

Supplementary materials

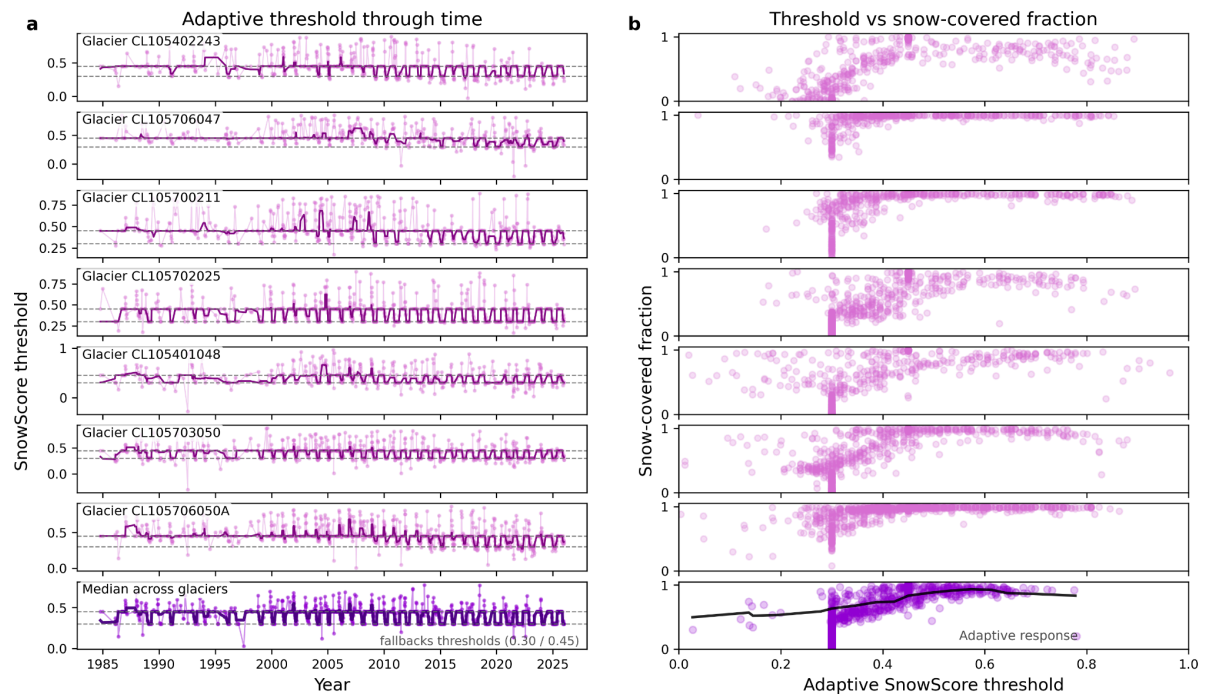


Figure S1. Adaptive SnowScore thresholds across representative glaciers and their relationship with snow-covered fraction. Panels show (a) temporal evolution and (b) dependence on snow-covered fraction.

