DOE/UCAR Cooperative Agreement

Regional and Global Climate Modeling Program

Probability of US Heat Waves Affected by a Subseasonal Planetary Wave Pattern

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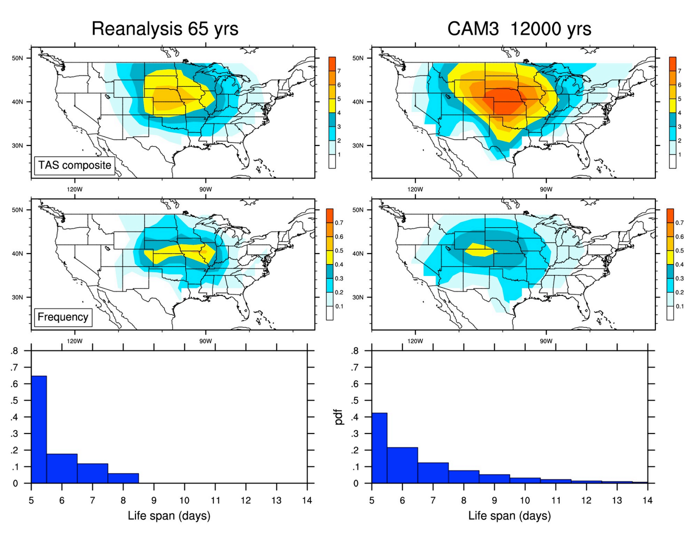
Summary

Based on 12,000-year integration of a CAM3 simulation forced with present-day climatological SSTs, we identify a pattern of subseasonal atmospheric variability that can help improve forecast skill for heat waves in the United States. We find that heat waves tend to be preceded by 15–20 days by a pattern of anomalous atmospheric planetary waves with a wavenumber of 5. This circulation pattern can arise as a result of internal atmospheric dynamics and is not necessarily linked to tropical heating. We conclude that some mid-latitude circulation anomalies that increase the probability of heat waves are predictable beyond the typical weather forecast range.

US heat wave statistics

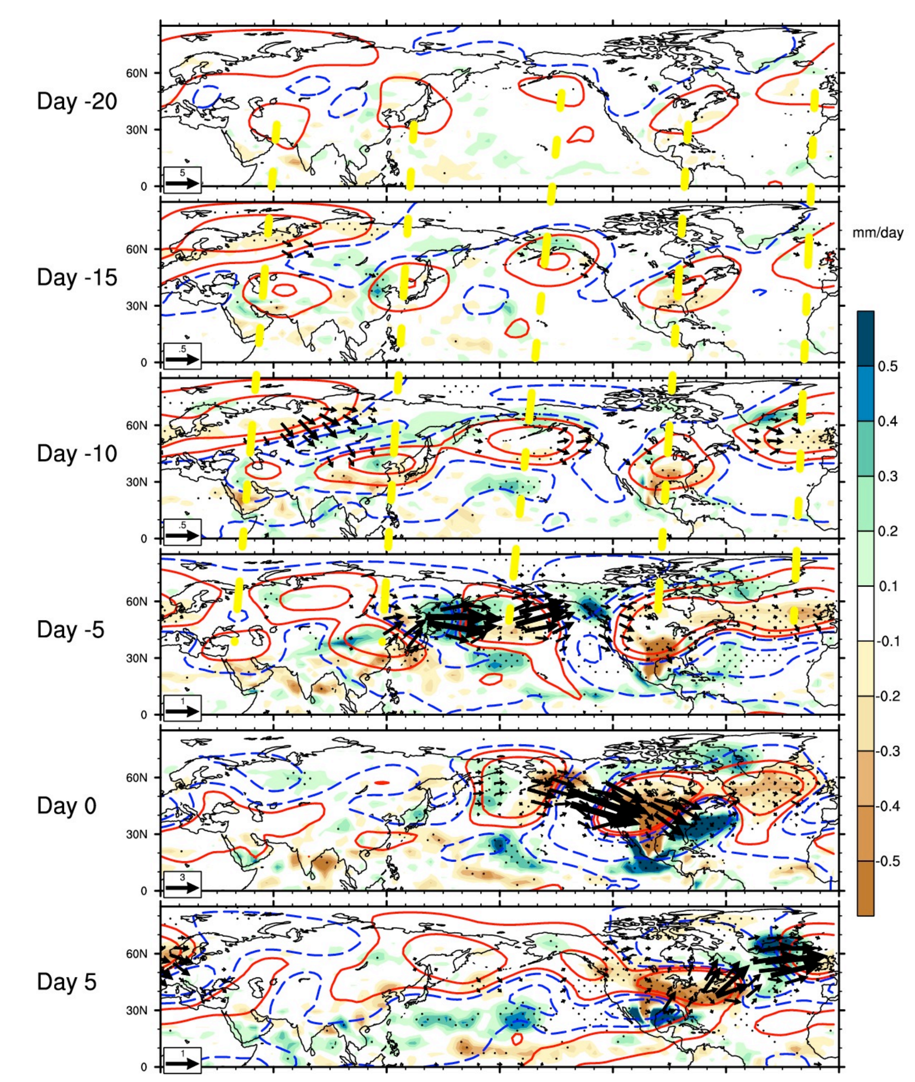
A day during JJA is considered to be a heat wave day if a) on that day and each of four succeeding days there are more than 10 grid points (at T42 resolution, corresponding to 5% of the searched domain) over the US continental area within the domain of 125°W-70°W, 25°N-50°N with daily averaged TAS exceeding the 97.5 percentile for historical daily temperatures, and b) the center of these warm points does not move faster than 5 degrees of latitude or longitude per day.



