SnowEx20 Grand Mesa IOP Lidar and GPR-Derived Snow Water Equivalent and Snow Density, Version 1

USER GUIDE

How to Cite These Data

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

Meehan, T. G. and A. Hojatimalekshah. 2024. *SnowEx20 Grand Mesa IOP Lidar and GPR-Derived Snow Water Equivalent and Snow Density, Version 1* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/LANQ53RTJ2DR. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX20_GM_SWE_SD

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

This data set contains snow depth, snow water equivalent (SWE), and snow density raster data derived from airborne lidar snow depth data and ground penetrating radar (GPR) two-way travel times. Spatially distributed SWE and snow density data were produced using a Multiple Linear Regression machine learning model. The data set represents snow-on conditions during the NASA SnowEx 2020 field campaign in Grand Mesa, Colorado in January 2020. Input data were sourced from several previously published data sets, including: ASO L4 Lidar Point Cloud Digital Terrain Model 3m UTM Grid, Version 1, SnowEx20 Grand Mesa IOP QSI Lidar Snow Depth Data, Version 1, SnowEx20 Grand Mesa IOP UNM 800 and 1600 MHz MALA GPR, Version 1, and SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR, Version 1.

1.2 File Information

1.2.1 Format

Data is provided in two comma-separated values (.csv) file and two GeoTIFF (.tif) files.

1.2.2 Naming Convention

The data set comprises four files, named:

```
SNEX20_GM_SWE_SD_Lidar-GPR_20200201_v01.0.csv
SNEX20_GM_SWE_SD_Lidar_Predictors_20200201_20200202_v01.0.csv
SNEX20_GM_SWE_SD_SnowDensity_20200201_v01.0.tif
SNEX20_GM_SWE_SD_SWE_20200201_v01.0.tif
```

They are named according to the following conventions and as described in Table 2:

```
SNEX20_GM_SWE_SD_[parameter]_[MMDDYYYY]_v01.[file extension]
SNEX20_GM_SWE_SD_[parameter]_[MMDDYYYY_MMDDYYYY]_v01.[file_extension]
```

Table 1. File Naming Convention

Variable	Description
SNEX20_GM_SWE_SD	SnowEx 2020 Grand Mesa Snow Water Equivalent and Snow Density
parameter	Data type: Lidar-GPR, SWE, SnowDensity, or Lidar_Predictors
MMDDYYYY or MMDDYYYY_MMDDYYYY	Date range, formatted as two-digit month, two-digit day, and 4-digit year.

Variable	**Description**
`v01`	Data set version
`File_extension`	File extension, either `.csv` or `.tif`

1.2.3 File Contents

The data files below are discussed in the order in which they were processed (see Section 2.3):

`SNEX20_GM_SWE_SD_Lidar-GPR_20200201_v01.0.csv` contains the snow density and SWE data used as training data used as training data for the distributed snow depth machine learning model. This file includes the following variables:

Table 2. Variables in SNEX20_GM_SWE_SD_Lidar-GPR_20200201_v01.0.csv

Variable	**Description**
Index	Data point identification number
X (WGS84 UTM 12N)	X coordinate of the data point measured in UTM
Y (WGS84 UTM 12N)	Y coordinate of the data point measured in UTM
TWT (ns)	Two-way travel time measured in nanoseconds
Depth (cm)	Snow depth measured in cm
Density (kg/m3)	Snow density measured in kg/m3
SWE (mm)	Snow water equivalent measured in mm
Velocity (m/ns)	Radar wave velocity
Permittivity	Snow dielectric permittivity

`SNEX20_GM_SWE_SD_Lidar_Predictors_20200201_20200202_v01.0.csv` contains columnized raster data which represents the lidar-derived, normalized predictor variables produced by the machine learning algorithm. Note: this file is too large to view with the most common programs used for reading .csv files. The file can be previewed using a data-wrangling tool such as OpenRefine. Figure 1 below shows a subset of the data, while Table 3 describes the variables.

