SnowEx23 Mar23 Snow Pit Measurements, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Mason, M., C. Vuyovich, S. Stuefer, K. Elder, D. Vas, H.P. Marshall, and M. Durand. 2024. *SnowEx23 Mar23 Snow Pit Measurements, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/SJZ90KNPKCYR. [Date Accessed].

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FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX23_MAR23_SP

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Summary

The data set presents snow pit measurements collected during the NASA SnowEx March 2023 Intensive Observation Period (IOP) in Alaska, USA. In total, 170 snow pits were excavated between the five sites at locations representing a range of snow depth, vegetation, and topographic conditions. Three study areas represented boreal forest snow near Fairbanks, AK: Farmers Loop Creamers Field (FLCF), Caribou Poker Creek Research Watershed (CPCRW), and Bonanza Creek Experimental Forest (BCEF). Two study areas represented Arctic tundra snow: Arctic Coastal Plain (ACP) and Upper Kuparuk Toolik (UKT).

1.2 Parameters

Available measured parameters are:

- Snow depth
- Snow density
- Snow water equivalent (SWE)
- Liquid water content (LWC)
- Snow temperature
- Snow grain size
- Snow grain type
- Manual wetness
- Layer hardness
- Snow void depth
- Vegetation conditions
- Ground/substrate conditions
- Environmental conditions, including qualitative weather observations

Also available are photos of the field notes and snow pits. Table 1 describes the available measured parameters in more detail.

1.3 File Information

1.3.1 Format

Data can be sorted into four categories: snow pit sheets, individual parameter data, site photographs, and summary data. Snow pit sheets are provided as Microsoft Excel (.xlsx) files. Individual parameter (density, gap-filled density, LWC, site details, stratigraphy, and temperature) data are provided as individual comma-separated value (.csv) files for each snow pit. Snow pit site photographs are provided in

Joint Photographic Experts Group (.jpg) format. Summary (SWE and environment) data are provided as .csv files, and contain summary data for all snow pits across the entire time series.

1.3.2 File Contents

1.3.2.1 Data File Granules

Two multi-file data granules are available for each snow pit: a data granule and a photo granule. The data granule includes the pit sheet and individual parameter (site details, density, gap-filled density, LWC, temperature, and stratigraphy) files. These file types and their content descriptions are summarized in Table 1. The photo granule contains photos of the pit sheet and the site (if available); site photos might include pictures of the snow pit wall, the site from the four cardinal directions, the overhead canopy conditions, and the downward view of pit location.

Table 1. Description of Data File Types

File Type	Contents
Snow pit sheet	File contains all data from the snow pits as an .xlsx.
Site Details	Location, site and pit ID, date/time, UTM coordinates, Latitude, Longitude, height of snow (HS), observers, density cutter/instrument, weather, environment conditions, and comments.
Density	Density (kg/m^3) profiles at 10 cm intervals (e.g. 96-86, 86-76, ... 26-26, 16-6).
gapFilled_Density	Extrapolated and interpolated density (kg/m^3); used to compute SWE in summary file relative to the stratigraphy profile (i.e. snow voids not included when gap filling density at the bottom of the pit).
LWC	Dielectric constant and calculated LWC profiles centered on 10 cm density intervals (e.g. 91, 81, 71, ... 21, 11).
Temperature	Temperature (°C) at surface and 10 cm intervals on even 10s (e.g. 96, 90, 80, … 10, 0).
Stratigraphy	Layer thickness, grain size, grain type, manual wetness, hand hardness, and comments.
Site photos	Photos taken of pit sheets, snow pit wall, the site in four cardinal directions, upwards and downwards in the excavated pit.

1.3.2.2 Summary File Granules

Two summary files are available as separate granules, an Environment file (`SNEX23_MAR23_SP_Summary_Environment_v01.0.csv`) and a SWE file

(`SNEX23_MAR23_SP_Summary_SWE_v01.0.csv`). These files and their content descriptions are summarized in Table 2.

