The Future of Persistent High Impact Blocks

Department of Physics, University of Toronto

Eylon Vakrat, Paul Kushner

Eylon.Vakrat@mail.utoronto.ca

Overview

- Heat waves that involve simultaneous extremes in temperature and humidity pose well-known health dangers and have many other socio-economic and ecological consequences (Seneviratne et al, 2021).
- Blocking highs typically drive such heat waves during the European summer. The dynamics, surface impacts, representation in climate models, and sensitivity to climate forcing of blocking events are of great interest.
- First, we investigate the dynamic characterization of a heat wave.
- Then, we perform a persistence analysis on historic mid-tropospheric flow, using a so-called "Θ^{-1}" technique rooted in dynamical systems theory. This connects the most persistent days to heat waves' synoptic conditions. CMIP6 models exhibit the same synoptic conditions.
- Finally, we find the distribution of Θ^{-1} under strong anthropogenic warming shifts towards more persistent flow.

Objectives

- Connecting the persistence metric Θ^{-1} to blocking highs and heat waves with extreme heat and humidity.
- Using Θ^{-1} extremes as a proxy for projected changes to mid-tropospheric flow and high-impact blocks.

Data & Methods

- 1979-2018 interpolated station data creating a daily temperature and relative humidity grid (E-OBS, Cornes et al, 2018) of the European mainland (35N° – 70N°, 25W° – 30E°).
- Using this data and the Epstein and Moran (2006) discomfort index (DI), which is the average of the wet bulb temperature (T_w) and the dry bulb temperature (T_d), we define a heat wave as three or more consecutive days in which 20% of the grid points are in the top 10% at a given grid point's DI, within a sequence of 5-year epochs (i.e., 1979-1984, 1984-1989…)

$$DI = 0.5(T_w + T_d)$$

- The full synoptic state (DI, geopotential 500 hPa, sea level pressure, and 500 hPa zonal wind) is analyzed using ERA5 reanalysis.
- Dynamical systems theory characterizes recurring atmospheric states combining Poincaré recurrences and extreme value theory (Lucarini et al. 2012). This analysis ranks atmospheric states by their persistence measured by "Θ^{-1}". High Θ^{-1} states are more persistent.
- We carry out the persistence analysis for ERA5 and four CMIP6 GCMs: IPSL-CM6A-LR, CanESM5, CNRM-ESM2-1, and HadGEM3-GC31-LL (historical, SSP1-2.6, SSP3-7.0, SSP5-8.5).

Linking persistent days and heat waves in ERA5

- A comparison of heat waves and the most persistent midtropospheric flow days (Fig. 1) yields a connection between the two. Synoptically, there is a positive DI anomaly over Norway and Sweden. The DI centre of action is more localized for the high Θ^{-1} composite.

