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Estimating robust melt factors and temperature thresholds for snow modelling across the Northern Hemisphere

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S1 Gap filling and quality control

We apply a simple gap-filling and quality control procedure for the temperature time series, similar to Serreze et al. (1999). For each station, an average daily climatology is calculated, and we remove values that are more or less than three times the standard deviation of the daily temperature climatology, which is a conservative estimate. We also remove temperatures above or below +/- 55 °C. We fill gaps of one day by linear interpolation, and gaps of two days with the corresponding neighbour. For larger gap sizes, we fill the gap with the climatological mean, but only if the length of the gap is less than 20% of the climatological winter. The climatological winter is defined as the period with temperatures lower than the mean temperature minus two times the standard deviation of daily temperatures. In the final database, only 3% of temperature data is gap-filled. We do not gap-fill the precipitation time series, but we remove daily precipitation values higher than 176 mm, considered outliers. This value corresponds to the 99.99th percentile of all daily precipitation observations over all gathered precipitation time series.

Serreze, M. C., Clark, M. P., Armstrong, R. L., McGinnis, D. A., and Pulwarty, R. S.: Characteristics of the western United States snowpack from snowpack telemetry (SNOTEL) data, Water Resources Research, 35, 2145–2160, 1999.

S2 Supplementary figures

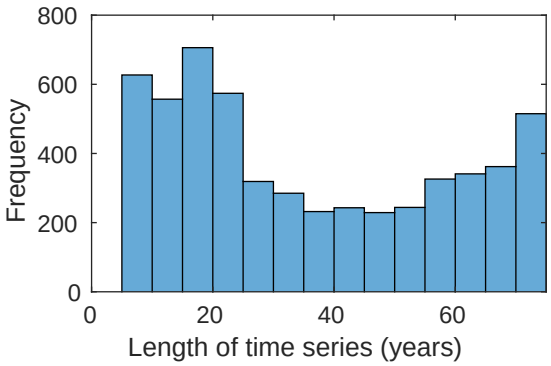

Figure S1: Length of station time series in this study.

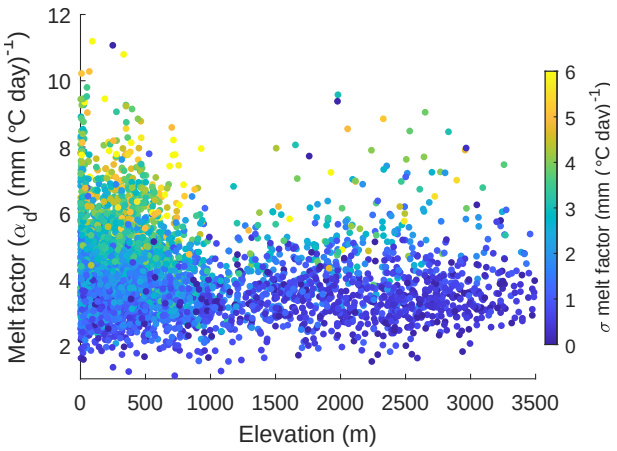

Figure S2: Median melt factor and elevation, coloured by its interannual variability (σ).

