SnowEx21 Time Series 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., H. P. Marshall, D. Craaybeek, K. Elder, C. Vuyovich, and the Time Series Site Leads and Field Teams. 2024. *SnowEx21 Time Series 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/QIANJYJGRWOV. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX21_TS_SP

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

The data set is a time series of snow pit measurements obtained by the SnowEx community during the 2021 campaign. Between November 2020 and May 2021, data from 247 snow pits were collected at 24 unique sites distributed throughout Colorado, Idaho, Montana, and Utah. Five of the unique sites had a single visit to establish baseline conditions, while the remaining 19 sites had three or more repeat visits throughout the season, with a median visit count of 11.5 At repeat site visits, a snow pit was dug approximately 1 m from the previous snow pit's location. Available measured parameters are:

- Snow depth
- Snow temperature
- Snow density
- Stratigraphy
- Grain size
- Wetness
- Liquid water content (LWC)
- Snow water equivalent (SWE)
- Environmental conditions

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

1.2 File Information

1.2.1 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, LWC, site details, stratigraphy, and temperature) data are provided as separate .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 comma-separated value (.csv) files, and contain summary data for all snow pits across the entire time series.

1.2.2 File Contents

1.2.2.1 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 (density, LWC, site details, stratigraphy, and temperature) 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 4 cardinal directions, the overhead canopy conditions, and the downward view of pit location.

Table 1. Description of File Types

File Type	Content description
Snow pit sheet	File contains all data from the snow pits in multiple formats
Site photos	Photos taken of pit sheets, snow pit wall, the site in 4 cardinal directions, upwards and downwards in the excavated pit.
Site Details	Location, site and pit ID, date/time, UTM coordinates, Latitude, Longitude, total height of snow (HS), observers, weather, environment conditions, comments, and any associated data flags
Density	Density (kg/m3) profiles at 10 cm intervals (e.g. 96-86, 86-76, ... 26-26, 16-6)
gapFilled_Density	Extrapolated and interpolated density (kg/m3) profiles; used to compute SWE in summary SWE file.
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
Note - if data were not recorded in the field then they appear as blanks in the snow pit sheets, and are -9999 in the individual parameter csv files	

1.2.2.2 Summary Data Set Files

Two summary files are available as separate granules: SNEX21_TS_SP_Summary_SWE_v01.csv and SNEX21_TS_SP_Summary_Environment_v01.csv.

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: 40.5189º N, 105.8918º W.

The Summary SWE file contains snow water equivalents for all snow pits at each timestamp. Each row contains the site and snow pit ID, date/time, UTM zone, easting, northing, 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), snow depth (cm, same as height of snow (HS) from the pit sheet), and any relevant flags.

The Summary Environment file contains qualitative environmental observations for each site visit. Each row contains qualitative observations about potentially impactful environmental conditions, such as precipitation, cloud cover, wind, and ground cover.

1.2.2.3 Technical References

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

The Parameter Summary Graphs file (SNEX21_TS_SP_Summary_Graphs.pdf) presents bulk density, snow depth, and SWE data for all snow pits, organized by site region. Also available are graphs showing density profile values, A2 WISe sensor permittivity values, and A2 WISe sensor liquid water content by volume.

The Snow Pit Sheet Template Explanations file (SNEX21_Snow-Pit-Sheet-Template-Explanation.xlsx) includes descriptions of each parameter in the snow pit sheet template.

The Snow Pit Mean Locations file (SNEX21_TS_SP_Mean_Locations.csv) contains geographic information for each time-series site, including state, latitude and longitude, easting and northing, number of pits, as well as full time-series site name and pit ID.

The Time Series Pit Revisions file (SNEX21-TimeSeries-Pits-Revisions.xlsx) documents any changes that were made to correct or standardize the pit sheet for consistency across all measurement sites. For example, when a positive temperature value was recorded in the field, it was changed to 0°C as positive snow temperatures are unrealistic, but within the error of the instrument. Use the revision file to see precise edits that are not accounted for in the broad list of corrections and standardization methods listed in Section 2.3.

