SnowEx23 Oct22 IOP Snow Pit Measurements, Version 1 Technical Reference

1 INTRODUCTION

1.1 Data Set Overview

The data set presents snow pit measurements collected during the NASA SnowEx October 2022 Intensive Observation Period (IOP) in Alaska, USA. In total, 186 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 File Information

1.2.1 Format

The data are available in 188 multifile granules compressed into `.tgz` files. 186 of the granules comprise the primary data files; each granule represents a single snow pit and contains five data files formatted as .xlsx files or comma-separated value files (`.csv`). One granule contains site photos for each snow pit (.jpg) and a scan of the handwritten field notes for each pit (.pdf). The remaining granule contains four summary files, formatted as comma-separated value files (`.csv`).

1.2.2 Naming Convention and File Contents

The granules containing the primary data files are named according to the following convention:

`SNEX23_OCT22_SP_[SITE]_[REGION]_[PIT_ID]_[YYYMMDD]_v01.0.tgz`,

where `SNEX23_Oct22_SP` is the data set short name, `SITE` is the name of the field site, `REGION` is a geographic descriptor (i.e., `NORTH`, `WEST`, `NNE`), `PIT_ID` is the snow pit identification number, and `YYYYMMDD` is the date of data collection.

The data files within the granules follow a similar naming convention but are appended with the data parameter as such:

`SNEX23_OCT22_SP_[SITE]_[PIT_ID]_[YYYMMDD]_[PARAMETER].v01.0`

Available parameter files for each snow pit are described in Table 1 below.

Table 1. Parameters available for each snow pit

Parameter File	Contents	File Format
pitSheet	All snow pit data	.xlsx
siteDetails	Location, site and pit ID, date/time, UTM coordinates, Latitude, Longitude, height of snow (HS), observers, weather, environment conditions, vegetation characteristics, and comments,	.csv
Stratigraphy	Layer thickness, grain size, grain type, manual wetness, hand hardness, and comments	.csv
sweTube	Three SWE Tube samples with measured snow depth (cm) and snow water equivalent (SWE) (mm) and calculated density (kg/m^3)	.csv
temperature	Temperature (°C) at surface and 10 cm intervals on 10s (e.g. 27, 20, 10, 0)	.csv

The granule containing the summary files follows a similar naming convention, and is named:

`SNEX23_Oct22_SP_Summaries_20221022-20221027_v01.0.`

The data files within the summary granule follow a similar naming convention but are appended with the data parameter as such:

`SNEX23_OCT22_SP_Summary_[PARAMETER].v01.0`

A description of each available summary parameter is described in Table 2 below.

Table 2. Available summary files

Parameter File	Contents	File Format
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, vegetation heights, forest type, and percent canopy cover.	.xlsx
Substrate	One summary file for all snow pits. Each row contains metadata related to the snow pit (see SWE list below), along with substrate depths and conditions for the following top and bottom layer heights for vegetation, organic soil, and mineral soil. If a soil moisture sample was collected it is marked by Yes/No column along with the top and bottom	.csv

Parameter File	Contents	File Format
	depth of the SM sample. The top and bottom layer of the frozen substrate is also noted.	
SWE	One summary file for all snow pits. Each row contains the site and snow pit ID, date/time, UTM coordinates, Latitude, Longitude, height of snow (HS) (cm), snow thickness (cm), mean SWE (mm), mean density (kg/m^3), and stratigraphy profile void space (cm) caused by snow over vegetation or air gaps.	.csv
SWE_v01_pandasReady	Contains the same data as the SWE file, but formatted for ease of use with Pandas	.csv

The granule containing the image files follows a similar naming convention and is named:

`SNEX23_Oct22_SP_sitePhotos_20221022-20221027_v01.0.`

The files within the image granule follow a similar naming convention but are appended with the image type as such:

`SNEX23_OCT22_SP_[SITE]_[PIT_ID]_[YYYMMDD]_[#]_TYPE].v01.0`

A description of each available image type is described in Table 3 below.

Table 3. Available image files

Type	Contents	File Format
Directional: • north • east • south • west • up • down • oblique	The image type listed in the file name describes the orientation of the image relative to the snow pit. Not all orientations are available for each snow pit	.jpg
Pit 1, Pit 2	All photos labeled as pit are taken showing the extent of the pit. Pit photos are not always available for each snow pit	.csv
soil	All photos labeled as soil are images of soil samples. Soil samples were not collected from all snow pits.	.csv
book	A scan of the handwritten pit sheet (field notes) collected at each snow pit. Data from these sheets was transcribed to create the digital pit sheets.	.pdf

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 70.08434° N

Southernmost Latitude: 64.69925° N

Easternmost Longitude: 147.48583° W

Westernmost Longitude: 149.59716° W

1.3.2 Geolocation

This data set conforms to the WGS 84 coordinate reference system (EPSG 4326).

