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Session: HS7.4 – Future hydroclimatic scenarios in a changing world

European snow dynamics and changing patterns under climate variability

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This presentation participates in OSPP
Outstanding Student & PhD candidate Presentation contest

Research Question

Why do snow dynamics matter?

- Snow patterns are changing across Europe
- Regional responses differ between MED, CEU, and NEU
- Water-availability impacts remain uncertain

Objective

Regional and multi-scale SWE variability

- How does SWE vary across MED, CEU, and NEU?
- Are SWE trends consistent across annual, 10-year, and 30-year scales?
- How strongly is SWE related to temperature?
- Can long-term persistence explain part of the variability?

Data & Method

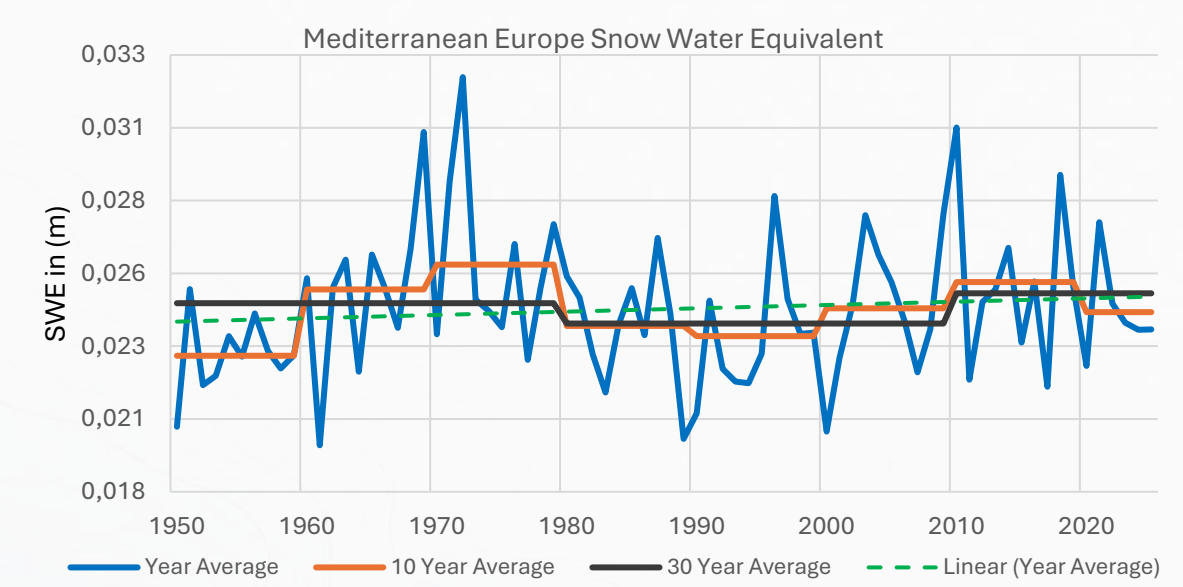
Data

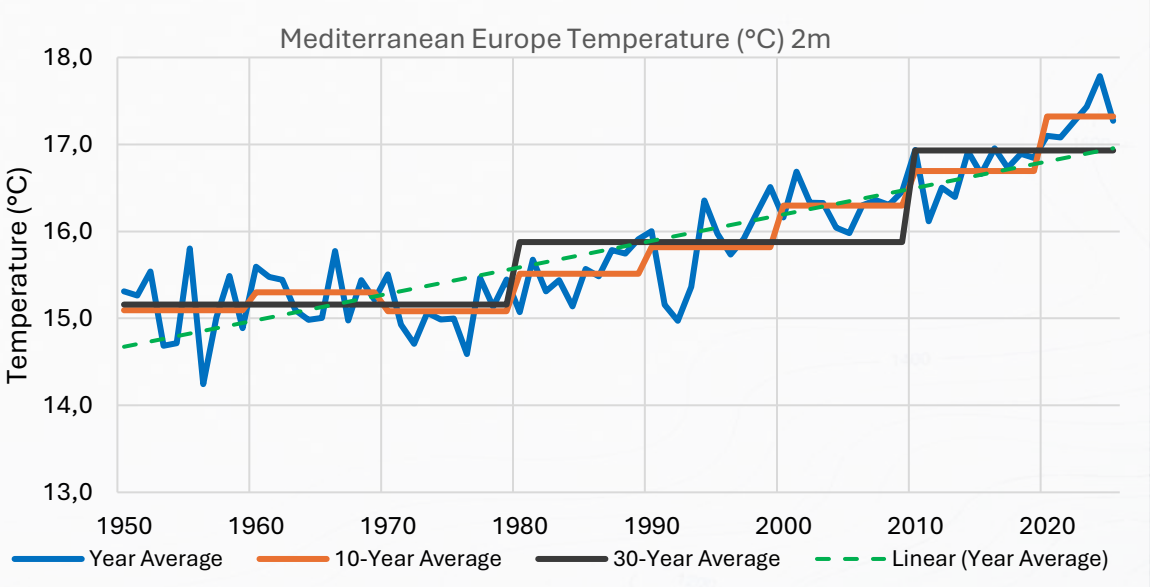
- ERA5 monthly reanalysis via KNMI Climate Explorer
- Europe, 1950–2025
- SWE and 2 m air temperature (mean, max, min)

Method

- Annual, 10-year, and 30-year aggregation
- Trend and variability analysis
- SWE–temperature correlation
- Hurst–Kolmogorov persistence analysis

