# SnowEx17 GPR and Lidar-Derived Snowpack Relative Permittivities and Densities, 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, R. W. Webb, K. E. Hale, T. G. Meehan, and H.P. Marshall. 2024. *SnowEx17 GPR and Lidar-Derived Snowpack Relative Permittivities and Densities, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/91X6GO5XNNEV. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/SNEX17_SD_Perm

# TABLE OF CONTENTS

# 1 DATA DESCRIPTION

## 1.1 Parameters

This data set contains the results of 1 GHz ground-penetrating radar surveys (GPR) conducted in Colorado, USA as part of the NASA SnowEx 2017 field campaign. Data was collected between 08 Feb 2017 to 25 Feb 2017 from Grand Mesa, a snow-covered, forested area about 40 miles east of Grand Junction. Data include two-way travel (TWT) time, lidar-measured snow depth, calculated snow water equivalent (SWE), calculated snow density, and calculated relative permittivity.

## 1.2 File Information

### 1.2.1 Format

Data are provided in a comma-separated value (.csv) format.

### 1.2.2 File Contents

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

Table 1. Data Parameters

| Column Heading | Description | Unit/Format |
|---|---|---|
| Date[mmddyy] | Date using six digits representing month, day, and year | [mmddyy] |
| Time[HHMMSS] | Six digits representing hour, minute, and second. For this data set, no time data was collected (listed as NaN). | [HHMMSS] |
| Longitude[DD] | Longitude | decimal degrees |
| Latitude[DD] | Latitude | decimal degrees |
| ElevationWGS84[mae] | Mean Absolute Elevation using World Geodetic System 1984 (WGS84) | m |
| Easting[m] | Easting | m |
| Northing[m] | Northing | m |
| UTM_Zone | Universal Transverse Mercator zone | N/A |
| TWT[ns] | Two-way travel time (through snow) | ns |
| Depth[cm] | Snow depth | cm |
| SWE[mm] | Snow water equivalent | mm |
| Density[kg m-3] | Snow density | kg / $m^3$ |
| Permittivity[unitless] | Snow permittivity | N/A |

### 1.2.3 Naming Convention

The data file is named: `SNEX17_SD_Perm_GM_GPR_20170208_20170225_v01.0.csv`. `SNEX17` refers to the SnowEx 2017 Field Campaign. `SD` refers to snow depth. `Perm` refers to relative permittivity. `GM` refers to the Grand Mesa, Colorado field site. `20170208_20170225` represents the start and end of the data set temporal coverage formatted as `MMDDYYYY`.

## 1.3 Spatial Information

### 1.3.1 Coverage

Northernmost Latitude: 39.1060° N

Southernmost Latitude: 39.0005° N

Easternmost Longitude: 107.8600° W

Westernmost Longitude: 108.2195° W

### 1.3.2 Resolution

Point measurements.

### 1.3.3 Geolocation

Table 2. Geolocation Details

| | |
|---|---|
| **Geographic coordinate system** | WGS84 |
| **Projected coordinate system** | WGS84 / UTM Zone 13 North |
| **Longitude of true origin** | -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** | 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

08 Feb 2017 to 25 Feb 2017.

### 1.4.2 Resolution

Data were collected coinciding with three consecutive ASO flight dates: 8, 16, and 25 February 2017.

# 2 DATA ACQUISITION AND PROCESSING

## 2.1 Background

This data set contains snowpack relative permittivities and densities derived from combining two-way travel times of snowpack thickness measured by ground-penetrating radar (GPR) and airborne lidar-measured snow depth. GPR two-way travel times were sourced from SnowEx17 Ground Penetrating Radar, Version 2, while the lidar measured snow depths were sourced from ASO L4 Lidar Snow Depth 3m UTM Grid, Version 1.

## 2.2 Acquisition

Input lidar-derived snow depths were acquired on 8, 16, and 25 February 2017 as part of the NASA/JPL Airborne Snow Observatory (ASO) aircraft survey campaigns. The input GPR two-way travel times were collected during the NASA 2017 SnowEx field campaign, which was timed to coincide with the ASO flights. GPR two-way travel times were acquired on 6–10 February for the 8 February ASO flight, 14–18 February for the 16 February ASO flight, and 21–25 February for the 25 February ASO flight. Minimal precipitation occurred during the given ground-penetrating radar survey dates and it is therefore assumed that two-way travel time changed minimally within the date intervals.