1.4 Temporal Information

1.4.1 Coverage and Resolution

22 October 2022 to 27 October 2022

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Snow pit and ground condition measurements were collected during the NASA SnowEx October 2022 Intensive Observation Period (IOP) for use in calibrating and validating coincident airborne lidar measurements and ground-based radar systems. These measurements supported the SnowEx strategy for quantifying snow water equivalent (SWE) and snow depth (HS). The NASA SWESARR instrument was planned to fly during this IOP; however, aircraft readiness delays prevented background (no/low-snow) SWESARR data collection until October 2023. Airborne lidar surveys were acquired at all study areas concurrently with ground-based measurements. Snow pits were excavated at two Arctic tundra sites (ACP, UKT) and three Boreal Forest sites (FLCF, CPCRW, BCEF) between October 22–27, 2022. In total, 186 snow pits were completed, spanning a range of snow depths, vegetation types, and topographic conditions across the five sites.

Table 4. Snow Pit Overview

Site Name	Site ID	Site Series No.	Pit Count	Site Lead
Farmer's Loop / Creamer's Field	FLCF	001 – 108	37	Carrie Vuyovich
Caribou Poker Creek Research Watershed	CPCRW	200 – 283	26	Dragos Vas
Bonanza Creek Experimental Forest	BCEF	300 – 482	47	Kelly Elder, Mike Durand
Upper Kuparuk and Toolik-Galbraith	UKT	500 – 566	63	Svetlana Stuefer, HP Marhsall
Arctic Coastal Plain	ACP	600 – 810	14	Glen Liston

2.2 Acquisition

Snow pit data were collected according to a standard protocol for low-snow, early winter background ground conditions. At each site, observers navigated to the point of interest and delineated a study plot that measured 5x5 m. The GPS point of the southeast plot corner was marked and later shifted to the center of the plot to best represent the snow pit sampling location during the data processing. The snow pit sampling took place in the middle of the study plot where a 1x1 m area was excavated to collect snow pit measurements. All pit face measurements (depth, temperature, stratigraphy) were taken on the north-facing pit wall. SWE and computed density were taken on the undisturbed snow behind the excavated pit wall.

Pit measurements were collected using a standard snow pit kit, except for the box density cutters and digital scale normally used for density measurements. Instead, a SWE tube sampler and spring scale were used to collect three SWE samples at each plot, with density computed from those samples. SWE tubes were selected because snow depth at most sites was less than 30 cm. A pocket microscope and 2 mm gridded crystal card were used to identify snow layer stratigraphy, and digital thermometers were used to measure snow temperature profiles. At some Tundra sites a dual temperature and stratigraphy profile were recorded to capture the variability within the snow pit. For those cases, an A, B, or C label distinguishes the profile and correlates to the location of the three SWE tube samples. See the electronic pit sheet for any transferred sketches that further illustrate the sampling conditions. A full list of instruments is provided in Table 5. There were no liquid water content measurements taken during the fall sampling period.

Snow pit crews consisted of two primary observers: one to take measurements and one to record data. Pits were excavated with a smooth, north-facing wall. The ruler was placed so that 0 cm was flush with the ground surface, and it was used to record height of snow (HS) and mark the height of other measurements. In all cases where the snow had not yet compressed any underlying vegetation and was perched above it; snow depth (HS) was recorded as the total height above shrubs or other low-lying vegetation, using the ground surface as the 0 cm reference. This approach ensures that HS values are consistent with what would be expected for airborne lidar validation. In addition to HS, a secondary variable—snow thickness—was added to represent only the depth of the predominant snow layer at the surface. For example, a shrub 25 cm tall with 10 cm of snow above it has an HS of 35 cm and a snow thickness of 10 cm. Snow thickness was calculated as HS minus the height of the bottom stratigraphic layer with only a few exceptions where a manual value was assigned during the data processing. A final variable — snow void — represents any void space from vegetation or air gaps between the ground surface and was based off the early season snowpack.

A snow temperature profile was collected by measuring the shaded snow surface temperature and then repeated at 10 cm intervals on even 10 cm increments (e.g. 27, 20, 10, 0 cm). The start and stop time of the temperature profile was also recorded. Stratigraphic layers were marked and recorded according to grain type, grain size, hand hardness, and manual wetness. Any additional comments relevant to stratigraphy were noted for each layer. See Figure 2 for a stratigraphy reference. Lastly, 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 — grassy mounds —along with the average height and horizontal distance apart over a 5x5 m study plot. The forest canopy cover was a qualitative assessment from the center of the study plot with an overhead cone of influence of 45 degrees.

