SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR CMP Snow Water Equivalent, Version 1

USER GUIDE

How to Cite These Data

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

Meehan, T. G. 2021. *SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR CMP Snow Water Equivalent, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/SOFEX3867ECJ. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX20_BSU_CMP_SWE

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

This data product is derived from *SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR CMP Travel Times, Version 1*; which itself is derived from *SnowEx20 Grand Mesa IOP BSU Multi-polarization 1 GHz GPR CMP Raw, Version 1*.

1.1 Parameters

This data set contains estimates of snow depth, snow density and snow water equivalence (SWE) retrieved from radar travel-times of Ground Penetrating Radar (GPR) Common-Mid-Point (CMP) measurements. Table 1 lists the full list of data columns.

1.2 File Information

1.2.1 Format

Data are provided in comma-separated values (.csv) format and accompanied by figures in portable network graphics (.png) format.

1.2.2 File Contents

Each .csv file contains 17 or more data columns with the initial row of the .csv file being the column headers. Column titles, data type and descriptions are given in Table 1.

Table 1. Data Columns

Column number	Column title	Data Type	Description [unit]
1	UTCyear	integer	Year of data acquisition in Coordinated Universal Time [YYYY]
2	UTCdoy	integer	Day of year of data acquisition in Coordinated Universal Time [dd]
3	UTCtod	float	Time of day of data acquisition in Coordinated Universal Time [HHMMSS.sss]
4	UTMzone	string	Universal Transverse Mercator (UTM) time zone of data acquisition (12S). See “Section 1.3.3 | Geolocation” for more details.
5	Easting	float	UTM Easting (X) Coordinate [m]
6	Northing	float	UTM Northing (Y) Coordinate [m]

Column number	Column title	Data Type	Description [unit]
7	Elevation	float	EGM96 elevation corrected for geoid and antenna height [m a.s.l.]
8	t0LMO1	float	Zero offset radar one-way travel-time of the snow surface wave [ns]
9	vLMO1	float	Radar wavespeed of the snow surface wave [m/ns]
10	zLMO1	float	Depth of surface wave [cm] - approximated as vLMO/f where f is central radar frequency (1 GHz)
11	rhoLMO1	float	Average density of surface snow [kg/m3] - approximated using Complex Refractive Index Method (CRIM) equation
12	sweLMO1	float	Snow Water Equivalent contained in the near-surface snow [mm]
13	t0NMO1	float	Zero offset radar two-way travel-time of reflection 1 [ns]
14	vNMO1	float	Bulk radar wave-speed of snow up to reflection 1 [m/ns]
15	zNMO1	float	Depth of radar reflection [cm]
16	rhoNMO1	float	Average density of snow overlying reflection 1 [kg/m3]
17	sweNMO1	float	Snow Water Equivalent overlying reflection 1 [mm]
Note: If more than one reflection was picked on the CMP gather, additional columns are appended to the data (e.g. sweNMO2). The last picked reflection is always the ground reflection.			

Columns 8-17 are statistical distributions of the respective parameters that were determined by linear regression with Monte Carlo bootstrapping. 250 Monte Carlo simulations generated these distributions. Columns 1-7 contain the CMP metadata for each Monte Carlo simulation.

The ground reflection was picked in each of the CMP gathers, such that the bulk properties of the entire snowpack are estimated. If internal snowpack reflections were picked, NMO parameters are ordered by increasing t0NMO, such that the ground reflection parameter distributions will be last.

1.2.3 Naming Convention

The data files follow the following naming convention with details described in Table 2.

`SNEX20_BSU_CMP_SWE_[ddmmyyyy]_CMP[n]_HH.[ext]`

Table 2. File Naming Convention

Variable	Description
SNEX20_BSU_CMP_SWE	SnowEx 2020 field campaign Boise State University Common-Mid-Point Snow Water Equivalent data
[ddmmyyyy]	Day, month and year of data acquisition
CMP[n]	CMP number, see detailed description on data acquisition location in Table 3
HH	Polarization referring to HH (horizontal transmitted and horizontal received)
.[ext]	File type: .csv (data file) or .png (quick look)

Example: `SNEX20_BSU_CMP_SWE_01312020_CMP2_HH.csv`

Note: SWE data files (.csv) are only reported for the HH polarization. Quick look figures (.png) are provided as browse files.