Table 2. Summary File Types

File Type	Contents
Environment	One summary file for all snow pits. Each row contains qualitative observations about potentially impactful environmental conditions, such as precipitation, cloud cover, wind, ground cover characteristics, vegetation type and heights, forest type, and percent canopy cover.
Snow Water Equivalent (SWE)	One summary file for all snow pits. Each row contains the site and snow pit ID, date/time, UTM coordinates, Latitude, Longitude, density A mean (kg/m^3), density B mean (kg/m^3), mean density (kg/m^3), SWE A (mm), SWE B (mm), mean SWE (mm), height of snow (HS), and stratigraphy profile void space (cm) caused by compressed vegetation or air gaps.

Note: Although the summary files apply to all snow pits, metadata constraints require the designation of a point coordinate for the data granules. The two summary files have been geographically assigned the following location: 64.86588º N, 147.72157º W.

1.3.2.3 Technical References

Three supporting files are available to download from the Technical References section of the data set landing page.

Two files represent examples of the snow pit sheets used when collecting and transcribing data. The Pit Sheet Field Form represents a digital version of the pit sheet used in the field. Multiple copies of this file were printed and compiled into spiral bound “pit books”, which were used by field teams to record handwritten snow pit measurements and observations. The Pit Sheet Electronic Form represents a blank template of the .xlsx file into which the handwritten field data was transcribed. These forms were used to transfer data and to generate the summary files and the parameter files for each snow pit.

The March 2023 Snow Pit Revision Log contains a record of all post-processing data cleaning tasks performed outside general nomenclature and transcription error corrections.

Additionally, a Github repository containing all NASA SnowEx snow pit processing scripts is available here. Please refer to the S23 folder for all scripts used in processing the March 2023 snow pit data presented in this data set.

1.3.3 Naming Convention

1.3.3.1 Snow Pit Sheet File Naming Convention

Snow pit sheets are named according to the following convention and as described in Table 3.

```
SNEX23_Mar23_SP_<sitetype>_<yyyymmdd>_<sitename>_[pitID]>_data_pitSheet_ vnn.n.xlsx
```

Table 3. Snow Pit Sheet File Naming Convention

Variable	Description
SNEX23_Mar23_SP	SnowEx March 2023 Pit Measurements
sitetype	Keyword representing the biome for each snow pit site • Forest: Boreal Forest, represents all pits located near Fairbanks, AK • Tundra: Arctic Tundra, represents all pits located on the North Slope, AK
<yyyymmdd>	Date and time of data collection, formatted as 4-digit year, two-digit month, and two-digit day
sitename	Site name abbreviation • ACP: Arctic Coastal Plain • UKT: Upper Kuparuk Toolik • BCEF: Bonanza Creek Experimental Forest • CPCW: Caribou Poker Creek Research Watershed • FLCF: Farmers Loop Creamers Field
pitID	Snow Pit ID code with either of the following formats: • Forest sites: Unique pit ID composed of a 1-letter vegetation class, a 1-letter snow class, and a 3-digit site number • Tundra sites: Unique pit ID composed of a 1-letter snow class and a 3-digit site number
data_pitSheet	Indicates file contains data from a snow pit sheet
v<nn.n>	Indicates version number of the data set
.xlsx	File extension: Microsoft Excel file

The snow pit sheet file name from snow pit DA375 is shown below:

```
SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_pitSheet_v01.0.xlsx
```

1.3.3.2 Individual Parameter File Naming Convention

Individual parameter files are named according to the following convention and as described in Table 4:

```
SNEX23_Mar23_SP_<sitetype>_<yyyymmdd>_<sitename>_[pitID]>_data_<param>_v<nn.n>.csv
```

