Enhancing Resilience to Heat Extremes: Multi-model Forecasting of Excessive Heat Events at Subseasonal Lead Times

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Outline:

- **Motivation: Why developing Early Warning Systems for Excessive Heat?**

- **Current quasi-operational status of the baseline system:**
  - **Defining heat events**
  - **Monitoring/Forecasting/Verification methodology**
  - **Importance of Multi-Model-Ensemble methods**

Transition to quasi-operational status with the aid of CPC collaborators: Jon Gottschalck, Mike Halpert, Adam Allgood.

- **Current development status:**
  - **Revisiting the definition of Excessive Heat Events (EHEs).**
  - **Validating Excessive Heat Event definition versus mortality.**

- **Conclusions and future work**

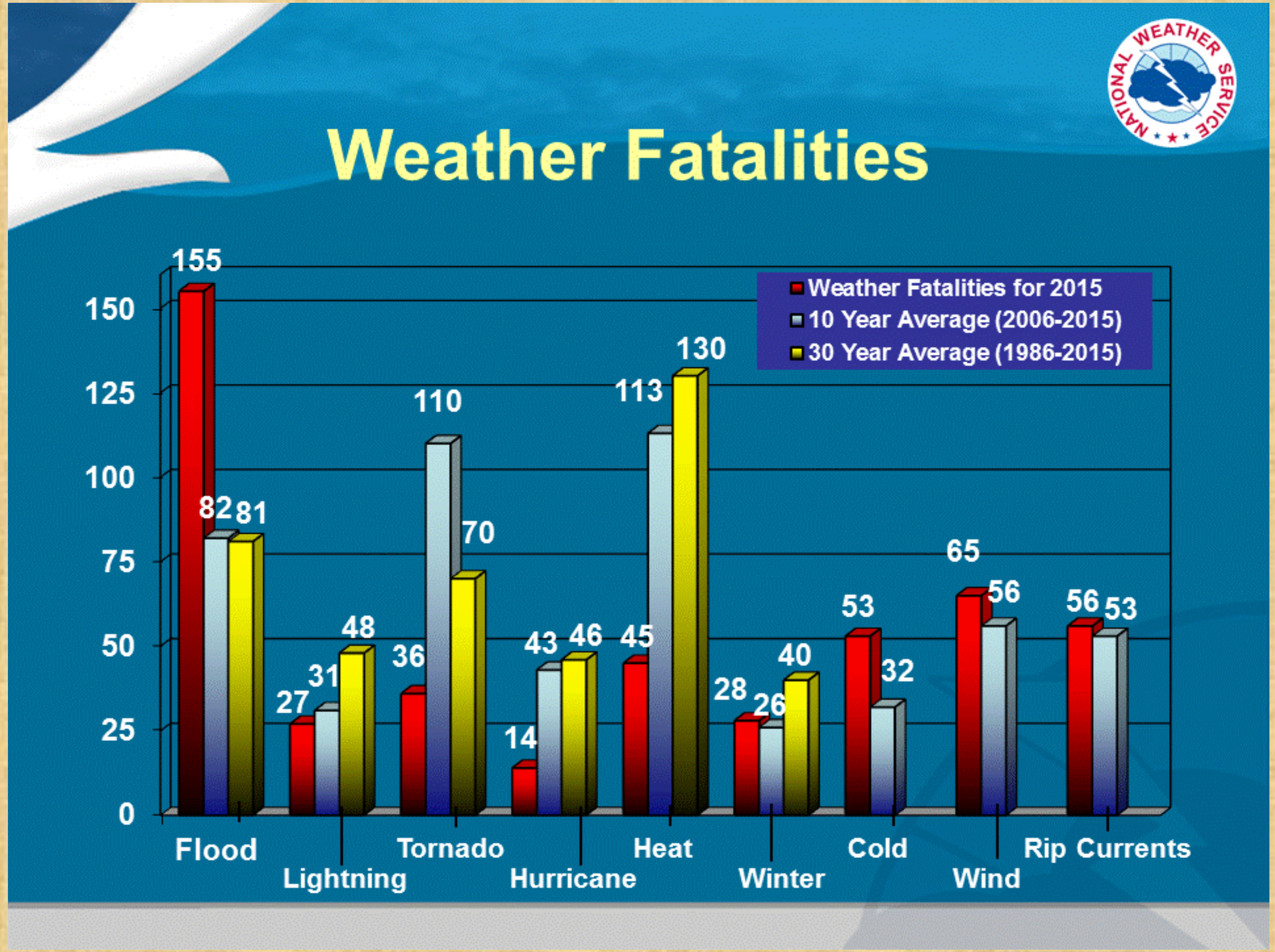
Motivation: Why develop Early Warning Systems for Excessive Heat?

