A climatology of air temperature extremes in the Mediterranean region for the 85-year period 1940-2024

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Outline

- Background & Motivation
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- Future Work

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Background & Motivation

- Climate change is one of the most vital challenges of the 21st century affecting our everyday lives and shaping our future
- Rising temperatures threaten human health and ecosystems
- Extreme temperatures fuel heatwaves, droughts and intense weather events
- The Mediterranean region is at risk: extreme temperature events are associated with increased heat related mortality and have a negative impact on the economic sector which heavily depends on agriculture and tourism
- Studying extremes & synoptic drivers is key to understanding and mitigation

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Data

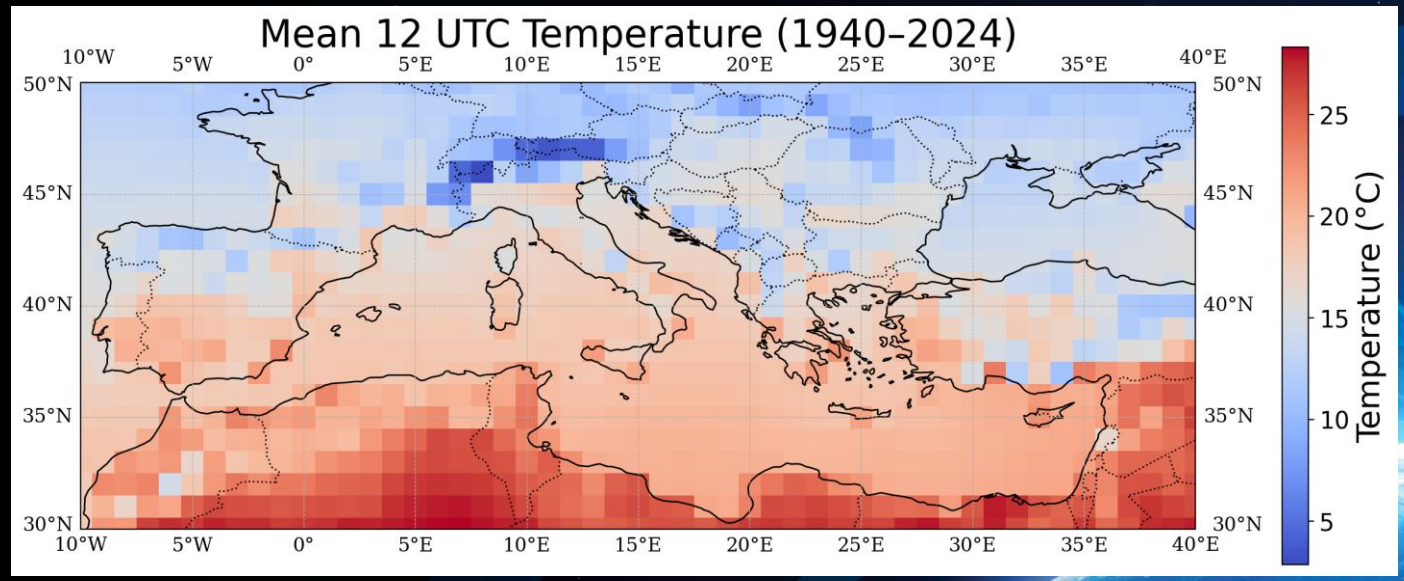
ERA5 reanalysis hourly data at 04UTC and 12UTC

Spatial resolution: 1° × 1°

Time period: 1940 – 2024 (85 years)

Variables:

- 2m temperature (T),
- 850 hPa temperature (T850),
- geopotential height at 1000hPa (GH1000),
- geopotential height at 500hPa (GH500)



The long-term mean of 12 UTC 2 m air temperature (1940–2024) over the geographical domain of the greater Mediterranean region

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Methodology (1) – Definition of Extreme Temperature Days

- 12UTC temperature values are used for the definition of Extremely High Temperature Days (EHTDs)
- 04UTC temperature values are used for the definition of Extremely Low Temperature Days (ELTDs)
- Definition of extreme case:
  - Calculation of the long-term mean values and standard deviation of T for each date of the year (1/1 – 31/12) at each grid point of the domain
  - 5-day moving average smoothing applied. Each daily value (T_d) is replaced by the average value of the 5 closest days (T_{d-2}, T_{d-1}, T, T_{d+1}, T_{d+2})
  - Temperature anomaly (TA) is calculated by subtracting the corresponding 5-day moving averages from the daily T values
  - Spatial threshold of 5% of the grid points (54 out of 1071) is followed
    - If TA > 2 * T_{stdev} for at least 54 grid points, then the day is classified as EHTD
    - If TA < -2 * T_{stdev} for at least 54 grid points, then the day is classified as ELTD

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Methodology (2) – Statistical Analysis

