Supplementary material to:

Historical snow and ice temperature observations document the recent warming of the Greenland ice sheet

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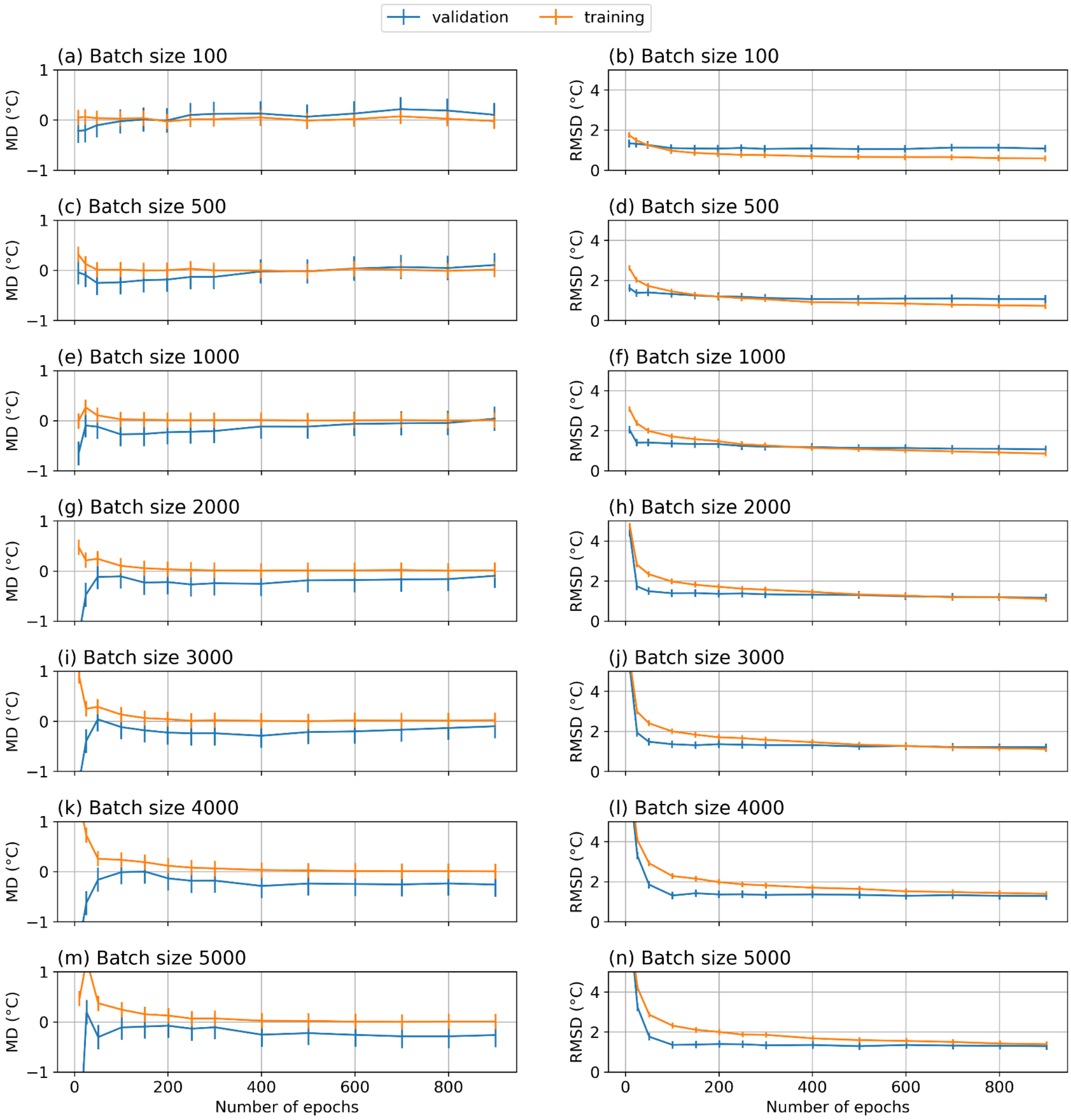
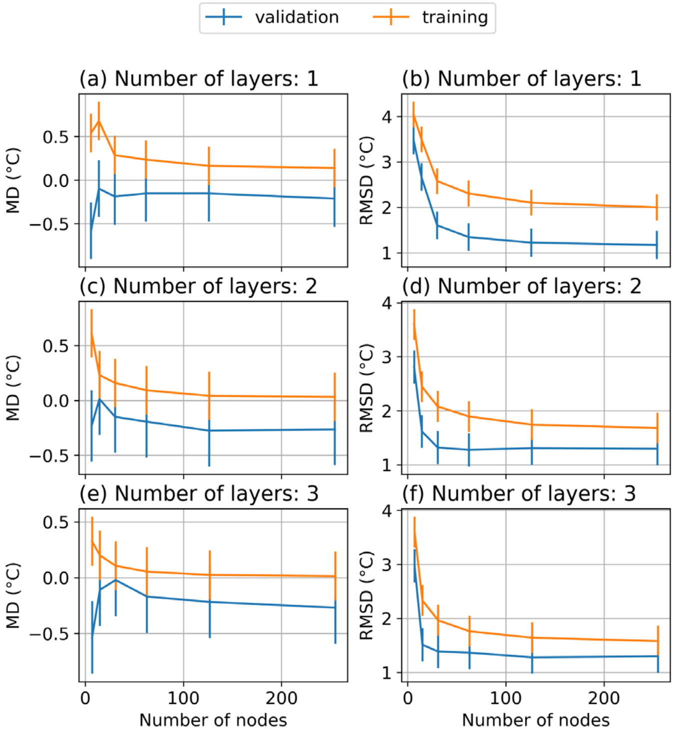
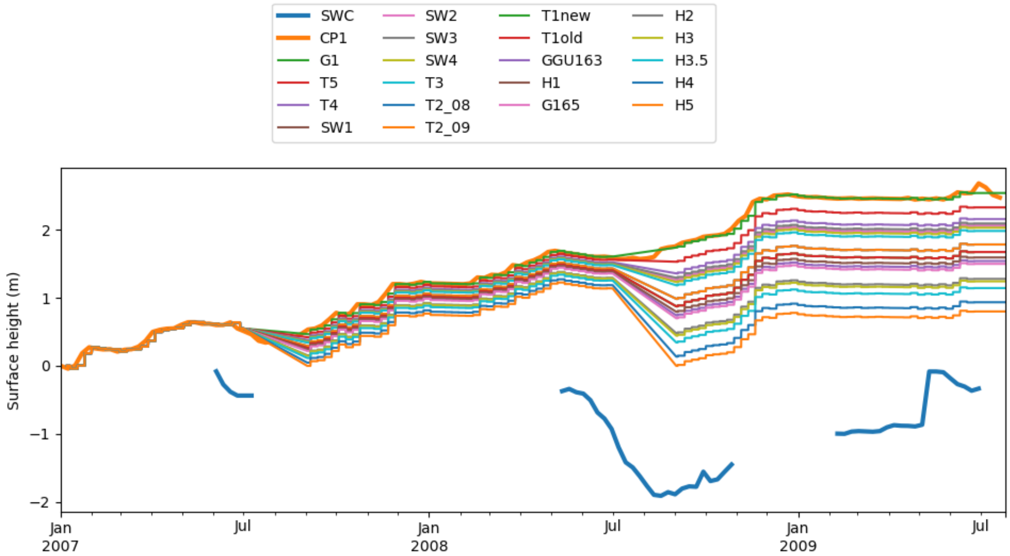