At present Excessive Heat results to more casualties than any other atmospheric extreme. From 1986 to 2015 the annual mean fatalities over the United States:

Heat = 130
Flood = 81
Tornado = 70
Lightning = 48
Hurricane = 46

As the population becomes older and excessive heat is projected to be more intense and frequent the number of casualties from excessive heat will increase.

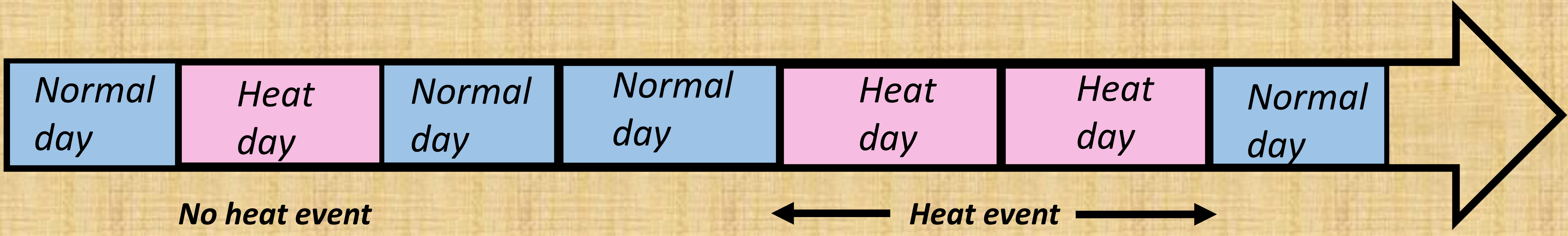
Early warnings to relief agencies will help to build resilience.



Baseline definition of Excessive Heat Event

We defined heat events using **percentiles of apparent temperature:**

- A Heat Day is a day with Maximum Heat Index exceeding a given percentile **α** computed from the historical record for the geographical location and time-frame within the warm season.
- A Heat Event is 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%).



Benefits from this definition: Addressing physiological effects of heat AND some challenges of subseasonal ensemble forecasting. Easily extendable to Week-3&4 and seasonal forecasting.

Inconveniences of this definition: Based on expensive reforecasts

July 1995 heat event (Chicago> 700 casualties)

Week of 11-17 July 1995

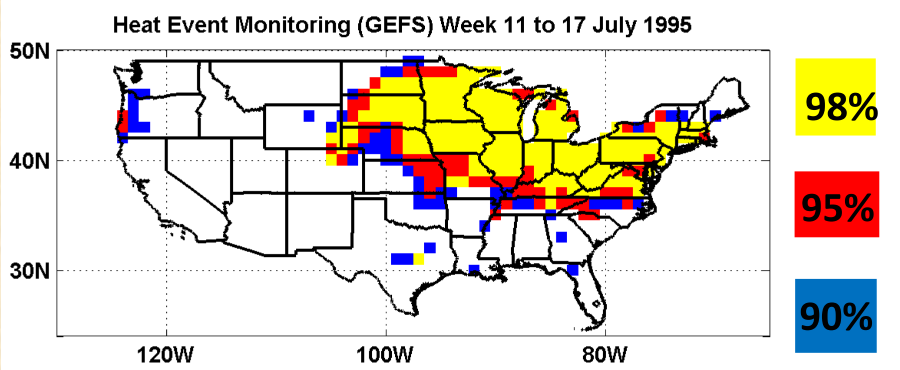
Weekly snapshot:

- A given week is a Heat Week if it contains at least one Heat Event.
- We can define a start day of the heat event within this week
- We can define the duration of this heat event.

