5	4.2	2.2
20-May	6.9		3.9		12.0	0.02			0.0			10.2	3.7	1.5	1.1
21-May	6.2		2.6		12.0	0.0							2.8	1.5	0.6
22-May	6.2		1		11.4								2.2	0.1	0.4
23-May	5.7		0.2		10.7							10.2	1.9	0.0	
24-May	4.4		0.0		10.5			15.3				9.0	1.4		
25-May	1.8				9.3							6.6	0.7		
26-May	0.9				8.6			14.6				4.8	0.4		
27-May	0.6	11.4			7.6			13.9				2.6	2.5		
28-May	0.3	11.2			4.5			13.9					2.2		
29-May	0.1	10.2			2.0			14.1				1.6	2.2		
30-May	0.0	10.2			0.0			13.7				0.4	0.8		
31-May		8.9						13.0					0.6		
1-Jun		7.4						10.8				0.0	0.0		
2-Jun		5.1						9.7							
3-Jun		4.1						8.8							
4-Jun		2.3						7.5							
5-Jun		0.3						5.8							

6-Jun		**0.0**						**5.1**							
7-Jun								**5.2**							
8-Jun								**4.0**							
9-Jun								**2.7**							
10-Jun								**1.0**							
11-Jun								**0.0**							

Appendix B1b. Snow water equivalent (cm) in the Imnavait Creek basin 00-13 (basin average).

Month and -Day	00	01	02	03	04	05	06	07	08	09	10	11	12	13
30-Apr														
1-May														
2-May														
3-May														
4-May														
5-May														
6-May														
7-May						12								
8-May														
9-May				15.7	12.0									
10-May				14.4										
11-May				14.9										
12-May				14.3				11.3	8.3					
13-May				14.4		5.7	9.6		8.4					
14-May				14.4	9.3	4.5			8.8					
15-May		13	12.4	15.1	8.2	3.3	6.8	12.4					13.8	
16-May			12.2	15.1	7.8	1.4		11.0	7.7					
17-May			12.6	15.4	6.0	2.1	4.0	11.3	5.9				13.1	
18-May		13	12.1	14.8	4.3		3.4	11.1	4.9	16.9				
19-May	11.2	14	11.2	15.2	2.0	1.8	2.9	10.4	4.3	17.4			12.1	
20-May	10.7		11.1	15.4	2.1	2.1	1.3		2.9	16.1				
21-May	10.2	14	9.3	18.5	1.8	1.0	0.3	9.5	2.6	15.4			10.5	
22-May	9.2		7.0	18.4	1.1	0.9	0.5	9.4	2.8	15.0				
23-May	9.5	14	5.4	16.4	0.2	0.8	0.1	6.7	0.2	12.9			8.6	19.3
24-May	9.3		0.5	15.3	0.0	0.4	0.0	5.0	0.1	12.8				19.0
25-May	8.0	14	0.0	17.1		0.2		3.0	0.0	10.0				18.4
26-May	7.5	13		17.3		0.1		1.8		11.1				17.1
27-May	7.3	12		15.1		0.0		0.9		12.4			3.9	14.9
28-May	6.4	12		15.3				0.2		13.4				13.3
29-May	3.9	12		14.5				0.0		12.6			0.8	11.9
30-May	0.2	9.6		12.8						12.4				11.7
31-May	0.01	4.6		11.4						10.8			0.0	9.6
1-Jun	0.0	6.0		11.7						9.4				9.5

2-Jun		5.9		7.2						6.6				7.0
3-Jun		3.1		3.6						2.3				6.5
4-Jun		2.2		0.4						0.0				6.1
5-Jun		0.8		0.0										5.5
6-Jun		0.2												5.6
7-Jun		0.0												6.9
8-Jun														2.8
9-Jun														1.4
10-Jun														3.0
11-Jun														0.6
12-Jun														0.0