- Factor Analysis (FA)
  - A multivariate statistical method that is frequently applied in climatological studies as a dimensionality reduction technique with the lowest possible loss of the initial data's total variance.
  - A new set of variables are created, called factors, and the initial variables are linearly correlated with the one or more factors, showing how strongly each variable is associated with any factor (higher values indicate strong correlation and representation).
  - Rotation of the axis (varimax) is applied to maximize the explained variance leading to a clearer separation of the variables across factors
- Cluster Analysis (CA)
  - A classification technique used for the categorization of variables into distinct and homogeneous groups, called clusters. The Euclidian distance is used as a mean for classification
  - In the n-dimensional space of CA, each variable is assigned to the cluster whose centroid it is nearest to, ensuring that variables within the same cluster are more similar to each other than to those in other clusters
  - To determine the optimal number of clusters, CA is run multiple times for different number of clusters, and a statistical test (distortion test) is applied that indicated the best possible classification.

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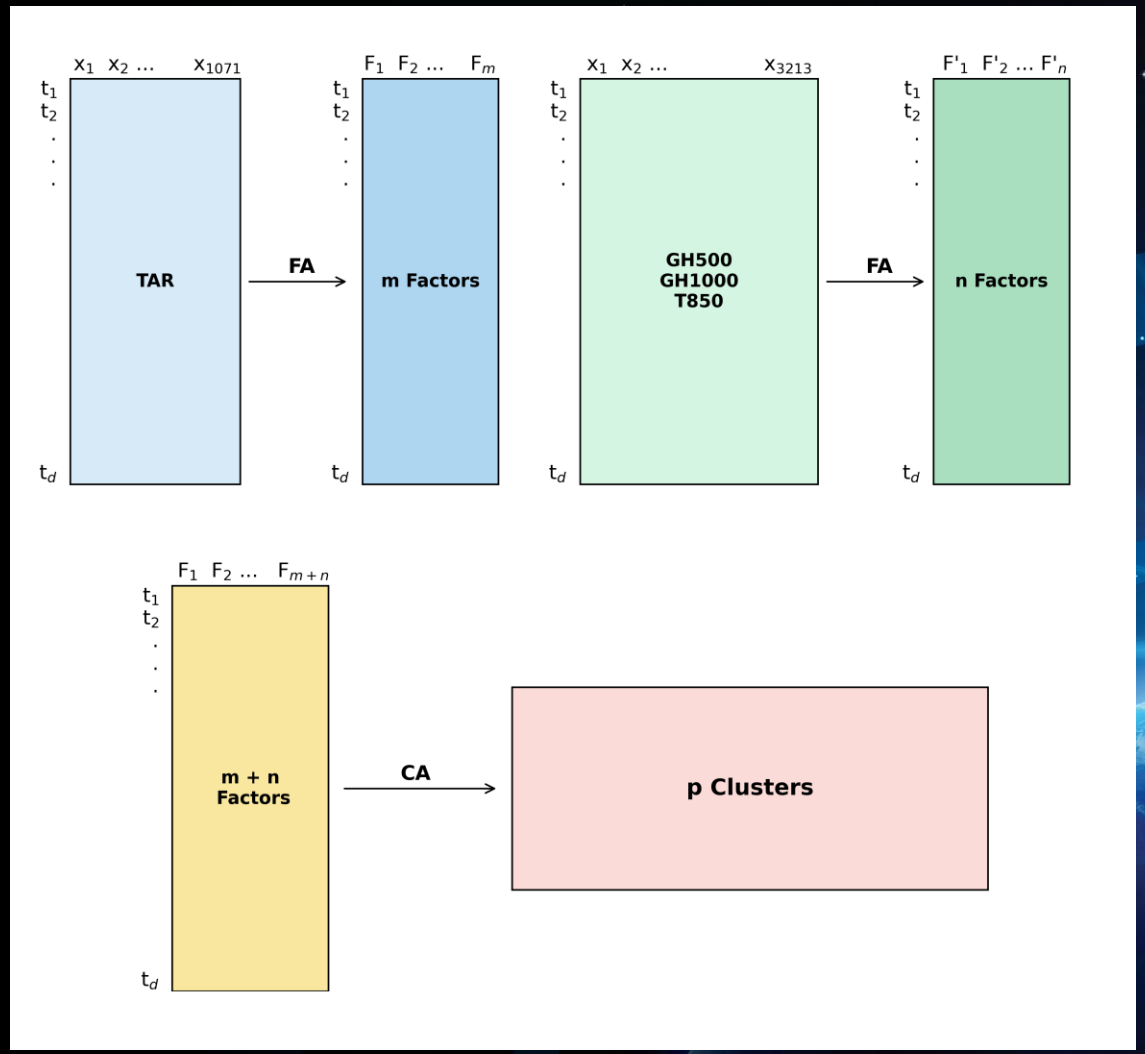
Methodology (3)