Climatological surface air temperature anomalies (°C, top) and frequency of occurrence (middle) of the US heat wave days and life span of the events (bottom) in the NCEP/NCAR reanalysis (left) and CAM3 simulation (right).

We apply the same procedure to the NCEP/NCAR reanalysis during the period of 1948-2012 and the 12,000-year CAM3 integration. There are qualitative similarities regarding the life span, intensity and frequency of the heat waves between the model and the reanalysis data.

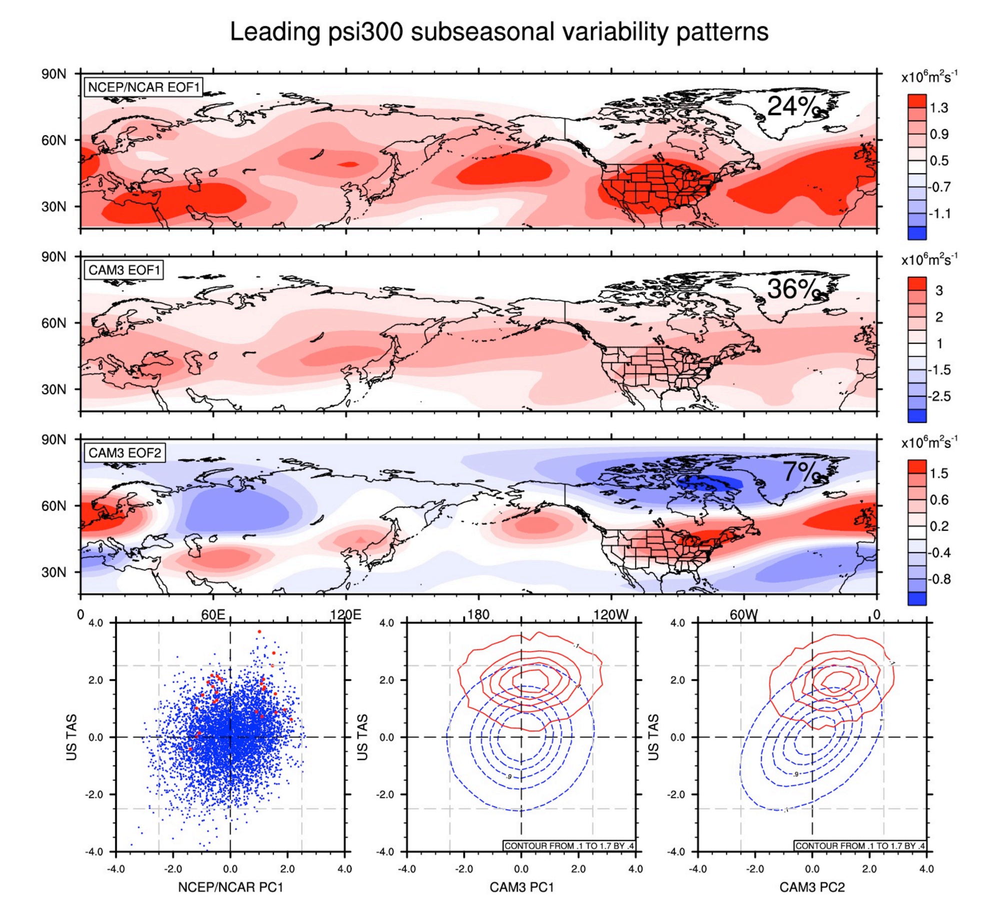
Temporal evolution of the heat waves



Contours represent 300 hPa streamfunction anomalies at ± 0.2, ±1.0 x10^{6}m^{2}s^{-1} levels (most areas with absolute values larger than 0.2 x10^{6}m^{2}s^{-1} are significant at the 95% level. Shading represents composite precipitation, with stippling indicating the 95% significance level from Student's t test, and arrows are the Plumb flux vectors with magnitudes larger than 0.1 m^{2}s^{-2}.