SWE-Temperature Trends in MED



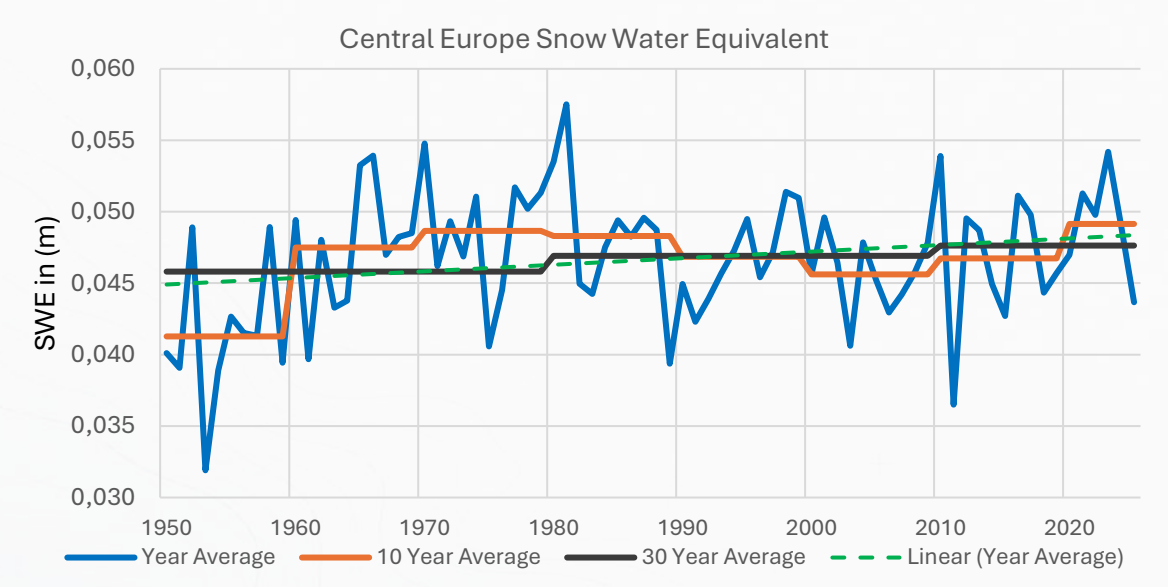


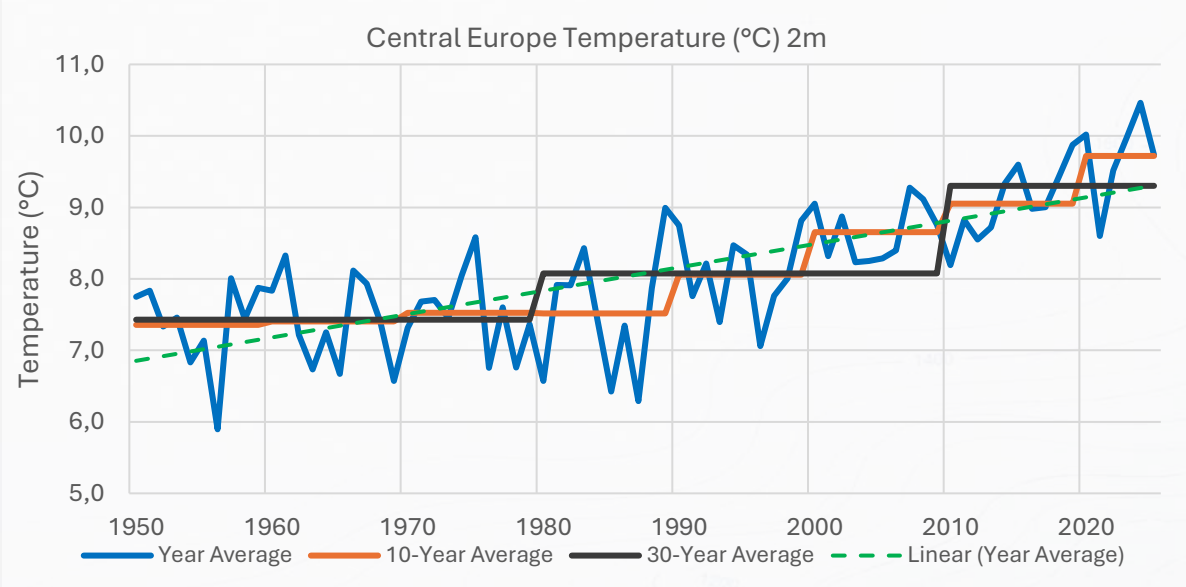
Key Result:

- Clear warming signal in MED
- No corresponding SWE decline
- SWE variability dominates the weak trend

Slope	
Snow Water E. m/year	1,14E-05
Temperature °C/year	0,0304

SWE-Temperature Trends in CEU



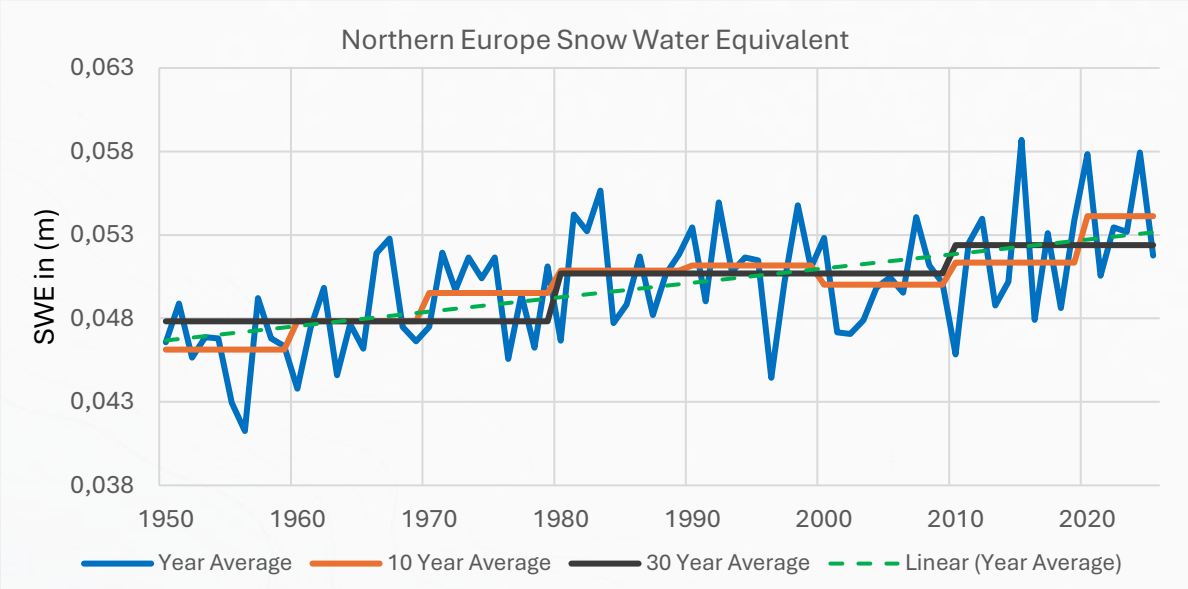


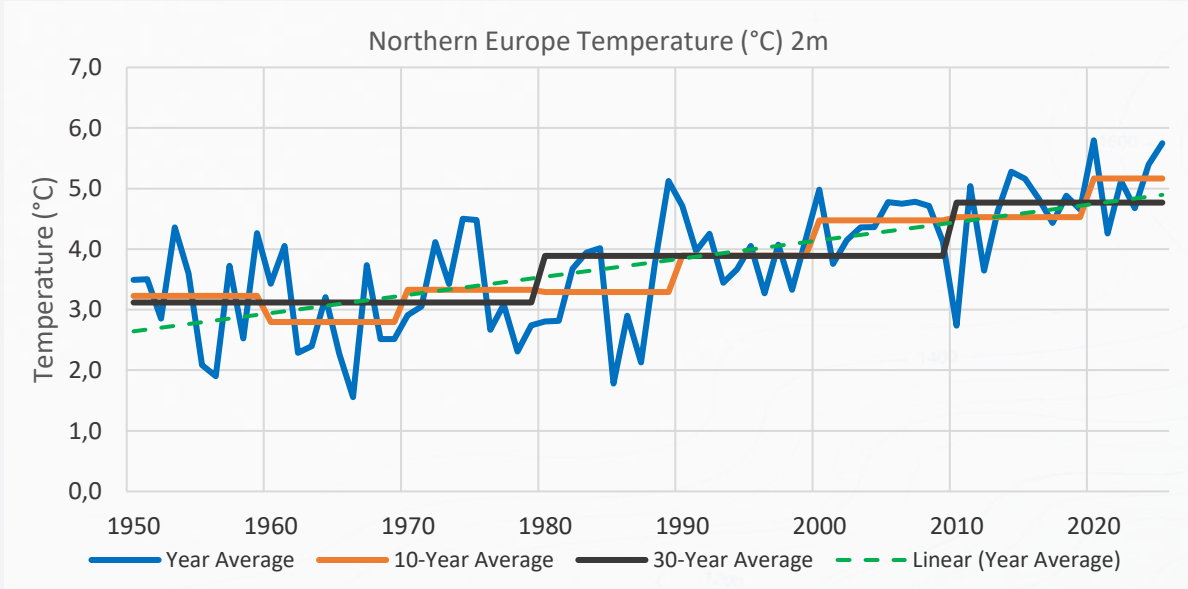
Key Result:

