Heatwave and Associated Atmospheric Circulation Patterns: Unraveling the Eurasia Climate Puzzle

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Research Objectives & Background

- In Eurasia, heatwave days have increased by an average of 0.61 days per decade, compared to 0.21 days per decade in the rest of the midlatitudes, indicating that heatwave days are increasing approximately three times faster in Eurasia. (Ajasse et al., 2018)
- To better understand the significant rise in the frequency and severity of heatwaves in Eurasia in recent decades, this study delves into the detailed characteristics of summertime heatwaves, with a particular focus on mean sea level pressure in the region.
- Analyzing long-term reanalysis and station data is crucial for examining the evolving features of Eurasian heatwaves over the years. This analysis provides a foundation for predicting future trends of these events.

Methods

Dataset

- Source: ERA5 reanalysis dataset provided by European Centre for Medium-Range Weather Forecasts (ECMWF)
- Temporal coverage: 1940 to 2023
- Spatial resolution: 1° x 1°
- Variables involved: temperature and mean sea level (MSL) pressure

Procedures

Identify **High-Temperature Grid Points**, which are grid points on land where the temperature exceeds the 95th percentile of the temperature distribution within a 15-day moving window.

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Apply DBSCAN algorithm to **classify** these high-temperature grid points into events based on their spatial and temporal distribution.

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Compute **Heatwave Magnitude Index (HWMI)**, M_d, for grid point classified into an event using the following formula. (Lo et al., 2021)

$$M_d(T_d) = \begin{cases} \frac{T_d - T_{25p}}{T_{75p} - T_{25p}}, & \text{if } T_d > T_{25p}; \\ 0, & \text{if } T_d \le T_{25p} \end{cases}$$

where,

- T_d is the mean temperature on day d
- T_{25p} is the 25th percentile of values chosen from the yearly mean temperature
- T_{75p} is the 75th percentile of values chosen from the yearly mean temperature

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Calculate **Heatwave Magnitude Scale (HWMS)** for each heatwave event by summing the HWMI of all grid points within the event.

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Compute the centroid of heatwave event on each day of the heatwave period for classification purpose using the following formula. (Liu et al., 2023)

$$\text{Centroid} = \left[\frac{\sum_{i=1}^{n} \text{Val}(k)_i \, \text{lon}_i}{\sum_{i=1}^{n} \text{Val}(k)_i}, \frac{\sum_{i=1}^{n} \text{Val}(k)_i \, \text{lat}_i}{\sum_{i=1}^{n} \text{Val}(k)_i} \right]$$

where,

- k is the day of heatwave event
- i is the grid point classified as part of the event
- Val(k) is the percentile of the mean temperature at that grid point

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Cluster the heatwave events using **hierarchical clustering** based on their respective HWMS.

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Investigate how the HWMI of each grid point varies in relation to MSL pressure within each cluster.

Results & Discussions

After categorizing the high-temperature grid points into separate heatwave events, the results are visualized to display the distribution and frequency of these events.

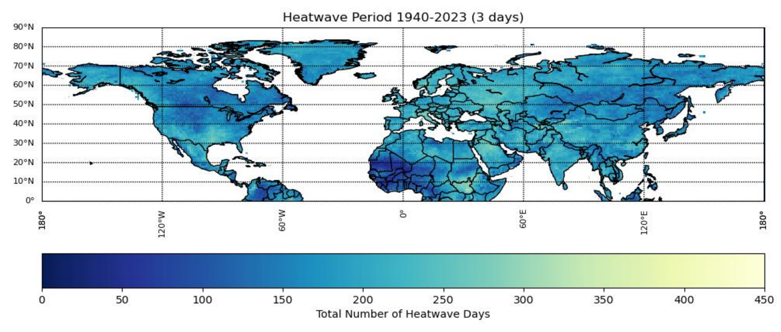

Figure 1. Heatmap showing the number of heatwave day in each part of northern hemisphere