Table 4. Individual Parameter File Naming Convention

Variable	Description
SNEX23_Mar23_SP	SnowEx March 2023 Pit Measurements
sitetype	Keyword representing the location type for each snow pit site • Forest: Boreal Forest, represents all pits located near Fairbanks, AK • Tundra: Arctic Tundra, represents all pits located on the North Slope, AK
<yyyymmdd>	Date and time of data collection, formatted as 4-digit year, two-digit month, and two-digit day
sitename	Site name abbreviation • ACP: Arctic Coastal Plain • UKT: Upper Kuparuk Toolik • BCEF: Bonanza Creek Experimental Forest • CPCW: Caribou Poker Creek Research Watershed • FLCF: Farmers Loop Creamers Field
pitID	Snow Pit ID code with either of the following formats: • Forest sites: Unique pit ID composed of a 1-letter vegetation class, a 1-letter snow class, and a 3-digit site number • Tundra sites: Unique pit ID composed of a 1-letter snow class and a 3-digit site number
<param>	Parameter contained within the file (see Table 1 for a description of each parameter): • density • gapFilled_Density • LWC • siteDetails • stratigraphy • temperature
V<nn.n>	Indicates version number of the data set
.csv	File extension for comma-separated value file

A complete list of parameter data files from snow pit DA375 is shown below:

- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_density_v01.0.csv
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_gapFilled_Density_v01.0.csv
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_LWC_v01.0.csv
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_siteDetails_v01.0.csv
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_stratigraphy_v01.0.csv
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_data_temperature_v01.0.csv

1.3.3.3 Site Photograph Naming Convention

Site photographs are named according to the following convention and as described in Table 5:

`SNEX23_Mar23_SP_<sitetype>_<yyyymmdd>_<sitename>_[pitID]>_photo_<content>_v<nn.n>.ext`

Table 5. Site Photograph File Naming Convention

Variable	Description
SNEX21_TS_SP	Short for SnowEx21 Time Series Snow Pit Measurements
sitetype	Keyword representing the location type for each snow pit site • Forest: Boreal Forest, represents all pits located near Fairbanks, AK • Tundra: Arctic Tundra, represents all pits located on the North Slope, AK
<yyyymmdd>	Date and time of data collection, formatted as 4-digit year, two-digit month, and two-digit day
sitename	Site name abbreviation • ACP: Arctic Coastal Plain • UKT: Upper Kuparuk Toolik • BCEF: Bonanza Creek Experimental Forest • CPCW: Caribou Poker Creek Research Watershed • FLCF: Farmers Loop Creamers Field
pitID	Snow Pit ID code with either of the following formats: • Forest sites: Unique pit ID composed of a 1-letter vegetation class, a 1-letter snow class, and a 3-digit site number • Tundra sites: Unique pit ID composed of a 1-letter snow class and a 3-digit site number
<content>	Contents of the file: • 00_book: picture of the physical snow pit sheet • 01_oblique: picture of the snow pit at an oblique angle from the SE corner • 02_ north: picture of the snow pit looking north • 03_east: picture of the snow pit looking east • 04_south: picture of the snow pit looking south • 05_west: picture of the snow pit looking west • 06_up: picture of the overhead conditions above the snow pit • 07_down: picture of the downward view of the shop pit • 08_pit1: picture of the snow pit before measurements were taken • 09_pit2: picture of the snow pit after measurements were taken
v<nn.n>	Indicates version number of the data set
ext	File extension • .jpg for photographs 01 to 09 • .pdf for file 00_book

A complete list of site photographs from snow pit DA375 is shown below:

- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_00_book_v01.pdf
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_01_oblique_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_02_north_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_03_east_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_04_south_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_05_west_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_06_up_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_07_down_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_08_pit1_v01.jpg
- SNEX23_MAR23_SP_Forest_20230316_BCEF_DA375_photo_09_pit2_v01.jpg

Note: When accessing these data in NASA Earthdata Search or the NSIDC DAAC Data Access Tool, users can use the wildcard search function to filter the dataset using components of the file or granule name. For example, users could filter data by sitetype (*Forest*), siteID (*BCEF*), or pitID (*DA375*). Searching *Summary* would return only the two Summary data files. Detailed instructions for filtering and accessing data are available for using NASA Earthdata Search and the NSIDC DAAC Data Access Tool.

1.4 Spatial Information

1.4.1 Coverage

Northernmost Latitude: 70.08434° N

Southernmost Latitude: 64.69925° N

Easternmost Longitude: 147.48583° W

Westernmost Longitude: 149.59716° W

1.4.2 Resolution

These data are point observations.