- Clear warming signal in CEU
- SWE does not show a consistent decline
- Variability remains large relative to the trend

Slope	
Snow Water E. m/year	4,61E-05
Temperature °C/year	0,0327

SWE-Temperature Trends in NEU





Key Result:

- NEU shows warming and increasing SWE
- SWE increase is more evident in NEU than in MED/CEU
- Regional variability still controls the signal

Slope	
Snow Water E. m/year	8,63E-05
Temperature °C/year	0,03

Hurst–Kolmogorov Variability Analysis

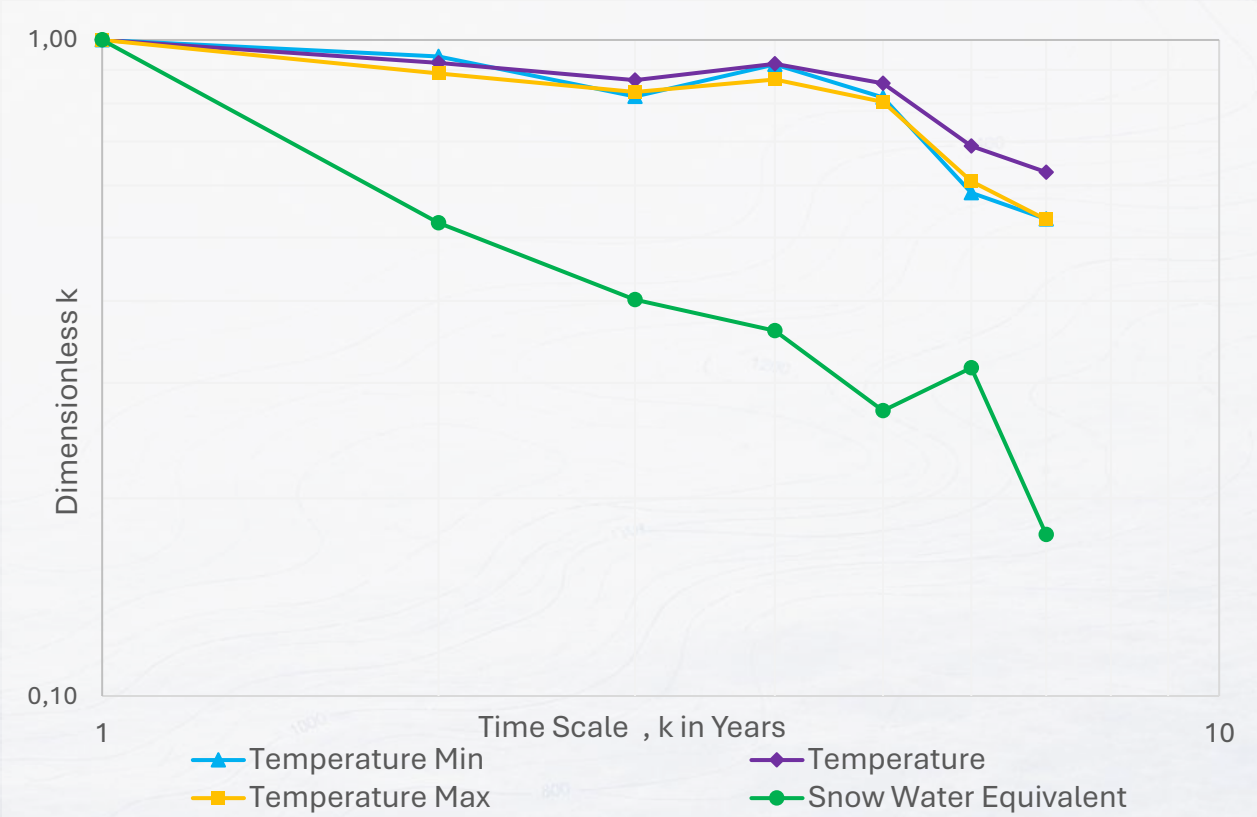
Long-term persistence

- Climacograms show how variability changes at longer time scales
- HK analysis helps distinguish trend from persistence

$$\gamma_k := var[\underline{x}_j^{(k)}] = \gamma_1/k^{2-2H}$$

Hurst	Empirical
Temperature	0,90
Temperature Min	0,86
Temperature Max	0,86
Snow Water Equivalent	0,62

Climacogram: Mediterranean region



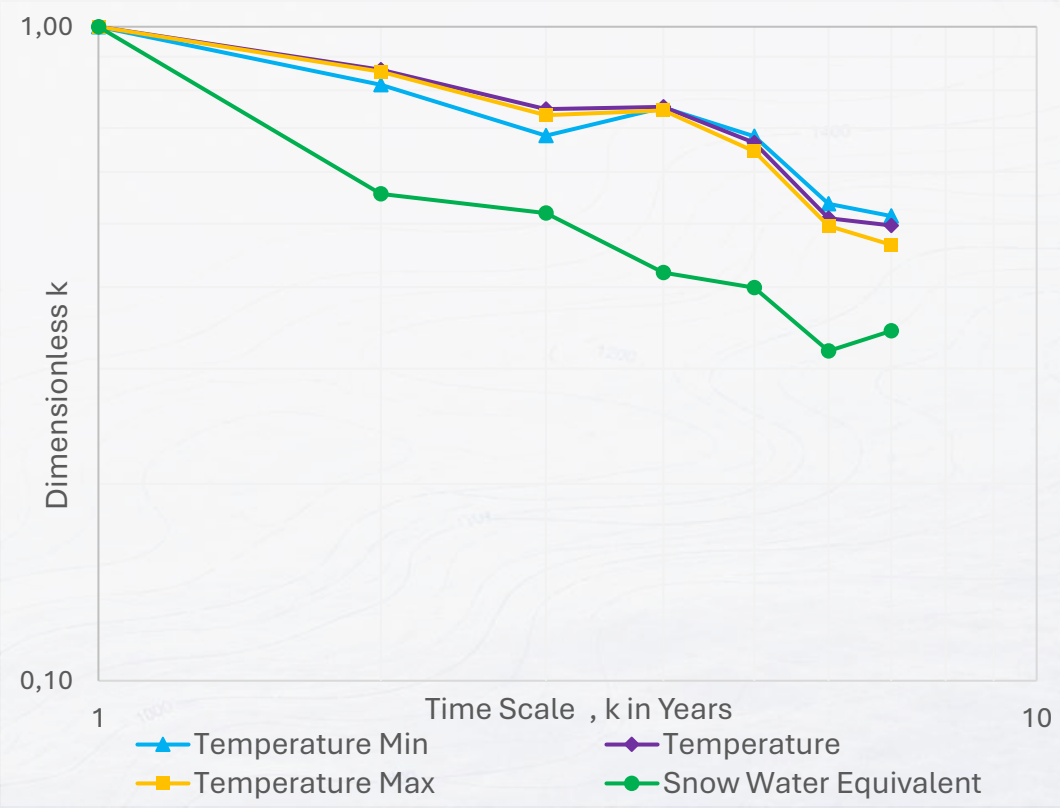
Hurst–Kolmogorov Variability Analysis

Long-term persistence

- Temperature remains more persistent than SWE
- SWE shows moderate persistence
- Snow-water variability remains more irregular than temperature