- Calculate Temperature Anomaly Ratio (TAR) by dividing TA with the standard deviation, normalizing anomalies across different locations
- FA on TAR -> m Factors
- FA on synoptic circulation parameters -> n Factors
- CA on m + n Factors -> p Clusters



t_i = extreme temperature days

x_i = grid points

F_i = factors

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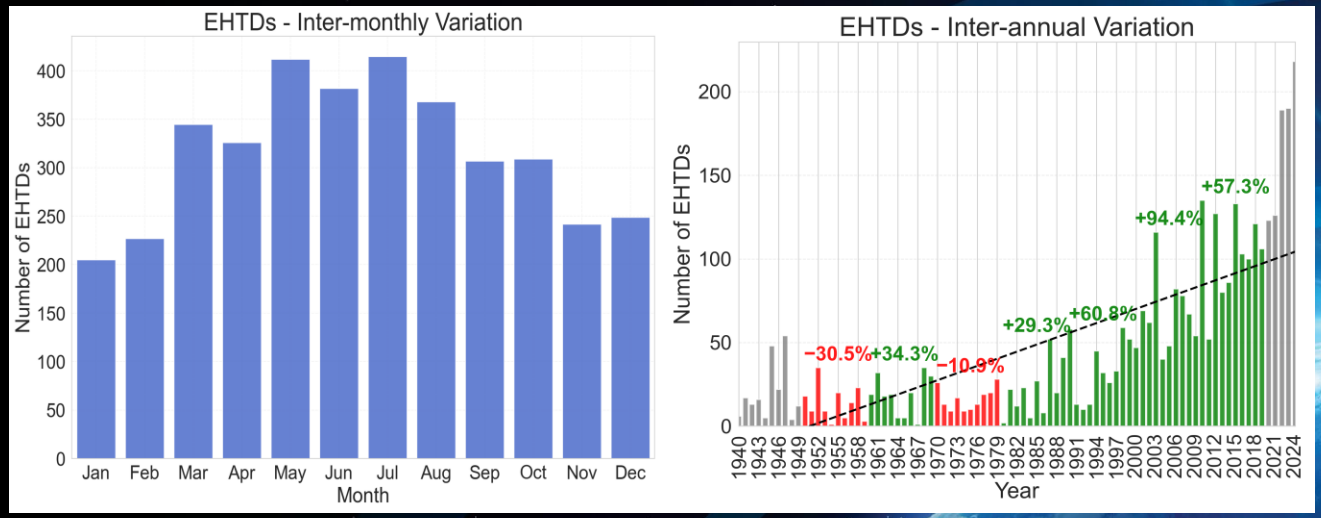
Results - EHTDs

- Defined 3787 EHTDs
- More frequent during the warm period of the year
- Statistically significant increase during the 85-year period (1940–2024)
- Rapid increase after 1980s'
- An increase of 305% is found between the periods 1940–1980 and 1981–2024 mean number of EHTDs



