

SnowEx23 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 Fairbanks, AK during the SnowEx 2022-2023 field campaign. Snow poles were 1.52 m (5 ft) vertical poles painted red with a 10.16-cm (4 in) yellow top. Collection occurred at 18 sites: 9 at the Bonanza Creek LTER and 9 at the Caribou-Poker Creeks Research Watershed. At each site, three snow depth measurements were extracted, beginning at 11:00 AM daily. The time-lapse images are archived separately at NSIDC ([SNEX23_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 2023 measurement campaign.

1.2.2 Naming Convention

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

SNEX23_SD_TLI_[datatype]_20221014-20240601_V01.0.csv,

where SNEX23_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 20221014-20240601 is the date ranges of data acquisition.

1.2.3 File Contents

The snowdepth data file contains predicted snow depth, location, and temperature information for all images between October 1 and June 1 for years 2022-2023 and 2023-2024 ($n = 16,689$ images), with additional data columns described in Table 1. The labels data file contains labeled data ($n = 2,177$ images) used for model training, with columns described in Table 2. The polemetadata file 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 depth for all images (n = 23,029 images). Variables camera_name, datetime, longitude, latitude, and filename match the metadata for each image provided from the image dataset, [SNEX23_TLI](#). Temperature was derived using the temperature information from the camera's temperature logger. Snow depth, top_x, top_y, bottom_x, bottom_y, length_of_pole_px, were derived from predictions from the snowpole keypoint detection model described in Section 2.2.

Parameter Short Name	Description	Unit
camera_name	5-digit camera name and the water year (2023 or 2024), in the following format: "CameraID_WaterYear." See SNEX23_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
longitude_degrees	Camera location longitude	degrees (°)
latitude_degrees	Camera location latitude	degrees (°)
snow_depth_cm_raw	Image extracted snow depth (predicted from model)	cm
snow_depth_cm_clean	Image extracted snow depth (predicted from model); negative values set to 0	cm
temperature_celsius	Temperature at camera, values of -9999 indicate a faulty temperature sensor (e.g., CPSA5_2023 and CPSA5_2024)	Celsius
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
x1_pred_undistort_pixels	Predicted x coordinate at top of pole in image accounting for lens distortion	pixels
y1_pred_undistort_pixels	Predicted y coordinate at top of pole in image accounting for lens distortion	pixels
x2_pred_undistort_pixels	Predicted x coordinate at bottom of pole (relative to snow pack) in image accounting for lens distortion	pixels
y2_pred_undistort_pixels	Predicted y coordinate at bottom of pole (relative to snow pack) in image accounting for lens distortion	pixels
total_length_undistort_pixels	Predicted image pole length accounting for lens distortion	pixels

Table 2. Data parameters for labels ($n = 2,177$ 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 [SNEX23_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	5-digit camera name and the water year (2023 or 2024), in the following format: "CameraID_WaterYear." See SNEX23_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_pixels	Manually-selected x coordinate of top of pole	pixels
top_y_pixels	Manually-selected y coordinate of top of pole	pixels
bottom_x_pixels	Manually-selected x coordinate of bottom of pole	pixels
bottom_y_pixels	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
snow_depth_cm	Length of pole converted to snow depth using the centimeter per pixel conversion from pole metadata (see Table 3)	cm
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
x1_pixels	Manually-selected x coordinate of top of pole at 448 x 448 res.	pixels
y1_pixels	Manually-selected y coordinate of top of pole at 448 x 448 res.	pixels
x2_pixels	Manually-selected x coordinate of bottom of pole at 448 x 448 res.	pixels
y2_pixels	Manually-selected y coordinate of bottom of pole at 448 x 448 res.	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	5-digit camera name and the water year (2023 or 2024), in the following format: "CameraID_WaterYear." See SNEX23_TLI for details on naming convention.	n/a
year	2023 to mark data collected for water year 2022-2023 or 2024 to mark data collected for water year 2023-2024	2023 or 2024
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	cm
top10_section_px	length of the top 10-cm yellow portion used to identify the conversion in pixels	pixels
pixel_cm_conversion	Fraction of centimeters represented in a pixel to convert from depth in pixels to depth in centimeters	cm/ pixel
flag	Comment on why the snow-free pole length is not 152.2 cm in the image	N/A

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 65.1951° N

Southernmost Latitude: 64.6995° N

Easternmost Longitude: 147.3943° W

Westernmost Longitude: 148.3622° 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 limited to the 2022-2023 and 2023-2024 water years, specifically 1 October 2022 through 1 June 2023, and 1 October 2023 to 1 June 2024. Snow depth was extracted at the image's collection rate. Images were taken at 11AM, 12PM, and 1PM daily.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The dataset comprises snow depth extracted from time-lapse cameras placed near Fairbanks, AK. Specifically, nine cameras installed at Bonanza Creek Experimental Forest and six cameras installed at Caribou-Poker Creek Research Watershed where time-lapse images were collected as part of the SnowEx 2022-2023 field campaign. 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 tall and 10.16-cm diameter red-painted PVC pipe. At the top of the red-painted PVC pipe was a 10.16-cm yellow duct tape top, used to reference the height of the pole from the camera image.