The Comprehensive Data Set Summary file (SNEX21-Comprehensive-DataSet-Summary.csv) can be used to determine what data are available for each time-series site and for all timestamps. All parameters are listed with a yes/no option to identify which measurements are included in each snow pit/timestamp data granule. Any associated data flags are denoted in a separate column. The flags are coded with descriptions and recommended amendments for data users in Table 10. Every site visit contains the full suite of parameter files. If a parameter was not measured the values in the file are -9999. The last column in the spreadsheet lists which of eight standard photos are

included in the photo package. In a few cases, additional photos are supplied and given a descriptive name. Most additional photos come from the Cameron Pass, CO site where several stratigraphy layer photos are included to document grain size and type.

A suite of individual parameter files was generated for each snow pit. If a parameter was not measured at the site during the visit (e.g. instrument unusable/unavailable, or group did not adhere to all standard protocol observations), the parameter file will be populated with -9999. Use the Comprehensive Data Set Summary file and Table 2 to know how many pit visits have the parameter of interest.

Table 2. Total Snow Pit Profiles Available by Parameter

Parameter	Obs. Count
HS (Height of Snow)	247
Density Profiles	245
Temperature Profiles	233
Liquid Water Content Profiles	162
Stratigraphy Profile	234
Note: see comprehensive-dataset-summary file for more detail.	

1.2.3 File Naming Convention

1.2.3.1 Snow Pit Sheet File Naming Convention

Snow pit sheets are named according to the following convention and as described in Table 3:
`SNEX21_TS_SP_<yyyymmdd>_<hhmm>_<ssssss[nn]>_data_pitSheet_ v<nn>.xlsx`

Table 3. Snow Pit Sheet File Naming Convention

Variable	Description
`SNEX21_TS_SP`	Short for SnowEx 2021 Time Series Snow Pit Measurements
`<yyyymmdd>_<hhmm>`	Date and time of data collection, in year-month-day hour-minute format
`<ssssss[nn]>`	Site code with either of the following formats: • ssssss: Site code composed of a 2-letter state code, 2-letter location, and 2-letter study site. • sssssnn: Site code composed of a 2-letter state code, 2-letter location, 2-letter study site, and 2-digit site index number
`v<nn>`	Indicates version number of the data set

Variable	Description
.xlxs	File extension: Microsoft Excel file

The snow pit sheet file name from a single timestamp and time series site (2021-05-20 at 08:54 for COCPCP) is shown below:

- SNEX21_TS_SP_20210520_0845_COCPCP_data_pitSheet_v01.xlsx

1.2.3.2 Individual Parameter File Naming Convention

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

`SNEX21_TS_SP_<yyyymmdd>_<hhmm>_<ssssss[nn]>_data_<param>_v<nn>.csv`

Table 4. Individual Parameter File Naming Convention

Variable	Description
SNEX21_TS_SP	Short for SnowEx21 2020 Time Series Snow Pit Measurements
<yyyymmdd>_<hhmm>	8-digit date and time of data collection, in year-month-day hour-minute format
<ssssss[nn]>	Site code with either of the following formats: • ssssss: Site code composed of a 2-letter state code, 2-letter location, and 2-letter study site. • sssssnn: Site code composed of a 2-letter state code, 2-letter location, 2-letter study site, and 2-digit site index number (See section 2.1.1 for snow pit site naming details)
<param>	Parameter contained within the file (see Table 1 for a description of each parameter): • density • gapFilledDensity • LWC • siteDetails • stratigraphy • temperature
V<nn>	Indicates version number of the data set
.csv	File extension for comma-separated value file

A complete list of parameter data files from a single timestamp and time series site (2021-05-20 at 08:54 for COCPCP) is shown below:

- SNEX21_TS_SP_20210520_0845_COCPCP_data_density_v01.csv
- SNEX21_TS_SP_20210520_0845_COCPCP_data_gapFilledDensity_v01.csv
- SNEX21_TS_SP_20210520_0845_COCPCP _data_LWC_v01.csv
- SNEX21_TS_SP_20210520_0845_COCPCP _data_siteDetails_v01.csv
- SNEX21_TS_SP_20210520_0845_COCPCP _data_stratigraphy_v01.csv
- SNEX21_TS_SP_20210520_0845_COCPCP _data_temperature_v01.csv

1.2.3.3 Site Photograph Naming Convention

Site photographs are named according to the following convention and as described in Table 5:
`SNEX21_TS_SP_<yyyymmdd>_<hhmm>_<ssssss[nn]>_photo_<content>_v<nn>.jpg`

Table 5. Site Photograph File Naming Convention

Variable	Description
SNEX21_TS_SP	Short for SnowEx21 Time Series Snow Pit Measurements
<yyyymmdd>_<hhmm>	8-digit date and time of data collection, in year-month-day hour-minute format
<ssssss[nn[>	Site code with either of the following formats: • ssssss: Site code composed of a 2-letter state code, 2-letter location, and 2-letter study site. • sssssssnn: Site code composed of a 2-letter state code, 2-letter location, 2-letter study site, and 2-digit site index number (See section 2.1.1 for snow pit site naming details)
<content>	Contents of the image: • _book1 / _book2 = image of the field book in which snow pit data were documented • north = picture taken looking north of the snow pit • south = picture taken looking south of the snow pit • east = picture taken looking east of the snow pit • west = picture taken looking west of the snow pit • pit = picture of the snow pit wall • up = picture of the overhead conditions above the snow pit • down = picture of the downward view of the snow pit
v<nn>	Indicates version number of the data set
.jpg	File extension for compression mode of digital photograph

A complete list of site photographs from a single timestamp and time-series site (2021-05-20 at 08:54 for COCPCP) are shown below:

- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_book1_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_book2_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_north_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_east_v01.jpg

- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_south_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_west_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_pit_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_up_v01.jpg
- SNEX21_TS_SP_20210520_0845_COCPCP _ photo_down_v01.jpg

As a general rule, snow pit sheets consisted of two hand-written pages and were photographed as two separate images (_book1 and _book2). In a few cases snow pits were deep enough to require a third pit sheet page. These images are named _book3. If no photos of a physical pit sheet were available, a filler photo named _book1 is provided.

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 47.06075º N
Southernmost Latitude: 37.9071º N
Easternmost Longitude: 105.86093° W
Westernmost Longitude: 116.12351° W

1.3.2 Resolution

These data are point observations.

This data set contains measurements from 247 unique time series sites across 24 regional locations throughout Colorado, Idaho, Montana, and Utah (see Table 7 for more details). Each site has a general zone of interest (i.e. protected study plot) and at each site visit a new snow pit was dug roughly one meter from the previous pit. Snow pit coordinates were recorded as protocol during every visit with mid-grade GPS units or GPS enabled handheld phones. The estimated uncertainty is 5-15 m depending on the location and satellite coverage available during the measurement. In some locations, the study site size required placement of subsequent snow pits in 2 or 3 columns, or in a workable space given forest conditions and overhead canopy. Points at these sites will plot as a cluster and should be averaged to show a representative snow pit area.

1.3.3 Geolocation

Table 6 provides information for geolocating this data set. Depending on the location of a certain snow pit, the coordinate reference system (CRS) is WGS 84 / UTM zone 11N, 12N, or 13N. The seven time series sites where snow pit observations were conducted are presented in Table 7 with Lower Left and Upper Right bounding box coordinate pairs, along with the location lead, number of unique sites, and total pit count at each location. The CRS for an individual snow pit is noted in the

corresponding siteDetails file and an averaged center point for each unique site is provided in Table 8.