CA on EHTDs led to 9 clusters

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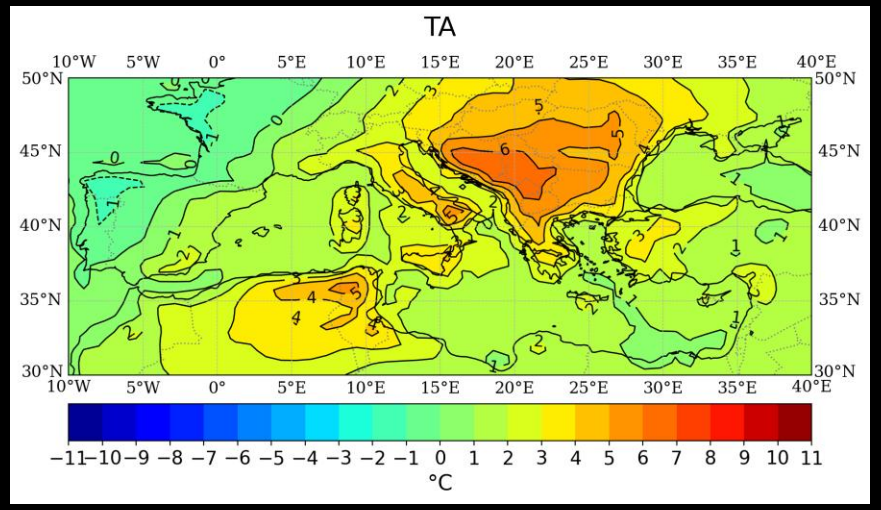
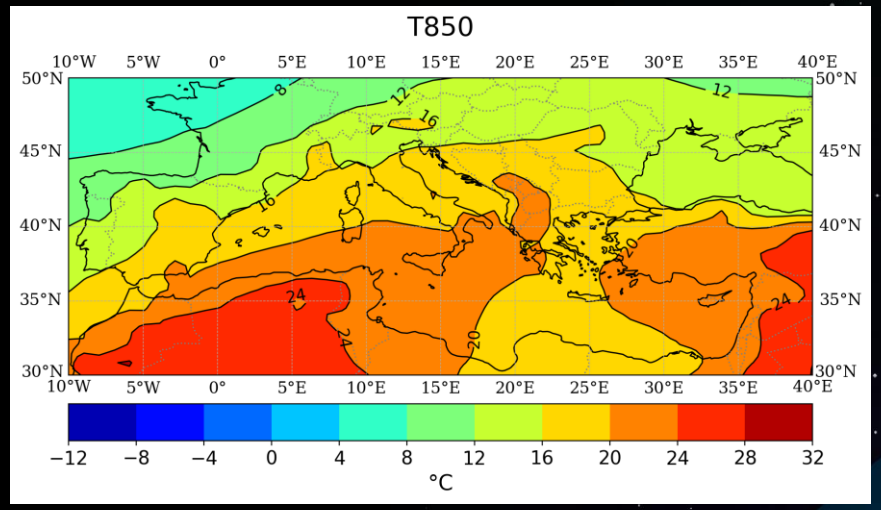
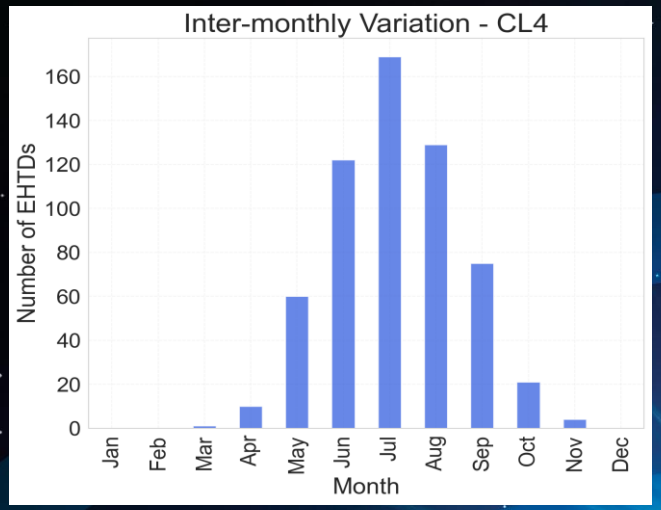
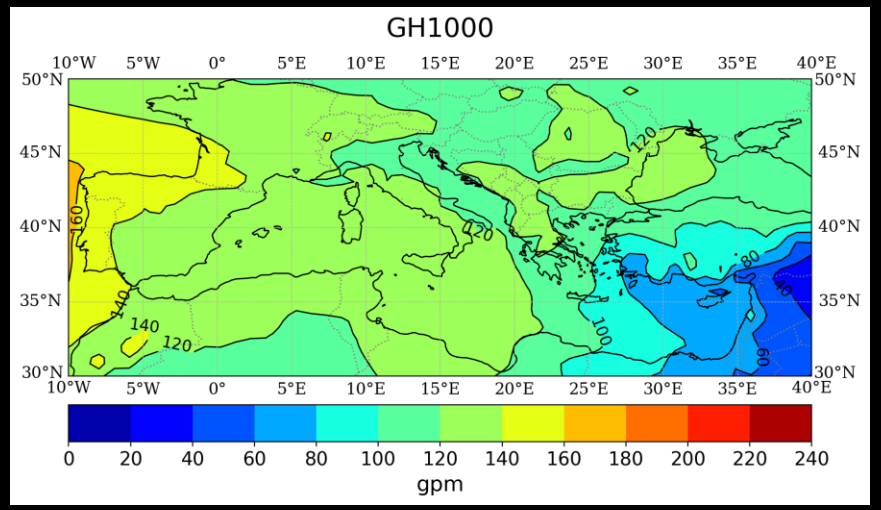
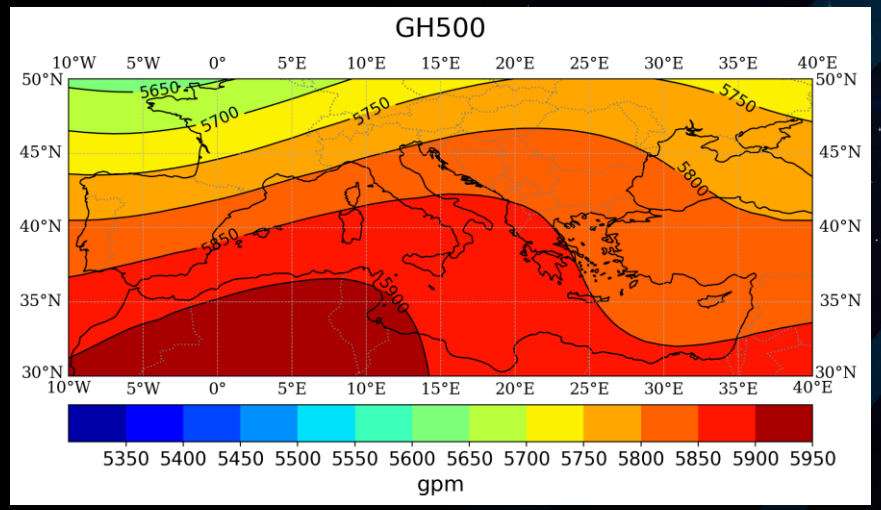
CL4 – Mediterranean & Balkans