Each date and CMP number combination refers to a specific snow pit and data acquisition location described in Table 3:

Table 3. Data Acquisition Details

Data Acquisition Date	CMP[n]	Snow Pit	Data Acquisition Location
01312020	CMP1	2N12	On the groomed snowmobile road.
01312020	CMP2	2N12	In fresh snow behind the pit wall after all other snow observations were acquired.
01312020	CMP3	2N12	In the right rut of the Small Unit Support Vehicle (SUSV) track.
02012020	CMP1	1S8	In the right rut of the SUSV track.
02012020	CMP2	1S8	In the left rut of the SUSV track.
02012020	CMP3	1S8	In fresh snow behind the pit wall after all other snow observations were acquired.
Note: See APPENDIX A for details on the snow pit naming convention			

1.3 Spatial Information

1.3.1 Coverage

Data were collected in two separate point locations within the Grand Mesa, Colorado study area:

- 31 January 2020: 39.034670° N, 108.198261° W

- 01 February 2020: 39.021584° N, 108.197754° W

1.3.2 Resolution

Point measurements with depth resolution of approximately 0.025 m.

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 12 North
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	https://epsg.io/32612

NOTE: Users should be aware that UTM Grid Zone 12S falls within the projected coordinate system WGS 84 / UTM Zone 12 North. The plain text files indicate that all geographic coordinates fall within UTM Grid Zone 12S. This designation corresponds to the intersection of longitudinal projection zone 12 and latitudinal projection zone S, as shown in Figure 1.

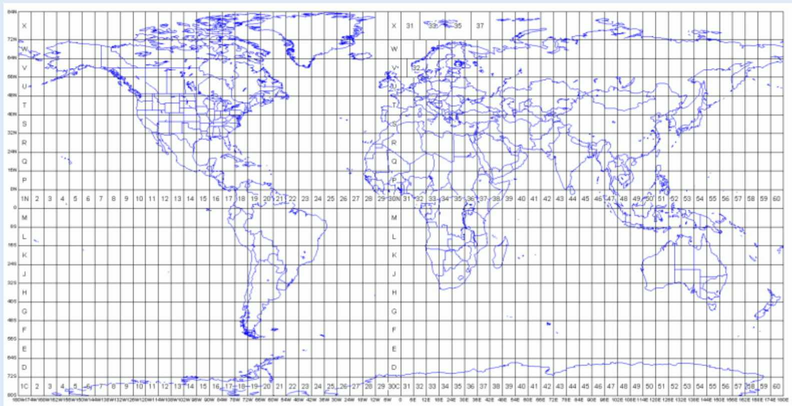

Figure 1. UTM Grid Zone

1.4 Temporal Information

1.4.1 Coverage

31 January 2020 to 01 February 2020

1.4.2 Resolution

N/A

2 DATA ACQUISITION AND PROCESSING

2.1 Background

This data set was collected during the 2020 NASA SnowEx Intensive Observation Period at Grand Mesa, Colorado. These data estimate snow depth, snow density, and snow water equivalence (SWE) from radar travel-times, and may also be used to validate airborne snow observations.

2.2 Acquisition

Radar imagery was acquired using the Sensors & Software pulseEKKO PRO 1 GHz ground-penetrating radar. Multi-offset gathers were collected by placing the antennas on the snow surface and expanding the antenna separation about a fixed midpoint out to 2 m offset. CPR gathers were collected in HH (horizontal transmitted and horizontal received) and HV (horizontal transmitted and vertical received) polarizations.

2.3 Processing

Probability distributions of snow depth, density, and SWE were generated by least-square regression of the travel-time versus offset data. A link for the travel-time and offset data is given in "Section 5 | Related Data Sets". Regression was performed in a Monte Carlo process with random re-sampling of the travel-time data. The snow parameter distributions were created from 250 Monte Carlo simulations.

