

SnowEx17 Snow Depth from Time-Lapse Imagery

Version 1 Technical Reference

1 INTRODUCTION

1.1 Data Set Overview

The dataset comprises snow depth measurements extracted from snow poles in time-lapse images near near Grand Mesa, CO during the SnowEx 2016-2017 field campaign. Snow poles were 3.048 m (10 ft) vertical poles painted orange. Collection occurred at 18 sites. At each site, five snow depth measurements were extracted every two hours, beginning at 8:00 AM daily. The time-lapse images are archived separately at NSIDC ([SNEX17_TLI](#)).

1.2 File Information

1.2.1 Format

Data is available in three comma separated value files (.csv). An additional browse file (.png) is available displaying all snow depth data over the course of the SnowEx 2017 measurement campaign.

1.2.2 Naming Convention

The three data files are named according to the following convention:

SNEX17_SD_TLI_[datatype]_20161001-20170601_V01.0.csv,

where SNEX17_SD_TLI is the data set identifier, [datatype] refers to the file contents (snowdepth, labels, or polemetadata) as described in Section 1.2.3 below, and 20161001-20170601 is the date ranges of data acquisition.

1.2.3 File Contents

The snow_depth.csv data file contains predicted snow depth information, location, and temperature information for all images between 1 October 2016 and 1 June 2017 ($n = 20,400$ images), with additional data columns described in Table 1. The labels csv contains labeled data ($n = 1228$ images) used for model training, with columns described in Table 2. The polemetadata csv contains the metadata to convert between labels in pixels to centimeters for each camera with columns described in Table 3.

Table 1. Data parameters for snow Data parameters for snow depth for all images ($n = 20,400$ images). Variables camera_name, filename, datetime, longitude_degrees, and latitude_degrees match the metadata for each image provided from the image dataset, SNEX17_TLI. Column names snow_depth_cm, top_x_pixels, top_y_pixels, bottom_x_pixels, bottom_y_pixels, total_length_pixels, were derived from predictions from the snowpole keypoint detection model described in section 2.2.

Parameter Short Name	Description	Unit
camera_name	Camera name. See SNEX17_TLI for details on naming convention.	n/a
filename	Image filename	n/a
datetime	Date of Acquisition using the following format: YYYY-MM-DDTHH:MM:SS	n/a
longitude_degrees	Camera location longitude	degrees (°)
latitude_degrees	Camera location latitude	degrees (°)
snow_depth_cm	Image extracted snow depth (predicted from model)	centimeters
top_x_pixels	Predicted x coordinate at top of pole in image	pixels
top_y_pixels	Predicted y coordinate at top of pole in image	pixels
bottom_x_pixels	Predicted x coordinate at bottom of pole (relative to snow pack) in image	pixels
bottom_y_pixels	Predicted y coordinate at bottom of pole (relative to snow pack) in image	pixels
total_length_pixels	Predicted image pole length	pixels
top_x_pixels_undistort	Predicted x coordinate at top of pole accounted for lens distortion	pixels
top_y_pixels_undistort	Predicted y coordinate at top of pole accounted for lens distortion	pixels
bottom_x_pixels_undistort	Predicted x coordinate at bottom of pole (relative to snow pack) accounted for lens distortion	pixels
bottom_y_pixels_undistort	Predicted y coordinate at bottom of pole (relative to snow pack) accounted for lens distortion	pixels
total_length_pixels_undistort	Predicted image pole length accounted for lens distortion	pixels
camera_name	Camera name. See SNEX17_TLI for details on naming convention.	n/a
filename	Image filename	n/a

Table 2. parameters for labels ($n = 1228$ images). Labeling procedures are described in section 2.2. Variables camera_name, filename, and datetime match the metadata for the images provided in Table 1 and from SNEX17_TLI. Variables top_x, top_y, bottom_x, and bottom_y are the manually selected points in the image.

Parameter Short Name	Description	Unit
camera_name	Camera name. See SNEX17_TLI for details on naming convention.	n/a
filename	Image filename	n/a
datetime	Date of acquisition using the following format: MM-DD-YYYY HH:MM:SS	n/a
top_x	Manually-selected x coordinate of top of pole	pixels
top_y	Manually-selected y coordinate of top of pole	pixels
bottom_x	Manually-selected x coordinate of bottom of pole	pixels
bottom_y	Manually-selected y coordinate of bottom of pole	pixels
total_length_pixels	Length of pole (in pixels) derived from the distance formula using the top and bottom x and y coordinates	pixels
storm_flag	0 indicates storm-free, 1 indicates storm obscured the pole	n/a
veg_flag	0 indicates no vegetation obscuring pole, 1 indicates vegetation (e.g., branches) obscured pole	n/a
pole_tilt_flag	0 indicates no tilt, 1 indicates pole tilt	n/a
camera_name	Camera name. See SNEX17_TLI for details on naming convention.	n/a
filename	Image filename	n/a
datetime	Date of acquisition using the following format: MM-DD-YYYY HH:MM:SS	n/a
top_x	Manually-selected x coordinate of top of pole	pixels
top_y	Manually-selected y coordinate of top of pole	pixels

