SnowEx20-21 Cameron Pass Derived Snowpack Relative Permittivities and Densities from Ground Penetrating Radar, Version 1

USER GUIDE

How to Cite These Data

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

Bonnell, R., D. McGrath, T.G. Meehan, H.P. Marshall, and R.W. Webb. 2024. *SnowEx20-21 Cameron Pass Derived Snowpack Relative Permittivities and Densities from Ground Penetrating Radar, Version 1* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/W0EJNWUZBYSL. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX20_COCP_SPD

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

This data set contains the results of ground-penetrating radar surveys conducted at Cameron Pass, Colorado during the SnowEx20 campaign. Data include two-way travel time, lidar-measured snow depth, derived snow water equivalent, derived snow density, and derived relative permittivity. Ground-penetrating radar two-way travel times were sourced from two previously published data sets: SnowEx20 Cameron Pass Ground Penetrating Radar, Version 1 and SnowEx21 Cameron Pass Ground Penetrating Radar, Version 1.

1.2 File Information

1.2.1 Format

All data is collected in a single comma-separated value (.csv) file.

1.2.2 File Contents

The .csv file contains 13 columns with the parameters listed in Table 1.

Table 1. Data Parameters

Name	Description	Unit/Format
Date[mmddyy]	Six-digit date, represented as two-digit month, two-digit day and the last two digits of year	[mmddyy]
Time_HHMMSS	Six-digit time, represented as two-digit hour, two-digit minute and two-digit seconds	[HHMMSS]
Longitude[DD]	Longitude	degree
Latitude[DD]	Latitude	degree
ElevationWGS84[mae]	Elevation	m
Easting[m]	Easting	m
Northing[m]	Northing	m
UTM_Zone	Universal Transverse Mercator time zone	N/A
TWT[ns]	Two-way travel time	ns
Depth[cm]	Snow depth	kg m^{-3}
SWE[mm]	Snow density	cm
Density[kg m-3]	Snow water equivalent	kg/m^3
Permittivity[unitless]	Permittivity	-

1.2.3 Naming Convention

The single data file is named `SNEX20_COCP_SPD_20191218_20210527.csv`. `SNEX20_COCP_SPD` refers to the SnowEx 2020 (`SNEX20`) Cameron Pass, Colorado (`COCP`) snow permittivity and density (`SPD`) data; `21091218_20210527` represents the start and ending date of the collected data.

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 40.5204° N
Southernmost Latitude: 40.5154° N
Easternmost Longitude: 105.8889° W
Westernmost Longitude: 105.8931° W

1.3.2 Resolution

3 meters

1.3.3 Geolocation

The following table provides information for geolocating this data set.

Table 2. Geolocation Details

Geographic coordinate system	**WGS 84**
Projected coordinate system	UTM zone 13N
Longitude of true origin	-105
Latitude of true origin	0
Scale factor at longitude of true origin	0.9996
Datum	WGS 84
Ellipsoid/spheroid	WGS 84
Units	meters
False easting	500000
False northing	0
EPSG code	32613
PROJ4 string	+proj=utm +zone=13 +datum=WGS84 +units=m +no_defs +type=crs
Reference	https://epsg.io/32613

1.4 Temporal Information

1.4.1 Coverage

18 December 2019 to 27 May 2021

1.4.2 Resolution

Input data was collected weekly, biweekly, or monthly depending on month and field site. Derived data were produced only when snow was on the ground and when a terrestrial lidar scan accompanied the ground-penetrating radar surveys

2 DATA ACQUISITION AND PROCESSING

2.1 Background

This data set contains snow water equivalent (SWE), snow density, and relative permittivity derived from ground-penetrating radar (GPR) surveys and terrestrial lidar scans conducted at Cameron Pass, Colorado during the SnowEx20 and SnowEx21 field campaigns. SnowEx20 GPR data were collected between 18 December 2019 and 12 March 2020 along three pre-determined transects that were surveyed weekly to monthly coinciding with NASA UAVSAR overflights. SnowEx21 GPR data were collected between 13 January 2021 and 27 May 2021 along two pre-determined lines that were surveyed weekly until late March, coinciding with NASA UAVSAR overflights, and then biweekly from April to May. GPR data from both SnowEx20 and SnowEx21 were previously published at the NSIDC DAAC: SnowEx20 Cameron Pass Ground Penetrating Radar, Version 1 and SnowEx21 Cameron Pass Ground Penetrating Radar, Version 1. The new data presented here represents a recalculation of the snow water equivalent (SWE), snow density, and relative permittivity using terrestrial lidar scan (TLS) data. The TLS data was collected between 25 April 2019 and 12 March 2020, also as part of the SnowEx20 field campaign, and can be accessed as SnowEx20 Cameron Pass UNAVCO Terrestrial Lidar Scans, Version 1. More information about the difference between these data and the previously published data can be found below.

