Role of atmospheric ridging in the June 2023 Mexico-Texas heatwave

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Abstract

Summer 2023 set numerous heat records across Mexico and Texas, with hundreds of heat-related fatalities, especially among the most vulnerable populations, and large spikes in heat-related emergency room visits. This record-breaking summer included unusually high and persistent heat early in the season that blanketed much of the region, with several locations experiencing their all-time record maximums in excess of 45°C. We examine the characteristics and drivers of this early-season heatwave. The heatwave was associated with record low soil moisture conditions and a strong, persistent atmospheric ridge. We quantify the relative role of atmospheric ridging and soil moisture anomalies in driving this record-breaking heatwave and summer.

Key Findings

Circulation and record-low soil moisture conditions explain between 40-60% of the temperature anomalies on most of the June 2023 heatwave days.

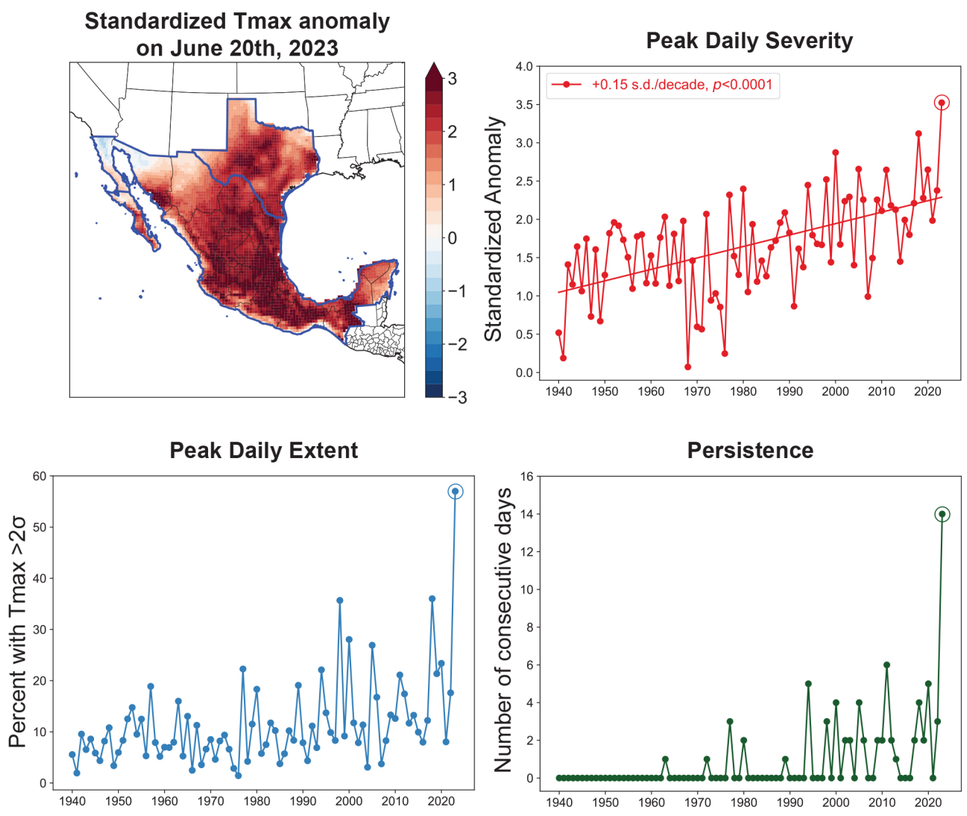
Long-term warming added ~1.4°C to the severity of the heatwave above the contribution of circulation and soil moisture.

The event: The June 2023 was record-breaking in its severity, spatial extent, and persistence

Severity: Daily area-averaged maximum temperature (Tmax) anomalies were ~ 3.52σ (previous record 3.12 σ)

Extent: 57% of the region experienced temperature anomalies exceeding 2σ at the peak of the heatwave (previous record 36.1%)

Persistence: 14 consecutive days with area-average Tmax > 2σ (previous record 6 days)



Data and Methods

We use a constructured analogues approach to characterize the role of circulation in driving the June 2023 heatwave, similar to Zhuang et al. 2021, Faranda et al. 2022. Circulation patterns are examined using the 500-hPa geopotential heights (Z500) from ERA5 reanalysis.

Identifying analogues: For each day in summer 2023, we identify the 40 closest circulation patterns from all years between 1940-2022. These are identified using Pearson's correlation coefficients between the spatial pattern of daily standardized and detrended Z500 anomalies on historical days with a day in 2023. We search for analogues on all historical days within a 31-day centered window of a given calendar day to account for the seasonal cycle.

Predicting Tmax: Based on variables on the identified analog days, domain-averaged, detrended Tmax for each day in June 2023 is predicted using two regression models. First, we use a linear regression of detrended domain-averaged Tmax with detrended domain-maximum Z500. Second, to account for soil moisture (SM) conditions, we also make Tmax predictions using a multiple linear regression with domain-averaged, detrended domain-maximum Z500 and soil moisture anomalies.