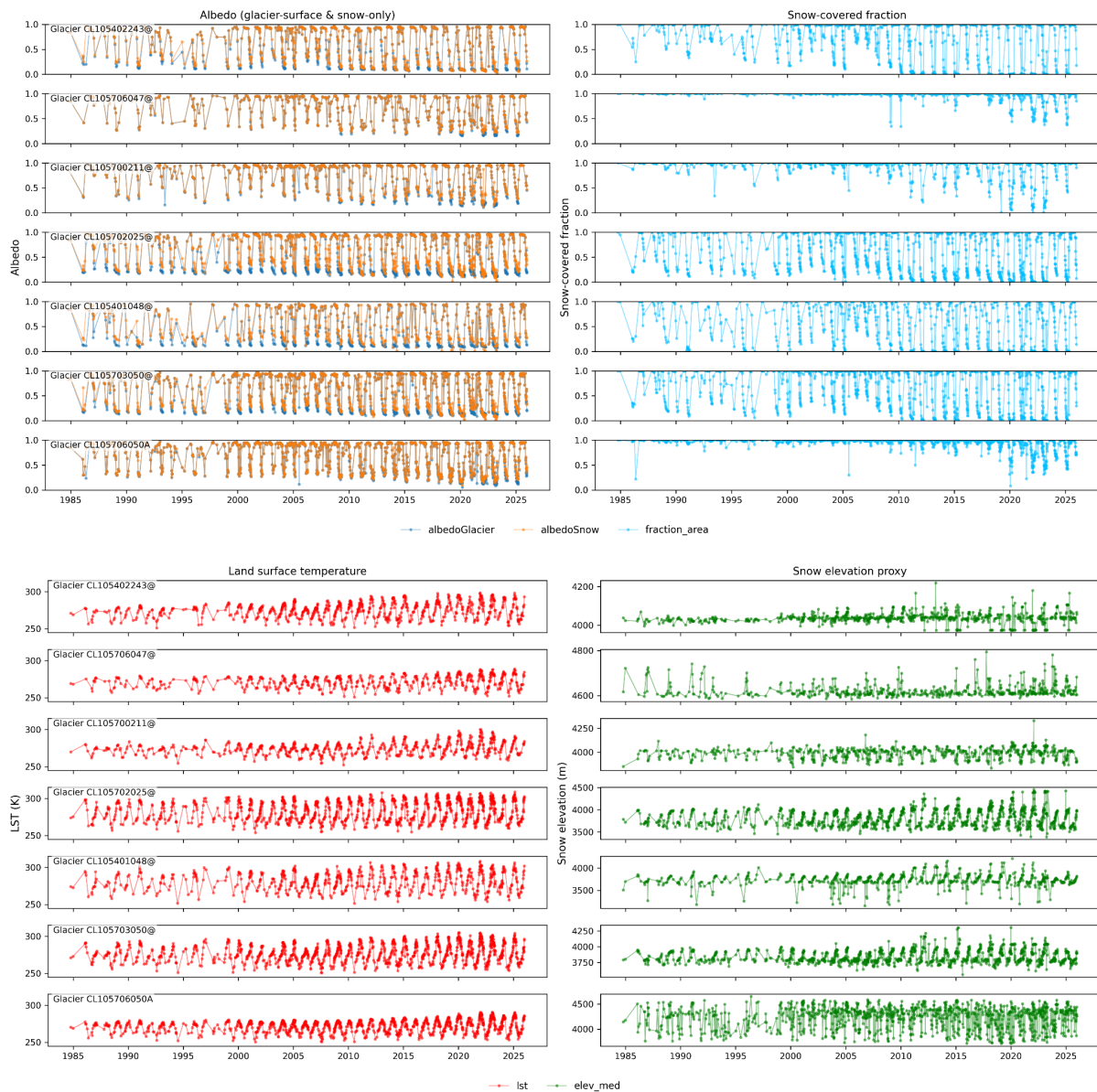


Figure S2. Examples of glacier-scale proxy time series for seven representative glaciers. The top panels show (left) surface albedo for glacier-wide and snow-covered pixels and (right) fractional snow-covered area. Bottom panels show (left) land surface temperature and (right) snow elevation proxy. All variables exhibit clear seasonal cycles and interannual variability, with consistent relationships across proxies reflecting underlying cryospheric processes.

