Supplementary Materials

Table S1. Meteorological stations (ordered by elevation) with available daily snow-depth observations from Meteomanz (data source: land SYNOP and BUFR) between July 2014–September 2025, used to validate the MOD10A1 Terra CGF (NDSI-based) snow metrics and to quantify associated uncertainties.

Meteo Station	Longitude	Latitude	Elevation (m)
Dumbrăvița de Codru	22.1712	46.6446	586
Câmpeni	23.0404	46.3638	591
Petroșani	23.3767	45.4063	607
Miercurea Ciuc	25.7726	46.3713	661
Toplița	25.3599	46.9264	687
Întorsura Buzăului	26.0568	45.6683	707
Joseni	25.5156	46.7057	750
Poiana Stampei	25.1344	47.3246	923
Predeal	25.5835	45.5063	1090
Stâna de Vale	22.6234	46.6898	1108
Roșia Montană	23.139	46.3176	1196
Bucin	25.2965	46.649	1282
Băișoara	23.3102	46.5355	1360
Fundata	25.2715	45.4315	1384
Semenic	22.0558	45.1814	1432
Cuntu	22.5015	45.3005	1456
Sinaia	25.5142	45.355	1510
Parâng	23.4631	45.3874	1548
Penteleu	26.4098	45.6027	1632
Lăcăuți	26.3755	45.8239	1776
Iezer	24.649	47.6026	1785
Vlădeasa	22.7942	46.7592	1836
Călimani	25.2462	47.0979	2022
Bălea Lac	24.6147	45.6039	2070
Țarcu	22.5327	45.2810	2180
Vf. Omu	25.4567	45.4458	2504

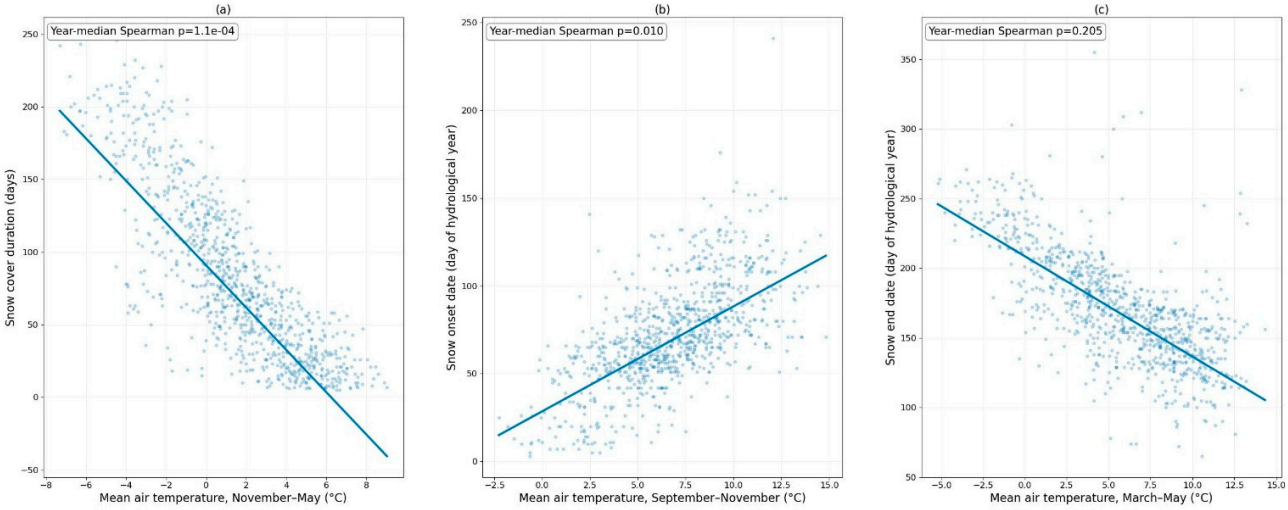


Figure S1. *Station–year relationships between seasonal air temperature and snow-phenology metrics. Panels show (a) snow-cover duration (SCD) versus Nov–May mean air temperature, (b) snow onset date (SOD) versus Sep–Nov mean air temperature, and (c) snow end date (SED) versus Mar–May mean air temperature. Points represent station–year pairs (snow metrics sampled from the MODIS snow point(s) overlapping each station for the corresponding hydrological year). Solid lines indicate linear fits for visualization. Reported Spearman p-values are based on year-level medians (median climate across stations versus median snow metric across station-overlapping snow points).*