Table 3. Data parameters for pole metadata, including camera_name, first_pole_length_px, pole_length_cm, and pixel_cm_conversion. Each pole has a unique conversion between depth in pixels and depth in centimeters, depending on the placement of the pole in the image. Additionally, to identify a snow depth, a pole with no snow (i.e., snow-free pole) must be used as a reference. See section 2.2 for steps to identify the conversion and snow-free pole for each camera.

Parameter Short Name	Description	Unit
camera_name	Camera name. See SNEX17_TLI for details on naming convention.	n/a

Parameter Short Name	Description	Unit
first_pole_length_px	length of snow-free pole in pixels	pixels
full_pole_length_cm	length of snow-free pole converted to centimeters using the pixel_cm_conversion value	centimeters
pixel_cm_conversion	Fraction of centimeters represented in a pixel to convert from depth in pixels to depth in centimeters	centimeters per pixel
flag	Description of errors that may affect pole measurements	n/a
camera_name	Camera name. See SNEX17_TLI for details on naming convention.	n/a
first_pole_length_px	length of snow-free pole in pixels	pixels

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 39.055° N

Southernmost Latitude: 39.007° N

Easternmost Longitude: 107.934° W

Westernmost Longitude: 108.216° W

1.3.2 Resolution

Point locations with 1 cm vertical resolution for snow depth measurements.

1.3.3 Geolocation

Geolocation information in this data set is available in WGS84 (decimal degrees).

1.4 Temporal Information

1.4.1 Coverage and Resolution

The temporal coverage for this data set is 1 October 2016 through 1 June 2017. Snow depth was extracted at the images collection rate. Images were taken at 8AM, 10AM, 12PM, 2PM, and 4PM daily.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The dataset comprises snow depth extracted from time-lapse cameras placed around Grand Mesa, CO. To collect time-lapse images of snow depth, we utilized WingscapesTimeLapsePro cameras in conjunction with a custom-made snow pole. The camera was securely mounted on a fence post and positioned to capture a clear view of the snow pole, which was constructed from a 1.52-m orange-painted PVC pipe.

2.2 Processing

1. A subset of images was labeled using a labeling script (labeling.py). We identified a subset by labeling every 20 images from each camera site ($n = 1228$ total labeled images). Labeling was conducted by clicking the top and bottom of the pole using python's *matplotlib* library and recording the horizontal and vertical pixel coordinates as well as the length of the pole in pixels.
2. To identify the conversion for snow depth in pixels to centimeters, we used the length in pixels of the first snow-free image for each camera, dividing by the height in cm (304.8 cm) using the pole_metadata.py script.
3. All labeled images were then manually inspected for any storm, vegetation, and pole tilt and flagged with a 1, indicating a presence of storm, vegetation or pole tilt, or 0, indicating no presence of storm, vegetation, or pole tilt, respectively.
4. Images were used to fine-tune the ResNet neural network from Breen et al. 2024. We used a learning of 0.001, batch size of 8, and an 80/20 data split ($n_{\text{training}} = 982$ images, $n_{\text{validation}} = 246$ images). We added an additional embedding to account for camera site, as categorical embeddings have demonstrated ability to improve model results on small datasets. The model was trained for 200 epochs, with the option for early stopping.
5. Model was evaluated to confirm proper training on the validation set ($n_{\text{validation}} = 200$ images). This model demonstrated an overall mean absolute error of 32.33 cm. This error was close to the results from Breen et al. 2024, where the mean absolute error on new data was equal to 4.0 cm, although likely higher because the model was predicting on a larger dataset and on more cameras.
6. We used a prediction script (predict.py) to predict the keypoints and snow depth across all images ($n = 20,400$ images). We inspected every 50 predictions (see Figure 1) to ensure stable model predictions. The model predicts the full length in pixels, converting to centimeters using the height of the pole in cm and the conversion between pixels and centimeters in the following formula:

$$\text{snow depth (cm)} = \text{Height of snowfree pole (cm)} - \text{length of pole (pixels)} \\ * \text{pixel centimeter conversion} \left(\frac{\text{cm}}{\text{pixels}} \right)$$