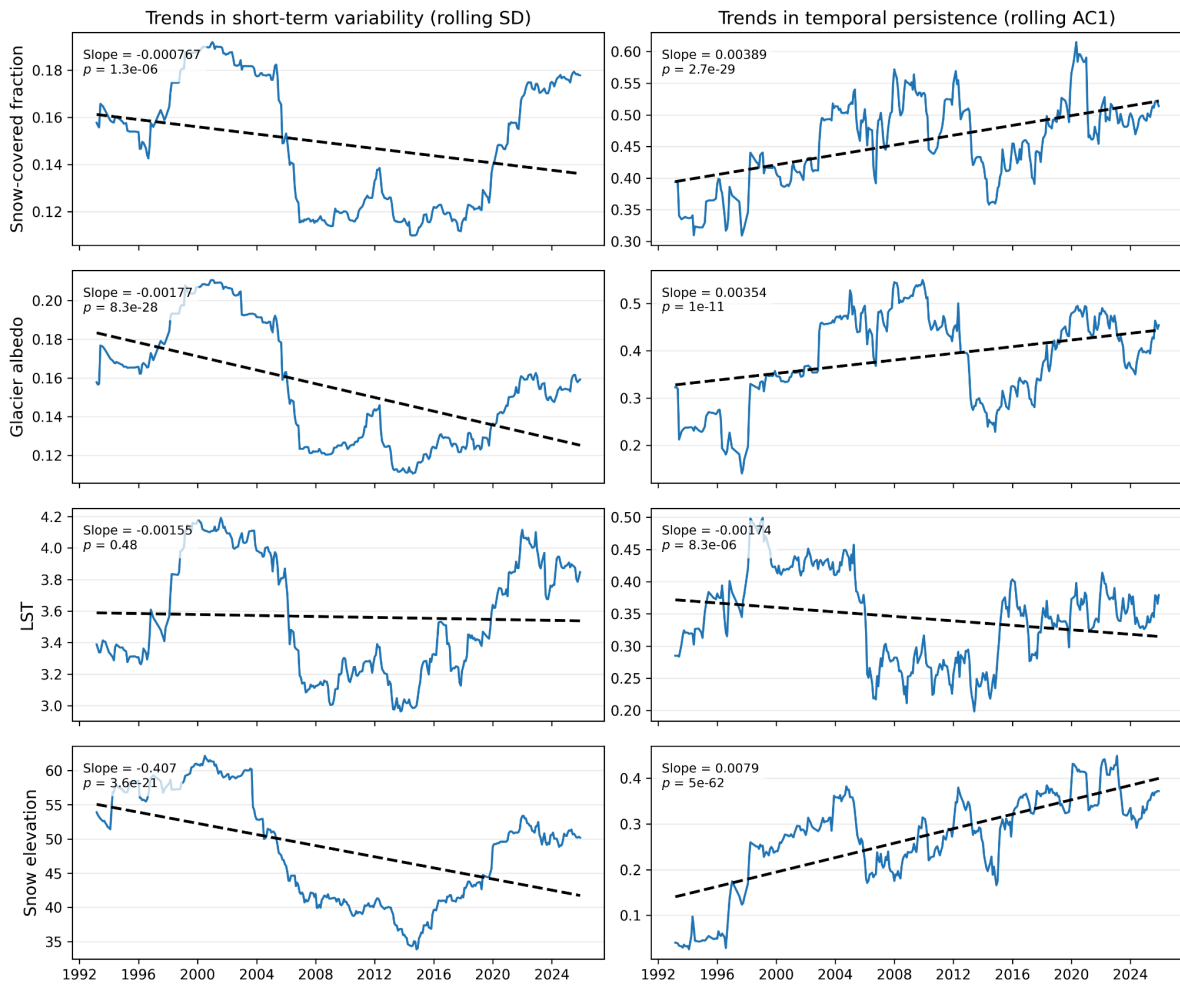


Figure S3. Temporal evolution of regional glacier-scale dynamics derived from deseasonalised monthly time series. Left column panel shows trends in short-term variability, quantified as rolling standard deviation (SD), while the right column panel shows trends in temporal persistence, quantified as lag-1 autocorrelation (AC1). The dashed lines indicate linear trend fits. Annotations report slope and statistical significance of regional trends (p -value).