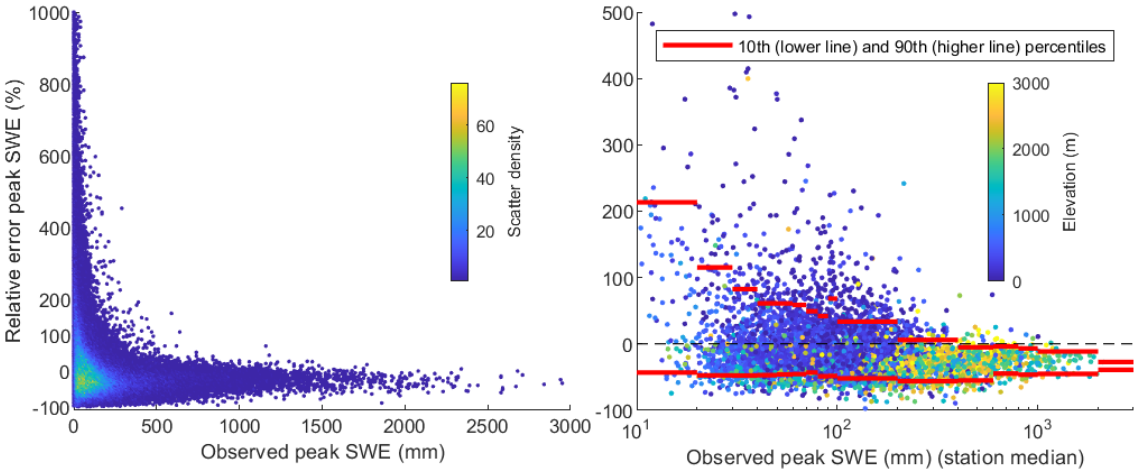

Figure S3: Analysis of relative errors of peak SWE. All station-years (left) and median per station (right).

Table S1: Mean values of climatic and performance variables for each of the three snow climate clusters (C1–C3). Percentages are relative to the mean of the entire period.

Cluster characteristic	**C1**	**C2**	**C3**
Elevation (m)	290	236	2348
Peak SWE (mm)	77.4	97.8	407.2
Snow cover duration (days)	110.0	192.0	198.0
$\overline{T}$ (°C)	6.0	-1.6	2.8
ΔT (°C)	12.9	18.0	10.3
Performance variable	**C1**	**C2**	**C3**
Accumulation onset (days)	-1.0	-1.0	4.5
Melt onset (days)	-2.0	-3.0	-12.0
End of snow season (days)	-0.5	1.0	-10.0
Peak SWE (%)	-17.1	20.1	-24.8
Snowmelt days (%)	20.0	40.6	11.1
Snowmelt rate (%)	-26.3	-13.5	-27.9

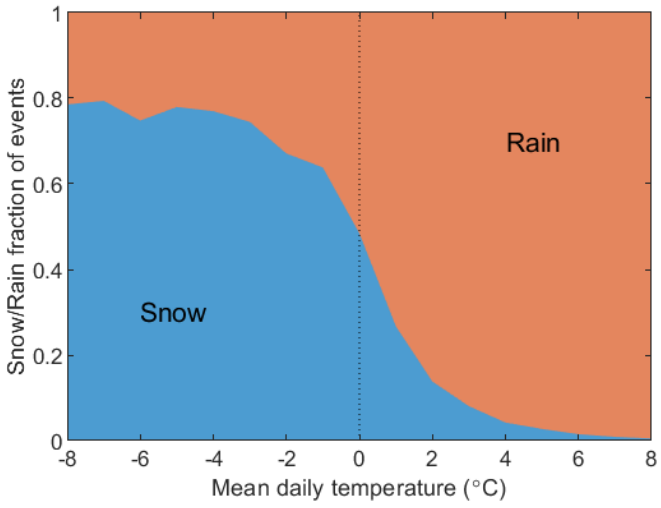

Figure S4: Fraction of events with snow accumulation and no snow accumulation (rain). Based on 1,321,260 days with observed precipitation of more than 10 mm. If the precipitation caused an increase in snow accumulation, the precipitation is considered as snow.