1.4.3 Geolocation

Table 6. Geolocation Details

Geographic coordinate system	WSG 84
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs +type=crs
Reference	https://epsg.io/4326

1.5 Temporal Information

1.5.1 Coverage

07 March 2023 to 16 March 2023

1.5.2 Resolution

Data points were collected one time.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Snow pit measurements were collected during the NASA SnowEx March 2023 Intensive Observation Period to use for calibration and validation with coincident airborne SWESARR and lidar measurements as part of the strategy focused on snow water equivalence (SWE) and snow depth (HS). Snow pits were collected at two sites in the Arctic tundra (ACP, UKT) and three sites in the Boreal Forest (FLCF, CPCRW, and BCEF). Measurements occurred from March 7-16, 2023. In total, 170 snow pits were excavated between the five sites at locations representing the range of snow depth, vegetation, and topographic conditions.

Table 7. Snow Pit Overview

Site Name	Site ID	Site Series No.	Pit Count	Site Lead
Farmer's Loop / Creamer's Field	FLCF	001 – 108	45	Carrie Vuyovich
Caribou Poker Creek Research Watershed	CPCRW	200 – 283	29	Dragos Vas
Bonanza Creek Experimental Forest	BCEF	300 – 482	44	Kelly Elder, Mike Durand
Upper Kuparuk and Toolik-Galbraith	UKT	500 – 566	38	Svetlana Stuefer, HP Marshall
Arctic Coastal Plain	ACP	600 – 810	14	Glen Liston

2.2 Acquisition

Snow pit data were collected according to a standard protocol followed by all field observers. At each site, observers navigated to the point of interest and delineated a study plot (5x5 m). The point of interest was shifted 5 m west of the October 2022 sampling location to not collect data on previously disrupted sites. The snow pit sampling took place in the middle of the study plot where a 1x1 m area was excavated to collect pit measurements. All pit face measurements (density, temperature, stratigraphy, etc.), were taken on the north-facing pit wall. Probing measurements, SnowMicroPen (SMP), SnowScope, and GPR transects, were made to the south, just beyond the pit face measurements (5-20 cm). Snow depths were collected around the study plot perimeter using 1 m spacing for all plots and then complemented by either 1) a spiral with 1-2 m spacing or 2) 20 m length L-shaped transects with 1 m spacing to the north and west of the plot origin, to add spatial information to the snow pit measurements.

Pit measurements were made using a standard snow pit kit, which included 1000 and 250 cc wedge-type and 100 cc box density cutters, a digital scale, pocket microscope and 2mm gridded crystal cards, and digital thermometers. A comprehensive list of instruments is given in Table 8 below.

Table 8. Instruments

Instrument	Brand	Measurement	Specs
Global Positioning System (GPS) field unit	Garmin 64/64st/ GPSMAP 66i, and/or personal cell phones	Latitude, Longitude / Easting, Northing, UTM zone	Horizontal error ±3-10 m in open, ±5-15 m in sparse or dense canopy
Digital Thermometer	Copper-Atkins model DFP450W	Snow temperature profiles	accuracy ±1°C, resolution 0.1°C, 121 mm stem
Snow Liquid Water Content (LWC) Sensor	A2 Photonics WISe	LWC profiles	0-20% range, ±1%
Digital Scale	AD-3000	Snow sample mass for density profiles	3100 g capacity, 1 g resolution, 1 g repeatability
Snow Density sampler, 1000 cc capacity	Snowmetrics RIP 1 – 1000 cc capacity	Snow density profiles	± <3% volume, 10 x 10 x 20 cm wedge-shaped cutter
Snow Density sampler, 250 cc capacity	Snowmetrics RIP 2 – 250 cc capacity	Snow density profiles	± <3% volume, 5 x 10 x 10 cm wedge-shaped cutter
Snow Density sampler, 100 cc capacity	Snow-Hydro	Snow density profiles	±<3% volume, 6 x 5.5 x 3 cm box-shaped cutter
SWE Tube and spring scale, 30 cm	Snowmetrics	Snow depth, SWE	± 2mm 30cm snow tube; ±- 0.3% spring scale
Microscope	RF Interscience Macroscope 25A	Snow crystal type identification and size quantification	30x magnification, 8 mm field of view, graduated reticle with 0.1 mm resolution
Folding ruler	Wiha Tools USA	Height of Snow (HS), stratigraphic boundary heights, layer thickness	2 m fiberglass folding rule, cm and mm graduations