Hurst	Empirical
Temperature	0,82
Temperature Min	0,84
Temperature Max	0,81
Snow Water Equivalent	0,72

Climacogram: Central region



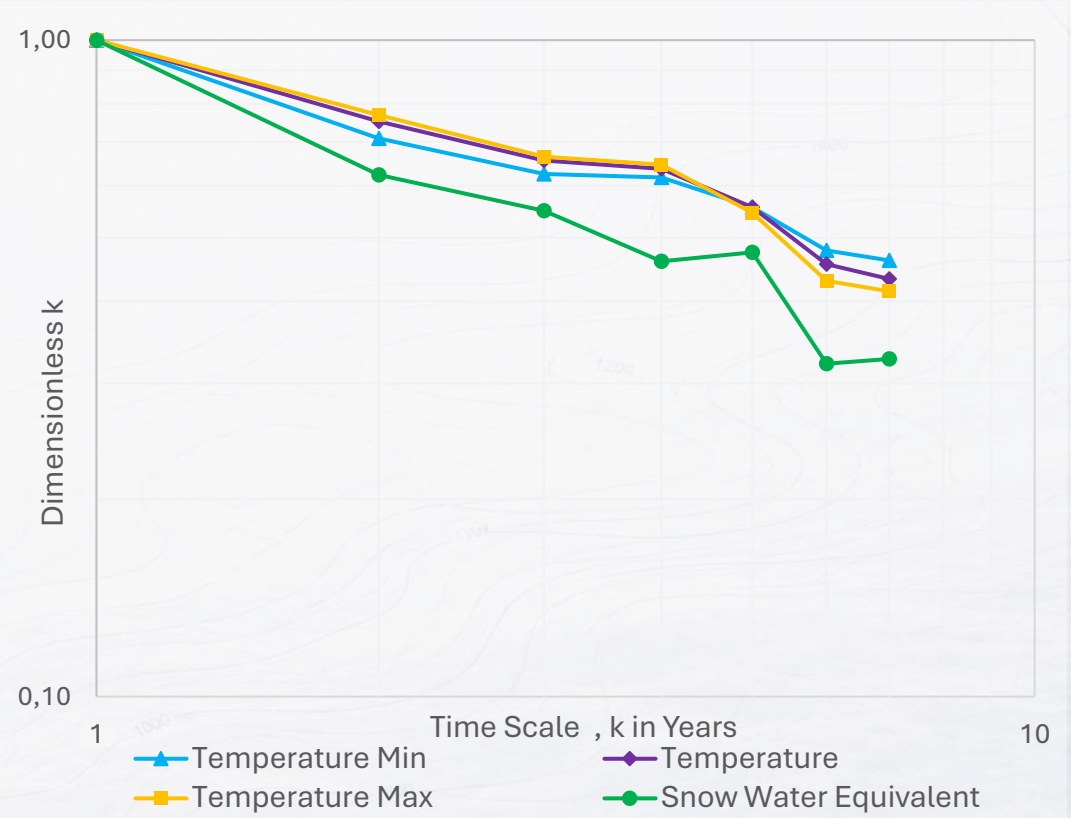
Hurst–Kolmogorov Variability Analysis

Long-term persistence

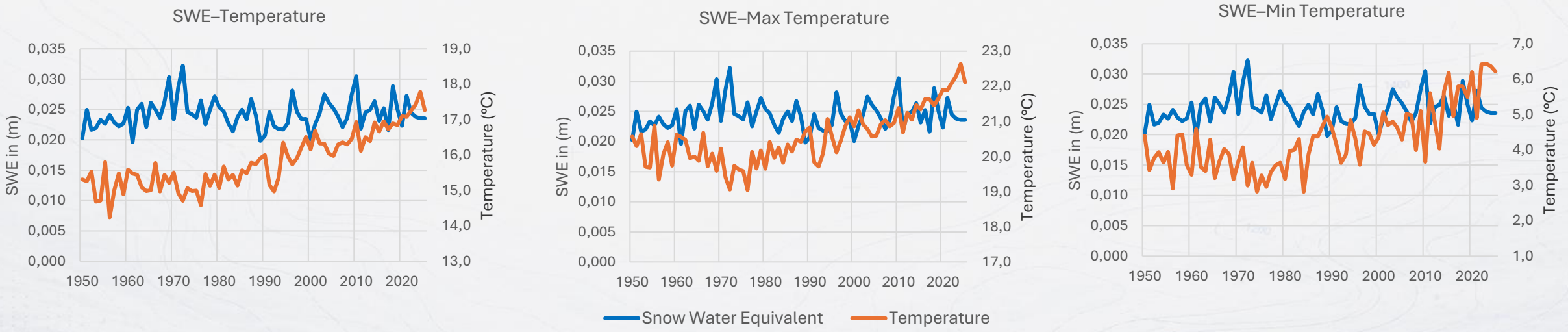
- SWE persistence is stronger in Northern Europe
- SWE variability is closer to temperature variability
- Snow-water conditions show a more stable multi-year signal

Hurst	Empirical
Temperature	0,79
Temperature Min	0,81
Temperature Max	0,78
Snow Water Equivalent	0,72