2.4 Quality, Errors, and Limitations

Data quality and errors can be ascertained from the snow parameter distributions. These data represent the average of the snow above the selected travel-time moveout curve. For the snow surface wave (LMO) the depth of averaging is assumed to be one wavelength. For the ground reflection (NMO) these data estimate the average snowpack properties within the length of the CMP array (2 m).

2.5 Instrumentation

2.5.1 Description

Data were collected using a Sensors & Software pulseEKKO PRO 1 GHz ground-penetrating radar.

3 SOFTWARE AND TOOLS

CSV files can be accessed using software that reads ASCII text.

4 VERSION HISTORY

Table 5. Version History Summary

Version	Release Date	Description of Changes
1	04 Feb 2021	initial release

5 RELATED DATA SETS

SnowEx at NSIDC| Data Sets
SnowEx20 Grand Mesa IOP BSU Multi-polarization 1 GHz GPR CMP Raw
SnowEx20 Grand Mesa IOP BSU 1 GHz Multi-polarization GPR CMP Travel Times

6 RELATED WEBSITES

SnowEx at NSIDC | Overview
NASA SnowEx

7 CONTACTS AND ACKNOWLEDGMENTS

Tate G. Meehan

Boise State University

8 REFERENCES

Meehan, T.G., H.P. Marshall, J.H. Bradford, R.L. Hawley, T.B. Overly, G. Lewis, K. Graeter, E. Osterberg, and F. McCarthy. 2020. Reconstruction of historical surface mass balance, 1984–2017 from GreenTrACS multi-offset ground-penetrating radar. *Journal of Glaciology* 1–10. https://doi.org/10.1017/jog.2020.91

9 DOCUMENT INFORMATION

9.1 Publication Date

February 2021

9.2 Date Last Updated

February 2021

APPENDIX A – SNOWEX GRAND MESA IOP SNOW PIT NAMING CONVENTION DESCRIPTION

The SnowEx Grand Mesa Intensive Observation Period (IOP) 2020 snow pits were used to validate snow remote sensing on Grand Mesa. Snow pits were selected to cover the full range of conditions found on Grand Mesa, from meadows to dense forests and from shallow snow depths to deep snowpack.

Potential Grand Mesa snow conditions were evaluated based on SnowEx 2017 airborne lidar and optical imagery (Figure A1). Specifically, the Airborne Snow Observatory's 08 February 2017 lidar-derived snow depths (ASO L4 Lidar Snow Depth 3m UTM Grid, Version 1) were binned into three classes: shallow (<90 cm), intermediate (90-122 cm), and deep (>122 cm). A tree density map created from November 2010 WorldView-2 imagery was also binned into three classes based on the percentage of tree-class pixels within a 50 m radius: treeless (0%), sparse (1-30%), and dense (31-100%). The two factors were combined to form a nine-point snow and tree matrix (Figure A1). Within this matrix, values 1-3, 4-6, and 7-9 represent treeless, sparse, and dense tree areas, respectively. These three ranges can be further subdivided into three categories of snow depth classification: shallow (lowest number in a range, e.g. 1), intermediate, and deep (highest number in a range, e.g. 3). Treeless areas were not split into shrub or meadow cover types. Water bodies and missing lidar data remain unclassified (grey areas in Figure A1).