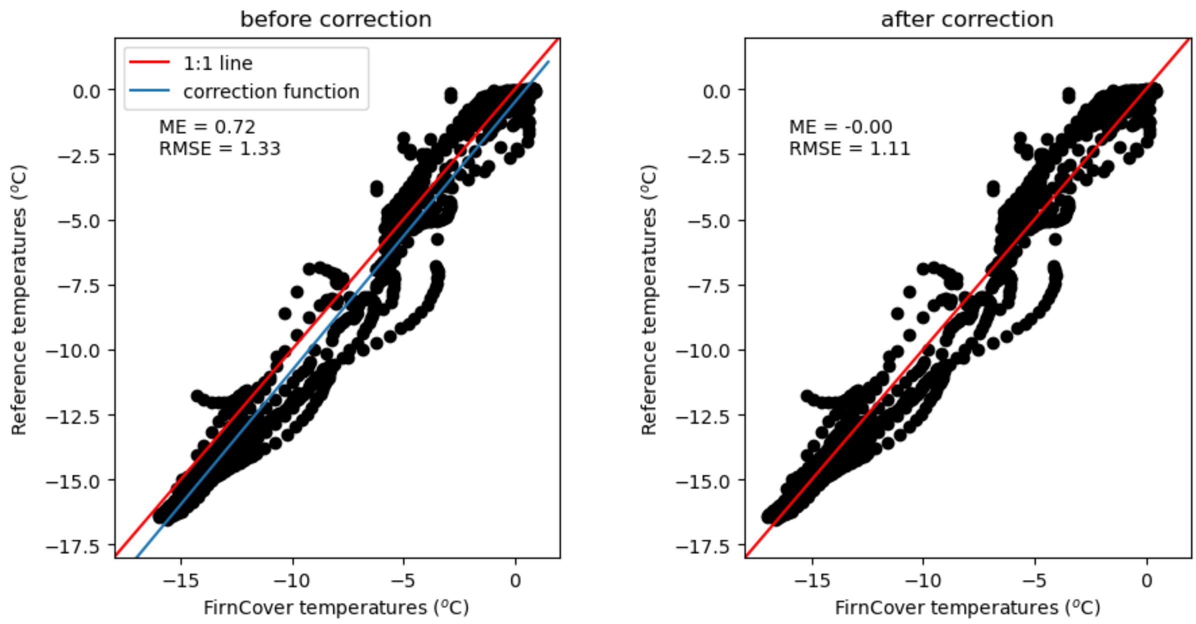
Supplementary Figure 1. Mean difference (MD) and root mean squared difference (RMSD) between observed and predicted T10m for different ANN designs.