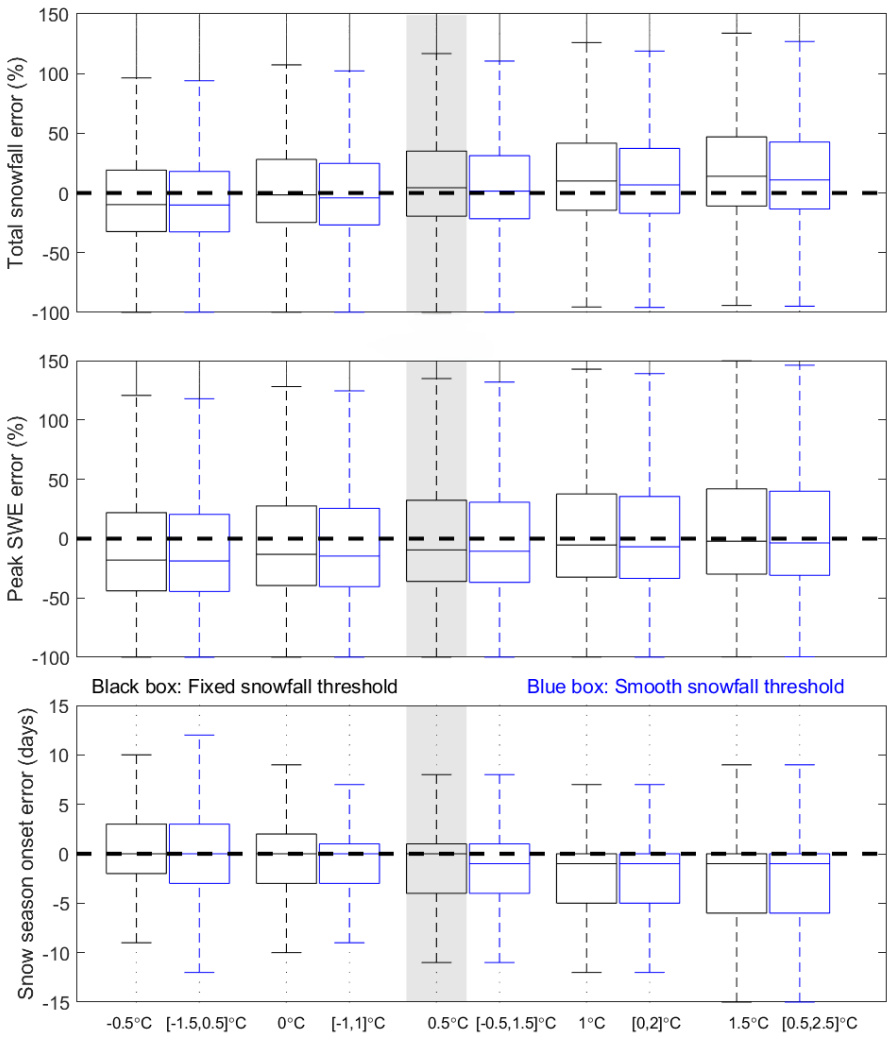

Figure S5: Sensitivity of results to varying fixed and smoothed snow accumulation temperature threshold. Black boxes indicate the results for fixed thresholds, and their neighbouring blue boxes show the results of a smooth snowfall threshold with a 1°C lower and 1°C higher range around the fixed threshold, where the amount of precipitation falling as snow linearly scales from all snow in the lowest temperature to all rain in the highest temperature. The grey shaded box indicates the threshold used for the first set of model simulations.

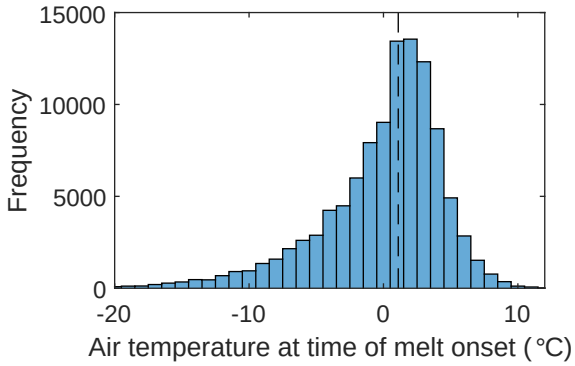

Figure S6: Distribution of daily temperatures at the time of snowmelt season onset. The median is +1.10°C and is indicated by the dashed line.