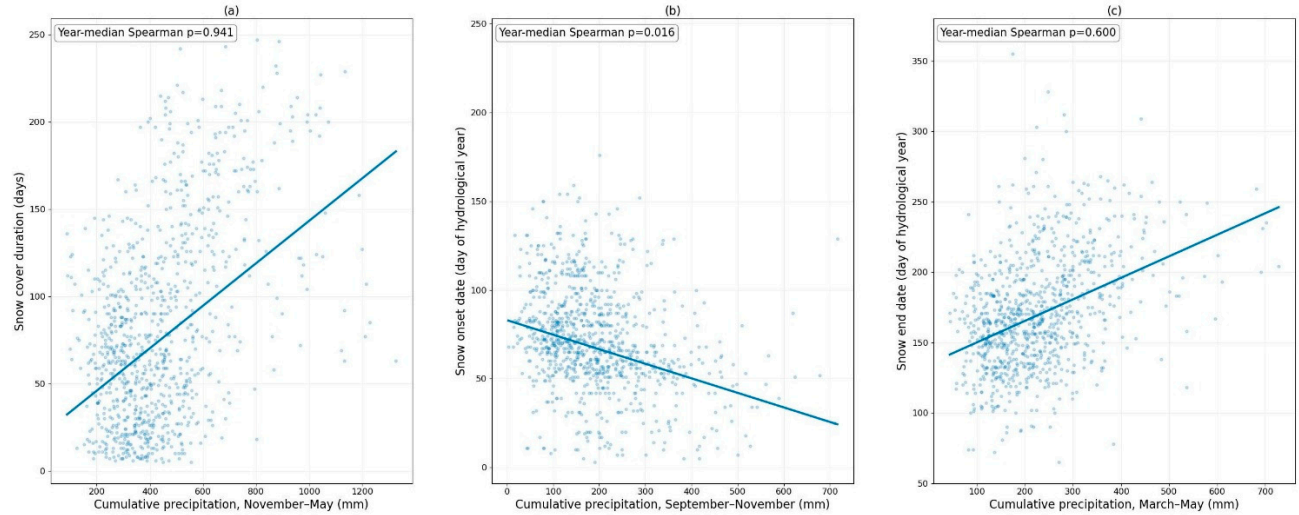


Figure S2. *Same as Fig. S1, but for seasonal precipitation. Panels show (a) SCD versus Nov–May cumulative precipitation, (b) SOD versus Sep–Nov cumulative precipitation, and (c) SED versus Mar–May cumulative precipitation. Points represent station–year pairs; solid lines indicate linear fits for visualization. Spearman p-values are computed from year-level medians as in Fig. S1.*

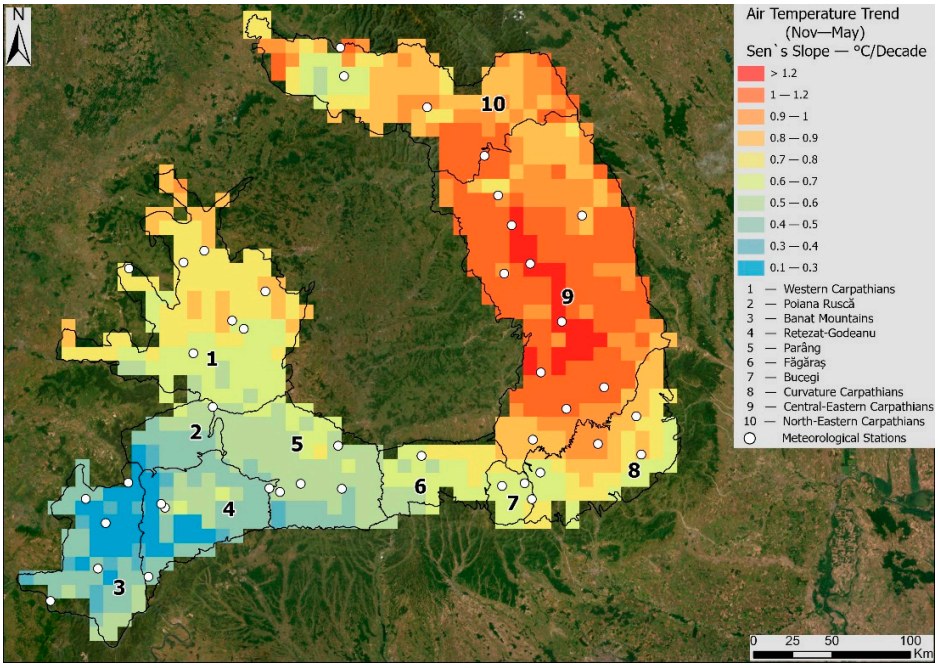


Figure S3. *Spatial distribution of cold-season (Nov–May) air-temperature trends over 2000–2023, expressed as Sen's slope (°C decade⁻¹) from monthly E-OBS gridded data across the study domain. White circles indicate the 43 meteorological stations used in the climate–snow analyses.*