Supplementary Figure 2. Mean difference (MD) and root mean squared difference (RMSD) between observed and predicted T_{10m} for different ANN designs.



Supplementary Figure 2. Reconstruction of surface height at the thermistor string locations from Humphrey et al. (2012) during the 2007-2009 period. The Crawford Point 1 (CP1) provides the snow accumulation for all sites, while the summer ablation is defined as a linear function of elevation between CP1 where no ablation is measured and Swiss Camp (SWC) where all the snow accumulated over the winter is considered to melt.



Supplementary Figure 3. Bias correction in the FirnCover dataset. ME stands for mean error and RMSE for root mean squared error.

Supplementary tables

Supplementary table 1. Uncertainty estimation that applies on the temperature measurements.

Site	Instrument 1	Instrument 2	Mean deviation	Root mean squared deviation
Summit	GC-Net	Giese and Hawley (2015)	-1.0	1.1
Camp Century	PROMICE	Camp Century Climate	0.1	0.3
Crawford Point	GC-Net (CP1)	GC-Net (CP2)	-0.2	0.3
Dye-2	FirnCover	Covi et al.	0.0	0.1
EKT	FirnCover	Covi et al.	0.2	0.2
KAN_U	FirnCover	PROMICE	-0.4	0.5
(Hills et al., 2018)	T-15a	T-14	-0.6	0.8
(Hills et al., 2018)	T-15b	T-14	-0.4	0.6
(Hills et al., 2018)	T-15c	T-14	-0.5	0.8
(Hills et al., 2018)	T-14	T-16	0.2	0.6
			Median:	0.5

Supplementary table 2. List of FirnCover sensors and their associated sensors in Samimi et al. (2021) and Heilig et al. (2018) at Dye-2.