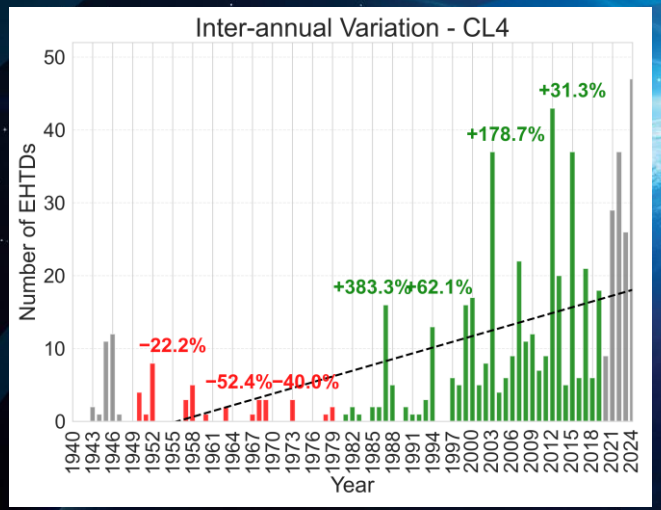












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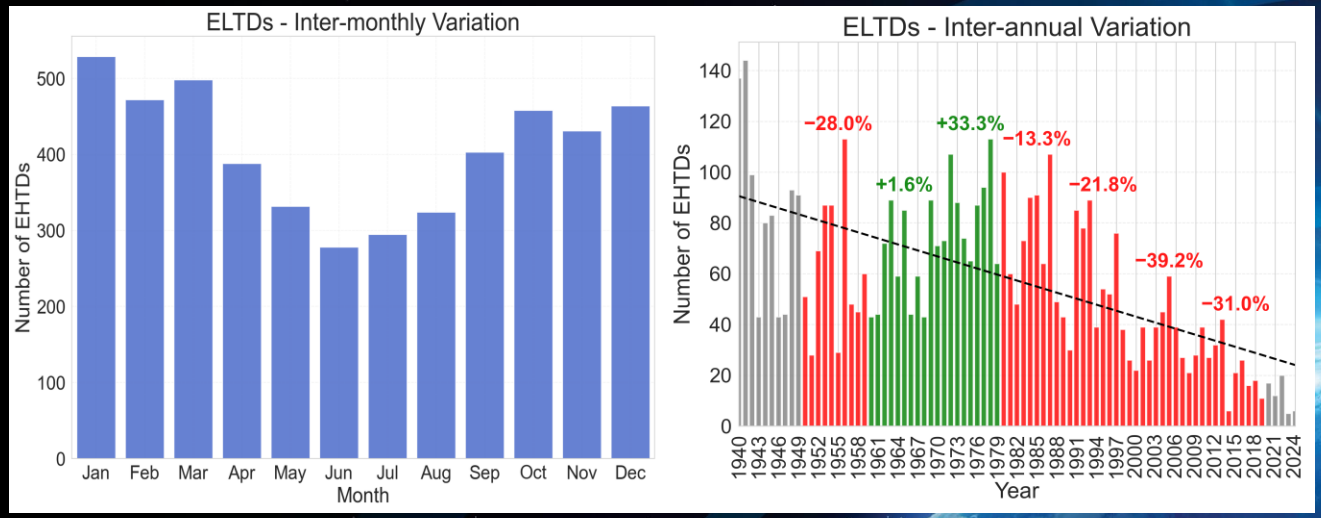
Results - ELTDs

- Defined 4872 ELTDs
- More frequent during the cold period of the year
- Statistically significant decrease during the 85-year period (1940–2024)
- Rapid decrease after 1980s'
- A decrease of 41% is found between the periods 1940–1980 and 1981–2024 mean number of ELTDs