Substrate conditions were assessed by digging into the frozen or unfrozen ground surface to obtain roughly a 10 cm deep soil moisture sample. Layer thickness was identified for the following categories: substrate vegetation (i.e. moss, lichen), organic soil, and mineral soil. The depth of frozen substrate was noted at most sites and the sample depth top and bottom marked. In general, observers took the top 10 cm of substrate material, but this is not true for every site and can be determined in the `Substrate` summary file. Soil plug photos are included in the suite in site photos.

Table 5. Summary of Instruments

Instrument	Brand	Measurement	Specs
Global Positioning System (GPS) field unit	Garmin 64st, Garmin 64, Garmin 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, 127 mm stem

Instrument	Brand	Measurement	Specs
SWE spring scale and tube	Snowmetrics	Snow depth, SWE	Accuracy ± 2mm layer thickness, 0.3% spring scale range for SWE, 30 cm long x 5.38 cm I.D. tube
Pocket 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
Crystal card	Snowmetrics	Snow grain type and size	10 x 8 cm, 2 mm grid, plastic, translucent blue
Folding rule	Wiha Tools USA	Height of snow (HS), stratigraphic boundary heights, layer thickness	2 m plastic/fiberglass folding rule, mm and cm graduations

Note - The uncertainty specifications depend on user experience and snow sampling conditions. The listed specifications may not adequately reflect all conditions where instrument measurements were collected during the Alaskan Tundra and Boreal Forest Field Campaign.

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

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 after the campaign. All measurements collected during the October 2022 IOP took place in Alaska Daylight Time and were converted to Alaska Standard Time (i.e., -1 hour).

The first review pass focused on correcting transcription errors or typos and identifying erroneous field coordinates. The second review pass standardized nomenclature, particularly for the stratigraphy, and methods to record HS for study plots that had snow on top of vegetation. 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 documented in the stratigraphic profile.

2.3.2 Snow Density

Snow density was calculated from the SWE tube sample using the measured SWE and the sampled depth, which was often less than the recorded pit-HS. This difference is typically caused by the challenges associated collecting the shallow snowpack over the variable ground conditions and influence by the low-lying vegetation at some sites. In many cases, the SWE tube sample reports a smaller depth because of the difficulties in isolating a complete column—such as when a melt-freeze crust impedes sampling or vegetation interferes with collection.

2.4 Quality, Errors, and Limitations

2.4.1 Height of Snow (HS)

Measuring snow height in the Arctic tundra and boreal forest presented many challenges, even in the early winter season when coverage was thin. The objective was to record a representative HS at the exposed pit wall that closely matched the SWE tube sample location. When extreme variability occurred—either at the snow surface or due to uneven ground—a range of snow heights was noted in the comments. For example, closely spaced tussock mounds can vary in vertical height by an average of 18 ± 15 cm. In tundra sites, observers noted that the ruler sometimes sank below the ground surface into the uneven, moss-covered substrate. When this variability was quantified, it was documented in the snow pit comments section and, if applicable, included in a pit diagram sketch transferred to the electronic `_pitSheet` .xlsx file.

In the boreal forest, dense shrubs and mounded grassy matrices also made HS difficult to measure. To maintain consistency, observers placed the ruler vertically with the base (0 cm) at the ground surface and recorded the top height of the snow as HS. If the snow layer rested on top of ground vegetation, the bottom of the layer was noted in the stratigraphy profile.

For data use, HS-snowpit from the `Summary_SWE` .csv file should be used when comparing airborne lidar or other remote sensing products where relative snow height is important. Snow thickness should be used when the interest is in the actual amount of snow present.

2.4.2 Snow Water Equivalence (SWE) and Snow Density (ρ)

SWE measurements are a top priory for the science questions addressed in the SWE/snow depth focused sampling strategy during the October 2022 measurement period. Therefore, 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. We predict a slight SWE bias from under sampling shallow snow under challenging sampling conditions such as when stratigraphic layers like melt–freeze crusts often caused tube samples to capture less snow than the representative snow pit HS. A total of three SWE tube samples is averaged for every study plot to better capture the variability and mitigate the sampling challenges. The protocol photos and snow pit comments will provide important additional information and should be reviewed when conducting instrument comparisons.

Snow density is obtained using the SWE (mm) and HS (cm) collected with the SWE tube samplers:

$$\rho_{snow} = \frac{SWE\ (mm)}{snow\ depth\ (cm)} * \ 100$$

then averaged across three samples.

2.4.3 Temperature Profiles

Digital thermometers were used to measure a vertical temperature profile. The snowpack in the boreal forest was very shallow, and, in some cases, there are no more than two temperature readings.