X (WGS84 UTM 12N)	Y (WGS84 UTM 12N)	c	Hs	aspctHs	slpHs	dyHs	dxHs	Zs	aspctZs	slpZs	dyZs	dxZs	Zg	aspctZg	slpZg	dyZg	dxZg	Hveg	Sveg
741499.049981986	4324988.65068641	1	0.4485	0.965011	-1.4584	0	0	-0.68	0.28409	1.1798	0.142	1.3284	-0.6	0.1983579	0.3617	0.2239	0.5176	0.23217	-0.0426
741499.049981986	4324987.65040061	1	0.4485	0.965011	-1.4537	0	0	-0.68	0.29718	1.2271	0.142	1.3325	-0.6	0.2324417	0.5057	0.2239	0.5853	0.25648	-0.0449
741499.049981987	4324986.65011482	1	0.4774	0.966620	-1.4537	0	0	-0.68	0.29749	1.2271	0.142	1.3325	-0.6	0.2524257	0.5634	0.2239	0.5893	0.28637	-0.0472
741499.049981987	4324985.64982902	1	0.3965	0.984487	-1.4573	0	0	-0.68	0.29749	1.1798	0.142	1.3325	-0.6	0.2524257	0.5634	0.2239	0.5893	0.30786	-0.0495
741499.049981986	4324984.64954322	1	0.2346	0.992689	-1.4573	0	0	-0.68	0.29749	1.13357	0.142	1.3325	-0.6	0.2524257	0.5634	0.2239	0.5893	0.31346	-0.0518
741499.049981987	4324983.64925743	1	0.2057	0.984487	-1.4690	0	0	-0.68	0.29749	1.13357	0.142	1.3325	-0.6	0.2524257	0.5634	0.2741	0.5893	0.31066	-0.0541
741499.049981986	4324982.64897163	1	0.1502	0.984487	-1.4690	0	0	-0.68	0.29749	1.13357	0.285	1.3325	-0.6	0.2524257	0.5634	0.3667	0.5893	0.30786	-0.0562
741499.049981987	4324981.64868584	1	0.1502	0.984487	-1.4690	0	0	-0.68	0.29749	1.13357	0.567	1.3325	-0.6	0.2524257	0.5634	0.4247	0.5893	0.30824	-0.0583

Figure 1. Subset of SNEX20_GM_SWE_SD_Lidar_Predictors_20200201_20200202_v01.0.csv.

Table 3. Variables in SNEX20_GM_SWE_SD_Lidar_Predictors_20200201_20200202_v01.0.csv

Variable	Description
X (WGS84 UTM 12N)	X coordinate of the data point measured in UTM
Y (WGS84 UTM 12N)	Y coordinate of the data point measured in UTM
c	1
Hs	Lidar derived snow depth (m)
aspctHs	Aspect of the snow depth
slpHs	Slope of the snow depth
dyHs	Y (north) derivative of the snow depth
dxHs	X (east) derivative of the snow depth
Zs	Elevation of the snow surface measured in meters above sea level using the Geoid12B geoid height
aspctZs	Aspect of the snow surface elevation
slpZs	Slope of the snow surface elevation
dyZs	Y (north) derivative of the snow surface elevation
dxZs	X (east) derivative of the snow surface elevation
Zg	Elevation of the bare ground surface measured in meters above sea level using the Geoid12B geoid height
aspctZg	Aspect of the ground surface elevation
slpZg	Slope of the ground surface elevation
dyZg	Y (north) derivative of the ground surface elevation
Hveg	Height of vegetation as segmented from the ASO 2016 lidar point cloud data
Sveg	Distance to the nearest vegetation taller than 0.5 meters.

`SNEX20_GM_SWE_SD_SnowDensity_20200201_v01.0.tif` contains rasterized, spatially-distributed snow density data (represented in kg/m^3). `SNEX20_GM_SWE_SD_SWE_20200201_v01.0.tif` contains rasterized, spatially distributed snow water equivalent (SWE) datam (represented in mm).

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 39.039456º N

Southernmost Latitude: 39.009209º N

Easternmost Longitude: 108.157747° W

Westernmost Longitude: 108.210920° W

1.3.2 Resolution

Varies

1.3.3 Geolocation

The following tables provide information for geolocating this data set

Table 4. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	WGS 84 / UTM zone 12N
Longitude of true origin	-111
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	32612
PROJ4 string	+proj=utm +zone=12 +datum=WGS84 +units=m +no_defs
Reference	http://epsg.io/32612

1.4 Temporal Information

1.4.1 Coverage

01 February 2020 to 02 February 2020

1.4.2 Resolution

Varies

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Previously published airborne lidar and ground-based GPR data collected during the NASA SnowEx 2020 Grand Mesa, Colorado Intensive Observation Period (IOP), as well as airborne lidar data collected in 2019 as part of the Airborne Snow Observatory (ASO) project, were used to derive new snow depth, snow density, and snow water equivalent (SWE) data. These Input data sets are: SnowEx20 Grand Mesa IOP QSI Lidar Snow Depth Data, Version 1, SnowEx20 Grand Mesa IOP UNM 800 and 1600 MHz MALA GPR, Version 1, SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR, Version 1, and ASO L4 Lidar Point Cloud Digital Terrain Model 3m UTM Grid, Version 1. Newly calculated GPR two-way travel time (TWT) estimates were combined with lidar-based snow depth data to generate along-transect snow density. Machine learning algorithms were then used to calculate spatially distributed estimates of snow density and snow water equivalent.

2.2 Acquisition

Input lidar data acquired as part of the ASO project were collected using a Riegl LMS-Q1560 airborne scanning lidar flown at a constant altitude. Snow-free data collected during the September 26, 2016 flight was selected for use as input data. For more details see Painter et al. (2016).