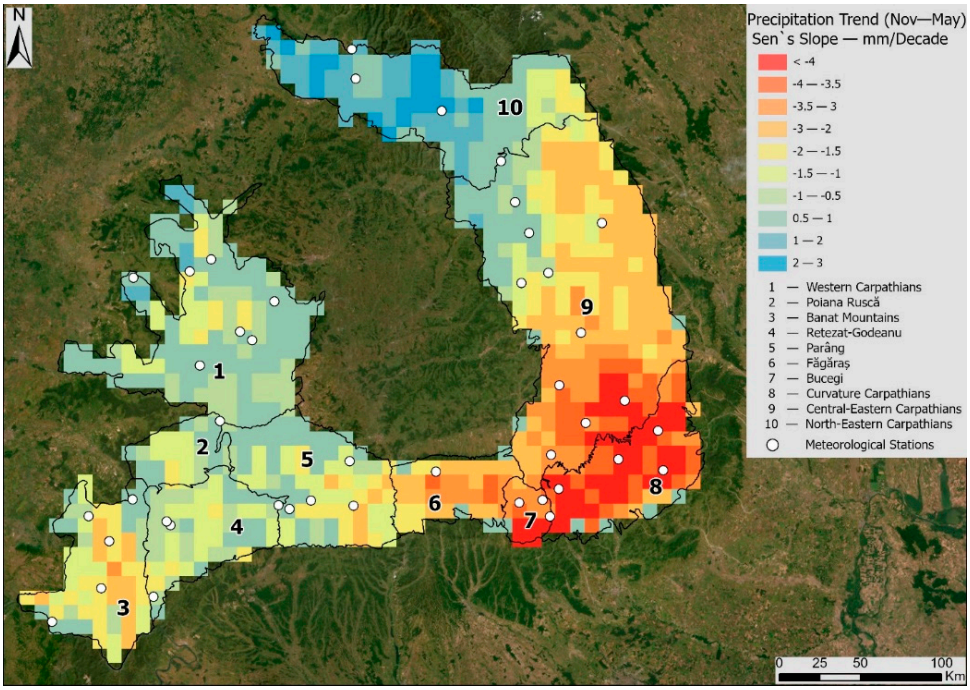


Figure S4. *Spatial distribution of cold-season (Nov–May) precipitation trends over 2000–2023, expressed as Sen's slope (mm decade⁻¹) from monthly E-OBS gridded data across the study domain. White circles indicate the 43 meteorological stations used in the climate–snow analyses.*

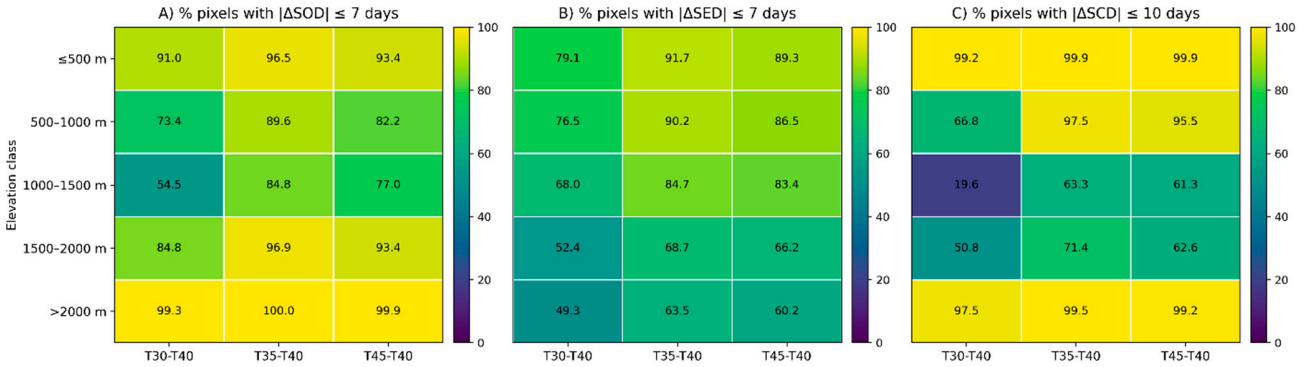


Figure S5. *Robustness of snow phenology metrics to NDSI threshold perturbations, expressed as the percentage of pixels within a tolerance window relative to the baseline threshold (T40). Panels show the fraction of pixels with (A) $|\Delta SOD| \leq 7$ days, (B) $|\Delta SED| \leq 7$ days, and (C) $|\Delta SCD| \leq 10$ days for T30, T35, and T45 compared against T40, summarized by elevation class.*

Table S2a. Trend robustness summary for SCD (snow cover duration) relative to the baseline NDSI threshold (T40). For each elevation class, the table reports worst-case diagnostics across alternative NDSI thresholds (T30, T35, T45) relative to T40: (i) minimum Pearson correlation r (time-series similarity), (ii) maximum absolute trend difference |Theil–Sen trend slope| (days yr^{-1}), and (iii) maximum interannual-variability difference |SD ratio − 1|, where SD ratio = SD(Tx)/SD(T40). The alternative threshold producing each extreme is given in parentheses.