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	12	13
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	19.7	
16-May	1.2			15.3	17.4			8.0	14.2	10.1		14.8	26.2	17.5	
17-May	1.0						9.1	7.8		11.8		12.6	25.3	16.5	
18-May	0.0			15.2	18.1	11.5		6.4	13.0	9.6		12.7	23.6	15.7	
19-May			14		18.7	9.8	7.2	4.5	13	7.2		11.0	21.4	14.2	
20-May		20.5	16			7.7	8.1	1.8		7.5	23.8	12.1	19.9	10.6	
21-May				12.6		9.2	5.5	0.0	11.8	5.6	20.3	13.9	16.6	11.0	25.7
22-May			17				0.3			4.0	16.7	10.0	12.5	8.6	
23-May				5.8		5.9			8.0	0.9		9.4	4.5	5.6	
24-May			17		17.6				5.4	0.0	12.4	7.0	1.1	2.5	24.2
25-May				0	17.9	1.1					9.2	3.2	0	1.4	
26-May			18		17.3	0.5			3.1		10.4	0.5			
27-May			15						0.0					0	21.0

28-May			**13**		**15.2**						**9.2**				
29-May			**15**								**6.2**				**18.1**
30-May			**13.3**		**13.1**										
31-May		**17.2**	**10.1**								**7.8**				**14.1**
1-Jun			**13.7**		**12.3**										
2-Jun		**17**	**9.7**		**10.6**						**7.2**				**13.7**
3-Jun					**7.9**										
4-Jun		**17**	**0**												**6.0**
5-Jun		**16**													
6-Jun		**9.8**													
7-Jun		**4.8**													**6.2**
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**	**12**
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**										**20.7**
17-May									**8.1**				**37.8**	
18-May				**9.6**						**20.0**		**14.9**		**18.9**
19-May		**15.3**				**17.4**		**22.0**						
20-May	**7.4**		**19**	**6.7**			**30.0**					**12.8**	**35.0**	**15.9**
21-May					**17.7**	**14.9**					**27.4**			
22-May	**10**			**0.8**				**14.1**	**7.8**	**16.2**		**14.9**		**9.8**

23-May				**0.0**	**11.1**	**14.7**	**28.6**						**30.7**	
24-May								**13**		**12.6**	**21.0**	**11.1**		**2.0**
25-May					**20.2**	**8.2**			**6.9**					
26-May			**14**				**26.7**	**8.2**		**6.2**	**15.6**	**6.6**	**12.1**	**0**
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	12
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**		**7.0**
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**	**2.1**
21-May		**3.9**												**0.0**			**8.4**	**4.8**					**0**			
22-May													**7.7**								**7.2**	**7.0**		**5.3**		**0**
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**	**12**
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**									**13.0**
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**	**9.8**
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**					**7.9**
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**				**6.1**
29-May											**22.9**	**7.8**						**2.9**							**2.2**	
30-May		**3.4**										**6.9**					**7.3**		**8**		**6.3**	**0**		**9.2**		
31-May					**2.8**							**6.7**		**14.7**			**14.6**							**5.8**		**5.2**
1-Jun		**1.6**										**4.7**			**13.4**			**2.3**	**6**		**5.8**			**5.5**		
2-Jun												**2.9**					**2.6**							**4.1**		**2.0**
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**		**0**
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	12
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	5.5
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							4.0
2-Jun			0				5.7				7.1	1.9			6.4					
3-Jun							4.5		4.1		6.5	1.3	3							2.2
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							0
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 Oil Spill Hill sites.

Day-Month 2010	Atigan Pass	Galbraith Lake	Oil Spill Hill
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			

Appendix B9. 2011 and 2013 snow water equivalent (cm) at the Anaktuvuk River, Chandler River, Upper Itkilik River and Lower Itkillik meteorological sites.

Day-Month 2011	Anaktuvuk River 11	Anaktuvuk River 13	Chandler River11	Chandler River13	Upper Itkilik River11	Upper Itkilik River13	Lower Itkilik River13
30-Apr	8.3	7.8	11.3	7.5		12.3	8.6
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	7.3		8.4	0	14.5	11.5
25-May							9.5
26-May	.1					14.7	8.7
27-May							8.4
28-May						10.4	9.0
29-May							7.1
30-May							3.6
31-May							3.7
1-Jun						3.3	
2-Jun							0.2
3-Jun							

Appendix B10. 2013 snow water equivalent (cm) at the Ambler Road Corridor project meteorological sites.

Day-Month 2013	DAS2 Alatna River 2013	DAS 3 South Fork Bedrock Creek 2013	DAS4 Reed River 2013
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			
16-May			
17-May			
18-May			
19-May	7.1	8.7	10.4
20-May			10.2
21-May			
22-May	3.8		8.4
23-May		3.7	6.6
24-May			