Climacogram: Northern region

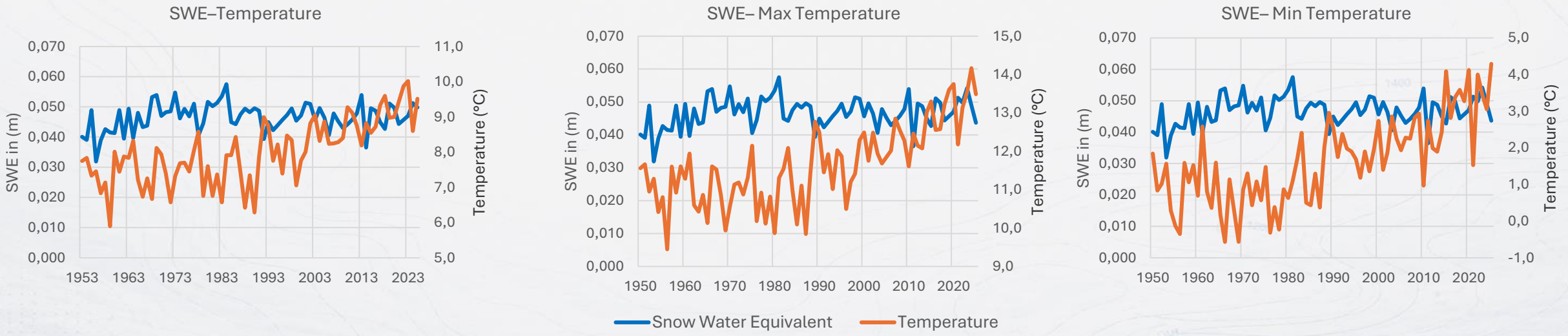


Mediterranean Europe: Warming-sensitive SWE variability



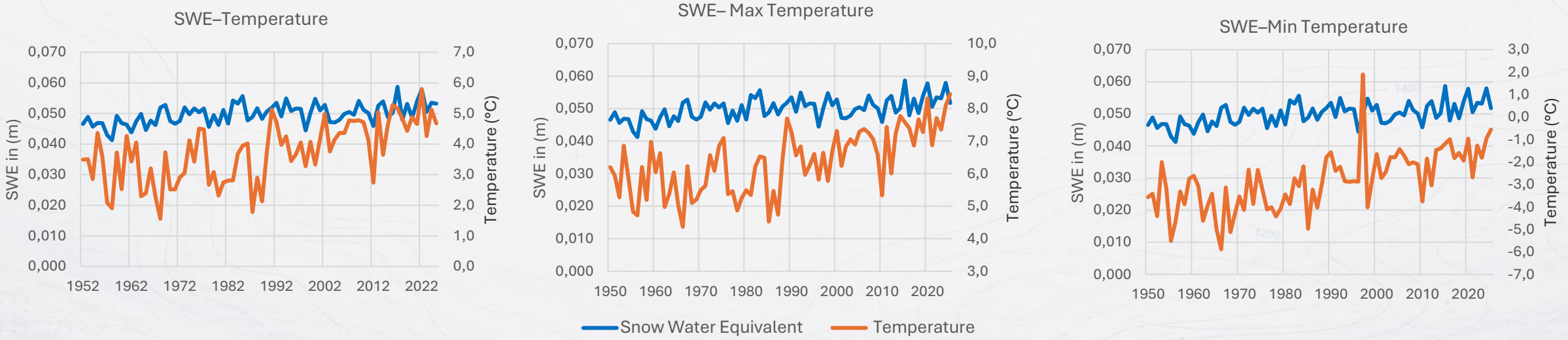
Mediterranean snowpack is highly sensitive to warming, making SWE increasingly variable and less reliable as seasonal water storage.

Central Europe:
Warming-driven shifts in SWE variability



Central European SWE shows high variability under warming, suggesting increasing temperature influence on snow-water dynamics.

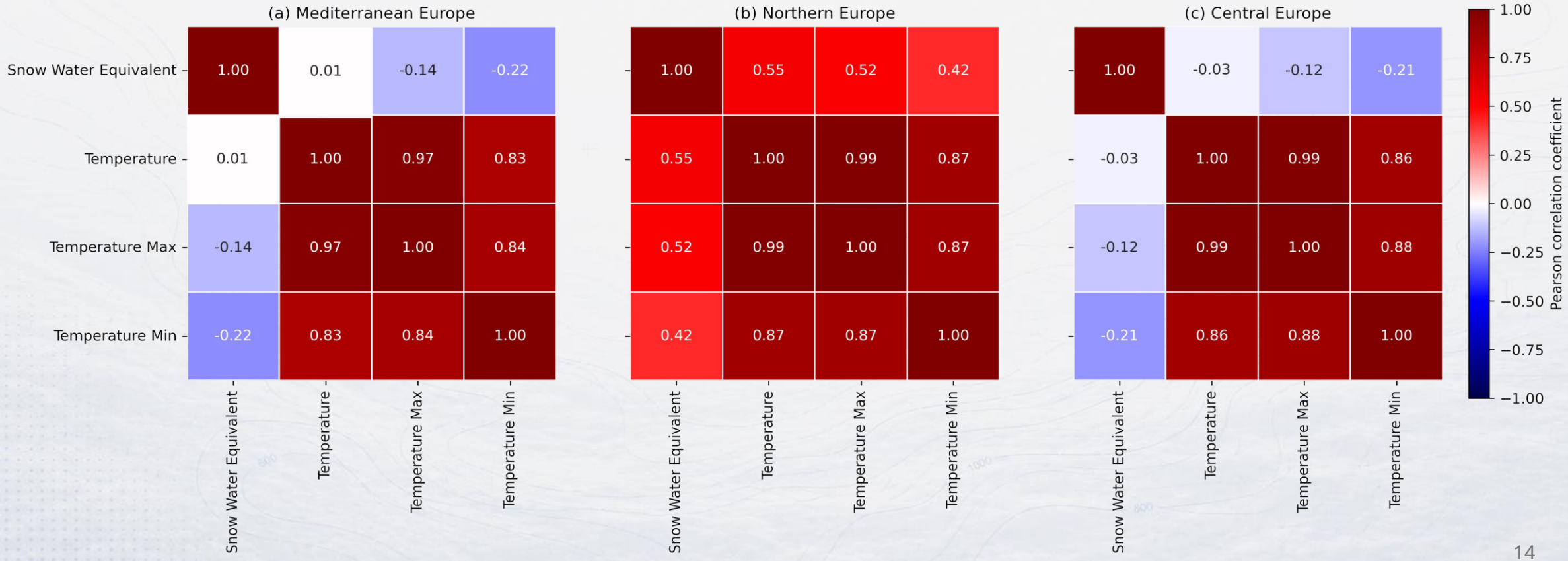
Northern Europe:
Positive SWE–temperature co-variability