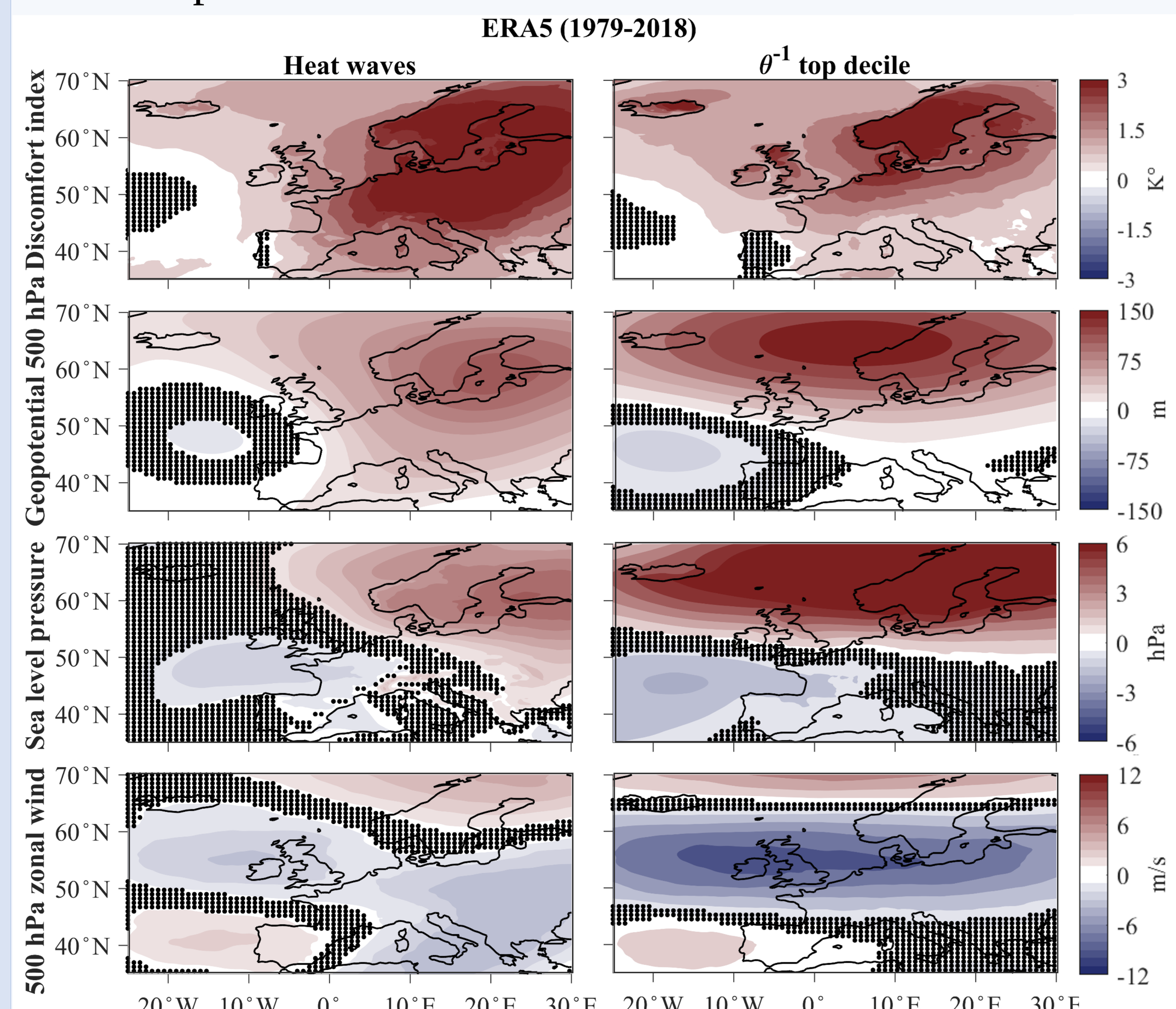

Figure 1 – Composites of DI extremes (heat waves, left column) and persistent pattern extremes (high- Θ^{-1}, right column) for DI, Z500, SLP, and U500. Non-significant differences are marked with black dots using a t-test at the 5% significance level.

- Notice the barotropic anticyclonic anomaly in Z500 and sea level pressure in both composites, which is stronger and more localized for the high Θ^{-1} days.
- The easterly anomaly in the zonal wind at 500 hPa in both composites suggests reduced eddy kinetic energy.
- Checking the Θ^{-1} distribution of heat wave days in comparison to non heat wave days (Fig. 2) shows a significantly higher median (2.39vs.2.02). Heat waves are 20% of the most persistent days in comparison to their 4% abundance in the historic data set.