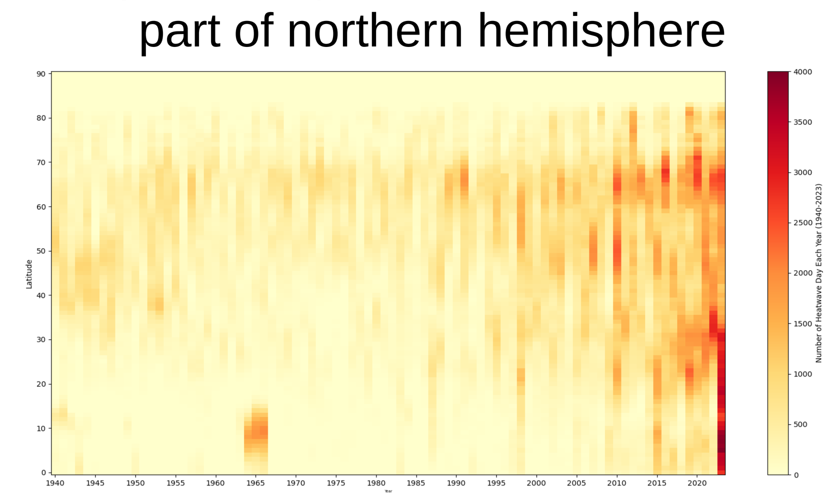

Figure 2. Climate strips showing the number of heatwave day across each latitude of northern hemisphere

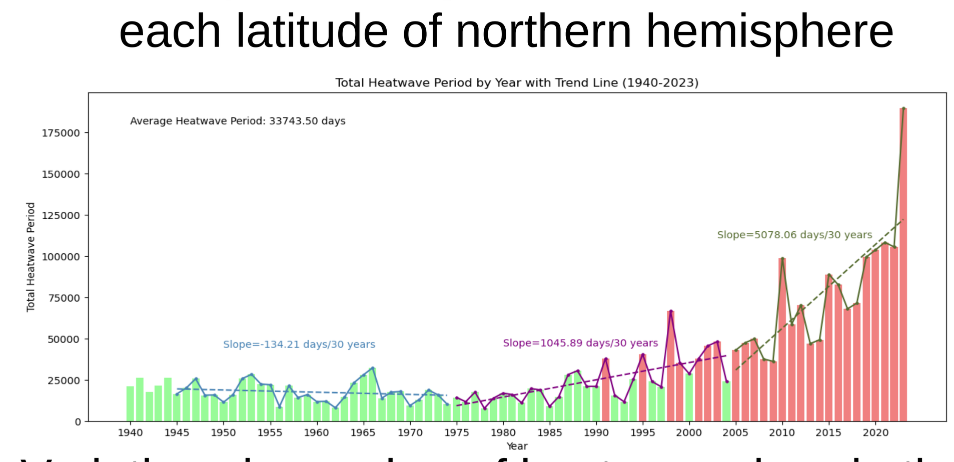

Figure 3. Variations in number of heatwave days in the 1940 - 2023 period across northern hemisphere. Green bars represent the number of heatwave days less than the average heatwave days, while the red bars denote above average. The dashed lines demonstrate trends in different periods.

The heatwave event happening around Eurasia is clustered based on their respective HWMS.

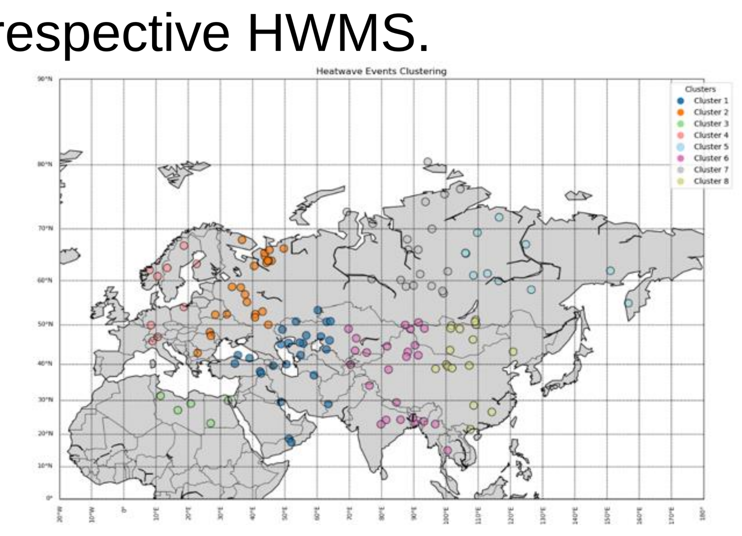

Figure 4. Spread and distribution of heatwave event for each cluster around Eurasia.