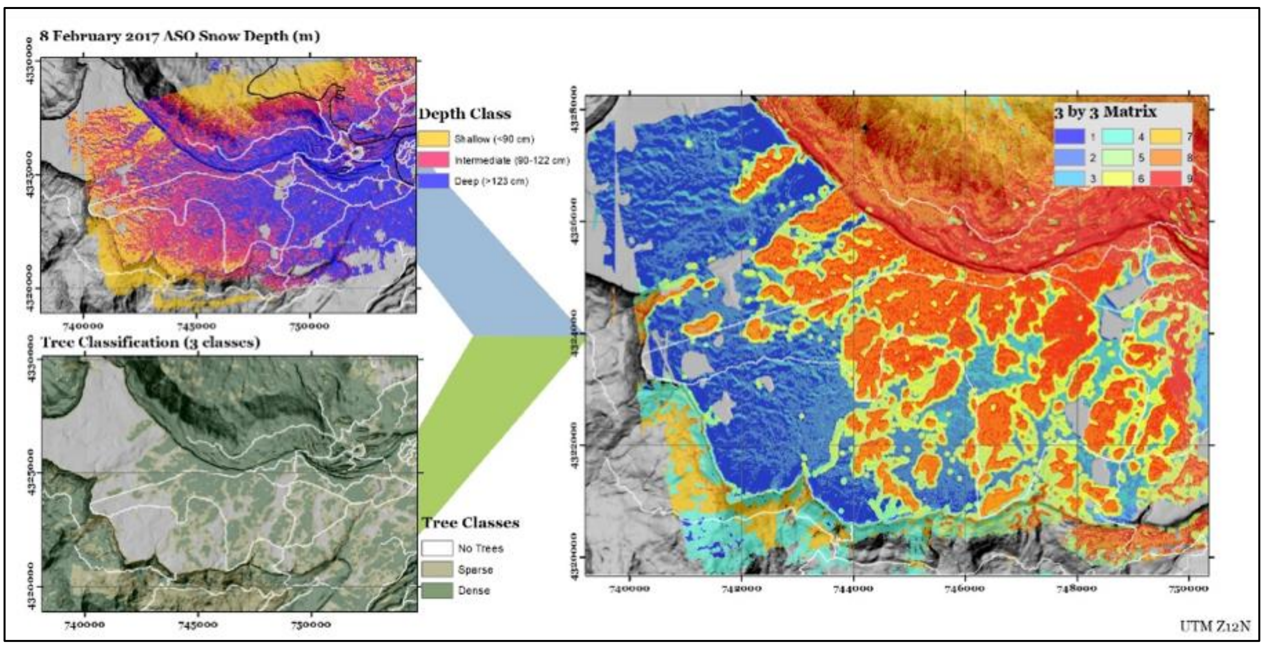

Figure A1. Separate vegetation and snow depth classifications for the Grand Mesa IOP study site are shown (left). These classifications were combined to form the final tree density and snow depth matrix used to describe snow pit locations (right). In all images, gray areas represent undefined regions (e.g. water bodies).

Finally, the Grand Mesa IOP study site was clipped into three flight lines (north, N; south, S; and cross, C) (Figure A2). These flight lines correspond to the scheduled IOP airborne observations.

Within the flight lines, 150 snow pit locations (approximately three weeks of work) were proportionally divided by the nine matrix classes, then randomly distributed amongst the three flight lines for each matrix class (Figure A2). Matrix classes were not evenly represented and varied in frequency; for example, there are 3 Class 4 snow pits and 33 Class 2 snow pits. Snow pit names use the following convention, as described in Table A1:

```
<matrix>[FlightLine]##
```

Table A1. Snow Pit Naming Convention Description

Variable	**Description**
Matrix	Number describing the measurement site conditions. Each number contains information about the amount of vegetation around the snow pit: • 1/2/3 = treeless (0% tree cover) • 4/5/6 = sparse (1-30% tree cover) • 7/8/9 = dense (31-100% tree cover) and the relative, expected snow pit depth: • 1/4/7 = shallow snowpack • 2/5/8 = medium snowpack • 3/6/9 = deep snowpack
[FlightLine]	Indicates on which flight line the snow pit resided: • N = North • S = South • C = Crossline
##	Pit ID number. Numbers are lowest in the West and North and increase incrementally by whole numbers as you move further East or South along a particular flight line.

For example, Pit “9S40” denotes matrix class 9 (deep snow and dense trees), South flight line, and the 40th total pit on the South line from west to east. Similarly, Pit “1C14” denotes matrix class 1 (shallow snow and no trees), Cross line, and the 14th pit along the Cross line from Northwest to Southeast.