Input lidar data acquired during the SnowEx 2020 IOP were collected using a RIEGL VQ-1560i airborne scanning lidar mounted on a twin-turboprop Beechcraft King Air aircraft. Snow-on data collected during the February 1, 2020 flight was selected for use as input data. For more details see the SnowEx 2020 Snow-On, Colorado and Idaho Lidar Technical Data Report.

GPR data were collected using two methods: 1) with a Sensors & Software pulseEKKO PRO 1 GHz GPR unit towed approximately 5 m behind a snowmobile, or 2) with a MALA Geosciences Professional Explorer (ProEx) GPR unit towed behind a skier. Additional details about GPR data collection and instrumentation can be found in the SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR, Version 1 User Guide and the SnowEx20 Grand Mesa IOP UNM 800 and 1600 MHz MALA GPR, Version 1 User Guide.

2.3 Processing

Two-way travel time data was calculated using a new method which maximizes the coherence between co-polarized and cross-polarized GPR channels. TWT data was used in conjunction with lidar-derived snow depths to calculate snow density estimates along the GPR tracks (provided in

SNEX20_GM_SWE_SD_Lidar-GPR_20200201_v01.0.csv). These estimates were used to train a Multiple Linear Regression model. The trained model was then used to predict average snow density over the entirety of the study area for which lidar coverage is available (provided in SNEX20_GM_SWE_SD_Lidar_Predictors_20200201_20200202_v01.0.csv and SNEX20_GM_SWE_SD_SWE_20200201_v01.0.tif). This spatially distributed snow density model data was used in conjunction with the lidar snow depth estimates to also produce spatially distributed SWE data (provided in SNEX20_GM_SWE_SD_SWE_20200201_v01.0.tif). A detailed description of the data processing methods is available in Meehan et al. (2024).

Note: All data, regardless of input data acquisition date, were detrended to represent a single time frame of February 1-2, 2020.

Complete details on input data processing can be found in the documentation linked in Section 2.2.

2.4 Quality, Errors, and Limitations

Accuracy of the TWT data was estimated by comparing data collected where GPR transects overlapped (N = 870, R = 0.78, RMSE = 0.9 ns). Lidar-based snow depths were compared with the snow depths estimated from the GPR TWT derived snow density estimates and were in agreement (R = 0.74, RMSE = 11 cm). However, the modeled density values do show spatial variability arising from local wind conditions, terrain, and vegetation. The calculated SWE estimates were compared with SWE values (available as SnowEx20 Grand Mesa Intensive Observation Period Snow Pit Measurements, Version 1) which were manually measured at individual snow pits within the study site (N = 96, R = 0.78, RMSE = 41 mm). A detailed description of the methods used to evaluate data accuracy and error is available in Meehan et al. (2024).

Details on input data quality can be found in the documentation linked in Section 2.2.

3 VERSION HISTORY

Table 5. Version History Summary

Version	Date Implemented	Impacted Temporal Coverage	Description of Changes
v01.0	July 2024	01 February 2020 – 02 February 2020	Initial early data release at Basic Level of Service
v01.0	August 2024	01 February 2020 – 02 February 2020	Update to Standard Level of Service

4 RELATED DATA SETS

SnowEx20 Grand Mesa IOP QSI Lidar Snow Depth Data, Version 1

SnowEx20 Grand Mesa IOP UNM 800 and 1600 MHz MALA GPR, Version 1

SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR, Version 1

ASO L4 Lidar Point Cloud Digital Terrain Model 3m UTM Grid, Version 1

SnowEx20 Grand Mesa Data Sets

5 RELATED WEBSITES

NASA SnowEx

NSIDC SnowEx | Overview

6 ACKNOWLEDGMENTS

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7 REFERENCES

Painter, T. H., Berisford, D. F., Boardman, J. W., Bormann, K. J., Deems, J. S., Gehrke, F., … Winstral, A. (2016). The Airborne Snow Observatory: Fusion of scanning lidar, imaging spectrometer, and physically-based modeling for mapping snow water equivalent and snow albedo. Remote Sensing of Environment, 184, 139–152. https://doi.org/10.1016/j.rse.2016.06.018

Meehan, T. G., Hojatimalekshah, A., Marshall, H.-P., Deeb, E. J., O'Neel, S., McGrath, D., Webb, R. W., Bonnell, R., Raleigh, M. S., Hiemstra, C., and Elder, K.: Spatially distributed snow depth, bulk density, and snow water equivalent from ground-based and airborne sensor integration at Grand Mesa, Colorado, USA, The Cryosphere, 18, 3253–3276, https://doi.org/10.5194/tc-18-3253-2024

8 DOCUMENT INFORMATION

8.1 Publication Date

August 2024

8.2 Date Last Updated

August 2024