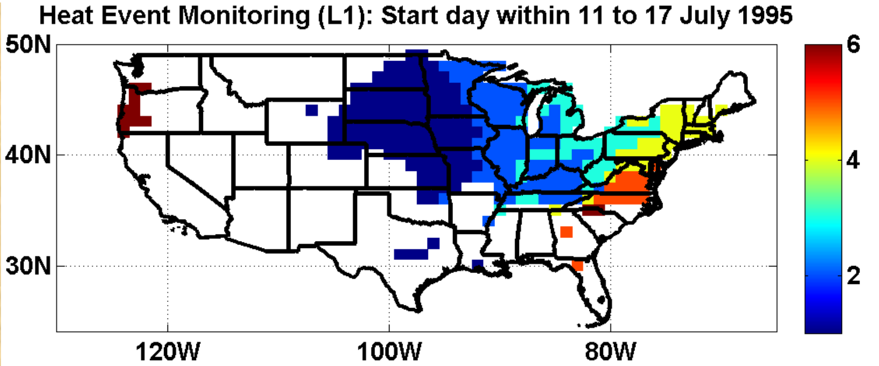
Example: The July 1995 Heat Event

- During the week of 11-17 July 1995 a Level-3 Heat Event (98% - yellow) was covering an extended area from the Upper Midwest to the Northeast and Mid-Atlantic.
- This heat event progressed from west to east during this week.
- The event lasted 5 days (for Level-1 intensity) in the Chicago area.

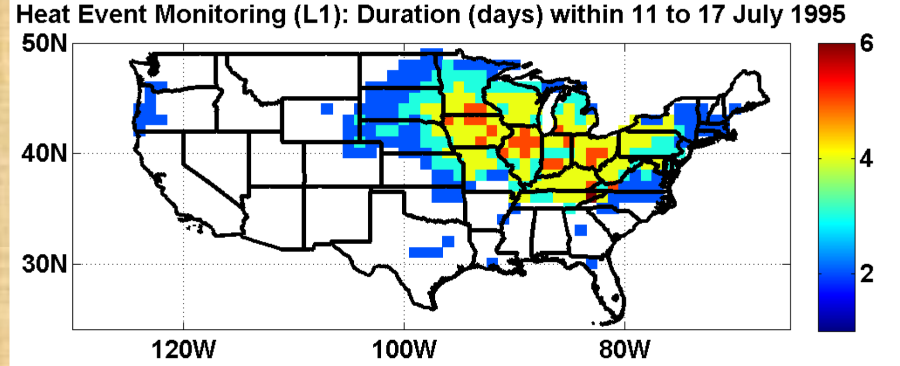
Occurrence



Start day (90%)



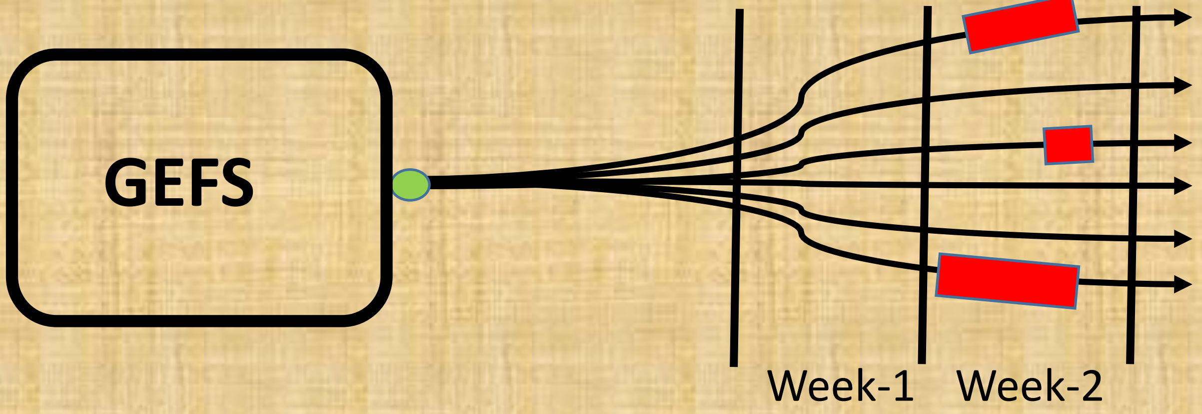
Duration (90%)



Forecasting excessive heat events: Baseline system

Baseline system: The NCEP Global Ensemble Forecast System (reforecast version).