2.4.4 Tussocks

Tussock(s) presences/absences, average vertical height and average horizontal spacing was measured in the full 5x5 m study plot. Data sheets contain a sketch of the tussock diagram and values are reported in the summary environment file. The October 2022 campaign included a more thorough protocol and effort to classify the ground conditions over the larger spatial domain, whereas in the March 2023 campaign protocol was reduced to only identify tussocks in the 1x1 m excavated snow pit area or make note of them at shallower plots if they were discovered.

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 (https://www.mrlc.gov/data/nlcd-2016-land-cover-alaska) 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.

2.5 Snow Pit Summary Figures

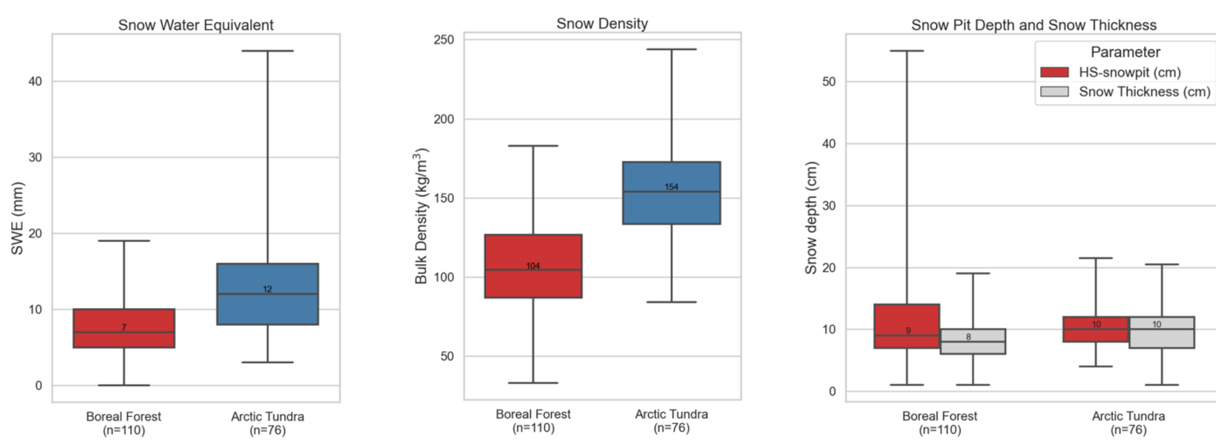

Figure 2. Boxplots show the median and interquartile range for SWE (a), calculated density (b) and snow pit depth and snow thickness (c), for two dominant snow classes in Alaska as measured from SWE tube samples.

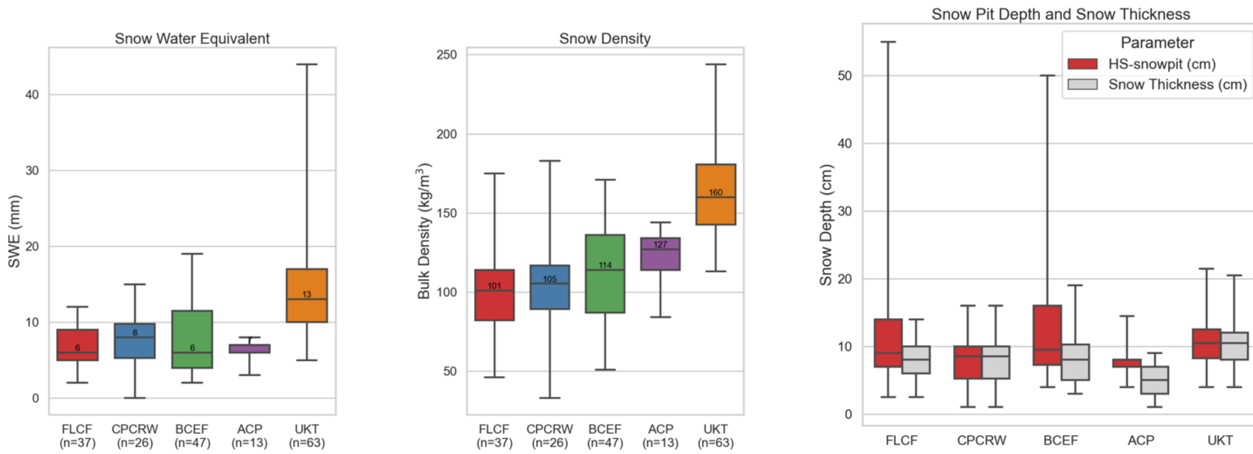

Figure 3. Boxplots show the median and interquartile range for SWE (a), calculated density (b) and snow pit depth and snow thickness (c), at each of the five sites selected for the SnowEx 2023 Alaska campaign as measured from SWE tube samples. The first three in the series (red, blue, green) are part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

3 ACKNOWLEDGEMENTS

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4 REFERENCES

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