2.2 Processing

1. A naming convention was implemented with the camera name added in front of the image file name along with the water year followed by an underscore (e.g., BC7TLEB_2023_WSCT0520.JPG, where BC7TLEB is the camera name and 2023 marks data collected during the 2022-2023 water year) to ensure unique identifiers for each camera image.
2. A subset of images was labeled using a labeling script (labeling.py). We identified a subset by labeling every 10 images from each camera site ($n = 2,177$ 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.
3. To identify the conversion for snow depth in pixels to centimeters, we used the first snow-free image for each camera to identify the length of the full pole in pixels, and the length of the top 10.16-cm section yellow top using the pole_metadata.py script. We included a lens distortion adjustment to account for warping, using the lens parameters from Breen et al. (2023). Except for poles where vegetation blocked the bottom of the pole for all snow free images or did not have a snow-free image, the poles ranged between 1.47 m and 1.55 m, with an average height of 1.51 ± 0.02 m.
4. 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.
5. 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 ($n_{\text{training}} = 1741$ images, $n_{\text{validation}}$

= 436 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.

6. Model was evaluated to confirm proper training on the validation set ($n_{\text{validation}} = 436$ images). This model demonstrated an overall mean absolute error of 6.23 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.
7. We used a prediction script (predict.py) to predict the keypoints and snow depth across all images. We inspected every 50 predictions (see Figure 1) to ensure stable model predictions.
8. Using the predicted keypoints, we projected the keypoints onto the same image but with an adjustment for lens distortion. The distance between the two keypoints was then converted to snow depth in centimeters, using the difference between a snow-free pole and the height of the pole with snow converted from pixels to centimeters in the following formula:

$$\text{snow depth (cm)} = 152.2 - \text{length of pole (pixels)} * \text{pixel centimeter conversion} \left(\frac{\text{cm}}{\text{pixels}} \right)$$

9. Snow depths were then limited to 2022-2023 and 2023-2024 water years.
10. Metadata from all images, including the image timestamp and the temperature value from the temperature logger extracted using the python *exif* library. One camera returned values equal to 196 degrees Celsius for all photos for both water years (camera CP5A5_2023 and CP5A5_2024). These values were updated to -9999 to indicate a faulty temperature sensor.
11. Occasionally the model would predict the keypoints such that the length of the pole would be longer than the snow free pole used as reference to calculate snow depth. In these cases, the prediction would return a negative value for snow depth. As a final step, we distinguished between the original predictions from the model (column: snow_depth_cm_raw) and snow depth predictions from the model after setting negative values to 0 (column: snow_depth_cm_clean) in the file named SNEX23_SD_TLI_snowdepth_20221014-20240601_V01.0.csv.

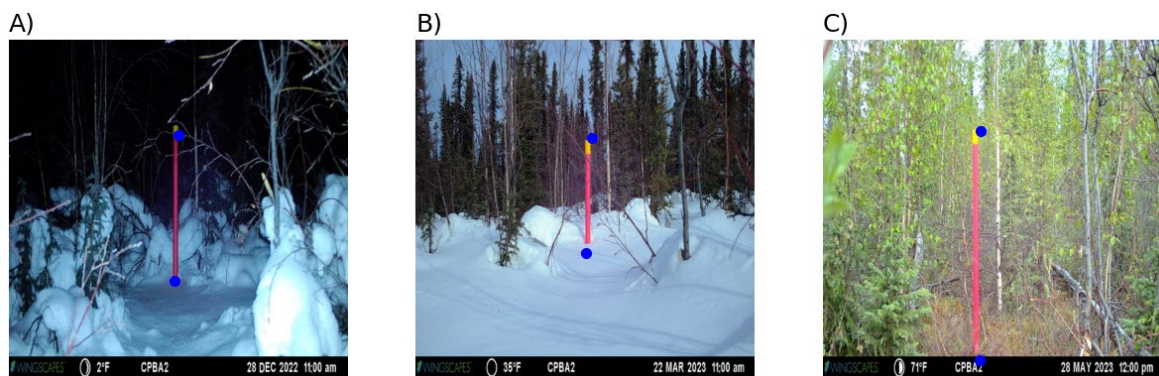


Figure 1. Example predictions from the fine-tuned model at three dates during the water year, A) accumulation (28 December 2022), B) melt (22 March 2023), and C) snow off (28 May 2023) for camera CP-BA-2. Blue points indicate the automated labels assigned by the neural network. Images were reduced from 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 6.23 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: We accounted for lens distortion, which can result in straight lines appearing curved, using the *undistort* function from python's cv2 package and the lens parameters for the same cameras defined from Breen et al. 2023.
- Height of pole: We recommend an additional uncertainty of ± 5 cm with all snow measurements given that during calibration we had measurements ranging 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>

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