FirnCover sensor	Corresponding sensors in	
	Samimi et al. (2021)	Heilig et al. (2018)
#2	A3, B5	-
#3	A4	#2
#4	A5	-
#5	-	#3
#7	-	#4

Supplementary text

Supplementary text 1: Estimation of the surface height for the Humphrey et al. (2012) dataset

The thermistor string installations from Humphrey et al. (2012) did not measure surface height. In an effort to produce the best interpolation of firn temperatures at 10 m depth, that takes into account the snow accumulation in the spring and the melt in the summer, we reconstruct the surface height at each site using the surface height measurements available at the Swiss Camp and CP1 GC-Net automated weather stations (Steffen et al., 1996, 2001, Vandecrux et al., 2023), respectively located at 1149 and 2022 m a.s.l. along the same elevation transect as the stations from Humphrey et al. (2012). While the data quality at Crawford point is good, the surface height at Swiss Camp only covers the 2008 ablation period. We therefore assume that all sites in Humphrey et al. (2012) have the same snow accumulation as Crawford Point and that the ablation that occurs between July and August is a linear function of elevation with no ablation at CP1 and total ablation of the accumulated snow at the lowest site H5 (Supplementary Figure 2). These surface heights are then used to estimate the depth of each sensor in the Humphrey et al. (2012) dataset before interpolation at 10 m depth.

Supplementary text 2: Bias correction in the FirnCover data

The FirnCover dataset, presented by MacFerrin et al. (2022), consists of measurements of firn temperature at six sites from 2015 to 2019 using uncalibrated Resistance Temperature Detectors (RTD). After interpolation at 10 m and monthly averaging, it was noticed that there could be significant differences with measurements of firn temperatures at the same sites from Covi et al. (2022), Samimi et al. (2021) and Heilig et al. (2018).

We evaluate the bias in the FirnCover dataset at DYE-2, where measurements from Samimi et al. (2021) and Heilig et al. (2018) are used as reference. We identify, whenever possible, the FirnCover sensors that are located at similar depths as sensors from Samimi et al. (2021) and Heilig et al. (2018) (Supplementary Table 2). For instance, the FirnCover sensor #2 is located at the same depth (within 10 cm) as sensors A3 and B5 (third sensor on string A and fifth sensor on string B) from Samimi et al. (2021). The FirnCover measurements are on average

0.72ºC higher (Supplementary Figure 3) than the measurements from Samimi et al. (2021) and Heilig et al. (2018) at similar depths. We fit a linear function of slope 1.031 and intercept -0.500 (Supplementary Figure 3) that is used to correct the FirnCover measurements. Applying this correction at other sites also improves comparison between the FirnCover measurements and observations from other sources, e.g. compared to PROMICE (Fausto et al., 2021) and SPLAZ (Charalampidis et al., 2016) data at KAN_U or compared to Covi, et al. (2022) data at EKT.

Several factors can potentially explain the bias in the FirnCover measurements. Installation depths and estimated surface height were thoroughly checked and are unlikely to explain such a systematic bias. The FirnCover sensors did not go through calibration. However miscalibration would affect sensors randomly and would not be the same at all sites and for all sensors. Lastly, RTDs appeared, according to certain sources, to suffer from internal warming when installed in a poorly conductive media. (electronicdesign.com, 2000). Nevertheless, no information about this issue was available from the RTD manufacturer, nor about how to correct it. Therefore we henceforth use the empirically corrected FirnCover measurements as our best estimate of the true subsurface temperatures.

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