

## Supplementary Material: Comparison With ERA5-Land

We compared the observational dataset to soil temperatures in ERA5-Land (ERA5L): a reanalysis product gridded at  $0.1^\circ \times 0.1^\circ$  resolution (Hersbach et al., 2020). This identifies whether previously described trends still hold true when evaluated with this larger dataset.

We downloaded ERA5L monthly means from 1960-2025 for the 4 soil temperature layers. Observed data were categorized into four discrete bins corresponding to the standardized ECMWF soil model layers: Layer 1 (0–7 cm), Layer 2 (7–28 cm), Layer 3 (28–100 cm), and Layer 4 (100–289 cm). Data below the model lower boundary were not used for this comparison. Monthly observational means were calculated only for site-depth combinations possessing >90 % data completion to minimize sampling-induced bias. For each observational record, we extracted the corresponding ERA5-Land grid cell using a nearest-neighbor approach based on coordinates and time.

We implemented a linear interpolation scheme using defined model midpoints (3.5, 17.5, 64, and 194.5 cm) to derive a continuous vertical temperature profile. This allowed for the estimation of interpolated ERA5 temperatures at the exact measured depth of each sensor. Model values were extrapolated with a constant value in the extremities but depths outside of the model domain (0-2.89 m) were not included.

Within depth bins, errors were calculated by comparing observations from the corresponding bin ( $T_{obs}$ ) to the interpolated grid cell value ( $T_{ERA5}$ ).

$$BIAS = T_{ERA5} - T_{obs} \quad (1)$$

Following Cao et al. (2020) we also aggregated all observations within the same grid cell and the same month to yield a Mean Bias Error (MBE). These were then plotted by month to show seasonal variation in bias.

### Correlation and Seasonal Bias

Direct comparison of observations within each layer shows temperature-dependent behaviour (Figure S1). In Layer 1, the two datasets correspond reasonably well in non-cryotic conditions but under cryotic conditions ERA5L exhibits a strong warm bias. An ERA5L warm bias in North America has been previously identified and attributed to the HTESSEL snowpack model used therein (Cao et al., 2020, 2022). At greater depths, the warm bias persists for cryotic observations but the correlation in non-cryotic conditions diminishes, likely due to the shallow model domain.

Looking at seasonal patterns (Figure S2), the strongest bias is in winter months. Again, this is consistent with previously work which identifies low snow density as the reason for this behaviour (Cao et al., 2020, 2022). The results from that study showed an annual warm bias from 0.95 to 5.48 °C for sites in Canada. Similarly, this dataset has a mean bias of 3.42 °C when evaluated over

all grid cells. While there is also a warm bias in the summer months, bias is at its lowest during thaw and freeze-up, during which time the total variation of ground temperature is likely reduced. However, some mismatch does occur at this time as shown by the sharp boundaries at 0 °C in Figure S1.