Table 6. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	WGS 84 UTM zone 11N / 12N / 13N
Longitude of true origin	-117 / -111/ -105
Latitude of true origin	0
Scale factor at longitude of true origin	0.9996
Datum	WGS_1984
Ellipsoid/spheroid	WGS 84
Units	meters
False easting	500000
False northing	0
EPSG code	32611 / 32612 / 32613
PROJ4 string	+proj=utm +zone=XX +datum=WGS84 +units=m +no_defs where XX has to be replaced by 11, 12, or 13 depending on the UTM zone.
Reference	http://epsg.io/32611 / http://epsg.io/32612 / http://epsg.io/32613

1.4 Temporal Information

1.4.1 Coverage

16 November 2020 to 27 May 2021

1.4.2 Resolution

The majority of snow pit observations were collected weekly during the winter season. This varies by location and site depending on the availability and travel conditions for field observers. Five sites were only visited a single time, but the rest have repeated weekly visits over a 3-5 month window.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Snow pit data collected during the SnowEx 2021 Time Series campaign can be used to validate snow remote sensing data. The 2021 winter season measurements were a continuation of the SnowEx 2020 Time Series campaign, which was abruptly discontinued due to the COVID-19 global pandemic. Both Time Series campaigns followed nearly the same protocol. There are some minor protocol differences or improved methods based on the review and lessons learned from the 2020 sampling period. Listed below are a few notable differences between the two campaigns.

- Plot perimeter snow depth measurements were conducted separately and are not included as part of the snow pit data set
- Slope, aspect, and air temperature were not collected, and are represented by -9999 values in the siteDetails.csv file
- Downward ('down') facing images are added to the list of protocol photos
- Start and end time of the snow temperature profile were recorded. This information is an additional column in the _temperature.csv parameter file. If the time was not observed, it is filled as -9999 in the parameter file.

The regional locations and time series sites cover a range of terrain, environmental conditions, and snow classes. The regional locations of the field experiments were chosen based on existing ground-based infrastructure, previous remote sensing experiments, and availability of local experienced observers. Each regional location is listed below along with the site lead, bounding box coordinates, and the number of time series sites and snow pits dug at each location.

Table 7. SnowEx 2021 Time Series Locations with Snow Pit Measurements

State	Location	Site Lead	LL (lat, lon)	UR (lat, lon)	No. of Sites*	Pit Count
CO	Cameron Pass	Dan McGrath	40.51886, -105.89188	40.56385, -105.86755	2	30
CO	Fraser Experimental Forest	Kelly Elder	39.87540, -105.88286	39.92961, -105.86093	6	101
CO	Grand Mesa	McKenzie Skiles	39.05087, -108.06130	39.05087, -108.06130	1	1
CO	Senator Beck	Andy Gleason	37.90710, -107.71130	37.90715, -107.71118	1	11
ID	Boise River Basin	Hans-Peter Marshall	43.73629, -116.12351	44.30421, -115.23453	9	72
MT	Central Agriculture Research Center	Eric Sproles	40.57174, -111.63762	40.59132, -111.62984	3	9

State	Location	Site Lead	LL (lat, lon)	UR (lat, lon)	No. of Sites*	Pit Count
UT	Little Cottonwood Canyon	McKenzie Skiles	47.05746, -109.95698	47.06075, -109.95176	2	23
				Total	**24**	**247**
Note: See Table 8 for a complete list of sites at each study location						

This SnowEx campaign aimed to visit all time series sites weekly. Some sites may not have obtained consistent weekly measurements due to availability of field observers and travel conditions, and five sites were only visited once (Boise River Basin: Banner Knob, Banner Open, Mores Mountain; Central Agriculture Research Center: Wheat; and Grand Mesa: Skyway Open). These data are still included as they supply baseline data for other coincident remote sensing data sets and modeling efforts.

Visits to each time series site involved digging a new snow pit 1m ahead of the prior snow pit wall. Each time series site has a 6-letter pit ID (Table 8) which, when combined with the observation date and time, provides a unique alphanumerical code for each snow pit observation. The coordinates found in Table 8 are an average location for each snow pit in a given time series to represent the zone of interest. See the Time Series Pit Revisions file for individual corrections applied to incorrectly recorded raw coordinate data.