Snow pit crews were composed of two primary observers: one to take measurements and one to record data. A snow pit was excavated with a smooth, north-facing pit wall. The ruler was placed in the snow pit to record the height of snow (HS) and to mark the height of other measurements. Density samples were collected with a blend of instruments depending on conditions. In most cases, conditions were favorable to sample density in 10 cm increments using the 1000 cc wedge cutters from Snowmetrics. Depending on the ground surface roughness or intermittent snow crust layers the 250 cc wedge cutter was utilized to collect measurements near the bottom. In a total of four cases, the 100 cc box cutter from Snow-Hydro was used to sample density in 5 cm intervals, and in six cases a Snowmetrics SWE tube was used instead of a density cutter, where layer density can be calculated by dividing SWE by layer thickness. A snow temperature profile was collected by measuring the shaded snow surface temperature and then repeated at 10 cm intervals on even 10's (e.g. 33, 30, 20, 10, 0 cm). The start and stop time of the temperature profile was also recorded. To measure snow liquid water content, the permittivity was measured with samples centered on the 10 cm density interval using the A2 WISe liquid water content sensor. Stratigraphic layers were marked and described according to multiple characteristics, including: grain type, grain size, hand hardness, and manual wetness, using a set of predetermined options for each characteristic (listed below). Figure 1 below provides a list of the provided options for each characteristic. Any additional observations relevant to stratigraphy were noted as comments for each layer.

Snow Grain Types*

- Surface Hoar (SH)
- Precipitation Particles (PP)
- Decomposing and Fragmented (DF)
- Rounded Grains (RG)
- Faceted Crystals, incl. depth hoar (FC)
- Melt Forms (MF)
- Ice Formations (IF)
- Near-Surface Facets (FCsf)
- Graupel (PPgp)
- Melt-freeze Crust (MFcr)

*Note - This is not a comprehensive list of snow grain classifications. Rather, these options were selected to include a range of likely grain types that would be encountered at the field sites and which were relevant to the remotely sensed data being collected from ground and airborne instruments. Wind-packed crusts are not subcategorized following the sampling protocol. They are classified by the main category, Rounded Grains (RG); users should look at density, hand harness and/or comments to determine wind crusts.

Snow Hand Hardness

- Fist (F)
- 4 Finger (4F)
- 1 Finger (1F)
- Pencil (eraser end) (P)
- Knife (K)
- Ice (I)

Snow Grain Size

- <1 mm
- 1-2 mm
- 2-4 mm
- 4-6 mm
- >6 mm

Snow Manual Wetness

- Dry (D): Will not pack
- Moist (M): Sticks together
- Wet (W): Perfect snowballs
- Very Wet (V): Water can be squeezed out
- Soaked (S): Water drains freely

Figure 1. Key to snow stratigraphy characteristics and options

Lastly, the environmental conditions such as the ground conditions (e.g. frozen/unfrozen), surface roughness, ground and surrounding vegetation/forest types were observed and recorded. Ground vegetation included the presence or absence of tussocks.