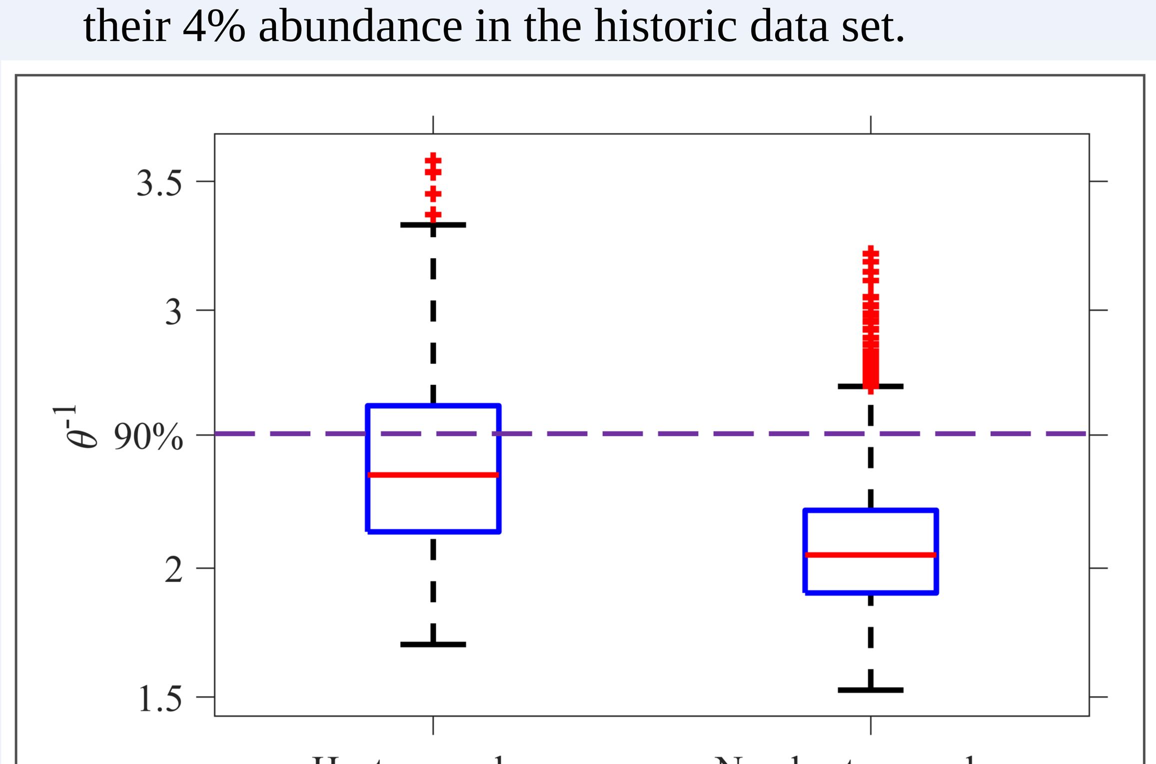

Figure 2 – Θ^{-1} distribution for heat wave days and non heat wave days. The dashed purple line marks the top decile value.

- **Key Point: ERA5 data show a significant connection between heat wave days and persistent days which could be understood through the process of blocking.**

Persistent days in GCMs

- For GCMs, the persistence analysis for historic runs shows a similar relationship between the DI anomaly and a persistent circulation (Fig. 3).

