AGU PUBLICATIONS

Geophysical Research Letters

Supporting Information for

Northern Hemisphere Heat Extremes in a Warmer Climate: More Probable but Less Colocated with Blocking

V. Narinesingh[1, 2], J. F. Booth[3], and Y. Ming[4]

[1]NOAA Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey

[2]Program in Atmospheric and Oceanic Sciences, Princeton University, Princeton, New Jersey

[3]Earth and Atmospheric Sciences, City University of New York - City College, New York, New York

[4]Department of Earth and Environmental Sciences, Boston College, Boston, Massachusetts

Contents of this file

Introduction

This Supporting Information section contains detailed explanations of the block tracking algorithm (S1) and significance calculations (S2) used in this article. In addition, this section shows the spatial distribution of heat extreme duration throughout the northern hemisphere extratropics in ERA5 reanalysis and the two climate model simulations of CM4 (Hist. and RCP).

Text S1: Block Tracking Algorithm

The block tracking algorithm used in this study follows that of Chan et al. (2019), which is a slight modification of the algorithm introduced by Dunn-Sigouin and Son (2013). This algorithm is implemented on the 500-hPa geopotential height field, Z_{500}.

First, the anomalous Z_{500} field, Z'_{500}, is calculated by subtracting the mean seasonal cycle and running annual mean at each gridpoint (Dunn-Sigouin 2013). Then, to be considered blocked, contiguous areas of positive Z'_{500} must meet the following criteria:

1. Anomaly amplitudes of at least 1 standard deviation
2. Area of 1.0 x 10^6 km^2 or greater
3. Within the contiguous positive anomaly, a reversal in sign of the meridional gradient of Z_{500} (see Dunn-Sigouin and Son 2013 for specific details)
4. An area overlap of 50% between successive days (quasi-stationary requirement)
5. Persistence: meeting the above requirements for 5 or more days

Text S2: Significance Testing

A 5% significance level is imposed for all significance testing throughout this paper. A bootstrapping approach (Vecchi et al. 2006, Bollasina et al. 2011) is used to determine if the conditional probability of blocking given a heat extreme, $P(B|H)$, is greater than the probability of blocking for all summer days, $P(B)$ (Figs. 1a-c, 2b-c, and 4b-c). Note $P(B|H)$ can be written as:

$$P(B|H) = \frac{P(B \cap H)}{P(H)} \text{ (SI Eq. 1)}$$

where $P(B \cap H)$ is the joint probability of a grid cell containing both blocking and a heat extreme. Bearing this in mind, the bootstrap is calculated as follows at each gridpoint for each model:

1. The 35-year data sets (ERA5, CM4 Hist., and CM4 RCP 8.5) each have a total of $n = 3220$ summer days. Each of these days are flagged as having either a block only, a heat extreme only, both, or neither.
2. Allowing for replacement, random selections of n days are drawn. From this draw, $P(B)$ is calculated. $P(H)$ and $P(B \cap H)$ for the random draw is also calculated and used to find $P(B|H)$.
3. Step 2 is then repeated N = 1000 times to get randomly generated distributions of $P(B)$ and $P(B|H)$.
4. If the 5^{th} percentile of $P(B|H)$ is greater than the 95^{th} percentile of $P(B)$, $P(B|H) > P(B)$ is considered significant.

This approach was found to give similar results as using a chi-squared test.

Significance testing of $P(B)$ in reanalysis vs. CM4 Historical (Fig. 2a) and CM4 Historical vs. CM4 RCP 8.5 (Fig. 4a) is calculated following Narinesingh et al. (2022). For a given model/integration, $P(B)$ is calculated for each summer. Then, to compare the models and/or the integrations, Wilcoxon rank-sum tests are performed at each gridpoint comparing $P(B)$ for each summer.

Fig. 3c also utilizes a bootstrapping approach to determine if the mean-state warming in CM4's RCP 8.5 as compared to the Historical integration (Fig. 3a) is significantly greater than the 90th percentile Historical temperature anomaly (Fig. 3b). The calculation is made as follows:

1. The 2-m temperature anomaly is calculated for each of the $n = 3220$ summer days in the 35-year CM4 Historical integration data set following Eqs. 1-3 in the main text.
2. Allowing for replacement, random selections of n days are drawn. The 90th percentile temperature anomaly is then calculated using the randomly selected data.
3. Step 2 is then repeated N = 1000 times to get a distribution of 90th percentile temperature anomaly values.
4. Mean state warming (RCP 8.5 minus Historical integration, Fig. 3a) exceeding the 95% confidence interval from the distribution generated in step 3 are considered significant.