CA on ELTDs led to 7 clusters

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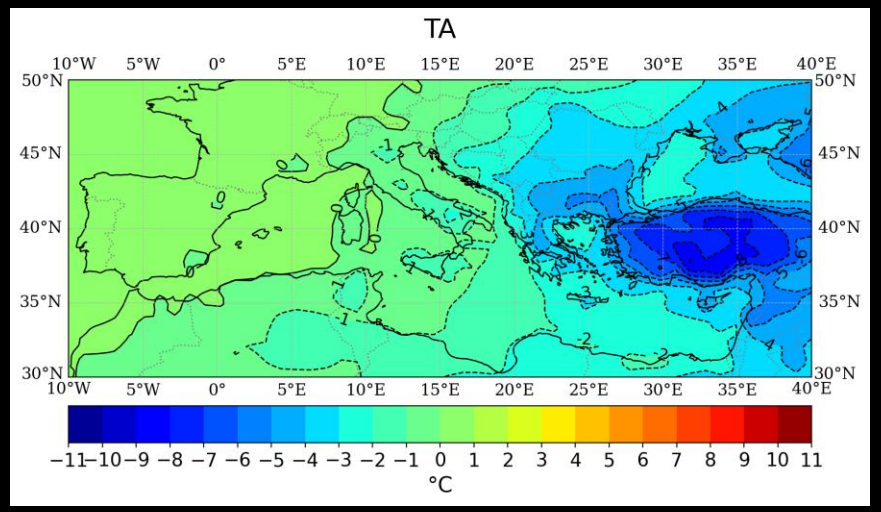
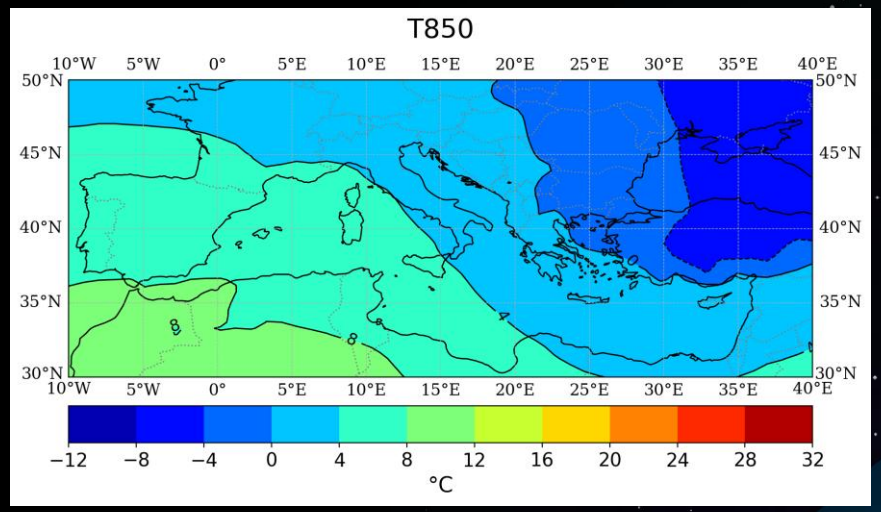
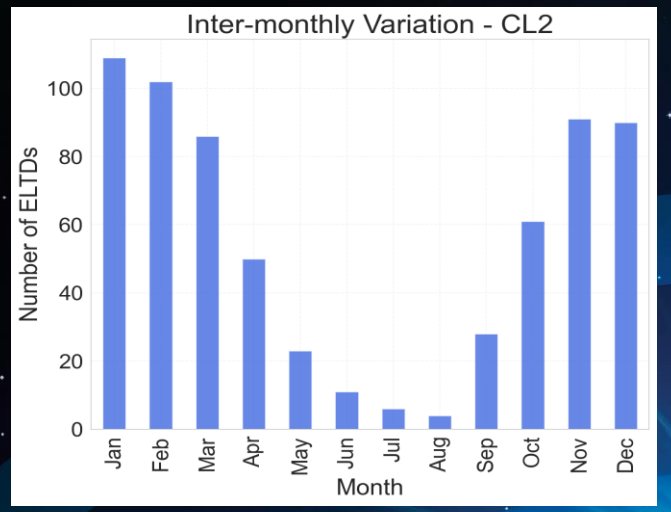
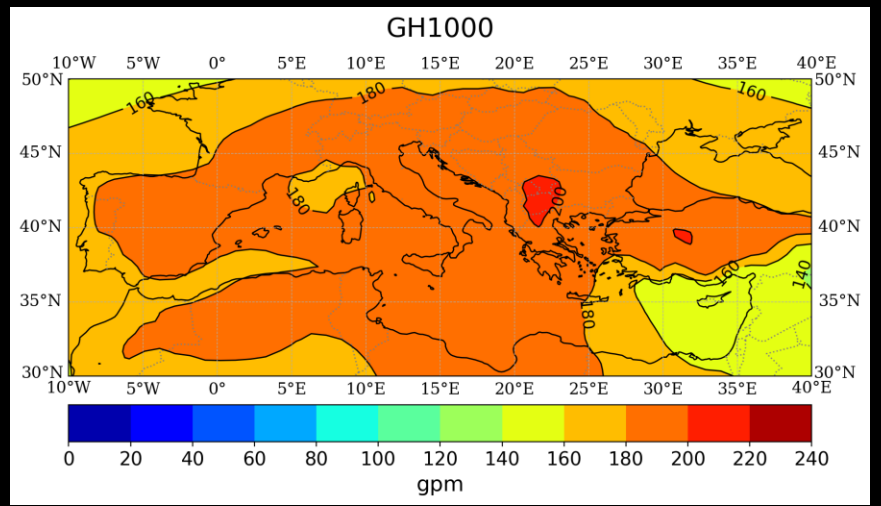
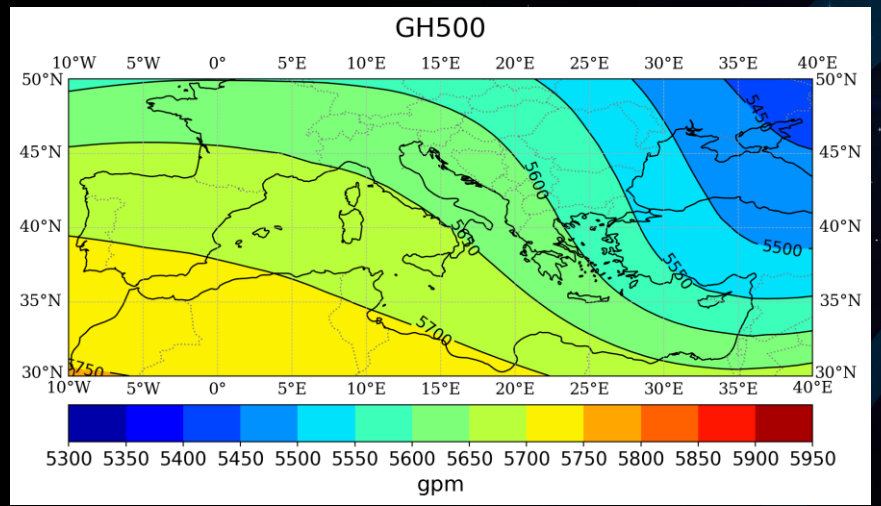
CL2 – E Mediterranean & Middle East