In order to look at the temporal evolution of planetary waves associated with the heat waves in the model, we designate the first day of a heat wave event as day0 and construct composites on each day from day-20 to day5 using daily subseasonal anomalies of 300 hPa streamfunction. To avoid contamination from previous heat wave events, we only use 2300 events that have no heat wave days in the preceding 20 days. From day-20 to day-5, there is a wavenumber-5 structure slowly propagating westward as highlighted by the yellow dashed lines. Both the spatial structure and the movement are reminiscent of atmospheric Rossby waves trapped in the midlatitude jetstream waveguide. There are no organized precipitation anomalies in either the Tropics or in the Asian summer monsoon region around day-15 or earlier.

Pattern of intrinsic subseasonal variability



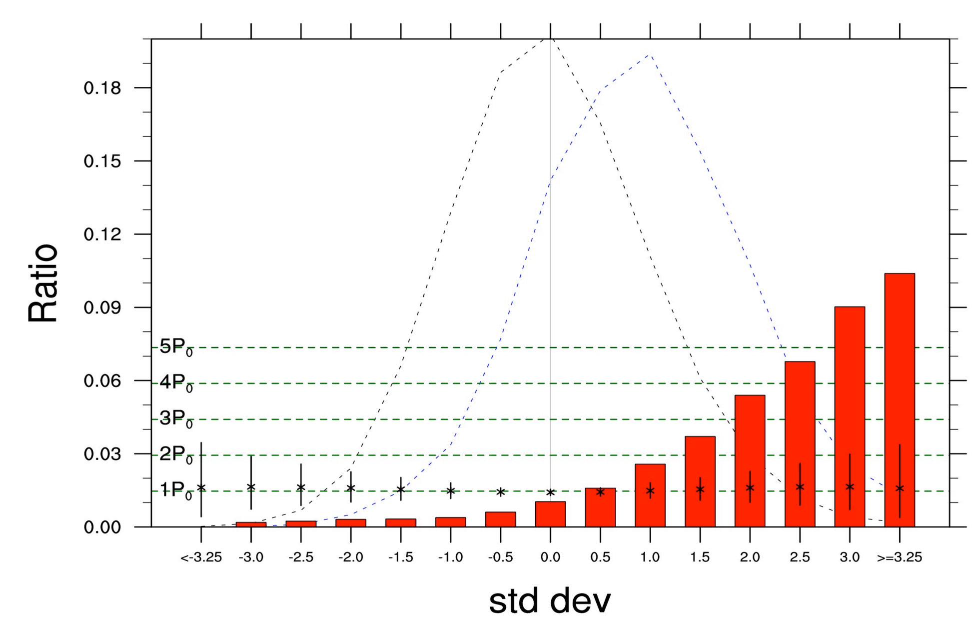
EOF1 of Jun-Aug subseasonal 300 hPa streamfunction monthly anomalies in the reanalysis (top), and the leading two EOFs (the second and third rows) in CAM3. The bottom row is a scatter plot of daily US continental TAS versus projections of daily streamfunction subseasonal anomalies on the zonally asymmetric component of EOF1 in the Reanalysis (left), and PDFs of daily US continental TAS and streamfunction projections onto the two leading EOFs in CAM3 (middle and right) for all summer days (blue) and the heat wave days (red).

A similar wavenumber-5 pattern has been noted in nature. It stands out as EOF1 (top row) of the subseasonal variability of 300 hPa stream function monthly anomalies in the reanalysis data. In CAM3, the wavenumber-5 pattern is represented by EOF2, while EOF1 emphasizes a zonally symmetric component of variations in the circulation (second and third rows). The CAM3 EOF2, with its distinctive wavenumber 5 pattern, has a stronger connection with US heat waves than does EOF1. This is seen by 2-dimensional probability distribution function (PDF) plots of TAS averaged over the continental US within 125°W-70°W, 25°N-50°N versus projections of daily 300 hPa streamfunction anomalies onto EOF1 and EOF2 (bottom row).

Implications for subseasonal predictions

We project 7-day running mean streamfunction anomalies onto the "precursor pattern", and calculate the fraction of cases that develop into heat waves 15 days later as a function of the strength of the projection. The conditional probability (red bars) indicates the stronger the amplitude of a positive episode of the precursor pattern the greater the likelihood of a heat wave two weeks later.

Without any precondition the probability of a randomly picked day being a heat wave day is about 1.5% (denoted as P_0). A 1-standard deviation projection onto the composite pattern doubles the chances of a heat wave 15 days later and a 2 standard deviation projection quadruples the chances compared to a randomly picked case.



The wavenumber-5 pattern, through its influence on the likelihood of US heat waves, may benefit probability forecasts of these extreme events on subseasonal time scales. This conclusion is based on the behavior of a general circulation model, but its applicability to nature is bolstered by the fact that the wavenumber-5 pattern is also a prominent subseasonal variability pattern in nature.

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