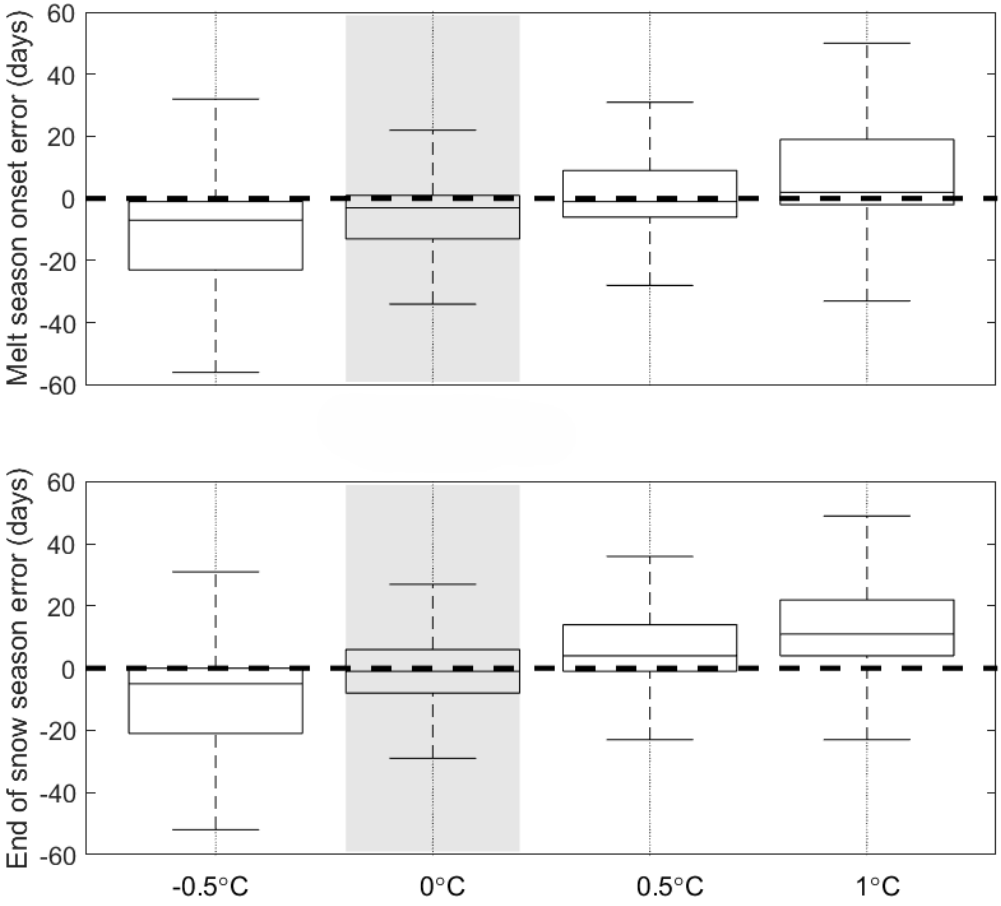

Figure S7: Sensitivity of results to varying melt temperature thresholds. The grey shaded box indicates the threshold used in this study.