Lidar data were collected using a Riegl LMS-Q1560 airborne scanning lidar flown at a constant altitude. For more details on ASO data acquisition, see Painter et al. (2016). Ground penetrating radar surveys were conducted using a MALA Geosciences Professional Explorer (ProEx) control unit and a shielded 1.6 GHz antenna. Both the MALA Geosciences ProEx unit and antenna were pulled in a plastic sled behind users, who were on skis, snowshoes, or snowmobiles. Additional description of GPR data acquisition can be found in the SnowEx17 Ground Penetrating Radar, Version 2 User Guide.

## 2.3 Processing

ASO-measured snow depths were combined with GPR-measured two-way travel times to derive spatially distributed relative tpermittivities, densities, and snow water equivalent (SWE). Two-way travel time data were aggregated to the 3m 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. The lidar-derived snow depth is used to constrain the equation that relates depth, two-way travel time and the velocity of the radar beam through the snow pack

For more information on the processing steps and the equations used to generate these data, refer to Bonnell et al. (2023).

## 2.4 Quality, Errors, and Limitations

Uncertainty estimates for the derived relative permittivities were calculated using Monte Carlo simulations for each survey date, while snow depth uncertainty estimates were determined by comparing the lidar-derived snow depth measurements with previously published snow depth probe measurements (Currier et al., 2019). Two-way travel time uncertainties were calculated using the mean within-pixel standard deviation for each survey date. Additional Monte Carlo simulations were then applied to determine the mean (μ) and standard deviations (σ) of the derived relative permittivity and snow density for each survey date, as shown below.

Table 3. Mean and Standard Deviation of Derived Data

| Study Site | Date | Relative Permittivity | | Snow Density (kg/m3) | |
|---|---|---|---|---|---|
| | | μ | σ | μ | σ |
| Grand Mesa | 08 Feb 2017 | 1.591 | 0.212 | 305 | 98 |
| Grand Mesa | 16 Feb 2017 | 1.568 | 0.179 | 295 | 84 |
| Grand Mesa | 25 Feb 2017 | 1.537 | 0.171 | 280 | 81 |

For further information on the quality of the data, see Bonnell et al. (2023).

# 3 VERSION HISTORY

Table 4. Version History Summary

| Version | Date Implemented | Impacted Temporal Coverage | Description of Changes |
|---|---|---|---|
| v01.0 | September 2024 | 08 Feb 2017 to 25 Feb 2017 | Initial release |

# 4 RELATED DATA SETS

SnowEx Data | Overview

SnowEx17 Ground Penetrating Radar, Version 2

ASO L4 Lidar Snow Depth 3m UTM Grid, Version 1

# 5 RELATED WEBSITES

NASA SnowEx

NASA ASO

# 6 ACKNOWLEDGEMENTS

Original GPR data collection was performed using a 1.6 GHz Mala ProEx GPR system provided by Noah Molotch.

# 7 REFERENCES

Bonnell, R., McGrath, D., Hedrick, A. R., Trujillo, E., Meehan, T. G., Williams, K., Marshall, H., 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 (Vol. 37, Issue 10). Wiley. https://doi.org/10.1002/hyp.14996

Currier, W. R., Pflug, J., Mazzotti, G., Jonas, T., Deems, J. S., Bormann, K. J., Painter, T. H., Hiemstra, C. A., Gelvin, A., Uhlmann, Z., Spaete, L., Glenn, N. F., & Lundquist, J. D. (2019). Comparing aerial lidar observations with terrestrial lidar and snow-probe transects from NASA's 2017 SnowEx campaign. Water Resources Research, 55(7), 6285–6294. https://doi.org/10.1029/2018WR024533

# 8 DOCUMENT INFORMATION

## 8.1 Publication Date

September 2024

## 8.2 Date Last Updated

September 2024