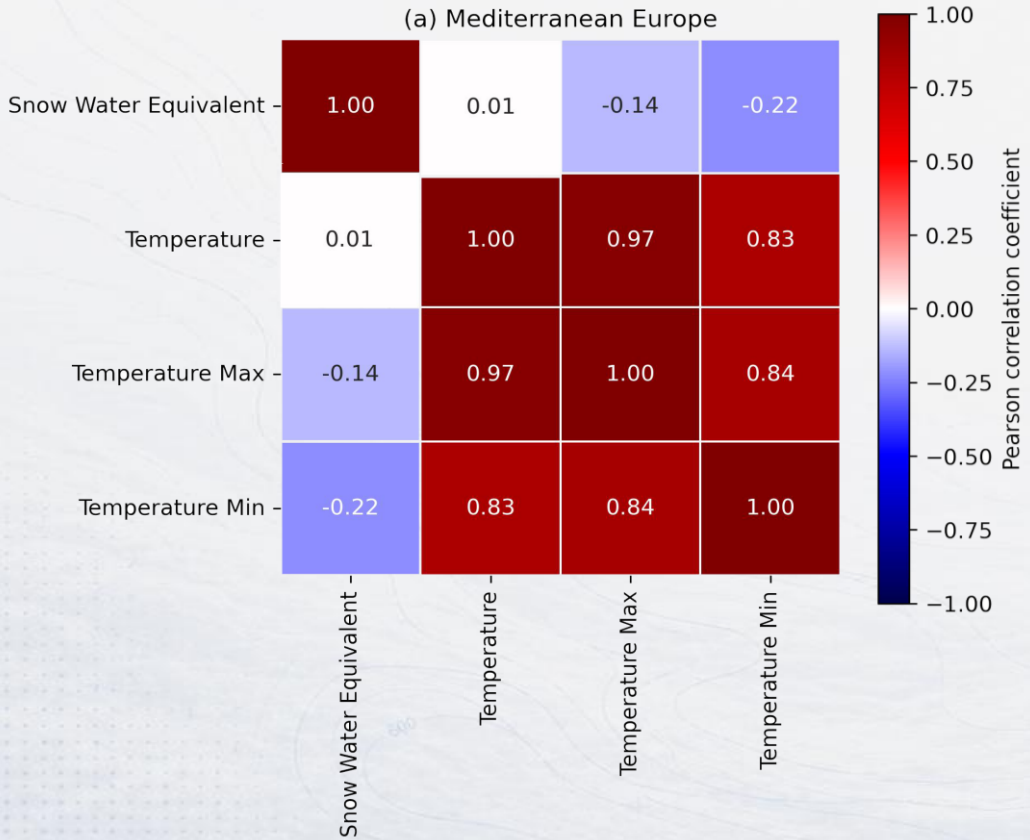
Northern Europe shows warming alongside persistent SWE, indicating that temperatures often remain cold enough for snowfall and snow storage to continue.

Pearson Correlation Analysis Across Three Regions

- $-1 \leq r \leq 1$
- Significant positive correlation: $r > 0.25$
- Significant negative correlation: $r < -0.25$

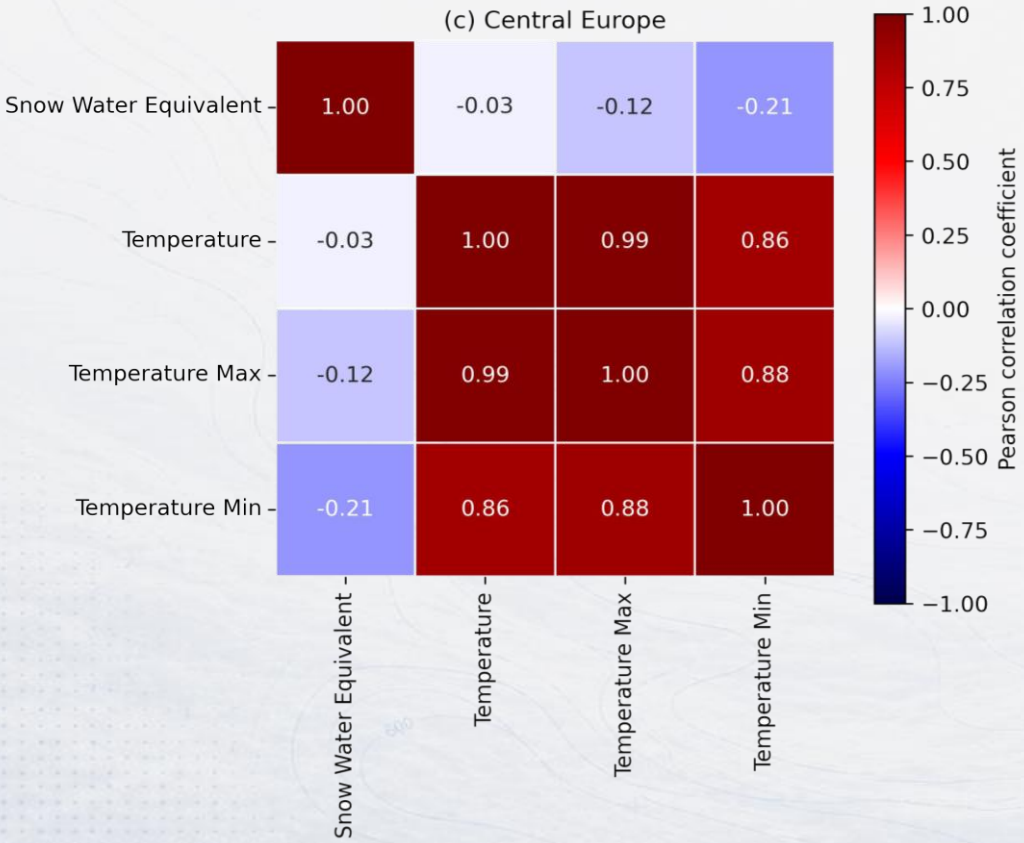


Temperature-driven SWE decline in Central and Mediterranean Europe



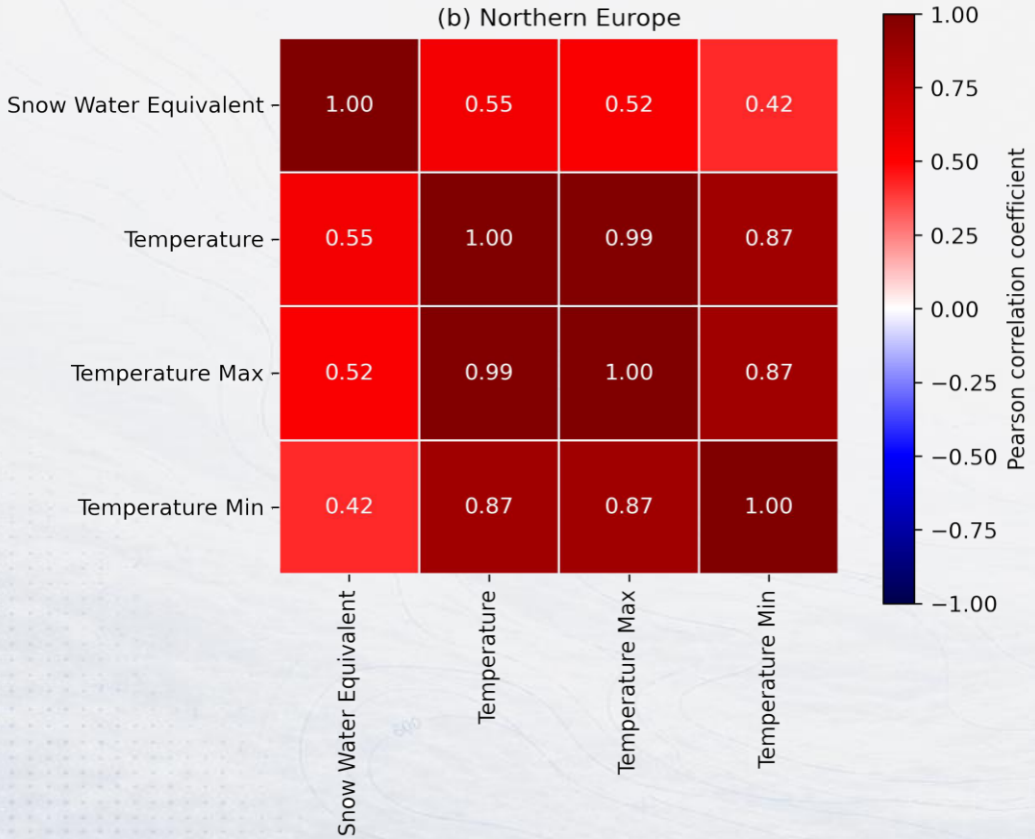
Central and Mediterranean Europe are closer to the 0°C rain–snow threshold, so higher temperatures reduce SWE by increasing melt, shortening snow persistence, and shifting precipitation from snow to rain. This reflects a temperature-controlled snow regime.

