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Brief communication: Monitoring snow depth using small, cheap, and easy-to-deploy snow–ground interface temperature sensors

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Section S1: Data Collection

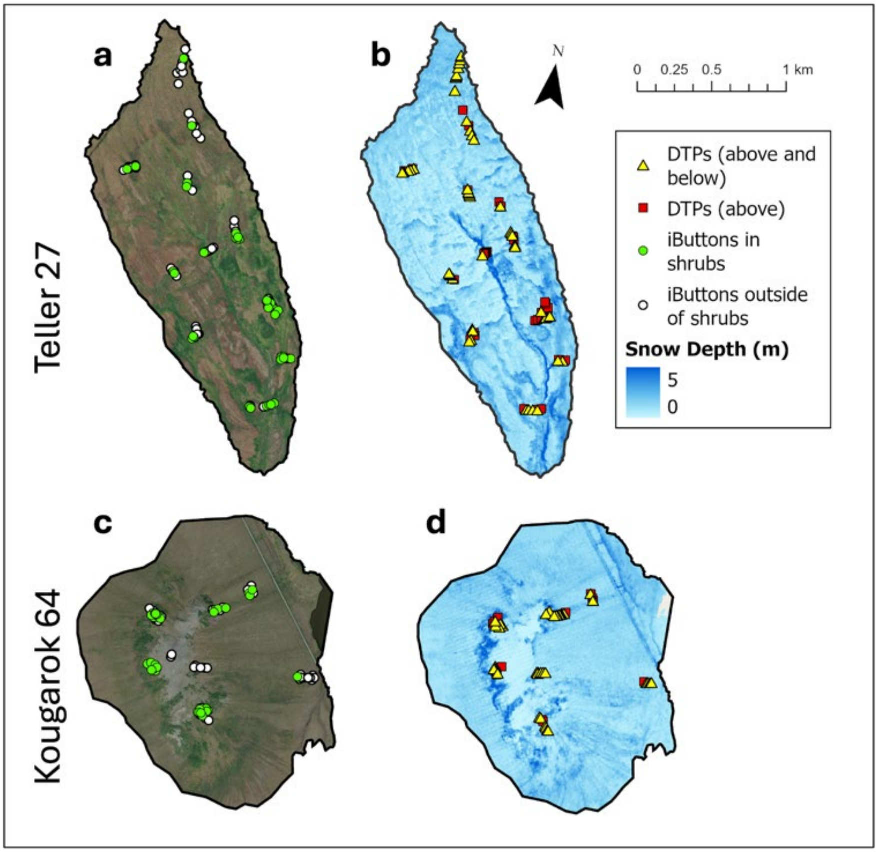

Figure S1. **Locations of iButton Link Thermochron (DS1921G-F5#) temperature sensors deployed in (green circles) and outside (white circles) of tall shrubs over the 2022 – 2023 snow season at a) Teller27 and c) Kougarok64 (Bennett et al., 2024). Background imagery from Esri, Garmin, USGS, Maxar, 2024, ArcGIS RGB Basemap. Locations of DTP temperature systems that recorded both above and below ground temperature (yellow triangles) or only above ground temperature (red squares) over the 2021 – 2022 snow season at b) Teller27 and d) Kougarok64 (Wang et al., 2024). Blue background imagery shows snow depth in April 2022 estimated using Light Detection and Ranging (LiDAR) data (Singhania et al., 2023a, b).**