Two sites in the Fraser Experimental Forest followed a modified sampling design in order to repeat the sampling conducted during the 2002-2003 CLPX field campaigns. Snow pits at Fool Creek (COFEFC) and St. Louis (COFESL) at the Fraser Experimental Forest in Colorado are on a 1 x 1 km grid with up to 17 randomized sampling locations. The pit ID naming convention for these two sites has an 8-letter ID. The first 6 letters match the other sites, while the last 2-letters indicate the 01-17 sampling location.

Much was learned during both the sampling and review process and applied to the 2021 time series campaign. All locations, with the exception of the Central Agriculture Research Center (CARC), Montana prairie site, were part of the SNEX20 data collection and had several repeat observers collecting snow measurements. Time series site leads participated in weekly tag-ups to discuss near real time data collection and coordination with the airborne UAVSAR platform.

2.1.1 Snow Pit Naming Convention

The majority of snow pit IDs consist of a 6-letter code composed of a 2-letter state code, 2-letter location code, and 2-letter/number study site code. A small number of snow pit IDs consist of an 8-letter code composed of 2-letter state code, 2-letter location code, 2-letter/number study site code, and a 2-digit site index number. For example, IDBRBS stands for Idaho (ID), Boise River Basin

(BR) Banner Snotel (BS). Table 8 lists all IDs with their corresponding state, regional, and time-series place names and the total number of snow pits dug per site. A complete table with mean locations of each snow pit site (SNEX21_TS_SP_Mean_Locations.xlsx) can be downloaded from the technical references on the dataset landing page.

Table 8. SnowEx 2021 Mean Location for Snow Pit Sites

State	Regional Location	Site	Pit ID	Pit Count
CO	Cameron Pass	Cameron Peak	COCPCP	16
CO	Cameron Pass	Michigan River	COCPMR	14
CO	Fraser Experimental Forest	CLPX Fool Creek	COFEFC	16
CO	Fraser Experimental Forest	CLPX St. Louis	COFESL	33
CO	Fraser Experimental Forest	JPL SoOp 1	COFEJ1	15
CO	Fraser Experimental Forest	JPL SoOp 2	COFEJ2	10
CO	Fraser Experimental Forest	SnowEx B1	COFEB1	15
CO	Fraser Experimental Forest	SnowEx B2	COFEB2	12
CO	Grand Mesa	Skyway Open	COGMSO	1
CO	Senator Beck	Swamp Angel	COSBSA	11
ID	Boise River Basin	Banner Knob	IDBRBK	1
ID	Boise River Basin	Banner Open	IDBRBO	1
ID	Boise River Basin	Banner Snotel	IDBRBS	13
ID	Boise River Basin	Bogus Lower	IDBRBL	18
ID	Boise River Basin	Bogus Lower Trees	IDBRBT	13
ID	Boise River Basin	Lower Deer Point - Open	IDBRLO	12
ID	Boise River Basin	Lower Deer Point - Tree	IDBRLT	10
ID	Boise River Basin	Mores Creek Summit	IDBRMC	3
ID	Boise River Basin	Mores Mountain	IDBRMM	1
MT	Central Agriculture Research Center	SnowEx-1	MTCASX	4
MT	Central Agriculture Research Center	Wheat	MTCAWH	1
MT	Central Agriculture Research Center	Wx	MTCAWX	4
UT	Little Cottonwood Canyon	Alta Collins	UTLCAC	10
UT	Little Cottonwood Canyon	Atwater	UTLCAW	13

Refer to section 8 of the SnowEx 2021 Experimental Plan for additional details specific to each time-series site.