To determine if differences in $P(B|H)$ between the Historical and RCP 8.5 integrations of CM4 are significant (Fig. 4b-c), a two-sample t-test is used on the randomly generated (N=1000) distributions of $P(B|H)$ for each integration.

Finally, to determine significant differences in 90th percentile heat extreme duration between RCP 8.5 and Hist., at each grid point heat extremes are grouped into separate continuous events. Heat extreme duration is classified as the number of successive days in which the temperature anomaly exceeds the 90th percentile. Note, the 5-day running mean at the beginning of the anomaly calculation smooths out any 1–3-day spikes or dips in the 2-m temperature field. Wilcoxon rank-sum tests are then performed on heat extreme durations in the Historical integration vs. RCP 8.5 at each grid point.

Text S3: Duration of 90th Percentile Heat Extremes in ERA5, CM4 Hist., and CM4 RCP 8.5

The average duration of 90th percentile heat extremes for reanalysis and the historical and RCP 8.5 integrations is plotted in Supporting Information Fig.1. CM4 Hist. does not exhibit many significant differences from ERA5 and generally captures the regional variation in heat extreme duration across the Northern Hemisphere midlatitudes. As discussed in the main text, the duration of heat extremes over land is unchanged in CM4 RCP 8.5 as compared to CM4 Historical.

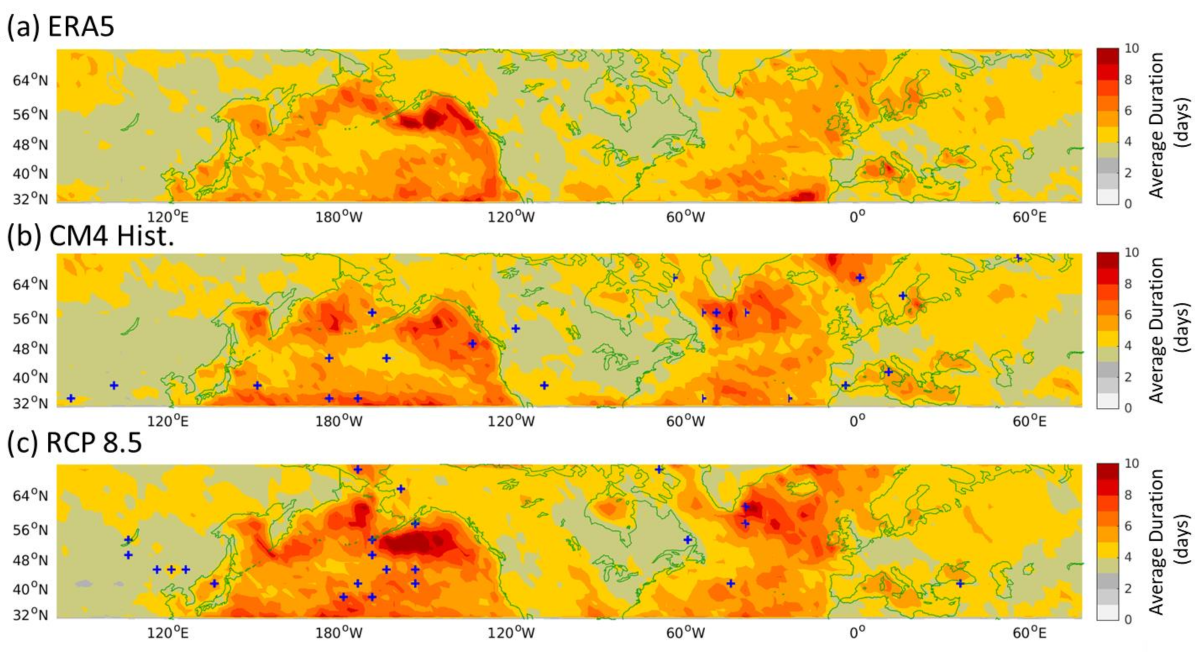

Figure S1. Average duration of 90th percentile heat extreme events in (a) ERA 5, (b) CM4 Hist., and (c) CM4 RCP 8.5. Blue stippling indicates significant differences in duration between (b) ERA5 and CM4 Hist., and (c) CM4 Hist. and CM4 RCP 8.5