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Enhancing Resilience to Heat Extremes: Forecasting Excessive Heat Events at Subseasonal Lead Times (Week-2 to 4)

Augustin Vintzileos[1], Jon Gottschalck[2], Mike Halpert[2], and Adam Allgood[2]

[1]*University of Maryland – ESSIC/CICS-MD*

[2]*Climate Prediction Center, NOAA/NWS/NCEP, College Park, Maryland*

1. Introduction

Heatwaves are among the most dangerous, yet invisible, of natural hazards. According to NOAA, the distribution of 30-year based annual mean fatalities from natural hazards in the U.S. ranks as follows; those from heat (130), floods (81), tornadoes (70), lightning (48) and hurricanes (46). Resilience to excessive heat events will be augmented by using multi-scale prognostic systems.

A scalable system for forecasting excessive heat events at lead times beyond Week-1 was developed at the University of Maryland and the NOAA Climate Prediction Center. This Subseasonal Excessive Heat Outlook System (SEHOS) consists of (a) a monitoring/verification component and (b) a forecasting component which in its baseline version uses NOAA's Global Ensemble Forecast System (GEFS) predictions of temperature and humidity from Day-8 to Day-14. In this presentation, we discuss the definition of heat events, sources of predictability and present the forecast skill of SEHOS for the GEFS reforecast period. Finally we argue on the importance of using multi-model approaches in SEHOS systems especially when targeting forecast leads beyond Week-2.

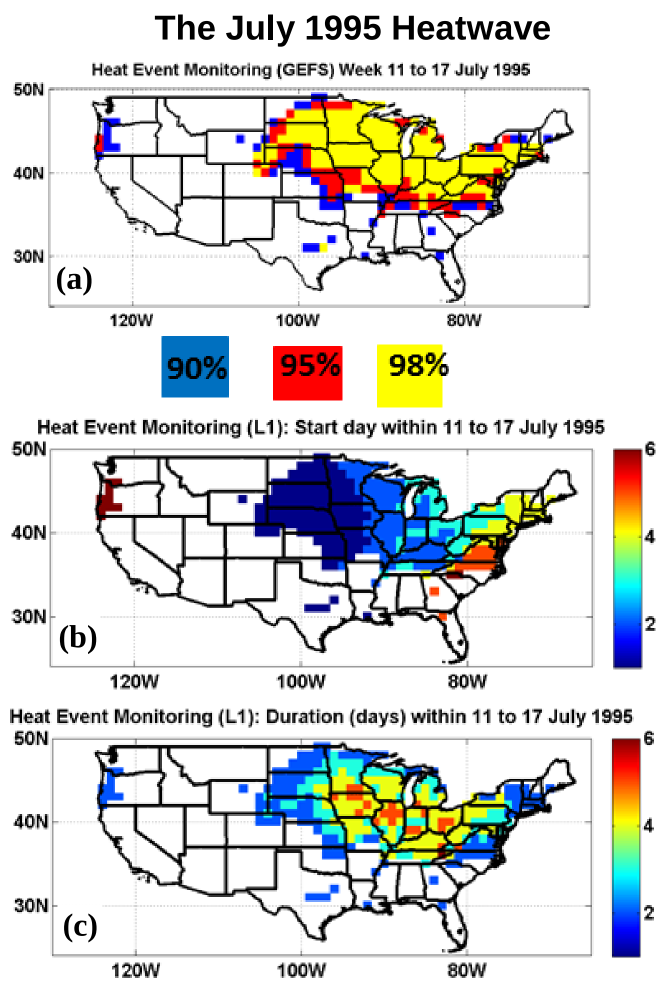

Fig. 1 (a) Grid cells with at least one EHE for the week 11-17 July 1995 for events defined at 90% (blue), 95% (red) and 98% (yellow), (b) the first day of the EHE within the given week for 90% events and (c) the duration (in days) of the EHE.

2. Definition of heat events

The first target was to develop a definition of heat waves which would include both the effects of heat on the human body and the restrictions of probabilistic subseasonal forecasting. The factors we considered in the development of the heatwave definition are:

(1) Impacts of heat grow non-linearly as temperature and humidity increase:

As a consequence the definition must be based on indices representing the thermal discomfort. In this work we use *NOAA's Heat Index*.

(2) Impacts of heat increase as a function of their duration:

Correspondence to: Augustin Vintzileos, University of Maryland – ESSIC/CICS-MD;
E-mail: augustin.vintzileos@noaa.gov

The heat load increases as a function of the duration of the heat wave. Therefore, it is necessary to include information about the number of consecutive days under heat stress.