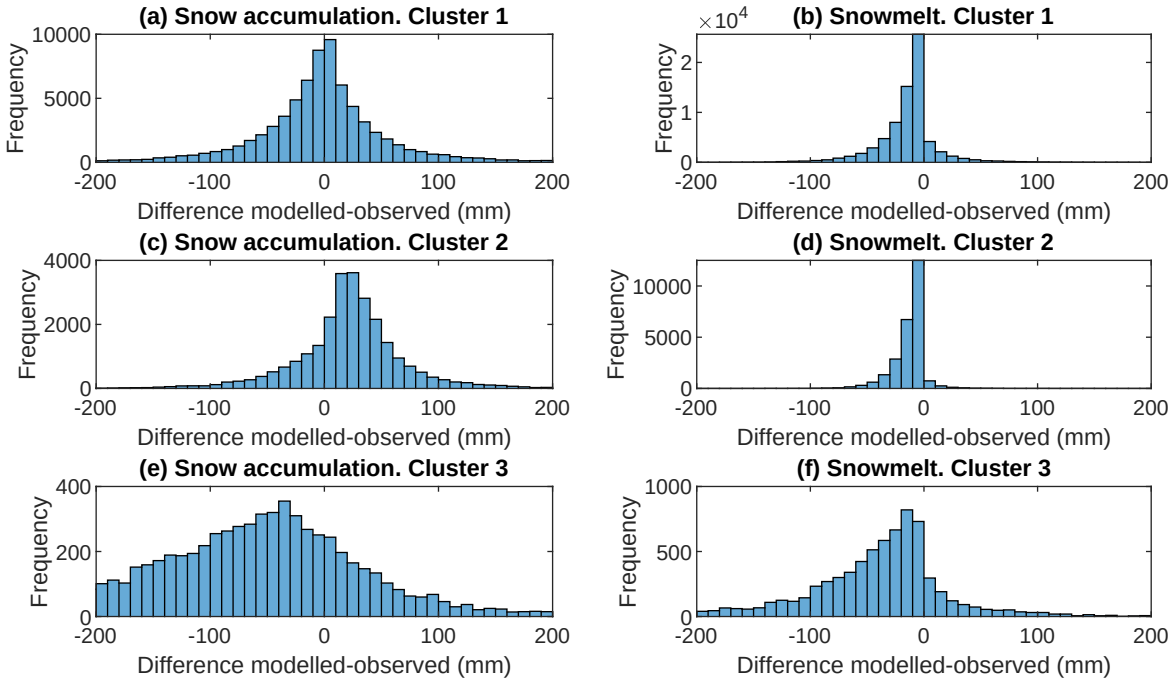

Figure S8: Snow accumulation vs snowmelt errors in the accumulation season. Left plots (a,c,e) show the difference between modelled and observed accumulated precipitation as snow during the accumulation season, per snow climate cluster. Right plots (a,c,e) show the difference between modelled and observed melt during the accumulation season, per snow climate cluster.

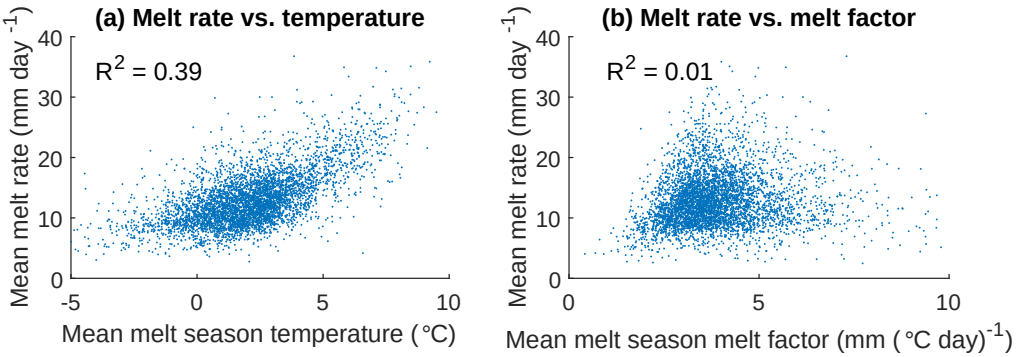

Figure S9: (a) The correlation between melt rate and melt season temperature, and (b) between melt rate and the melt factor.

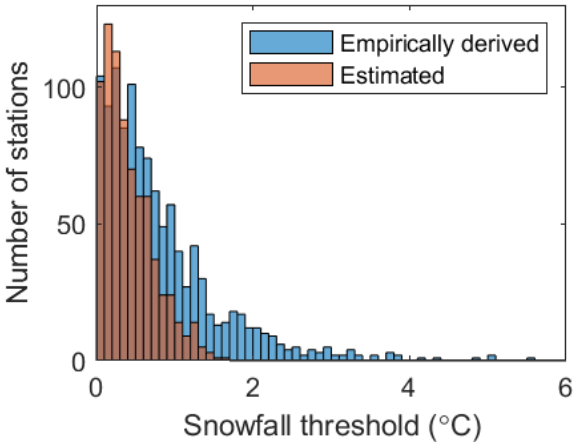

Figure S10: Distribution of the snowfall threshold in the empirically derived and estimated parameter set, excluding stations with a 0°C threshold (which represent 79% and 86% of stations for the empirically derived and estimated parameter set, respectively).