- Initialized daily at 00Z
- 20 perturbed forecasts per cycle resulting to 21-member ensemble per day
- 11 ensemble members per day for the 1985-2014 reforecast
- **For each ensemble member we compute whether Week-2 is a Heat Week based on statistics from the reforecast; the starting day and the duration of the heat event.**
- Compute the statistics: Probability of occurrence, mean start day, mean duration.

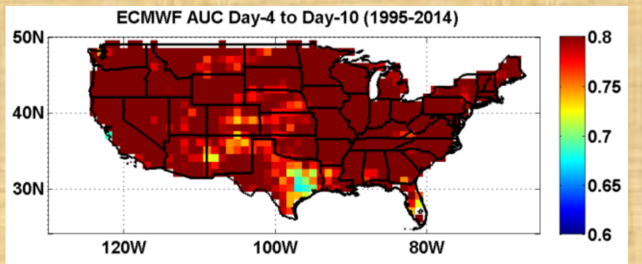


- Verification of reforecasts available at the S2S database using the Receiver Operating Characteristics (ROC) method and Area Under Curve (AUC)

Multi-model Ensemble forecasts: ROC Area Under Curve for 90% – events

Week~1

E C M W F



G E F S

We have not compute AUC for Week-1

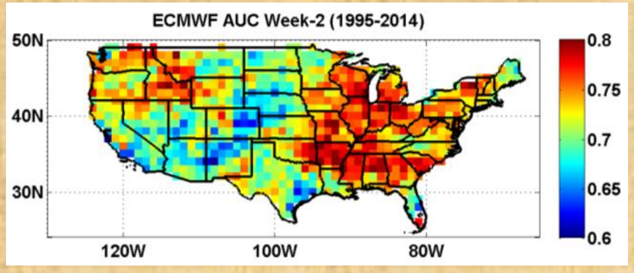
C F S

We have not compute AUC for Week-1

Multi-Model Ensemble Forecasting of Heat Events

Week-2

E C M W F



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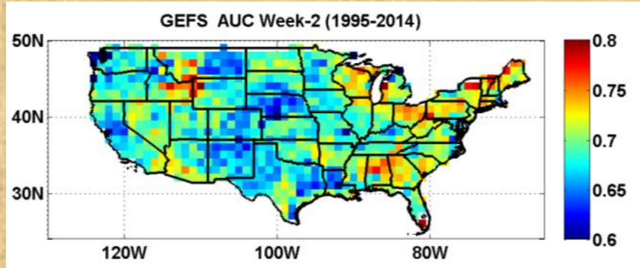
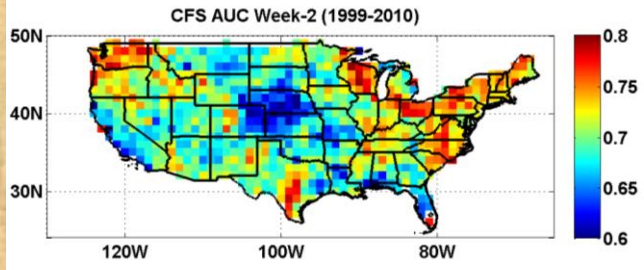
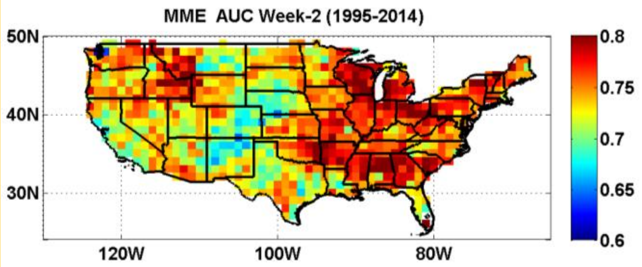