To illustrate the changing characteristics of MSL pressure associated with heatwave events in Eurasia, the concurrent MSL pressure is overlaid on a heatmap showing the HWMI for each grid point.

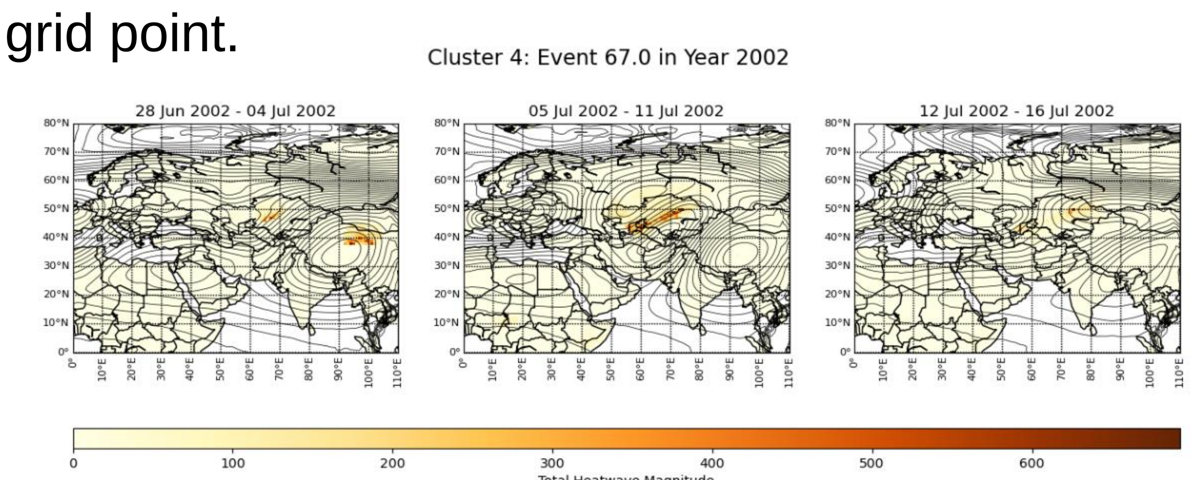

Figure 5. Sample output illustrating the variation of HWMI in relation to MSL pressure for the event labeled 2002, which is classified into cluster 4.

Conclusion & Future Prospect

- Beside the global warming trend, the frequency of heatwave event tends to be higher in regions with latitude between 30°N and 60°N. This latitude band often corresponds to regions with continental climates, which are more susceptible to extreme temperature variations.
- The variation of HWMI and MSL pressure is similar within and between each cluster. High HWMI always corresponds to a high-pressure system, as regions with the highest HWMI are often found within areas bounded by dense, tightly packed contour lines.
- However, plotting the MSL pressure in general does not provide much details on how the HWMI varies with the MSL pressure pattern. Therefore, additional effort is required to focus more on the region around grid points with higher HWMI.

Key References

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- Liu, Z., Zhou, W., & Yuan, Y. (2023). 3D DBSCAN detection and parameter sensitivity of the 2022 Yangtze river summertime heatwave and drought. Atmospheric and Oceanic Science Letters, 16(4), 100324. https://doi.org/10.1016/j.aosl.2022.100324
- Lo, S. H., Chen, C. T., Russo, S., Huang, W. R., & Shih, M. F. (2021). Tracking heatwave extremes from an event perspective. Weather and Climate Extremes, 34, 100371. https://doi.org/10.1016/j.wace.2021.100371