Are heat extremes still predictable?

Nir Y Krakauer

Associate Professor, Department of Civil Engineering and NOAA-CESSRST, The City College of New York

Recent years have seen long-standing temperature records in many countries broken by unprecedented amounts. The state-of-the-art ERA5 reanalysis shows this pattern well, with most of the globe reaching new record temperatures in the last 15 years.

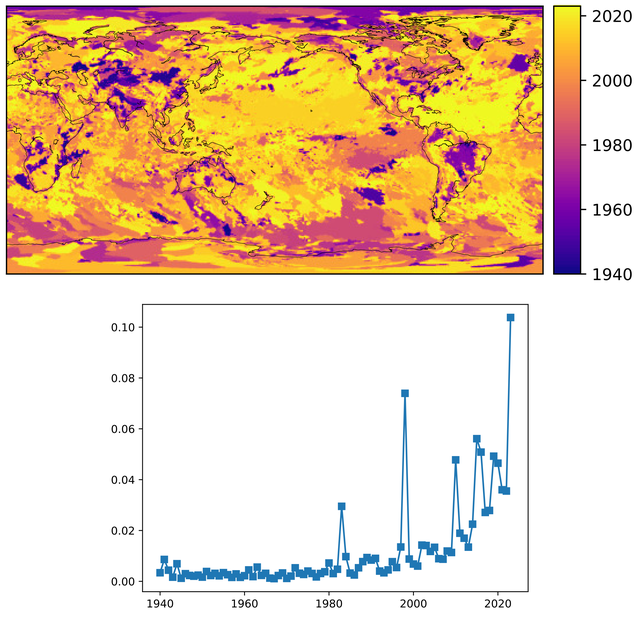

Figure 1. (a) Year of record temperature in ERA5 (using hourly, 0.25° resolution 2-m temperatures for 1940-2023). (b) Area percentage with record value for each year.

The ability of the generalized extreme value (GEV) distribution, with and without trend in parameters, to represent the patterns in annual maximum temperature across world regions was evaluated. To do this, a sample was taken of 100 populated land grid cells spaced at least 10° apart, sufficient for good global coverage.

Maximum-likelihood GEV fitting was applied to each grid cell's annual maximum temperature series to generate one-year-ahead probabilistic forecasts of maximum temperature beginning in 1970. The stationary GEV distribution was compared to one where the location parameter was linearly related to global mean temperature, which greatly improved the ability to forecast the warmer temperature extremes. On average, the annual maximum temperatures warmed 1.4 times as fast as global mean temperature. In most cases, the GEV with trend generally produced well calibrated forecasts of annual maximum temperature even for recent years with their many new records.

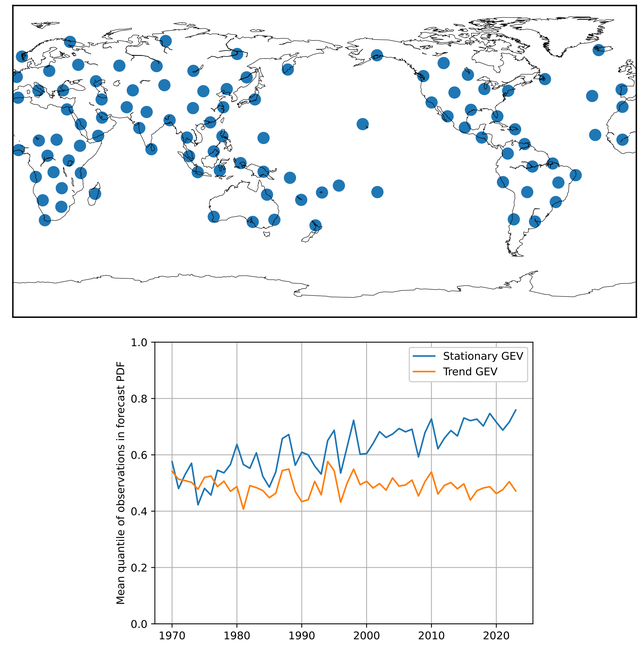

Figure 2. (a) Selected grid cells for statistical modeling of annual maximum temperature. (b) Mean location of the actual maximum temperature for each year in the nonstationary GEV forecast probability distribution (should be near 0.5 for well-calibrated forecasts).

The fitted GEV distributions typically had negative shape parameters, meaning that the forecast probability distributions had hard upper bounds. This meant that for the stationary GEV model, new records were sometimes 'impossible' given the past data; this was less common for the GEV with trend, although it still happened occasionally.

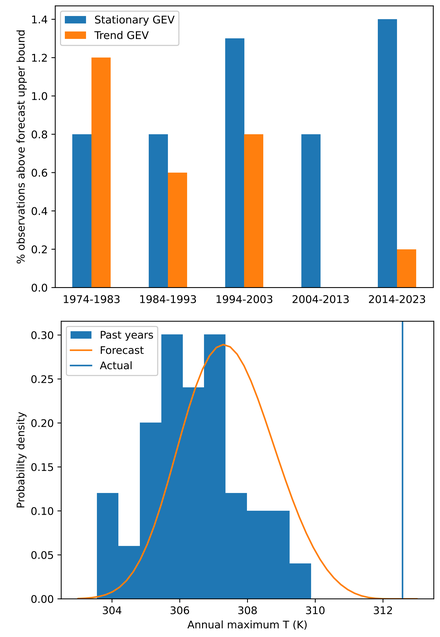

Figure 3. (a) 'Impossible' or surprising new temperature records by decade, with and without nonstationarity (trend). (b) Example of an 'impossible' new record from near Adelaide, Australia in Dec 2019, showing the histogram of the 1940-2018 annual maximum temperatures and the forecast for 2019 based on the GEV with trend.

Conclusions: In a sample of populated land areas, heat extremes do not seem to be getting more unpredictable when controlling for mean global temperature. That is, there is not evidence that the variance of heat extremes is increasing. Fitting annual maximum temperature series with the GEV distribution, even with trend in the parameters, typically results in forecast distributions with hard upper bounds, which are sometimes then exceeded. This could be avoided by using unbounded families of probability distributions or by accounting for parameter uncertainty.

See also:

NY Krakauer (2023), Amplification of extreme hot temperatures over recent decades, *Climate*, 11(2): 42.

NY Krakauer (2019), Temperature trends and prediction skill in NMME seasonal forecasts, *Climate Dynamics*, 53(12): 7201-7213.

H Aizenman, MD Grossberg, NY Krakauer, I Gladkova (2016), Ensemble forecasts: probabilistic seasonal forecasts based on a model ensemble, *Climate*, 4(2): 19.

`https://nirkrakauer.net nkrakauer@ccny.cuny.edu`