C F S

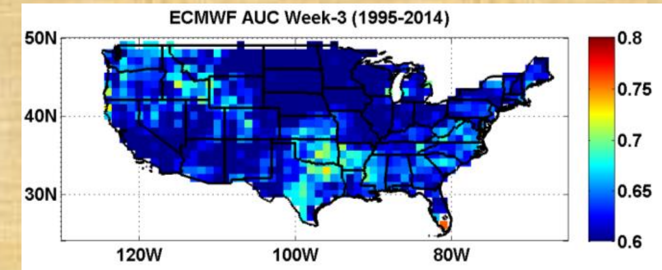


GEFS + ECMWF



Week-3

E C M W F

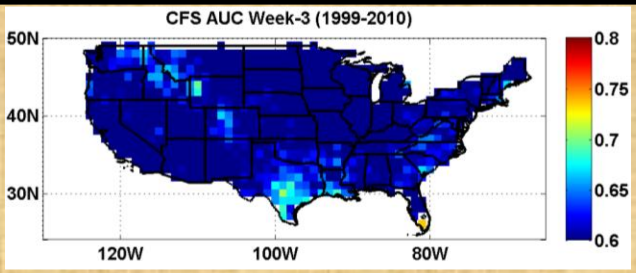


G E F S

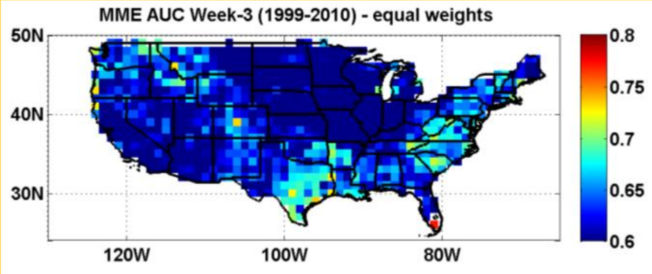
No Week-3 GEFS

(for the moment)

C F S



CFS + ECMWF



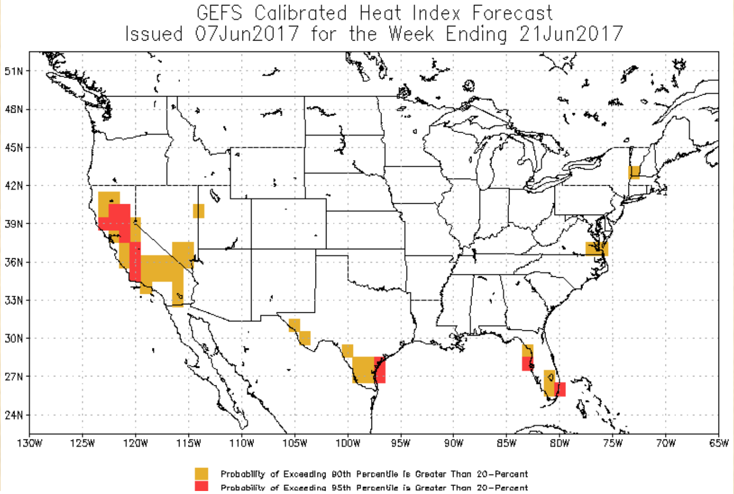
Realtime subseasonal excessive heat outlooks

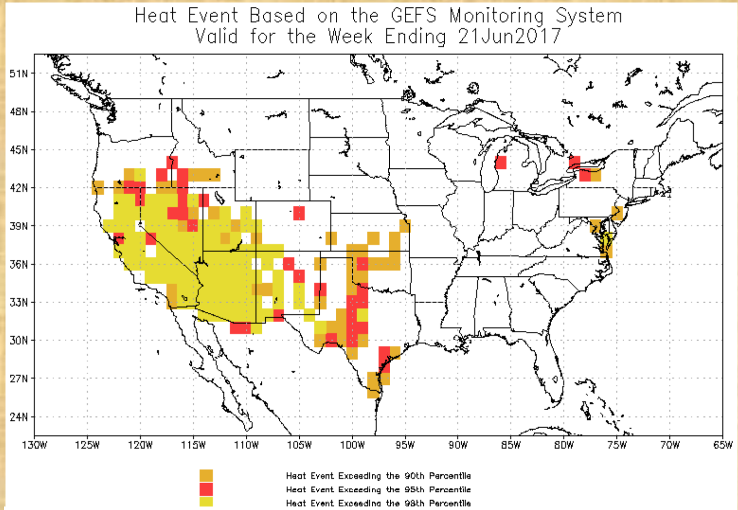
During Summers of 2016/17 we were providing daily realtime forecasts from the baseline system to CPC forecasters:

Forecast

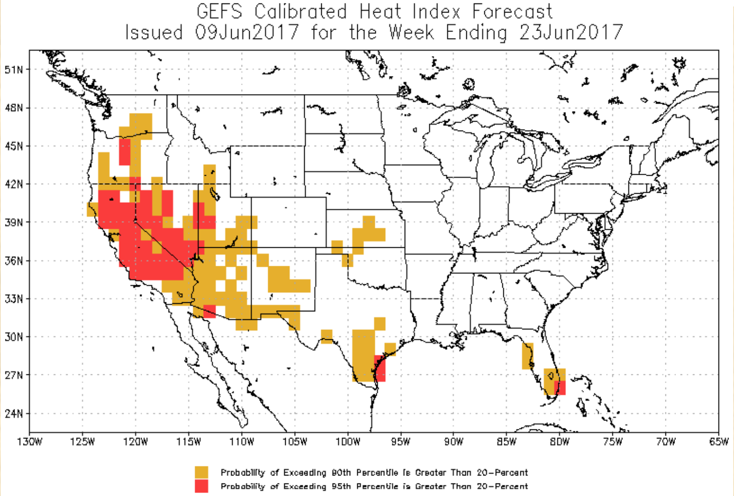
Verification (GEFS Day-1 based)

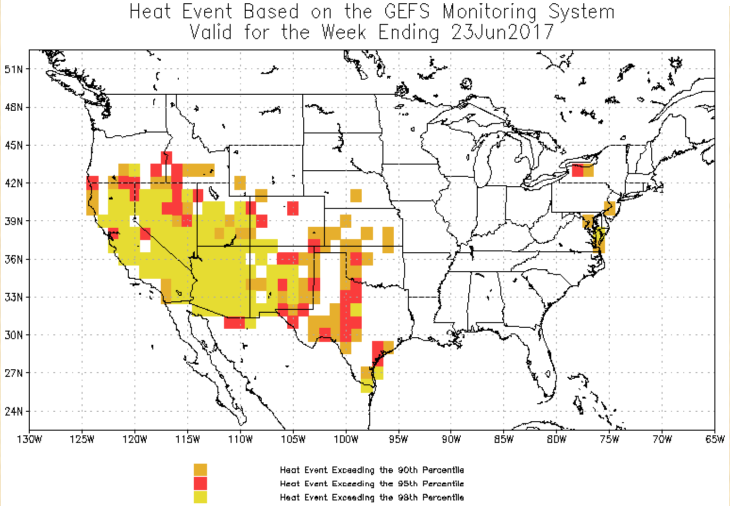
Week-2 ending 21 June 2017



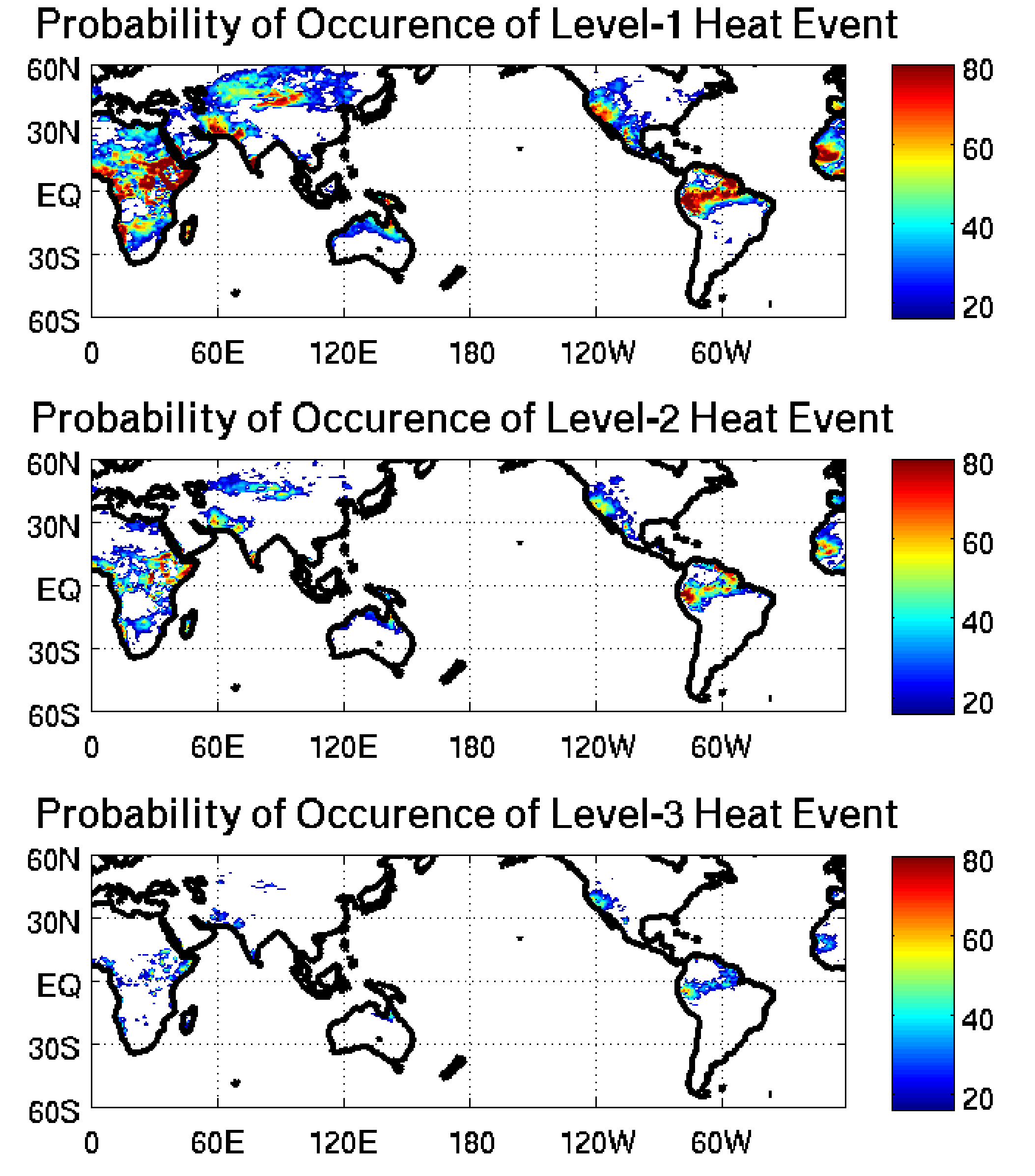


Week-2 ending 23 June 2017



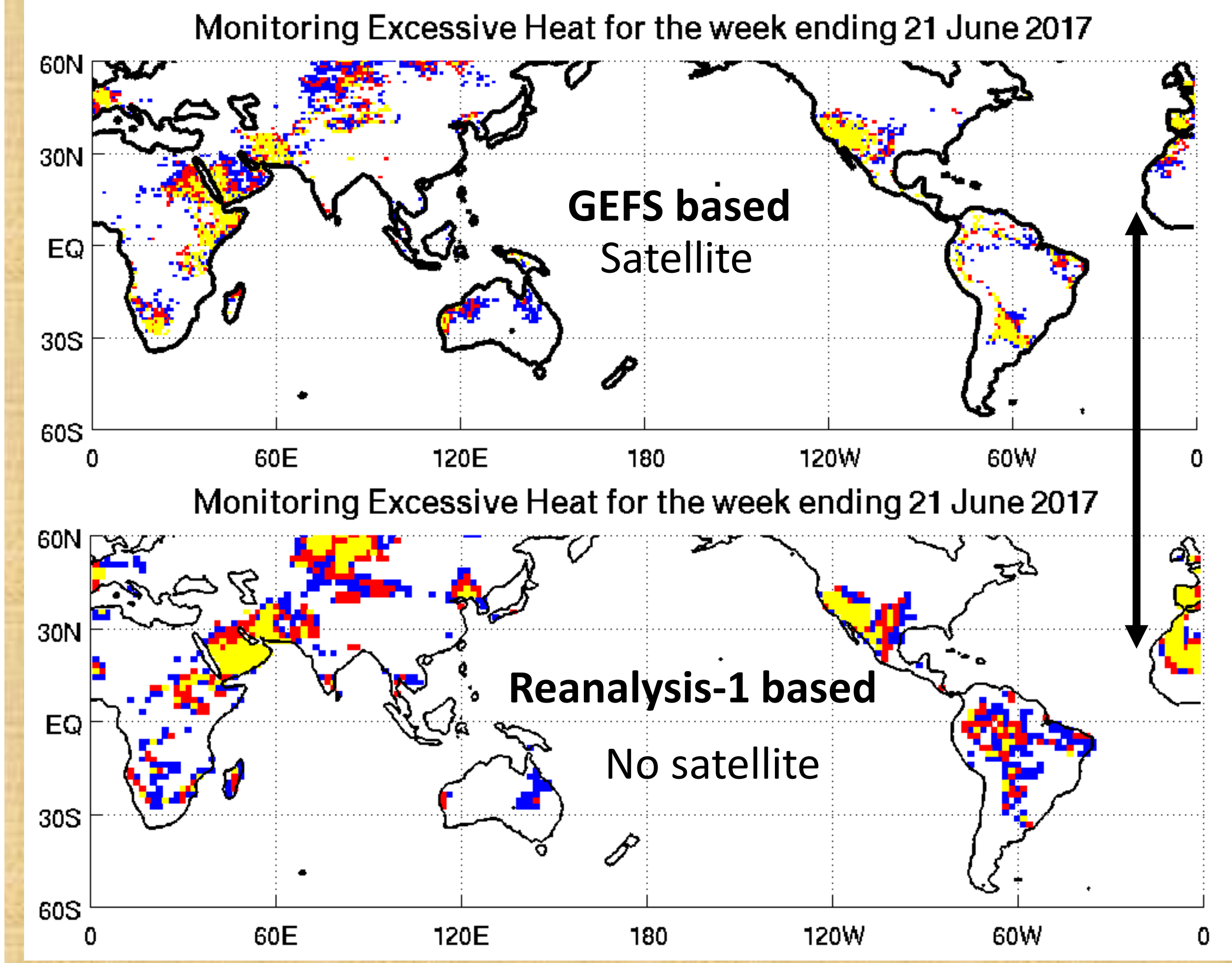


SEHOS-GLOB for Week-2 ending 21 June 2017



Verification for week ending 21 June 2017

Level-1 Level-2 Level-3



We can note significant differences in the tropics even at the monitoring level e.g. Africa.

Revisiting the definition of Excessive Heat Events

A weak point of models are physical parameterizations of the planetary boundary layer, this results to systematic drifts and large random errors in the computation of quantities relevant to EHEs