Table 3. Comparison of SnowEx GPR data

Data Set	SNEX20_COCP_GPR, SNEX21_COCP_GPR	SNEX20_COCP_SPD
TWT spacing	10 cm	3 m
Snow Depth	Calculated from GPR two-way travel times	Calculated from terrestrial lidar scans

Relative Permittivity	Single value for each date; calculated from mean snow pit density	Spatially varying; derived from combined two-way travel times and snow depth
Snow Density	Single value for each date; calculated from mean snow pit density	Spatially varying; calculated from derived relative permittivity
SWE	Calculated from GPR snow depth multiplied by single snow density estimate (scalar)	Calculated from lidar snow depth multiplied by spatially varying snow density

2.2 Acquisition

Ground-penetrating radar (GPR) surveys were conducted using a Sensors and Software PulseEKKO PRO radar system and a shielded 1000 MHz antenna. The control unit and antenna were pulled in a plastic sled behind the operators, who were on snowshoes. Individual GPR traces were geolocated using a Emlid RS2 (L1/L2) GPS receiver that was mounted on the sled. Terrestrial lidar data was collected a tripod-mounted Riegl VZ-2000/6000 lidar scanning system.

2.3 Processing

Median two-way travel time data was calculated at 3 m spacing using input data from two previously published data sets: SnowEx20 Cameron Pass Ground Penetrating Radar, Version 1 and SnowEx21 Cameron Pass Ground Penetrating Radar, Version 1. The input data was aggregated to the 3 m lidar snow depth grid, with the median taken for each point. Grid cells that did not meet the minimum requirement of 15 two-way travel time measurements were removed. Coincident lidar snow depths were then used to calculate spatially distributed relative permittivity and snow density. SWE was calculated by multiplying the lidar snow depth by the derived snow density. A detailed discussion of the analytical methods used can be found in Bonnell et al., 2023.

2.4 Quality, Errors, and Limitations

To reduce uncertainty, relative permittivity values which fell outside the inter-quartile range were removed, and the remaining values were smoothed by using a 21 m x 21 m moving window median filter. Lidar snow depth uncertainty was estimated by calculating the standard deviation of the difference in elevation between bare-earth and snow-on DEMs (digital elevation models). For the two-way travel time data, uncertainty was measured by determining the mean within-pixel standard deviation for each survey date. Monte Carlo simulations were used to estimate the standard deviation of the two-way travel time and the mean snow depth. These estimates were then used to determine the mean and standard deviation of the derived relative permittivity and snow density data for each survey date. See Table 4 below for estimated uncertainty. Additional details about uncertainty estimations can be found in Bonnell et al., 2023.

Table 4. Calculated uncertainty for each survey date

Survey Date	n	Lidar Snow Depths (m)		TWT (ns)		Relative Permittivity		Snow Density (kg/m^3)	
		μ	σ	μ	σ	μ	σ	μ	σ
18 Dec 2019	59	0.66	0.10	5.42	0.80	1.55	0.125	289	59
26 Feb 2020	52	1.34	0.23	11.05	1.70	1.539	0.078	284	37
12 Mar 2020	212	1.34	0.31	11.39	2.68	1.632	0.056	328	26
10 Feb 2021	100	1.16	0.30	9.41	2.53	1.509	0.180	268	88
24 Feb 2021	109	1.10	0.38	9.49	3.17	1.695	0.103	357	47
22 Mar 2021	114	1.44	0.33	12.16	2.75	1.608	0.070	317	33
27 May 2021	99	0.67	0.26	6.54	2.92	2.163	0.444	-	-

3 VERSION HISTORY

Table 5. Version History Summary

Version	Release Date	Description of Changes
1	April 2024	Initial release

4 RELATED DATA SETS

SnowEx at NSIDC | Data Sets

SnowEx20 Cameron Pass Ground Penetrating Radar, Version 1

SnowEx21 Cameron Pass Ground Penetrating Radar, Version 1

SnowEx20 Cameron Pass Ground Penetrating Radar Raw

SnowEx21 Cameron Pass Ground Penetrating Radar Raw

SnowEx20 Cameron Pass UNAVCO Terrestrial Lidar Scans, Version 1

5 RELATED WEBSITES

SnowEx at NSIDC | Overview

Snow Ex at NASA

6 ACKNOWLEDGMENTS

Keith Williams collected and prepared the lidar point clouds that were used to derive snow depth. Original GPR collection was aided by Ella Bump, Caroline Duncan, Alex Olsen-Mikitowicz, and Lucas Zeller. Julia Grabowski aided in original GPR processing.

7 REFERENCES

Bonnell, R., McGrath, D., Hedrick, A. R., Trujillo, E., Meehan, T. G., Williams, K., Marshall, H.-P., Sexstone, G., Fulton, J., Ronayne, M. J., Fassnacht, S. R., Webb, R. W., & Hale, K. E. 2023. Snowpack relative permittivity and density derived from near-coincident lidar and ground-penetrating radar. Hydrological Processes, 37(10), e14996. https://doi.org/10.1002/hyp.14996

2 DOCUMENT INFORMATION

2.1 Publication Date

April 2024

2.2 Date Last Updated

April 2024