7. Following model prediction, we limited the data to the water year, 1 October 2016 to 1 June 2017.

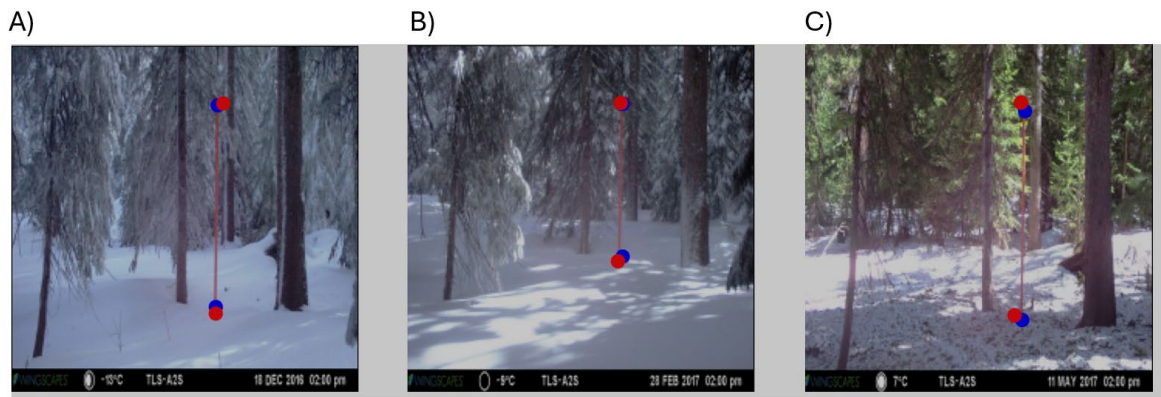


Figure 1. Example predictions from the fine-tuned model at three dates during the water year, A) accumulation (18 December 2016), B) mid-season (28 February 2016), and C) melt (11 May 2017) for camera TLS-A2S. Blue points indicate the automated labels assigned by the neural network. Images were reduced from their native resolution to 448 x 448 to increase processing time and reduce memory load.

2.3 Quality, Errors, and Limitations

These data have been quality controlled visually. Overall prediction error is 32.33 cm. Additional errors include:

- Pole obstruction: Labeled instances when storms, vegetation, or pole obscured accurate depth extraction are flagged (see Table 2).
- Resolution: The snow depth error is higher when the pole is farther away from the camera as the spatial resolution (pixels per centimeter) is lower.
- Camera calibration: Previous work from Breen et al. 2022 identified that when the poles were placed in the center of the image, lens distortion was minimal (± 1 cm). As a result, no lens distortion was implemented.
- Height of pole: We recommend an additional uncertainty of ± 5 cm with all snow measurements given that during calibration from other datasets (Breen et al. 2025) snow pole heights calibrated to ranges between 1.47 and 1.55 m for an expected pole height of 1.52 m. This would create a systematic offset as the height of the pole is what is used as reference when finding the snow depth.

3 REFERENCES

Breen, C. M., Currier, W. R., Vuyovich, C., Miao, Z., & Prugh, L. R. 2024. Snow Depth Extraction from Time-Lapse Imagery Using a Keypoint Deep Learning Model. *Water Resources Research*, 60(7). <https://doi.org/10.1029/2023wr036682>

Breen, C. M., Hiemstra, C., Vuyovich, C. M. & Mason, M. (2022). *SnowEx20 Grand Mesa Snow Depth from Snow Pole Time-Lapse Imagery*. (SNEX20_SD_TLI, Version 1). [Data Set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/14EU7OLF051V>. [describe subset used if applicable].

Breen, C., Vas, D., Baxter, B., Vuyovich, C. (2025). *SnowEx23 Snow Depth from Time-Lapse Imagery*. (SNEX23_SD_TLI, Version 1). [Data Set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/1SQYOLQLCJLD>

Raleigh, M. S., Currier, W. R., Lundquist, J. D., Houser, P. & Hiemstra, C. (2022). *SnowEx17 Time-Lapse Imagery*. (SNEX17_TLI, Version 1). [Data Set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center.
<https://doi.org/10.5067/WYRNU50R9L5R>.

Vas, D., Baxter, B., Maakestad, J., Bailey, J., Stuefer, S., Vuyovich, C. M., Elder, K., Mason, M., Marshall, H. & Durand, M. (2025). *SnowEx23 Time-Lapse Imagery*. (SNEX23_TLI, Version 1). [Data Set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/UB3A44RTR6JD>.