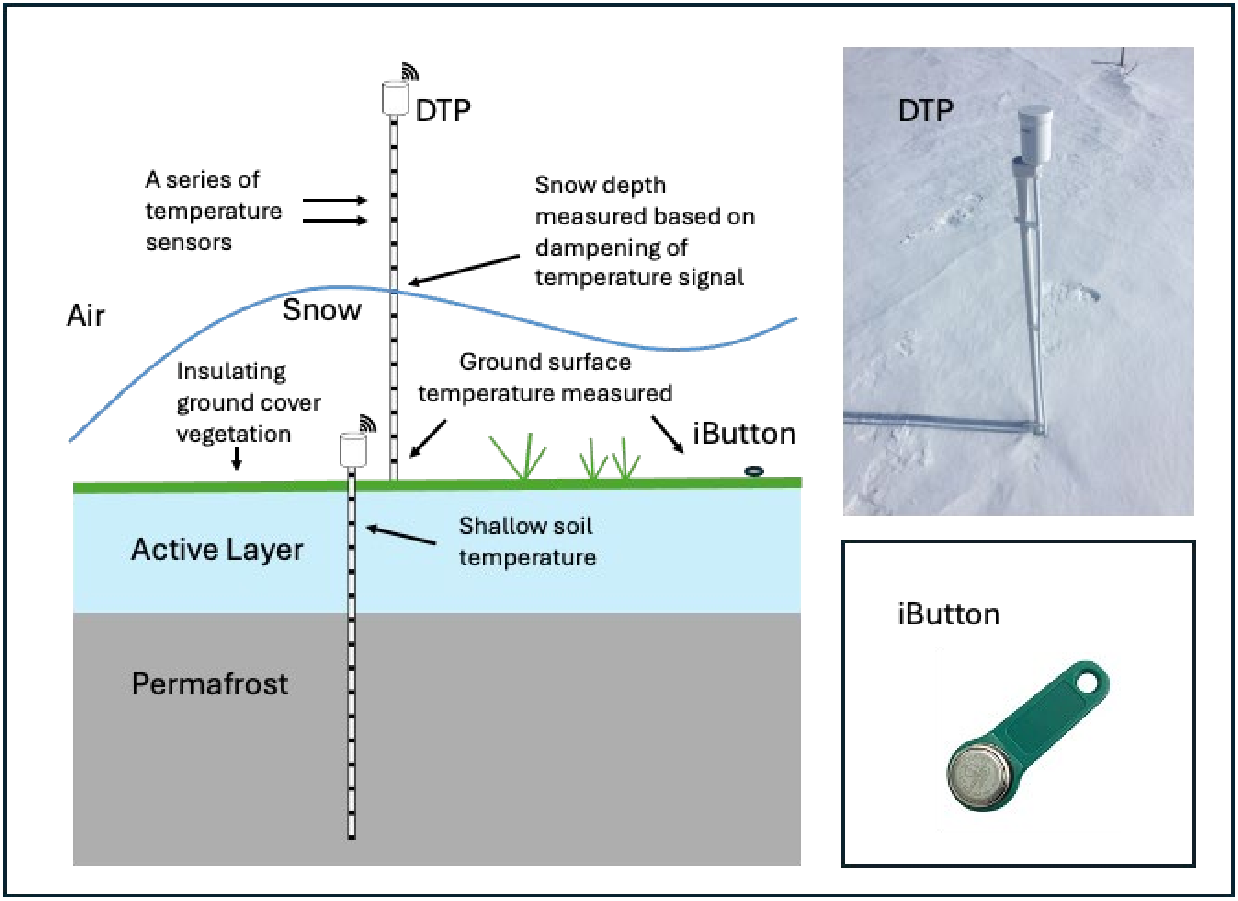

Figure S2. Set up of DTP systems and iButton temperature sensors. Only shallow soil temperature data was used in this study, but the soil DTP systems can measure temperature down to 100 to 160 cm of depth. Figure source: Bachand et al., 2024; https://doi.org/10.15485/2371854.

Section S2: Model Development

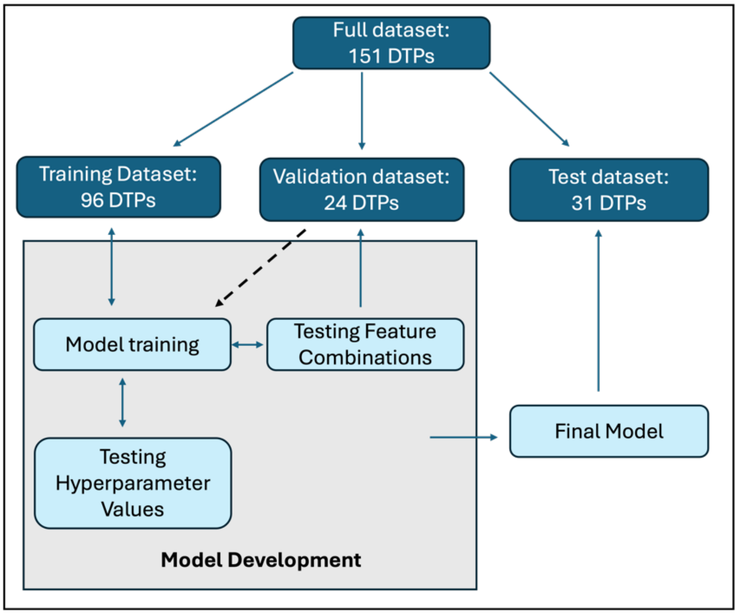

Figure S3. Use of training, validation, and test datasets in model development. We split the training data into groups of DTP systems rather than groups of daily data points to maintain the independence of entire snow depth/ temperature time series during model testing. Different combinations of input features were tested using the validation dataset. After the best-performing set of input features was determined, the final model was trained using both the training dataset and validation dataset. The test dataset was excluded completely from the model development process.

Parameter	**Value**
Number of decision trees	70
Maximum depth of decision tree	10 layers
Minimum number of samples required to form a yes/no split	15
Maximum amount of samples used to build a decision tree	80 %
Maximum number of features used in each decision tree	2

Table S1. Random forest parameters. To tune hyperparameters, we first visualized how different hyperparameter values affected model performance using the validation dataset. After selecting three candidate values for each hyperparameter, we used a 5-fold cross validation grid search algorithm to determine the best hyperparameter combination.