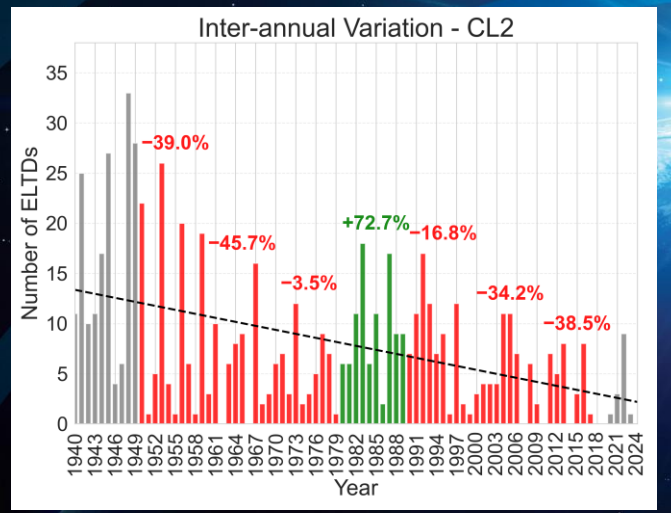












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Conclusions

- A clear intensification of temperature extremes was found. EHTDs display a significantly increased frequency, while ELTDs have significantly decreased, especially during the 21st century. These tendencies highlight a shifting of the temperature regime in the Mediterranean and are consistent with the regional warming trends linked to climate change.
- Distinct circulation patterns were associated with each type of extreme. EHTDs typically occur under strong anticyclonic conditions, promoting blocking, solar heating and warm advection. ELTDs are associated with radiative cooling, cold advection and polar air mass intrusions.
- Seasonal differences were revealed. Warm period EHTDs are dominated by mid tropospheric ridges leading to the occurrence of heatwaves, while cold period EHTDs involve atmospheric blocking systems favoring the development of heat domes. On the other hand, warm period ELTDs are characterized by persistent surface cyclonic systems resulting in cold air advection, while cold period ELTDs are associated with blocking highs favoring radiative cooling and polar air mass intrusions.

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Future Work

- Incorporating additional parameters, such as sea surface temperatures and upper air humidity, to better understand vertical and ocean–atmosphere interactions and their impact on temperature extremes.
- Applying the current clustering methodology to compound events like heatwaves with drought by utilizing 2 m temperature and precipitation anomalies and involving local-scale observations and downscaled model data
- Investigating the connection between temperature extremes and large-scale atmospheric oscillations (NAO, AO, EA-WR) using correlation and composite analysis techniques to improve forecasting capabilities and assist in the development of early warning strategies for Mediterranean climate extremes.