2.2 Acquisition

Measurements were made using a standard snow pit kit, which included 250 and 1000 cc Snowmetrics wedge-type density cutters, a digital scale, pocket microscope and 2mm gridded crystal cards for manual grain size, and digital thermometers. The dielectric constant was measured using a A2 Photonic WISe LWC sensor. In most cases, sensor serial numbers were recorded in the site details file. LWC was calculated using the below formulas 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/cm^3), averaged over all measurements taken at that layer; and W_v is the volumetric liquid water content. In practice, the following iteration was used to compute W_v:

Start with $W_v = 0$ and repeat 5 times $D_s = D - W_v$

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

For each layer, an average density was computed from the observations and used with each permittivity measured at that layer to compute LWC. For more information on the snow pit protocol, measurement details, and in-field instructions refer to the SnowEx 2021 Experimental Plan or the snow pit sheet template field protocol tabs.

2.3 Processing

Measurements and observations were recorded in handwritten snow pit sheets before being transcribed to electronic sheets. After all records in the data set were verified, transcription errors were manually corrected. Corrections broadly fall into categories of:

General Processing:

- Fixing general transcription errors.
- Making nomenclature consistent with field protocol.
- If blank, fill in the Height of Snow (HS) field using the density profile snow height.
- Correcting formatting errors that may interfere with automated scripts.
- Incorporating all handwritten comments on data sheets.

- Adjusting any positive snow temperature value recorded above 0 cm to 0 deg C if the temperature was within the error (+/- 1 deg C) of the thermometer and above the ground surface (0 cm).
- Removing unrealistic permittivity profile values. Any value >3 recorded with the A2 WISe LWC sensor was removed and noted in the revisions log.
- Grain sizes removed if given to an Ice Lens (IF).
- Converting field times to Standard Time to best overlap with airborne instrumentation methods. This means that any pit after March 14th, 2021, became minus 1-hour from the recorded field time.

Specialized Processing

- Stratigraphy and grain metamorphism review. In many cases, sites had difficulties when it came to the complications during the springtime transition where there was some confusion in identifying Rounded Grains (RG) to Melt Forms (MF). Keeping spatial variability in mind and knowing that the two grain types share similar geometry, reviewers concentrated on identifying instances where repeated layers alternated RG and MF throughout short time periods, since a transition of MF to RG is extremely unlikely over a weeklong interval. In cases of extreme uncertainty grain type data were removed and noted in the revision log, while other cases were able to be handled based on comments, discussion with observers, or additional photographs of grains.
- Flagging data as needed (Table 10) to support cases where the field sampling protocol deviated, or data users should consider how data were generated before proceeding with analysis.

Automated Parameter File

- Parameter files are generated by an automated script that extracts parameter information from the electronic pit sheets (.xlsx).
- Bulk density averages are computed using a weighted average given the 10cm sampling depth and dual sampling profile. If a 3rd density sample was collected it is averaged with the second (‘B’) profile prior to computing a layer average for both profile A and B. Where density sampling ends above the ground interface, the bottom few centimeters are extrapolated using the lowest recorded density sample for the bulk SWE calculation (e.g. 16-6 cm becomes 16-0 cm).

The data were then visually inspected for completeness and validity of data values. The majority of the quality control process was dedicated to reviewing the snow pit stratigraphy categories. See the Revisions file for a complete list of all edits/corrections.

2.4 Instrumentation

Table 9 lists all instruments used to record measurements for this data set.

Table 9. Instrument Specifications

Instrument	Brand	Measurement	Specs
Global Positioning System (GPS) field unit	Garmin rhino 755T and/or personal cell phones	Latitude, Longitude / Easting, Northing, UTM zone	horizontal error +/- 3 m in open, +/- 10 m in trees
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	+/-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	+/- <1% 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	+/- <1% volume, 5 x 10 x 10 cm wedge-shaped cutter
Macroscope	RF Insterscience 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	for measure snow height (HS), stratigraphic boundary heights, layer thickness,	2 m fiberglass folding rule, mm graduations

2.5 Quality, Errors, and Limitations

The SnowEx 2021 Time Series campaign was a community led effort. The same protocol was distributed to all site leads and observer crews. Even with a standard protocol in place, human variability is a factor, especially when considering some of the more subjective snow property measurements. The large variety in snow climates and local terrain means subjective decisions could be different across sites. The data set authors acknowledge that human variability is a limitation in collecting manual snow measurements, but efforts were made to ensure consistency in data collection methods between sites.