Model	**Number of training data points**	**Related figure**
RF-Seward (applied to the test dataset)	**20,963**	**1a**
RF-Seward (trained at Teller27 and tested at Kougarok64)	**17,171**	**1b**
RF-Seward (trained at Kougarok64 and tested at Teller27)	**9,272**	**1c**
RF-Seward (retrained on all DTP data; applied to evaluation sites)	**25,418**	**2a-g, i, j**
RF-Below (applied to the test dataset)	**15,197**	**1d**
RF-Below (trained at Teller27 and tested at Kougarok64)	**11,396**	**1e**
RF-Below (trained at Kougarok64 and tested at Teller27)	**7,980**	**1f**
RF-Below (retrained on all DTP data; applied to evaluation sites)	**18,968**	**2c-h**
RF-Deep (applied to first Senator Beck Basin Site)	**1,305**	**2i**
RF-Deep (applied to second Senator Beck Basin Site)	**3,294**	**2j**

Table S2. Number of training data points (days) used to train the random forest models.

Section S3: Model Evaluation Sites

Site	**Years**	**Sensor Details** (*vegetation description provided for belowground sensors)*	**End-of-Winter Snowpack Bulk Density**	**Source**
Bayelva Station, Svalbard, Norway	2003 - 2017	5 cm above the ground surface	350 kg m^{-3}	Boike et al., 2017, 2018
Senator Beck Basin, CO, USA (2 sites)	2003 - 2022	At the snow-ground interface	450 kg m^{-3} to 500 kg m^{-3}	Center for Snow and Avalanche Studies, 2024; Landry et al., 2014
Imnaviat Creek, North Slope, AK, USA	1990 - 1992	At the snow-ground interface	250 kg m^{-3}	Stuefer et al., 2020; Sturm and Holmgren, 1994
Los Alamos, NM, USA (18 iButtons deployed in pairs)	2023 - 2024	9 at the snow-ground interface; 9 1-5 cm below the ground surface; *bare ground with sparse grasses*	400 kg m^{-3} during the 2024 water year, according to the nearby Quemazon SNOTEL Station	Thomas et al., 2024; Snow depth data at site B is from https://weathermachine.lanl.gov/
SnowEx Grand Mesa Study Plot, CO, USA	2017 - 2022	5 cm below the ground surface; *forest clearing with sparse grasses*	400 kg m^{-3}, according to the nearby Mesa Lakes SNOTEL Station	Houser et al., 2022
Samoylov Island, Siberia, Russia	2002 - 2020	1 cm below the ground surface in low centered polygon; *wet tundra*	175 kg m^{-3} to 225 kg m^{-3}	Boike et al., 2019a, b
Council, Seward Peninsula, AK, USA (two sites)	2000 - 2004	0 to 1 cm below the soil surface; *tussock and mossy tundra*	Unknown	Hinzman et al., 2016
Ivotuk, North Slope, AK, USA	1998 - 2006	0 to 1 cm below the soil surface; *tussock sedge and dwarf-shrub tundra*	Unknown	Hinzman et al., 2016

Table S3. Description of model evaluation sites

References

Bachand, C., Wang, C., Dafflon, B., Thomas, L., Shirley, I., Maebius, S., Iversen, C., and Bennett, K.: Machine learning snow depth predictions at sites in Alaska, Norway, Siberia, Colorado and New Mexico, Next-Generation Ecosystem Experiments (NGEE) Arctic, ESS-DIVE repository [data set], https://doi.org/10.15485/2371854, 2024.

Bennett, K., Bachand, C., Thomas, L., Gasarch, E., Thaler, E., and Crumley, R.: iButton and Tinytag snow/ground interface temperature measurements at Teller 27 and Kougarok 64 from 2022–2023, Next-Generation Ecosystem Experiments (NGEE) Arctic, ESS-DIVE repository [data set], https://doi.org/10.15485/2319246, 2024.

Boike, J., Juszak, I., Lange, S., Chadburn, S., Burke, E. J., Overduin, P. P., Roth, K., Ippisch, O., Bornemann, N., Stern, L., Gouttevin, I., Hauber, E., and Westermann, S.: Measurements in soil and air at Bayelva Station, PANGAEA [data set], https://doi.org/10.1594/PANGAEA.880120, 2017.

Boike, J., Juszak, I., Lange, S., Chadburn, S., Burke, E., Overduin, P. P., Roth, K., Ippisch, O., Bornemann, N., Stern, L., Gouttevin, I., Hauber, E., and Westermann, S.: A 20-year record (1998–2017) of permafrost, active layer and meteorological conditions at a high Arctic permafrost research site (Bayelva, Spitsbergen), Earth Syst. Sci. Data, 10, 355–390, https://doi.org/10.5194/essd-10-355-2018, 2018.