Temperature-driven SWE decline in Central and Mediterranean Europe



Central and Mediterranean Europe are closer to the 0°C rain–snow threshold, so higher temperatures reduce SWE by increasing melt, shortening snow persistence, and shifting precipitation from snow to rain. This reflects a temperature-controlled snow regime.

Why does SWE increase with temperature in Northern Europe?



Northern Europe shows a positive SWE–temperature correlation because warming can coincide with wetter winters while temperatures remain below freezing.

However, continued warming may weaken this relationship by reducing snowfall fraction and snow retention.

Main Takeaway

European SWE response is regional, not uniform

- Warming is clear across European regions
- SWE trends are weak compared with variability
- Long-term persistence complicates simple trend interpretation.

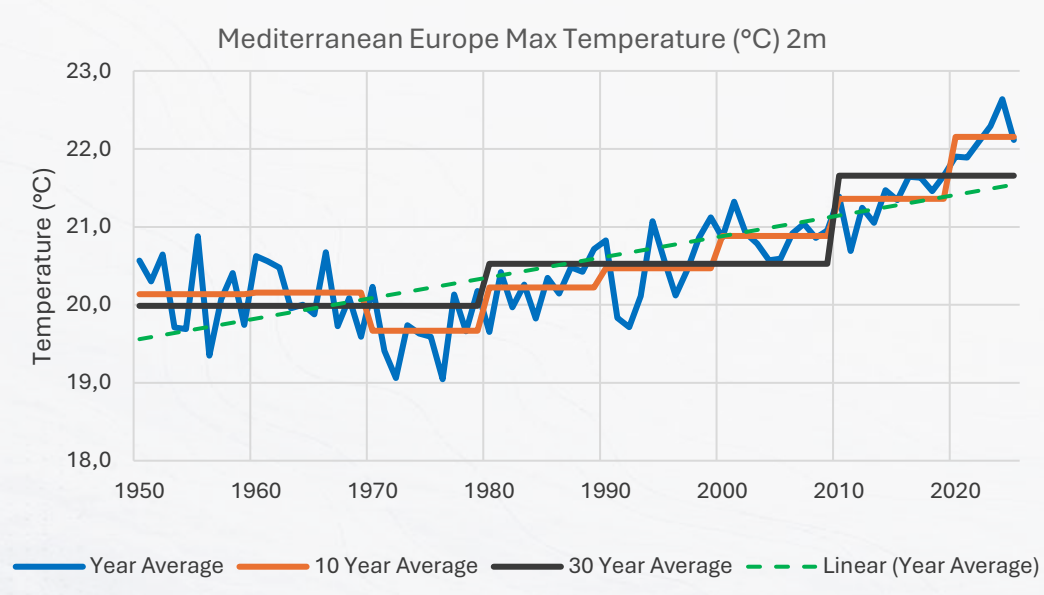
Key message:

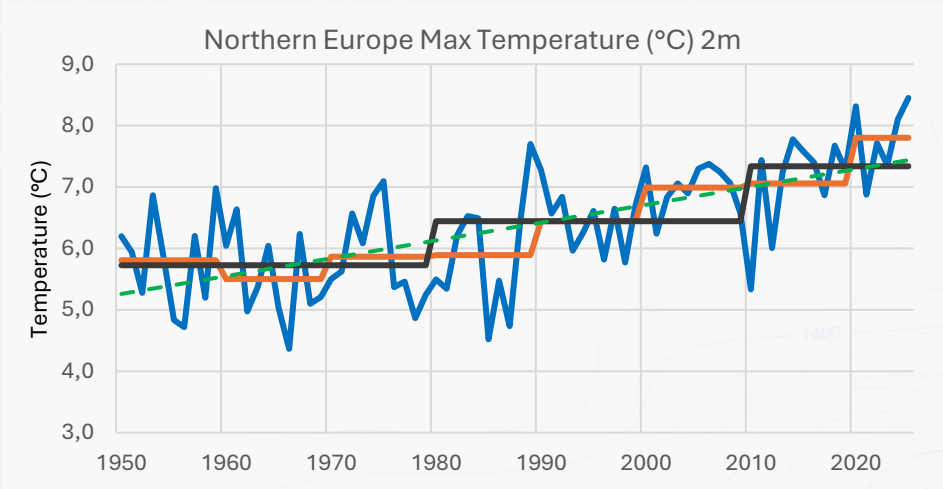
Temperature is important, but it does not explain

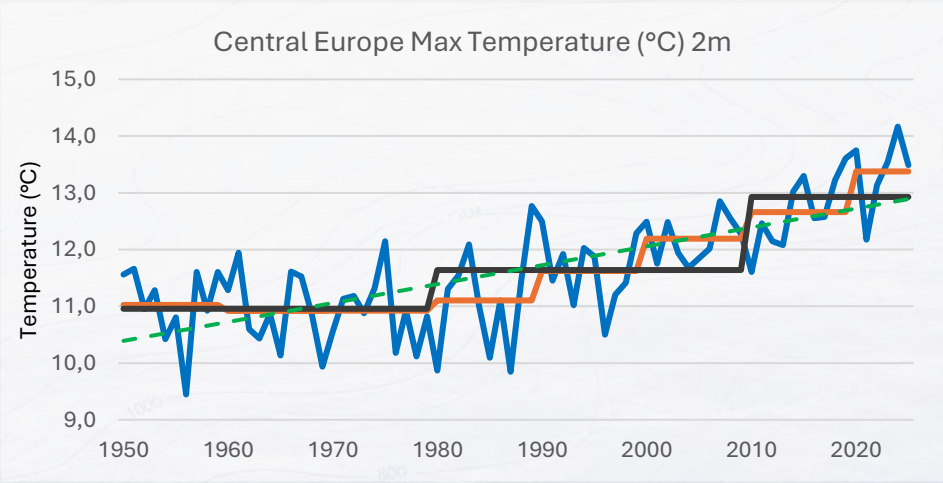
European SWE changes alone.