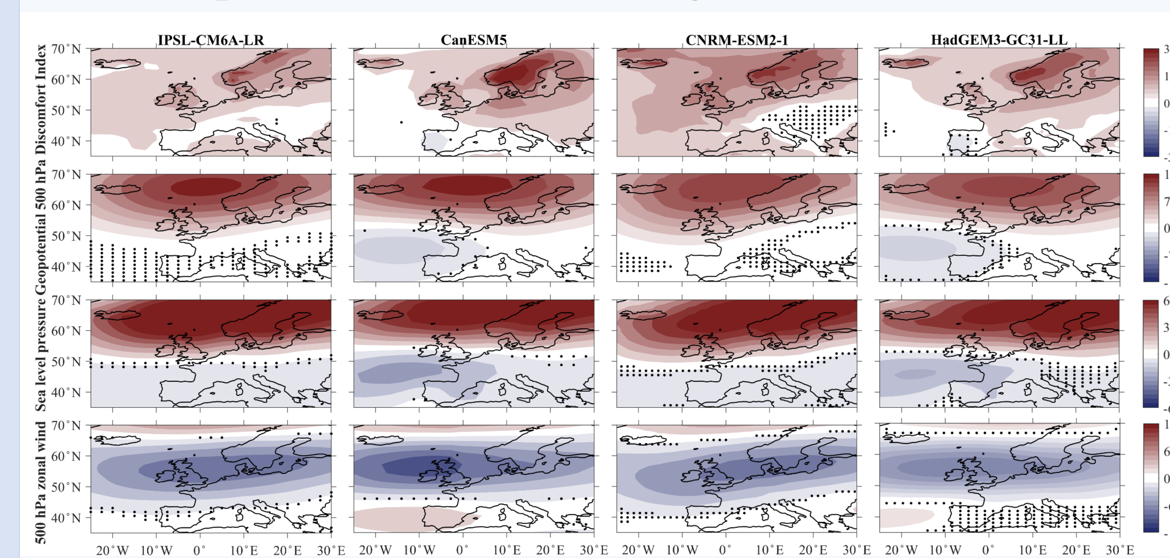

Figure 3 – Synoptic anomaly comparison of the most persistent days (top decile) in four different CMIP6 models historic runs. Each row describes a different synoptic variable.

- GCMs show a barotropic blocking structure similar to ERA5 in Z500, sea level pressure, and 500 hPa zonal wind.
- The connection between the block and the DI is translated well among all models, further connecting persistent flow with a corresponding extreme DI.
- **Key Point: GCMs and ERA5 show a similar blocking pattern for the most persistent days. The surface impacts of the blocking pattern are captured in the models, so we can use Θ^{-1} extremes as a proxy to assess the implications of climate change on the blocking heat wave process.**

Greenhouse warming increases persistence

- The persistence analysis for three future forcing scenarios: SSP1-2.6, SSP3-7.0, and SSP5-8.5 for the next century (2070-2100) respond with increased persistence under anthropogenic forcing (Fig. 5).

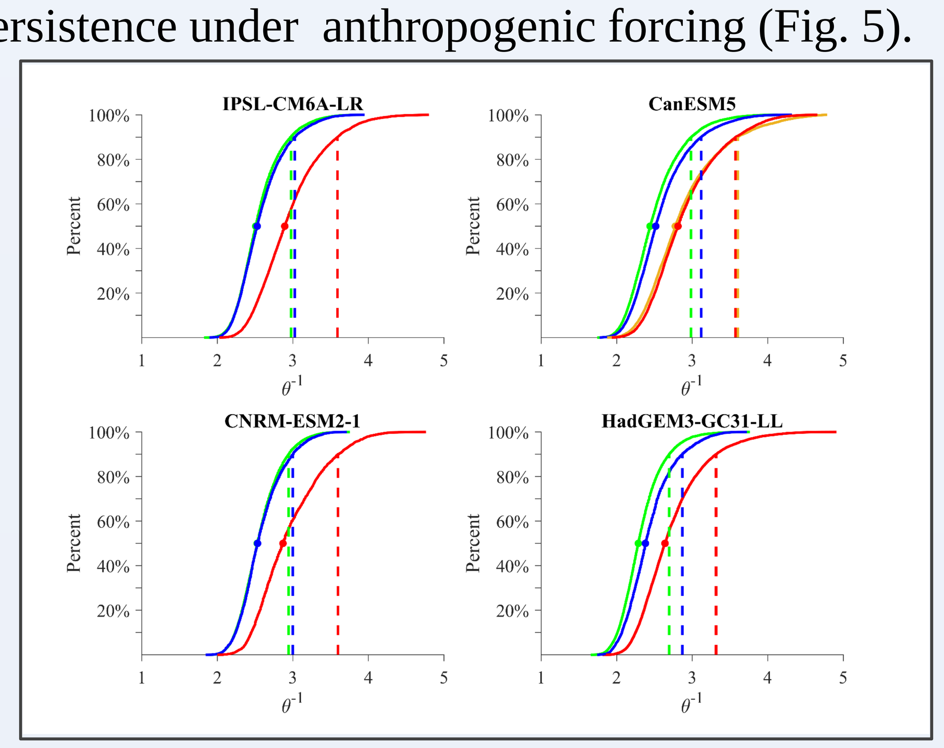

Figure 5 – Θ^{-1} distribution for historic simulations (green), SSP1-2.6 (blue), SSP3-7.0 (orange), and SSP5-8.5 (red) for different models. Dashed lines (points) show the 90th (50th) quantile of the in different simulations stands in future simulations.