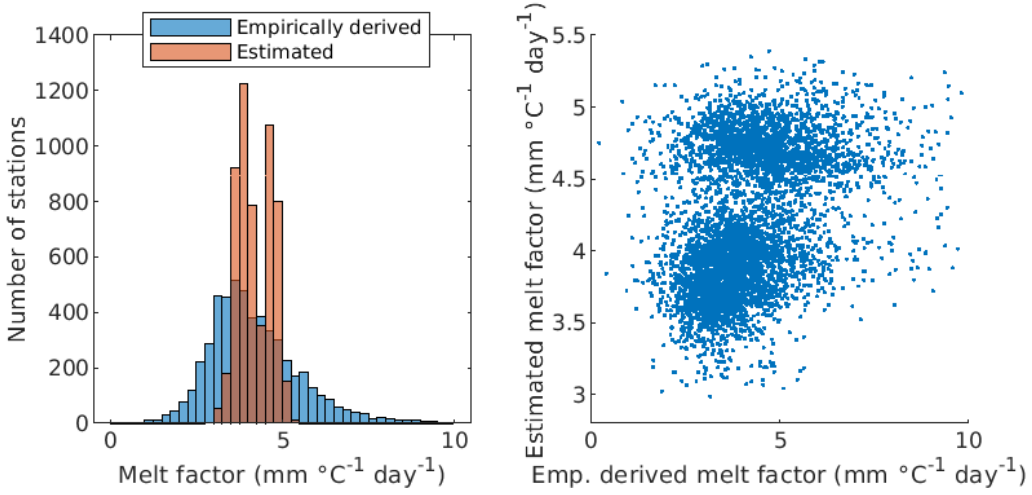

Figure S11: Melt factor distribution in the empirically derived parameter set vs the estimated parameter set based on climate variables. The bimodal distribution of melt factor is the result of the bimodal distribution of the station latitudes in the data set.

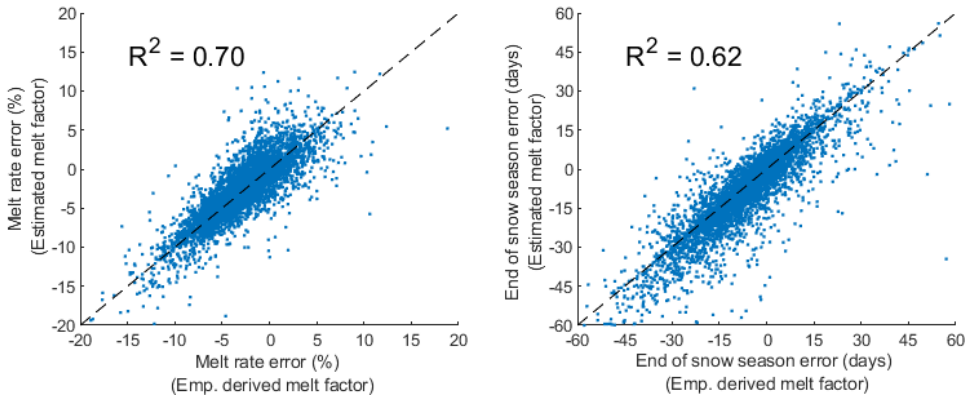

Figure S12: Model errors in the empirically derived parameter set vs the estimate parameter set based on climate variables. Melt rate error (left) and timing of end snow season error (right). Dashed line indicates the 1:1 line.