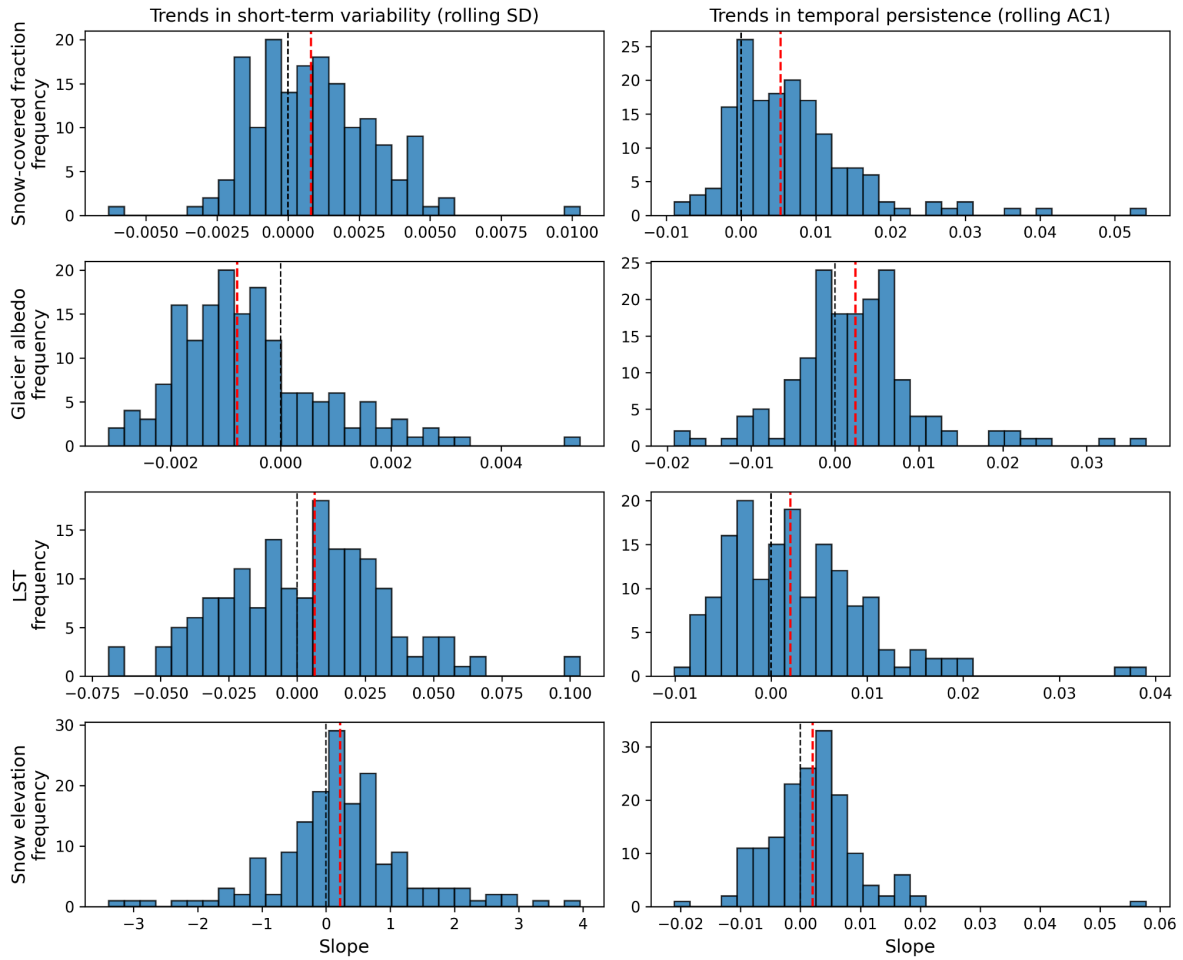


Figure S4. Distribution of glacier-specific trends in short-term variability (rolling standard deviation; left column panel) and temporal persistence (lag-1 autocorrelation; right column panel). Each ridge represents the density of slopes across glaciers for a given proxy. Black vertical dashed lines indicate zero trend while red vertical dashed lines indicate the median trend across glaciers.

Table S1. Summary statistics of glacier-specific trends in short-term variability (rolling standard deviation, SD) and temporal persistence (lag-1 autocorrelation, AC1). Median and weighted-median slopes are reported together with the fraction of glaciers exhibiting positive and statistically significant trends ($p \leq 0.05$).

Variable	Metric	Median slope	Weighted median slope	% positive	% significant positive
Snow fraction	SD	0.000800	-0.000340	62.13	56.80
Snow fraction	AC1	0.005251	0.004738	82.25	72.78
Glacier albedo	SD	-0.000787	-0.001165	24.26	21.30
Glacier albedo	AC1	0.002420	-0.000960	59.76	54.44
LST	SD	0.006477	0.009827	54.44	51.48
LST	AC1	0.002006	0.001761	60.36	52.66
Snow elevation	SD	0.218999	-0.465693	63.31	59.17
Snow elevation	AC1	0.002033	0.004640	62.13	52.66

Table S2. Multiple linear regression results linking glacier-response modes to streamflow lag using basin-level cluster-robust standard errors.

Predictor	Coefficient (β)	Std. Error	z-value	p-value	CI (2.5%)	CI (97.5%)
Intercept	0.000	0.125	0.000	1.000	-0.245	0.245
Trend mode	0.826	0.117	7.062	<0.001	0.597	1.056
Variability mode	-0.574	0.042	-13.612	<0.001	-0.656	-0.491
Memory mode	0.046	0.082	0.568	0.570	-0.114	0.207

Model performance: $R^2 = 0.715$; Adjusted $R^2 = 0.638$, $n = 15$, Covariance type: Cluster-robust (basin level)