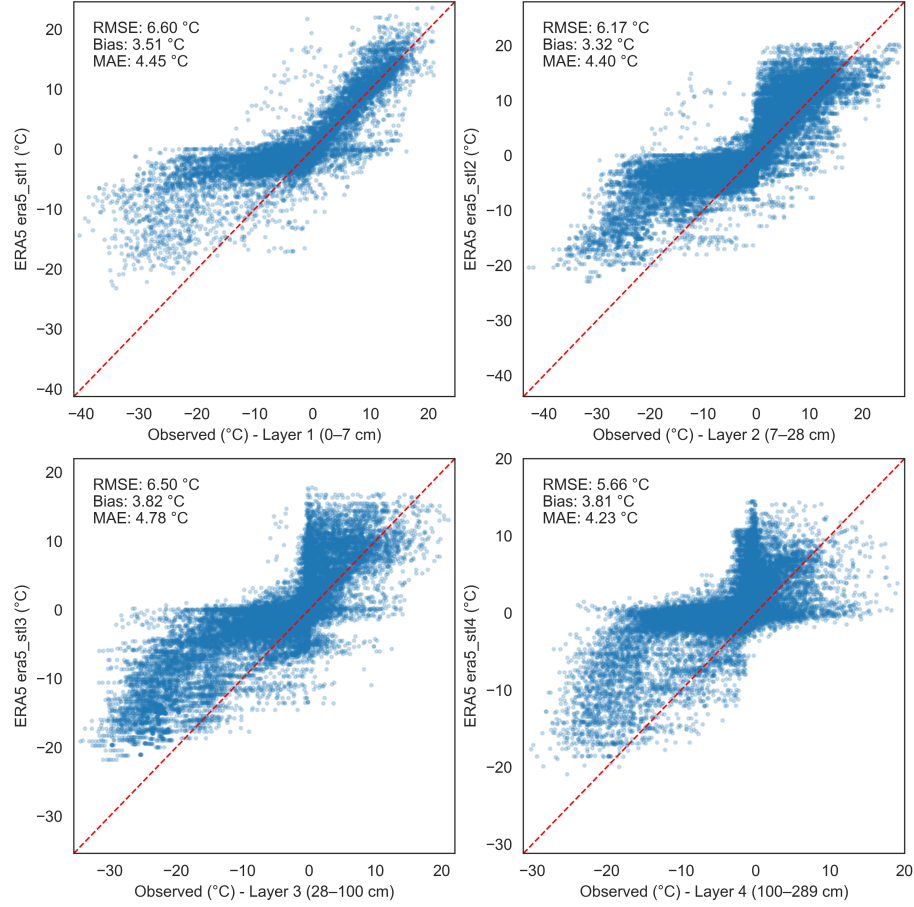


Fig. S1. Interpolated ERA5L ground temperature compared with observational data from this study. Non-cryotic ground surface temperatures show good correspondence, while cryotic observations show a characteristic warm bias as described in Cao et al. (2020). Sharp breaks at 0 °C in the distribution of points correspond to mismatch in the timing of the zero-curtain period.

Overall, the relationship of this dataset to ERA5L is consistent with results presented elsewhere, suggesting that it is representative of trends at a  $0.1^\circ \times 0.1^\circ$  grid cell scale Cao et al. (2020).

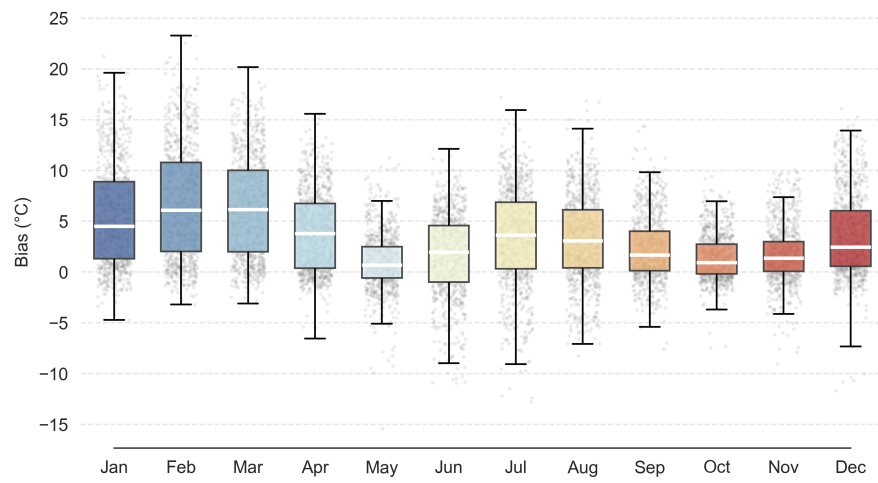


Fig. S2. Monthly ERA5L bias when compared to the ground temperature dataset. The mean bias over all grid cells is +3.42 °C.

# Bibliography

Cao, B., Gruber, S., Zheng, D., and Li, X.: The ERA5-Land soil temperature bias in permafrost regions, *The Cryosphere*, 14, 2581–2595, <https://doi.org/10.5194/tc-14-2581-2020>, 2020.

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