Multi-Decadal Annual Averages Across European Regions

Maximum Temperatures



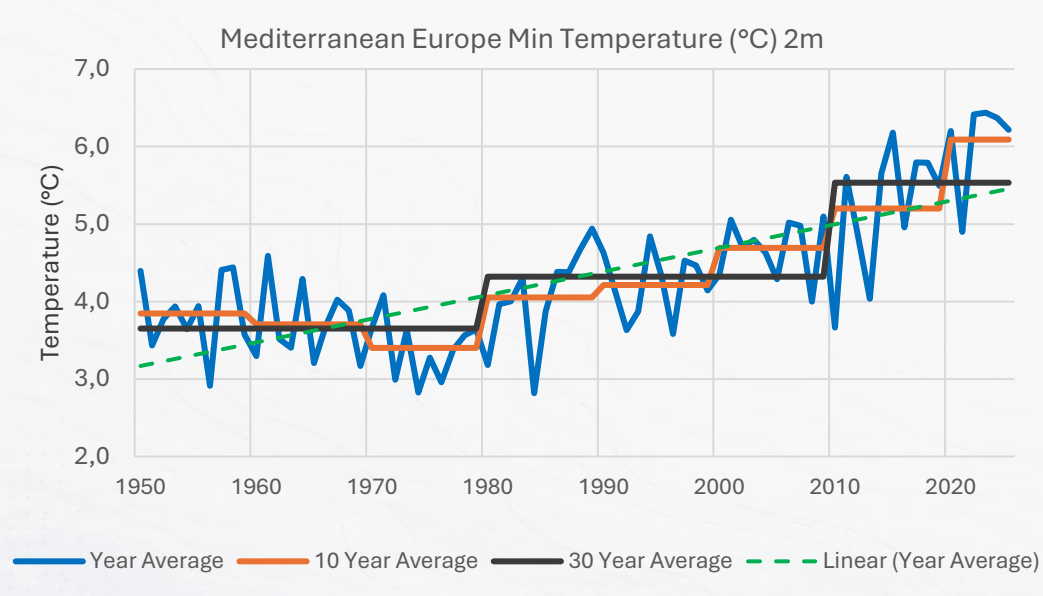




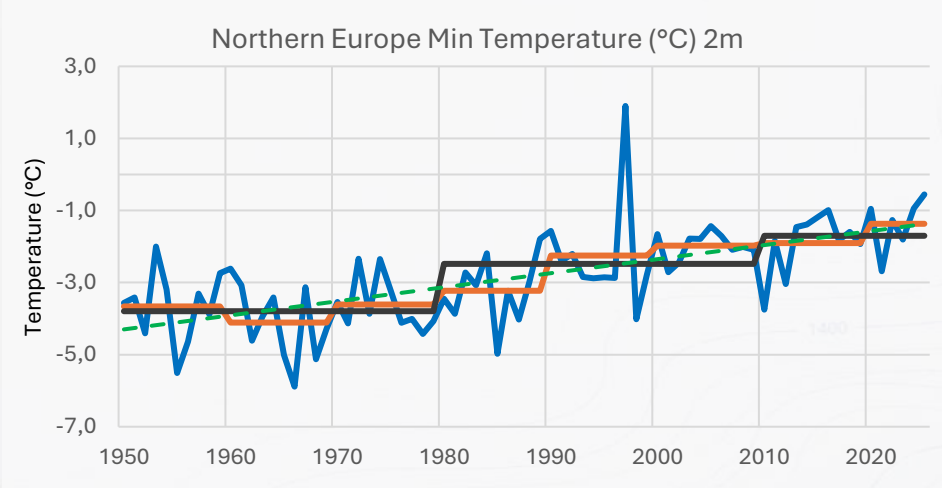
Region	Slope
Mediterranean	0,026
Central	0,033
Northern	0,029

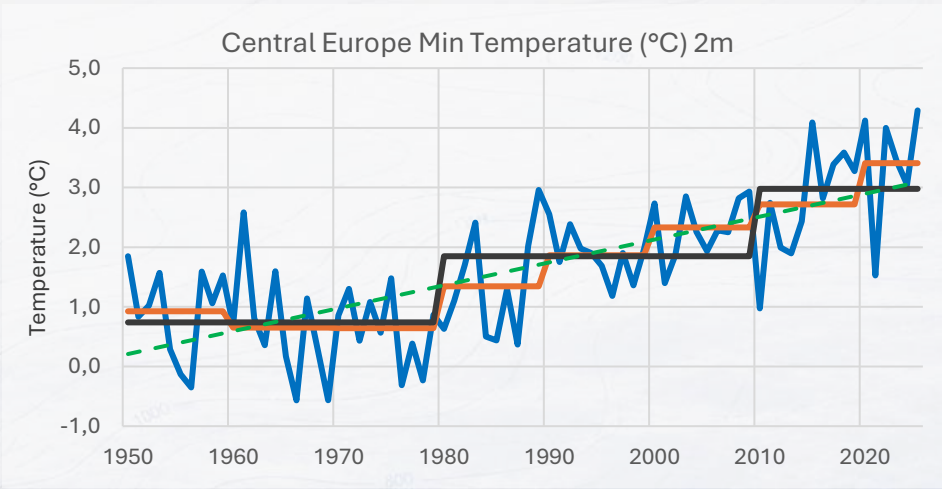
Multi-Decadal Annual Averages Across European Regions

Minimum Temperatures



Region	Slope
Mediterranean	0,030
Central	0,038
Northern	0,039





References

- Räisänen, J. (2021). Snow conditions in northern Europe: the dynamics of interannual variability versus projected long-term change. The Cryosphere, 15,
- Räisänen, J. (2008). Warmer climate: less or more snow? Climate Dynamics, 30(2–3),
- Koutsoyiannis, D. (2020). Is the global hydrological cycle intensifying? Hydrology and Earth System Sciences, 24, 3899–3932.
- Dimitriadis, P., Koutsoyiannis, D., Iliopoulou, T., & Papanicolaou, P. (2021). A global-scale investigation of stochastic similarities in hydrological-cycle processes. Hydrology, 8, 59.
- Iliopoulou, T., Lada, M., Stavropoulou, C.-I., Tourlaki, D.-M., Tepetidis, N., Dimitriadis, P., & Koutsoyiannis, D. (2026). Complexity of Hydroclimatic Changes in the Mediterranean: Exploring Climate Drivers Using ERA5 Reanalysis. Water, 18(3), 331. https://doi.org/10.3390/w18030331

References

- Hersbach, H., et al. (2018). ERA5 Hourly Data on Single Levels from 1979 to Present. Copernicus Climate Change Service (C3S), Climate Data Store.
- Koutsoyiannis, D. (2010). Hurst–Kolmogorov dynamics and uncertainty. Workshop on Nonstationarity, Hydrologic Frequency Analysis and Water Management, Boulder, CO.
- Koutsoyiannis, D. (2018). The climacogram: A tool for stochastic analysis and modeling of hydroclimatic time series. National Technical University of Athens.
- Dimitriadis, P., & Koutsoyiannis, D. (2015). Climacogram versus autocovariance and power spectrum in stochastic modelling for Markovian and Hurst–Kolmogorov processes. Stochastic Environmental Research & Risk Assessment, 29(6), 1649–1669. https://doi.org/10.1007/s00477-015-1023-7
- Sargentis, G.-F., et al. (2021). Agricultural Land or Photovoltaic Parks? The Water–Energy–Food Nexus and Land Development Perspectives in the Thessaly Plain, Greece. Sustainability, 13, 8935. https://doi.org/10.3390/su13168935