All variables are standardized using a 1991-2020 baseline.

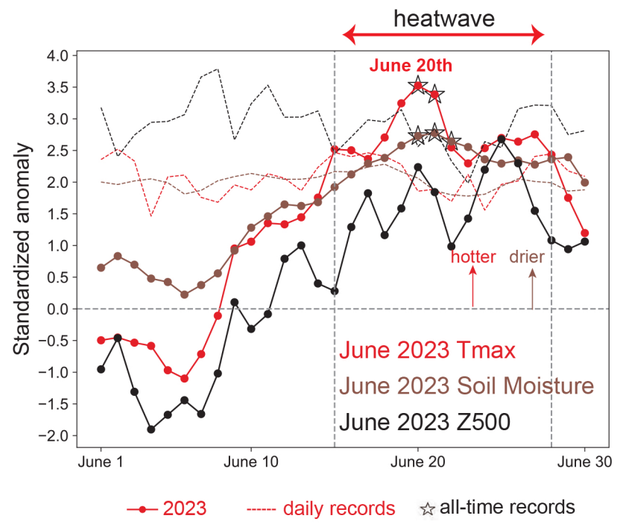
Refs:

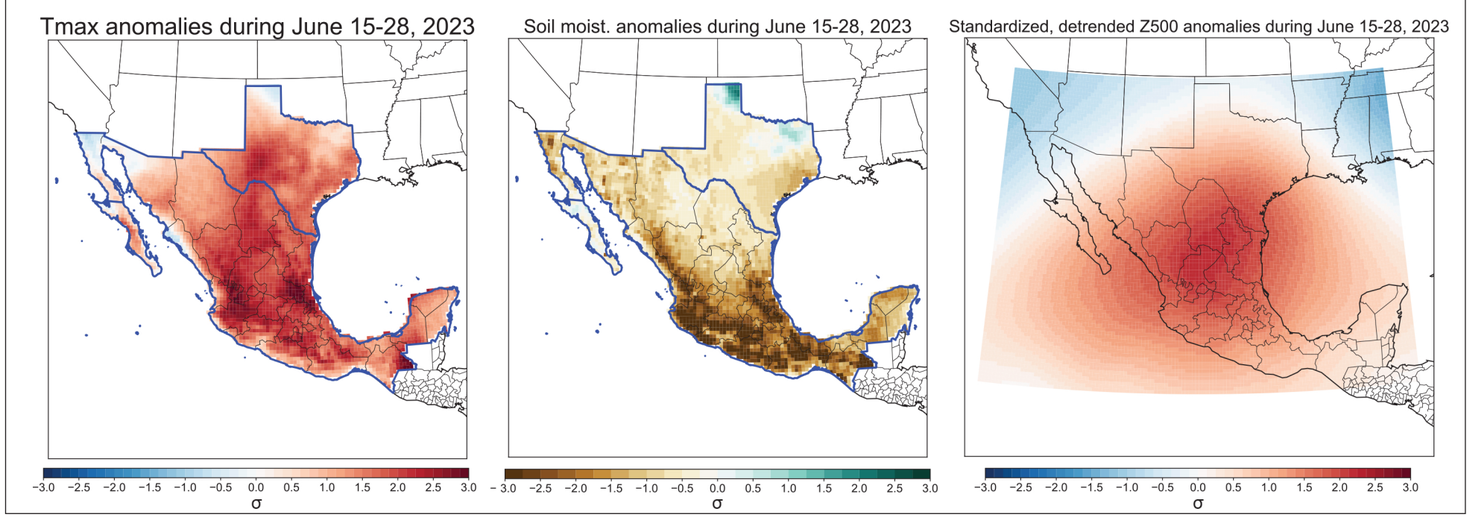
Zhuang, Yizhou & Fu, Rong & Santer, Benjamin & Dickinson, Robert & Hall, Alex. (2021). Quantifying contributions of natural variability and anthropogenic forcings on increased fire weather risk over the western United States. Proceedings of the National Academy of Sciences. 118. e2111875118. 10.1073/pnas.2111875118.

Faranda, D., Bourdin, S., Ginesta, M., Krouma, M., Noyelle, R., Pons, F., Yiou, P., and Messori, G.: A climate-change attribution retrospective of some impactful weather extremes of 2021, Weather Clim. Dynam., 3, 1311–1340, https://doi.org/10.5194/wcd-3-1311-2022, 2022.

Temporal Evolution of Tmax, Soil Moisture and Z500 anomalies

- Area-average Tmax anomalies exceeded 2σ between June 15-28th and broke previous daily records on several days. Composite anomalies during the heatwave were positive across much of the domain and exceeded 2σ across parts of western Texas and central Mexico.
- Low soil moisture conditions persisted throughout June, reaching their peak around the timing of peak Tmax anomalies. The largest soil moisture anomalies occurred in the typically wet parts of central and southern Mexico, coinciding with the largest composite Tmax anomalies.
- An atmospheric ridge centered on central Texas continued to strengthen through late-June. While Z500 anomalies were strong with core values in the composite >2σ, they did not approach record highs except on June 25th.