- **Key point: Under greenhouse forcing, the end of the century mean flow is more persistent by 15%. The 90th percentile Θ^{-1} value grows by 20%.**
- Persistent days keep the same blocking mechanism presented in Fig. 3, causing similar surface impacts.

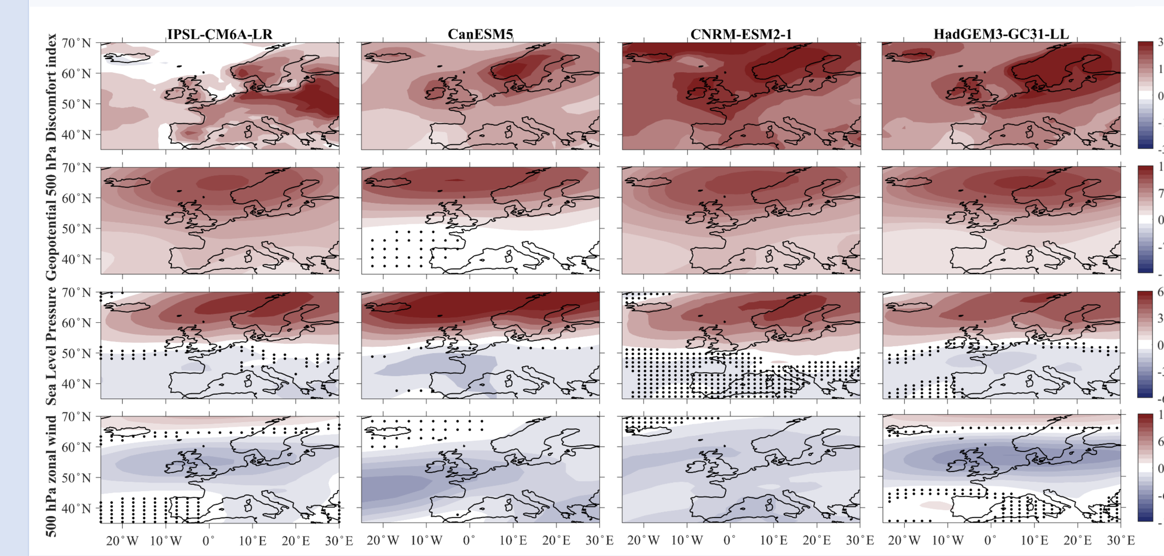

Figure 5 –Synoptic anomaly comparison of the most persistent days (top decile) in four different CMIP6 models under SSP5-8.5 anthropogenic forcing. Each row describes a different synoptic variable.

- The circulation anomalies are similar in the historical and projected climates, but greenhouse forcing simultaneously amplifies the strength of the DI anomalies. DI shows higher anomalies. This can be connected to the anthropogenic emissions that cause a higher warming effect.
- The greenhouse-forced increase in Θ^{-1} also means a more stationary block, which creates more cumulative stress on humans and agriculture during blocking events.
- **Key point: Key point: Projected blocking events are stronger and longer, creating a compounded effect.**

Conclusions

- **Θ^{-1} can be used proxy variable for blocking events in reanalysis data.**
- **Historic runs also show a correlation between blocking patterns and surface impact. Thus, Θ^{-1} serves as a proxy for persistent blocks dynamically and hot and humid surface conditions.**
- **Greenhouse forcing increases the persistence of midtropospheric flow, yielding longer blocks and amplified anomalous surface warming.**

References

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