(3) *Impacts of heat depend on geographical location:*

A heat event of the same intensity has graver impacts in locations in more northern latitudes.

(4) *High apparent temperatures are felt differently as a function of time within the warm season:*

Due to acclimatization to heat the impact of a heat wave during the beginning of the warm season will be graver.

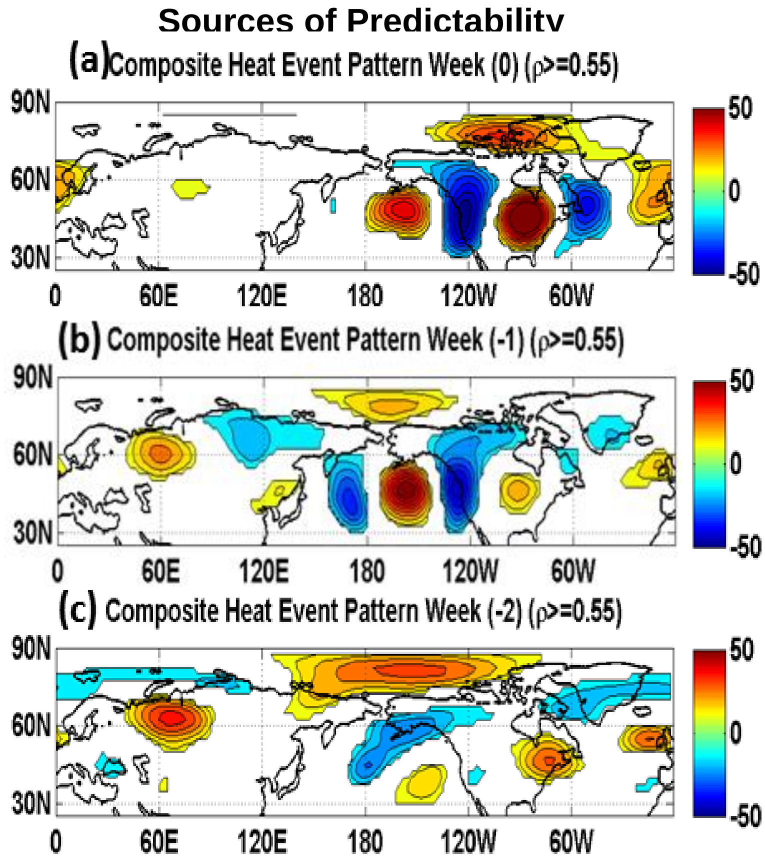

Fig. 2 Weekly mean anomalies of geopotential at 500hPa (in meters) composited for 42 EHE resembling the EHE of July 1995 for (a) during the week of the EHE, (b) the week prior to the EHE and (c) three weeks prior to the EHE.

Based on these considerations we define:

- An Excessive Heat Day as a day with Maximum Heat Index exceeding a given percentile **α** of the Cumulative Distribution Function computed from the historical record for the geographical location and time-frame within the warm season.
- An Excessive Heat Event (EHE) as a succession of at least two heat days. We define Heat Events at Level-1 (α=90%), Level-2 (α=95%), and Level-3 (α=98%).

As an example of the utility of this index Figure 1 shows the spatial structure and evolution of the excessive heat event that affected the Chicago area in July 1995 resulting to abnormal mortality that exceeded 700 cases. Meteorological data of temperature and relative humidity derived from surface pressure and specific humidity at 2 meters are from the NCEP/NCAR Reanalysis.

During the week between 11-17 July, 1995 we observe the occurrence of a very intense EHE with large geographical coverage (yellow color in Figure 1a). The EHE was initially detected at the center of the country (blue colors in Figure 1b) and then propagated eastward reaching the mid-Atlantic area 5 days later. The duration of the EHE (for level 90%) exceeded 4 days for the area around Chicago (red color in Figure 1c).

3. Sources of predictability of EHE

Sources of predictability at subseasonal lead times can be investigated based on the above definition of EHE. Figure 2 shows the composite weekly mean anomalies of geopotential at the level of 500hPa. The composite is based on 42 EHE similar to the EHE of July 1995. During the week of the composite EHE (Figure 2a) we note strong positive departures of height over the Midwest which are associated with the EHE. A similar large scale structure is seen for the week prior to the EHE. Therefore one source of predictability for such EHE at Week-2 is a large scale stationary Rossby wave. Figure 2c shows the composite weekly geopotential anomaly pattern during three weeks before the event. We are currently examining whether the pattern of Figure 2c can be considered as the 'seed' of the stationary Rossby wave.