2.3 Processing

2.3.1 General Processing Routine

Snow pit data were transcribed to electronic data sheets (.xlsx). Observers were asked to clarify comments or handwriting during and following the campaign measurement period. For dates of March 12 or later the local time recorded (daylight savings time) was converted to local standard time (i.e. -1 hour). The first round of reviews included making any transcription or typo corrections and identifying any erroneous field coordinates. The secondary round of review included standardizing nomenclature, most notably for the stratigraphy section and documenting individual protocol deviations in the revisions log. For example, observers had a variety of ways to note when the bottom of the snowpack was supported by a vegetation matrix rather than the ground surface, which created an air pocket or gap at the snow-ground interface. This gap was present in 15% of the boreal forest snow pits (18/118) and <3% of the North Slope snow pits (2/52). To be consistent, any mention of a lack of snow at the bottom of a snow pit was recorded as a 'Snow Void' in the stratigraphy comments and the height of snow recorded for the layer. All stratigraphic profiles end at the ground surface (0 cm) and a snow void, if present, is well documented in the stratigraphic profile. The snow void is accounted for in deriving total SWE at each site.

2.3.2 Snow Water Equivalent (SWE)

SWE is the product of the height of snow (HS) minus a snow void (if present) and a weighted average density. The following steps are taken to compute SWE for a single snow pit:

1. Due to uneven ground surfaces and vegetation interference, many measured density profiles stop around 10 cm above the ground surface. Density values are extrapolated to the bottom of the snow pit except in cases where the stratigraphy profile records a snow void. In the case of a snow void, the density value is extrapolated to the stratigraphy height recorded (e.g. final density value 34-24 cm, and stratigraphy notes a snow void from 12-0 cm, the density value is extrapolated to 12 cm).
2. Overlapping density samples at the bottom of the snow pit are shortened at the bottom sample so as to not double count SWE (e.g. 16-6, 12-2 cm --> 16-6, 6-0 cm).
3. Missing dual profile measurements are filled at the corresponding level before interpolating (e.g. A=235, B=-9999, profile B is filled with sample A).
4. Third density measurements (if taken) are averaged with profile B before taking the average of profile A and B. This is to compute a dual SWE profile (SWE A, SWE B) before averaging for a single bulk SWE. The average density used to compute LWC is a weighted average of all density samples at a given layer (A, B, C if taken).
5. The gap filled profile is saved and stored as a parameter file (_gapfilled_Density) and is used to derive SWE.
6. Final SWE values are output to the Summary_SWE.csv file which includes bulk Density A, Density B, Mean Density, SWE A, SWE B, SWE, HS, and Snow Void along with necessary metadata.

2.3.3 Liquid Water Content (LWC)

The dielectric constant of a layer was measured using a A2 Photonic WISe LWC sensor. Sensor serial numbers were recorded in the site details. LWC was calculated using the below formula taken from the WISe LWC user manual.

$$\varepsilon = 1 + 1.202 * (D - W_v) + 0.983 * (D - W_v)^2 + 21.3 * W_v$$

where ε is the permittivity of snow measured by the WISe sensor; D is the snow density (g/cm3), averaged over all measurements taken at that layer, and Wv is the volumetric liquid water content. In practice, the following iteration was used to compute Wv:

Start with W_v=0 and repeat five times D_s=D-W_v

$$W_v = \frac{\varepsilon - 1 - 1.202 * D_s - 0.983 * {D_s}^2}{21.3}$$

For each layer, an average weighted density was computed from the observations and used with each permittivity measured at that layer to compute LWC.

2.4 Quality, Errors, and Limitations

2.4.1 Height of Snow (HS)

Measuring the height of snow in the Arctic tundra and boreal forest presented many challenges. The measurement objective is to record a representative HS coincident with the exposed pit wall that aligns closely or matches the density profile. For instances with extreme variability found either at the snow surface or caused by the uneven ground surface a range of snow heights were noted in the comments. For example, closely spaced tussock mounds can have an average vertical height of 18 ±15 cm according to the October 2022 data. Field observers in the tundra observed that the ruler was sinking below the ground surface into the uneven moss-covered substrate. In cases where this variability was quantified it is recorded in the snow pit comments section and may be included in a pit diagram sketch, which has been transferred onto the electronic pit sheet xlsx file. In the boreal forest, sites with dense shrubs and mounded grassy matrices made HS a challenge to measure. The routine developed after studying the challenging sites was to identify the ground surface and place the ruler on the bottom, piercing through a dense grassy matrix or between tussock mounds and accurately describing the bottom of the snowpack in the comments and stratigraphy sections of the data sheet. If HS was adjusted during the review process it is stated in the revision log.