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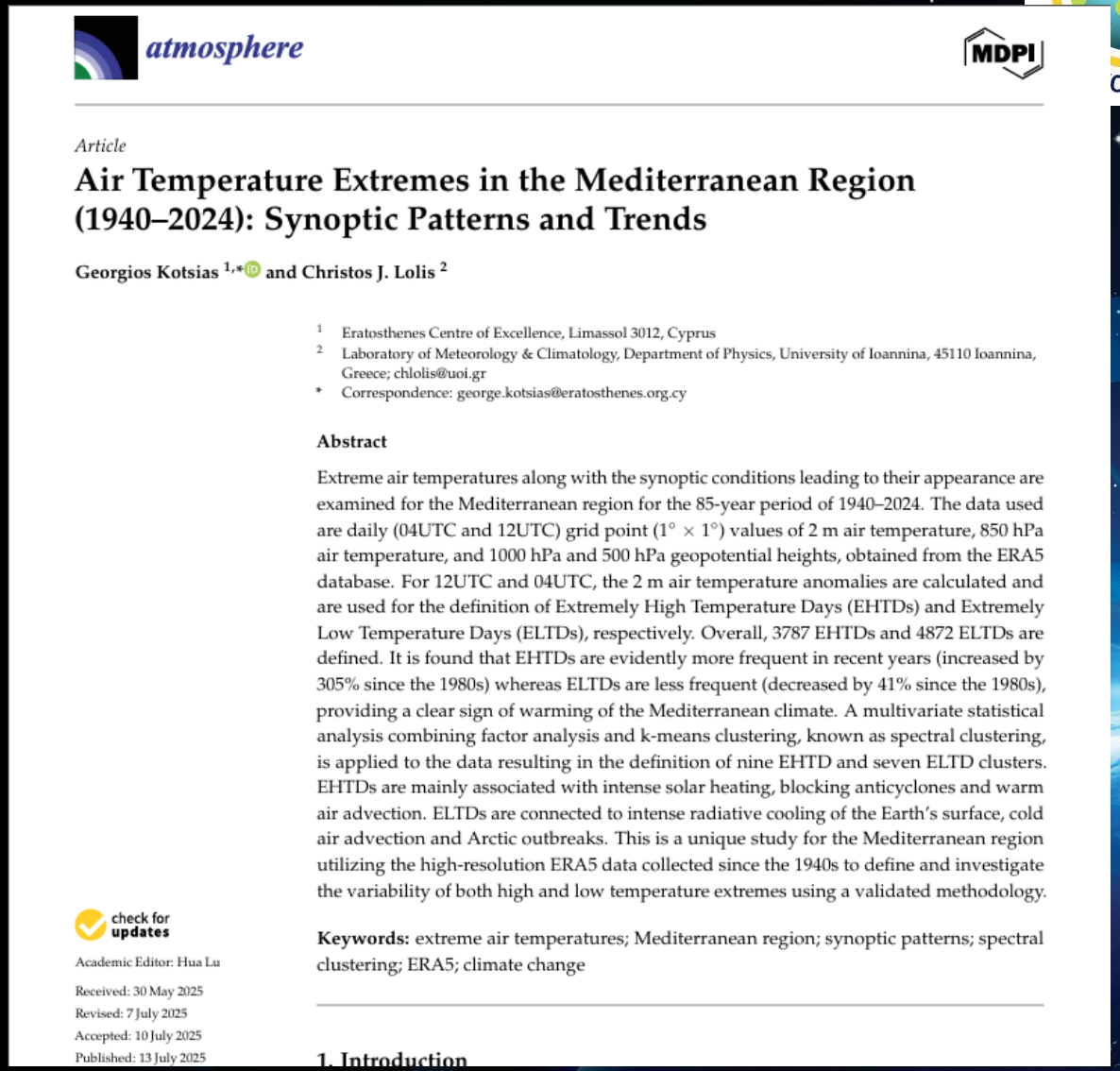

atmosphere

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Article

Air Temperature Extremes in the Mediterranean Region (1940–2024): Synoptic Patterns and Trends

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Abstract

Extreme air temperatures along with the synoptic conditions leading to their appearance are examined for the Mediterranean region for the 85-year period of 1940–2024. The data used are daily (04UTC and 12UTC) grid point (1° × 1°) values of 2 m air temperature, 850 hPa air temperature, and 1000 hPa and 500 hPa geopotential heights, obtained from the ERA5 database. For 12UTC and 04UTC, the 2 m air temperature anomalies are calculated and are used for the definition of Extremely High Temperature Days (EHTDs) and Extremely Low Temperature Days (ELTDs), respectively. Overall, 3787 EHTDs and 4872 ELTDs are defined. It is found that EHTDs are evidently more frequent in recent years (increased by 305% since the 1980s) whereas ELTDs are less frequent (decreased by 41% since the 1980s), providing a clear sign of warming of the Mediterranean climate. A multivariate statistical analysis combining factor analysis and k-means clustering, known as spectral clustering, is applied to the data resulting in the definition of nine EHTD and seven ELTD clusters. EHTDs are mainly associated with intense solar heating, blocking anticyclones and warm air advection. ELTDs are connected to intense radiative cooling of the Earth's surface, cold air advection and Arctic outbreaks. This is a unique study for the Mediterranean region utilizing the high-resolution ERA5 data collected since the 1940s to define and investigate the variability of both high and low temperature extremes using a validated methodology.

Keywords: extreme air temperatures; Mediterranean region; synoptic patterns; spectral clustering; ERA5; climate change

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1. Introduction

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