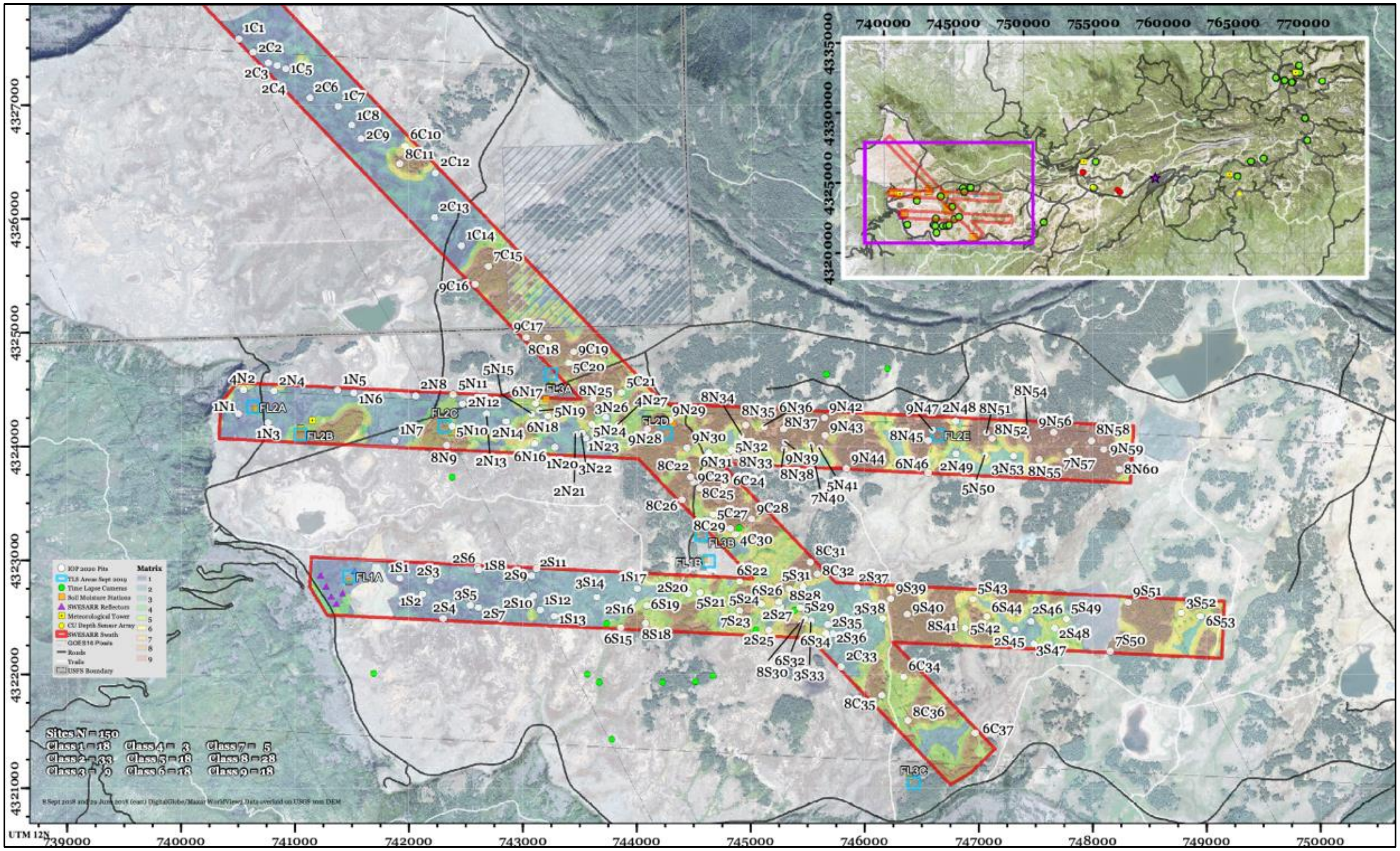

Figure A2. Location of the 150 Grand Mesa IOP snow pits. Snow pits were randomly spaced along the North (upper horizontal line), South (lower horizontal line), and Cross (diagonal line) flight lines, along which airborne measurements were collected. Snow pit naming conventions are described in Table A1. The inset in the top right shows the location of the IOP snow pits and flight lines relative to the rest of Grand Mesa and other SnowEx 2020 locations. Green dots show the location of time lapse cameras, red dots show the location of time series snow pits, yellow squares with black circles show the location of meteorological towers, and yellow circles show the location of snow depth sensors.