Boike, J., Nitzbon, J., Anders, K., Grigoriev, M., Bolshiyanov, D., Langer, M., Lange, S., Bornemann, N., Morgenstern, A., Schreiber, P., Wille, C., Chadburn, S., Gouttevin, I., Burke, E., and Kutzbach, L.: A 16-year record (2002–2017) of permafrost, active-layer, and meteorological conditions at the Samoylov Island Arctic permafrost research site, Lena River delta, northern Siberia: an opportunity to validate remote-sensing data and land surface, snow, and permafrost models, Earth Syst. Sci. Data, 11, 261–299, https://doi.org/10.5194/essd-11-261-2019, 2019a.

Boike, J., Nitzbon, J., Bolshiyanov, D., Langer, M., Lange, S., Bornemann, N., Morgenstern, A., Schreiber, P., Wille, C., Chadburn, S., Gouttevin, I., and Kutzbach, L.: Measurements in soil and air at Samoylov Station (2002–2018), version 201908, Alfred Wegener Institute – Research Unit Potsdam, PANGEA [dataset], https://doi.org/10.1594/PANGAEA.905236, 2019b.

Center for Snow and Avalanche Studies: Archival Data from Senator Beck Basin Study Area, https://snowstudies.org/archival-data/ (last access: 1 July 2024), 2024.

Hinzman, L. D., Kane, D. L., and Goering, D. J.: Meteorological, Radiation, Soil, and Snow Data from Alaska Sites, 1998–2008, Arctic Data Center [data set], https://doi.org/10.5065/D6G44NFV, 2016.

Houser, P., Rudisill, W., Johnston, J., Elder, K., Marshall, H. P., Vuyovich, C., Kim, E., and Mason, M.: SnowEx Meteorological Station Measurements from Grand Mesa, CO, Version 1, NASA National Snow and Ice Data Center Distributed Active Archive Center [data set], https://doi.org/10.5067/497NQVJ0CBEX, 2022.

Landry, C. C., Buck, K. A., Raleigh, M. S., and Clark, M. P.: Mountain system monitoring at Senator Beck Basin, San Juan Mountains, Colorado: A new integrative data source to develop and evaluate models of snow and hydrologic processes, Water Resour. Res., 50, 1773–1788, https://doi.org/10.1002/2013WR013711, 2014.

Singhania, A., Glennie, C., Fernandez-Diaz, J., and Hauser, D.: National Center for Airborne Laser Mapping (NCALM) LiDAR and DEM data from two NGEE Arctic Sites, Seward Peninsula, Alaska, Winter 2022, Gener. Ecosyst. Exp. Arct. Data Collect. Oak Ridge Natl. Lab. US Dep. Energy Oak Ridge Tenn. USA, NGA314 [data set], https://doi.org/10.5440/1984094, 2023a.

Singhania, A., Glennie, C., Fernandex-Diaz, J., and Hauser, D.: National Center for Airborne Laser Mapping (NCALM) Lidar DEM data from five NGEE Arctic Sites, Seward Peninsula, Alaska, August 2021, Gener. Ecosyst. Exp. Arct. Data Collect. Oak Ridge Natl. Lab. US Dep. Energy Oak Ridge Tenn. USA, NGA270 [data set], https://doi.org/10.5440/1832016, 2023b.

Stuefer, S. L., Kane, D. L., and Dean, K. M.: Snow Water Equivalent Measurements in Remote Arctic Alaska Watersheds, Water Resour. Res., 56, e2019WR025621, https://doi.org/10.1029/2019WR025621, 2020.

Sturm, M. and Holmgren, J.: Effects of microtopography on texture, temperature and heat flow in Arctic and sub-Arctic snow, Ann. Glaciol., 19, 63–68, https://doi.org/10.3189/1994AoG19-1-63-68, 1994.

Thomas, L., Bachand, C., and Maebius, S.: iButton snow-ground interface temperature measurements in Los Alamos, New Mexico from 2023 - 2024., Next-Generation Ecosystem Experiments (NGEE) Arctic, ESS-DIVE repository [data set], https://doi.org/10.15485/2338028, 2024.

Wang, C., Dafflon, B., Shirley, I., Wielandt, S., Fiolleau, S., Lamb, J., Uhlemann, S., and Ulrich, C.: Continuous snow depth, ground interface temperature and shallow soil temperature measurements from 2021-10-1 to 2022-6-14, Seward Peninsula, Alaska, Next-Generation Ecosystem Experiments (NGEE) Arctic, ESS-DIVE repository [data set], https://doi.org/10.15485/2475020, 2024.