2.4.2 Snow density and SWE

Snow density measurements were a top priority for the science questions addressed in the SWE/snow depth focused sampling strategy during the March 2023 measurement period. To that end, extreme detail is taken to record the highest quality measurements and document instances where sampling conditions were challenging typically due to ground vegetation interference (i.e. sub-snow vegetation), structural integrity of the snowpack, or restricted sampling space in dense canopied areas.

As a result of measuring snow in conditions with enhanced ground sampling challenges such as the dense boreal forest or the windblown tundra it is important to consider the inherent uncertainties that can propagate to a single SWE value. The protocol photos and snow pit comments will provide important additional information and should be reviewed when conducting instrument comparisons.

2.4.3 Temperature Profiles

Temperatures recorded in the bottom of the snowpack should be looked at cautiously. Halfway through the campaign observers noticed an unusual cooling trend near the base of the snowpack. This is likely a result of cool air pooling, a process that begins as soon as the pit wall is exposed and open to the ambient air. In this version release of the data the authors did not make a correction or remove any data, but instances where temperature gradients change near the base of the snowpack (i.e. colder) should be carefully considered based on the intended research scope.

2.4.4 Tussocks

Tussock presences/absences and average vertical height and horizontal spacing is included in this March 2023 snow pit data product. Due to the midwinter snowpack during the March IOP measurement period tussocks were identified if they were uncovered in the 1 x 1 m snow pit area or discovered while taking perimeter depth measurements. Whereas the low-snow measurement periods did a more thorough job at classifying the ground conditions over a larger spatial domain (5x5 m).

2.4.5 Boreal Forest Land Cover Classification

Land cover classifications were assigned to boreal forest snow plots and remained the same throughout the multiple measurement periods. The land cover type was assigned using the National Land Cover Data and can be decoded in the first letter of the boreal forest pit-IDs (D - Deciduous, E - Evergreen, S - Shrub, W - Wetland, C – Crop). While taking measurements, observers noted any discrepancies in the pre-assigned land cover type with what was observed the 5x5 m plot. Such discrepancies were documented both in the upper right section of the snow pit sheet and can be found in the '_siteDetails' file under the header 'Assigned Plot Cmts.' An example that occurred more than once was at CPCRW, where ‘Deciduous’ was assigned but the area was dominated by evergreen canopy.

3 VERSION HISTORY

Table 9. Version History

Version	Date Implemented	Impacted Temporal Coverage	Description of Changes
v01.0	December 2024	07 March 2023 to 16 March 2023	Initial release

4 RELATED DATA SETS

SnowEx23 Mar23 IOP Snow Depth Measurements, Version 1

SnowEx23 Airborne Lidar-Derived 0.5M Snow Depth and Canopy Height, Version 1

SnowEx23 Snow Water Equivalent, Version 1

5 RELATED WEBSITES

NASA SnowEx

NSIDC SnowEx | Overview

6 ACKNOWLEDGMENTS

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7 REFERENCES

Vuyovich, C., Stuefer, S., Durand, M., Marshall, H. P., Osmanoglu, B., Elder, K., Vas, D., Gelvin, A., Larsen, C., Pedersen, S., Hodkinson, D., Deeb, E., Mason, M., & Youcha, E. (2023). NASA SnowEx 2023 Experiment Plan. https://snow.nasa.gov/sites/default/files/users/user354/SNEX-Campaigns/2023/NASA_SnowEx_Experiment_Plan_2023_draft_20June2024.pdf