4. Forecasting excessive heat events

The baseline system for this research is the Global Ensemble Forecast System and the associated 1985-2014 reforecast conducted by NOAA/ESRL. The forecast methodology is the following. We first compute the historical distribution of the Heat Index at each grid point, during a 7-day window around the forecast day under consideration. In order to account for systematic biases this distribution is a function of forecast lead time from the reforecast. Then we compare the realtime forecast to this distribution and define the given forecast day as an Excessive Heat Day or not depending on the value of α (see section 1). Finally we compute whether a EHE occurs during forecast week-2 and its start day and duration. This algorithm is repeated for each forecast ensemble member and the statistics computed, *i.e.*, probability of occurrence, mean first day and mean duration of the forecast.

Verification of the baseline system is based on the reforecasts initialized daily from 13 May to 15 September from 1985-2014. For the sake of comparison with the ECMWF model we also evaluate the forecast skill for reforecasts that are initialized twice per day from 1995-2014, *i.e.*, following the initialization strategy of ECMWF. The verification technique is the Receiver Operating Characteristics (ROC) and the Area Under Curve (AUC) which we compute for each grid point. Figure 3 compares the AUC of the (a) ECMWF, (b) GEFS and, (c) GEFS+ECMWF super-ensemble. We must underline that the GEFS reforecasts are done with an older version of the model and are initialized using the CFS-Reforecasts and not its own analysis. This means that Figure 3 cannot be used for direct comparison of the models but rather as an indication of the possibility to forecast EHE at subseasonal lead times (starting from forecast Week-2).

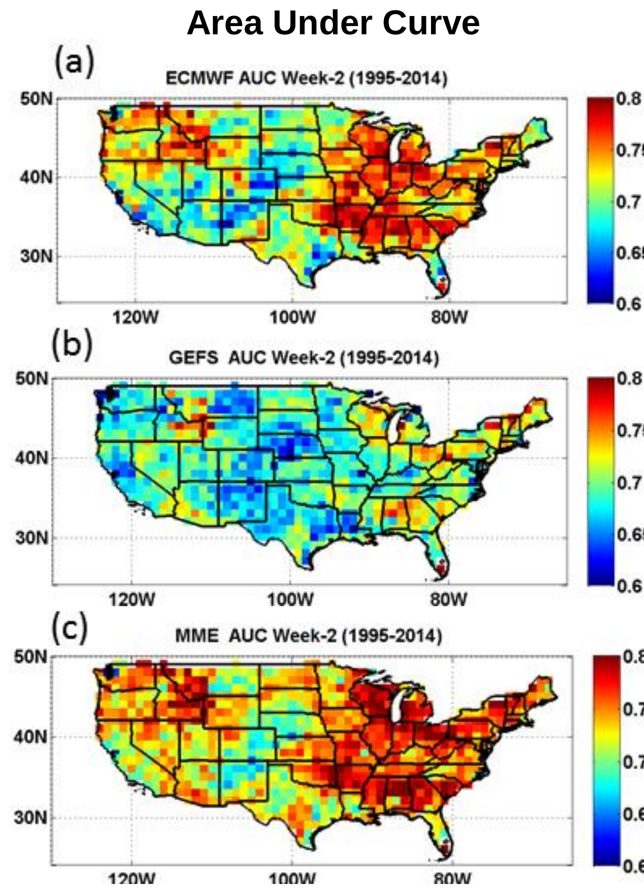

Fig. 3 Area under the ROC Curve (AUC) for (a) ECMWF, (b) GEFS and (c) GEFS and ECMWF combination. Values of AUC close to one (red) indicate a good forecast system to contrast values close to 0.5 (blue).

Comparison of Figures 3a and 3b shows that the most difficult areas for forecasting EHE is in the center parts of the CONUS. The ECMWF shows an overall better forecast quality for the reasons explained in the previous paragraph. It is important to note that by combining the GEFS and ECMWF models the forecast quality is superior to each model separately.

5. Conclusions

We introduced a definition of excessive heat events that is compatible with both requirements of accounting for the physiological effects of heat to the human body and the constraints of probabilistic subseasonal forecasting. We show that there is skill in forecasting EHE at forecast Week-2. We also computed the AUC for forecast Week-3 (not shown) finding a large decrease in forecast skill over most of the locations. However, multi-model approaches again show some promising results when used for forecast Week-3.

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