Data flags were assigned to some pits where close inspection of the raw data (available in .jpg files _book1 and _book2) is recommended before analysis. Flags note when there were deviations from the protocol or when observer comments are particularly useful for interpreting data. Flag codes

are listed in the comments portion of the electronic pit sheets and included in the header information of each parameter file. The flag code is also a column in the Comprehensive Data Set Summary file and can be used to filter snow pits. Table 10 outlines the flag codes, flag descriptions, and recommended amendments before analysis.

Table 10. Data Usage and Flag Information

Flag Code	Flag Description	Recommended Amendments
Density		
TDG	Top density gap - density profile starts at least 3 cm below recorded HS and has no further comments to explain the measurement gap.	Look at the corresponding stratigraphic layers and decide if the available density measurements are applicable or not depending on the layer hardness and grain size.
MDG	Middle density gap - density measurement has a gap within the profile.	Use comments to inform as to why measurement intervals were not continuous.
BDG	Bottom density gap - density profile ends above 10 cm, and SWE has been calculated using a density value from 10 cm or above.	Evaluate if the SWE interpolation to the ground with the given density is valid for your analyses.
Stratigraphy		
STCom	Stratigraphy comments - There is additional significant information in the comments column that could contribute to better understanding of the snow profile.	It is advised you look closely at the comments section.
STLay	Stratigraphy Layer - a layer was recorded in the field notes, but could not be added to the profile because no thickness was specified. See comments column for description of snow properties.	It is advised you look closely at the comments section, and evaluate whether or not the described feature(s) would show up in remote sensing/be relevant to your analyses.
MW	Manual Wetness - Examine/evaluate manual wetness values	Compare manual wetness values observed in the field to other snow properties (temperature, density) and assess whether or not the reported MW is reasonable for your purposes.

General		
AD	Additional Data - on this date at this site, additional data (outside of standard pit protocol) were collected.	Review the pit book photos (.jpgs) or contact the site PI for additional information. In some cases, the data may be in a separately published dataset available at NSIDC. Note this flag is not used to mark ALL occurrences of coincident field observations with unique instruments, but denotes any that have handwritten notes in the pit book images.
Note: the flag code, if applicable can be found in the last header line in all parameter files.		

3 VERSION HISTORY

Table 11. Version History Summary

Version	Release Date	Description of Changes
1	June 2024	Initial release

4 RELATED DATA SETS

SnowEx at NSIDC | Data sets
SnowEx20 Time Series Snow Pit Measurements, Version 1

5 RELATED WEBSITES

NASA SnowEx
NSIDC SnowEx | Overview

6 ACKNOWLEDGMENTS

This data set would not be possible without all the work of the time series leads (D. McGrath, A. Gleason, M. Skiles, E. Sproles, K. Elder, HP. Marshall) and their field crews. The authors are extremely grateful for everyone who participated at all the time series sites. Thank you for the time spent traveling to and from sites, taking snow pit measurements, entering data, and responding to reviewers' questions. The authors would also like to thank the tremendous logistic support provided by ATA Aerospace.

An immense effort was taken to standardize the snow pit data to create this legacy validation/calibration ground-based data set to study a wide variety of snow properties through

time. This was a collaborative QA/QC review effort shared amongst the following people: Megan Mason, Dylan Craaybeek, Kelly Elder, Carrie Vuyovich, and Hans-Peter Marshall. This group spent hours manually comparing and deciphering raw data sheets and matching them to the electronic pit sheets submitted by observation crews or generating electronic pit sheets if they were added post campaign work. In several cases methods needed to be verified with site leads and repeat observers to ensure accurate interpretation of data collection and local terminology used between a variety of field observers with various backgrounds and prior snow science experience.

7 REFERENCES

NASA SnowEx 2021 Experimental Plan

8 DOCUMENT INFORMATION

8.1 Publication Date

June 2024

8.2 Date Last Updated

June 2024