Elevation Class	Minimum Pearson r vs T40 (thr)	Maximum |Δtrend| vs T40 (|ΔTheil-Sen slope|, days·yr^{-1}; thr)	Maximum interannual variability difference vs T40 (|SD ratio - 1|; thr)
≤ 500 m	0.991 (T45)	0.250 (T45)	0.08 (T30)
500 – 1000 m	0.989 (T30)	0.537 (T30)	0.27 (T30)
1000 – 1500 m	0.983 (T30)	0.333 (T45)	0.28 (T30)
1500 – 2000 m	0.990 (T30)	0.250 (T30)	0.02 (T30)
> 2000 m	0.998 (T30)	0.200 (T30)	0.02 (T30)

Table S2b. Trend robustness summary for SOD (snow onset date) relative to the baseline threshold (T40). Same diagnostics as Table S2a. Parentheses indicate the threshold (T30/T35/T45) that produces the reported extreme.

Elevation Class	Minimum Pearson r vs T40 (thr)	Maximum |Δtrend| vs T40 (|ΔTheil-Sen slope|, days·yr^{-1}; thr)	Maximum interannual variability difference vs T40 (|SD ratio - 1|; thr)
≤ 500 m	0.994 (T30)	0.571 (T30)	0.01 (T45)
500 – 1000 m	0.895 (T30)	0.500 (T45)	0.07 (T30)
1000 – 1500 m	0.958 (T45)	0.133 (T35)	0.01 (T30)
1500 – 2000 m	0.989 (T30)	0.238 (T40)	0.00 (T45)
> 2000 m	0.993 (T30)	0.091 (T35)	0.02 (T35)

Table S2c. Trend robustness summary for SED (snow end date) relative to the baseline threshold (T40). Same diagnostics as Table S2a. Parentheses indicate the threshold (T30/T35/T45) that produces the reported extreme.

Elevation Class	Minimum Pearson r vs T40 (thr)	Maximum |Δtrend| vs T40 (|ΔTheil-Sen slope|, days·yr⁻¹; thr)	Maximum interannual variability difference vs T40 (|SD ratio - 1|; thr)
≤ 500 m	0.927 (T30)	0.318 (T30)	0.02 (T30)
500 – 1000 m	0.943 (T30)	0.891 (T30)	0.05 (T30)
1000 – 1500 m	0.963 (T30)	0.144 (T35)	0.13 (T30)
1500 – 2000 m	0.942 (T30)	0.442 (T30)	0.21 (T30)
> 2000 m	0.992 (T45)	0.210 (T45)	0.04 (T30)

Table S3a. Spatial coverage of the ≥2000 m elevation band on the MODIS 500 m grid (pixel count, area, and share of the study domain). This table is provided to document the limited spatial extent (sample size) of high-elevation terrain and to contextualize the statistical power of trend detection at ≥2000 m.

Metric	Value	Units	Notes
Pixel area	0.2034	km²	Derived from MODIS grid transform
Valid pixels (domain)	330,150	count	All pixels with valid DEM values
Total area (domain)	67154.67	km²	Valid pixels × pixel area
Pixels ≥ 2000 m	1,943	count	0.00 (T45)
Area ≥ 2000 m	395.2189	km²	Pixels ≥2000 m × pixel area
Area share ≥2000 m	0.5885	%	Area ≥2000 m / total area

Table S3b. Trend statistics for snow metrics (SCD, SOD, SED; 2000–2025) in the ≥2000 m elevation band derived from an area-aggregated hydrological-year time series. This aggregation is included to address potential low statistical power associated with pixel-level tests over a small high-elevation area, by evaluating trends on a single annual series for the ≥2000 m class. Trends are summarized using the Theil–Sen slope (days yr⁻¹) with 95% confidence intervals and the Mann–Kendall test (p-value, Kendall's τ).

Variable	Sen slope (days/year)	95% CI low	95% CI high	MK p-value	Kendall τ
Snow Cover Days Mean	-0.303	-1.313	0.835	0.6238	-0.073
Snow Onset Date Mean	0.012	-0.234	0.560	0.8153	0.037
Snow End Date Mean	0.079	-0.803	1.258	0.8335	0.033

Note: Sen slope and 95% CI from Theil–Sen estimator; MK = Mann–Kendall test on aggregated annual series.