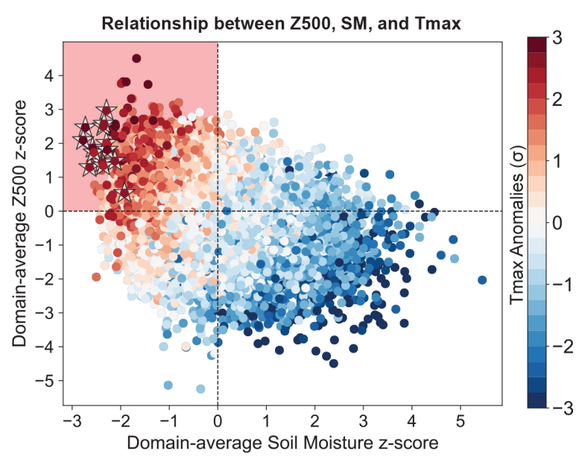


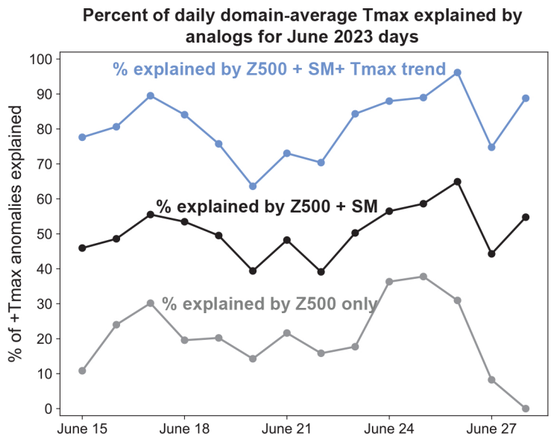


Quantifying the influence of soil moisture and circulation on Tmax

- Circulation analogues alone explain ≤ 40% of the Tmax anomalies on any June 2023 day
- Percent of Tmax anomaly explained by analogs increases to 40-65% after accounting for soil moisture conditions and to 60-95% after accounting for long-term warming
- June 2023 Tmax was 2-3.5°C warmer than predicted by 1940-2022 circulation analogs and soil moisture

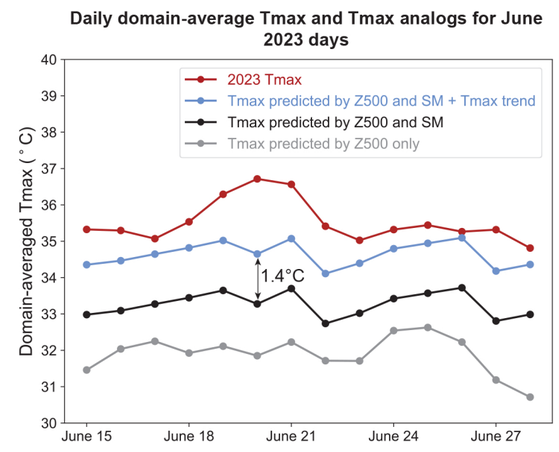
Highest Tmax anomalies are associated with high Z500 anomalies **and** low soil-moisture conditions. Therefore, constructed analogs must account for soil moisture conditions.

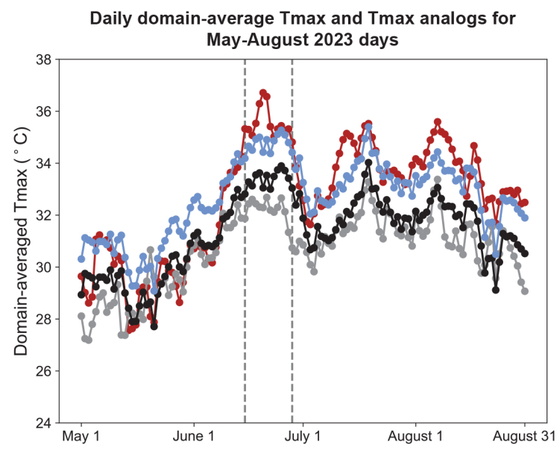




Constructed analogs capture Tmax anomalies closely on most days. Predicted daily Tmax from constructed analogs, soil moisture and the long-term warming is within 1 degree of actual Tmax on most days of the summer season except during the peaks of the 2023 heatwaves.

Overall, May-Aug 2023 was 2°C warmer than predicted by 1940-2022 analogs.





Was the June 20th atmospheric ridge exceptional?

The ridge associated with the peak heatwave day (June 20th, 2023) was not exceptionally strong but it occurred on 20 days in summer 2023, its highest frequency between 1940-2022. Based on the circulation analogues, the pattern does not show a long-term trend in occurrence. However, patterns analogous to this are associated with warmer anomalies in the present climate than in the mid-20th century climate. The standardized Tmax anomaly associated with this pattern was the highest in 2023.