8 DOCUMENT INFORMATION

8.1 Publication Date

December 2024

8.2 Date Last Updated

December 2024

APPENDIX A – SNOW PIT SUMMARY FIGURES

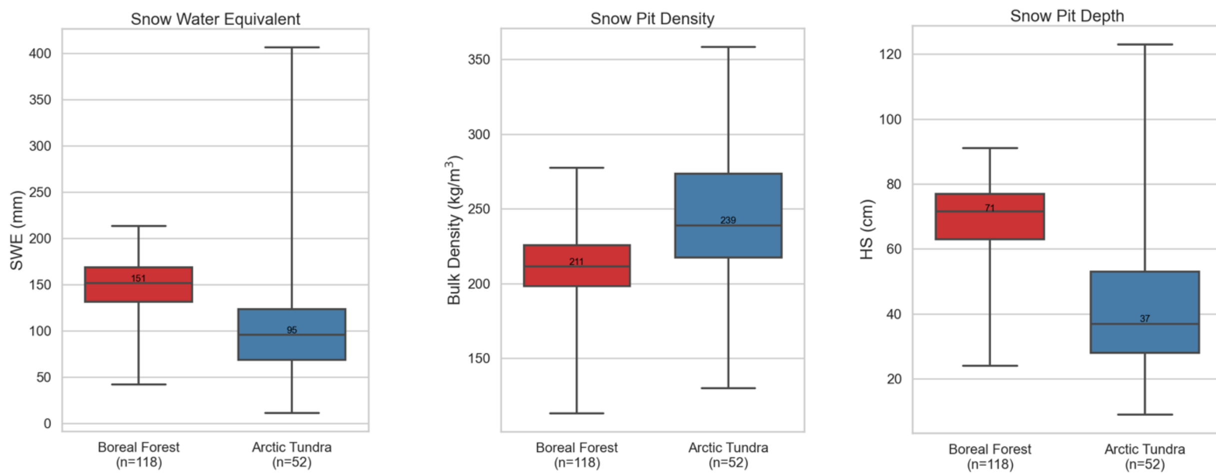

Figure 2. Box plots show the median and interquartile range for SWE (a), density (b) and snow depth (c), for two dominant snow classes in Alaska.

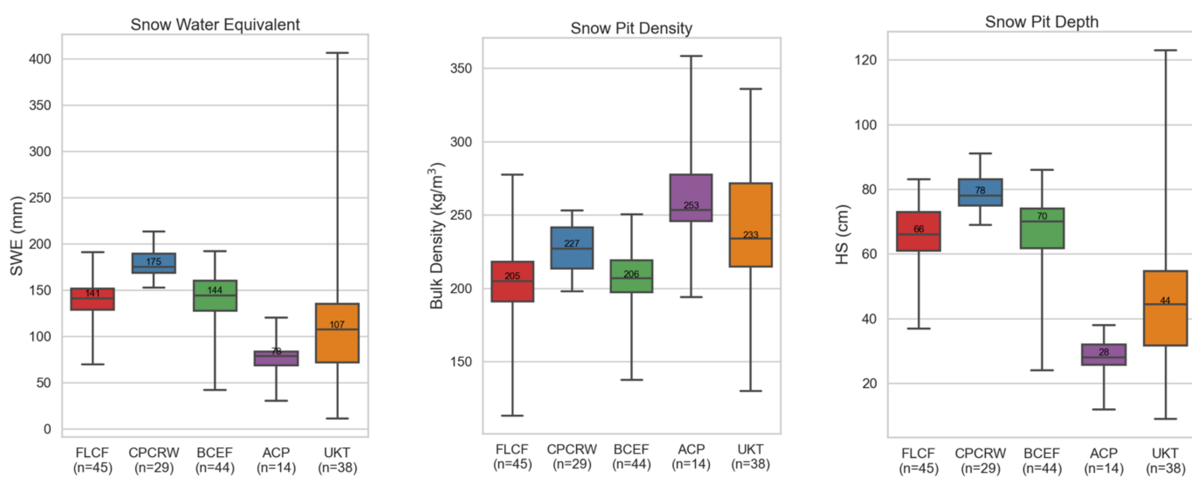

Figure 3. Boxplots show the median and interquartile range for SWE (a), density (b) and snow depth (c), at each of the five sites selected for the SnowEx 2023 Alaska campaign. The first three in the series (red, blue, green) are part of Interior Alaska (boreal forest), and the last two (purple, orange) are located on the North Slope (Arctic Tundra).