$$T(\tau) = T_{true}(\tau) + T_{bias}(\tau) + \varepsilon_T(\tau)$$

$$\mathrm{RH}(\tau) = RH_{true}(\tau) + RH_{bias}(\tau) + \varepsilon_{RH}(\tau)$$

$$HI = a + b \cdot T + c \cdot RH + d \cdot T \cdot RH + e \cdot T^2 + f \cdot RH^2 + g \cdot T^2 \cdot RH + h \cdot T \cdot RH^2 + w \cdot T^2 \cdot RH^2$$

Simplify the definition of thermal discomfort index as much as possible

(Short term solution)

Improve representation of the planetary boundary layer in models

(Long term solution)

Simplifying the definition of Extreme Heat Events

Let $\boldsymbol{Q}$ be a quantity relevant to thermal discomfort: daily maximum temperature, daily maximum dew point, daily minimum temperature and daily minimum dew point.

Let $\boldsymbol{P_{Q_d}}$ be the percentile of $\boldsymbol{Q}$ for day $\boldsymbol{d}$. The percentile computation is based on data from 7 days prior and seven days after day $\boldsymbol{d}$ for all years available

Normalized departure of the percentile from its median.

$$G_{Q_d} = 2P_{Q_d} - 1$$

This allows to introduce scenarios that include for example a warmer than average day followed by a colder than average night

Thermal discomfort index for day $\boldsymbol{d}$ as a linear combination of all factors $\boldsymbol{Q}$.

$$I_d = \sum_{Q} \beta_Q \cdot G_{Q_d}$$

Coefficients $\boldsymbol{\beta_Q}$ account for the relative importance of each factor **Q**. At this stage of the research we set $\boldsymbol{\beta_Q = 1}$

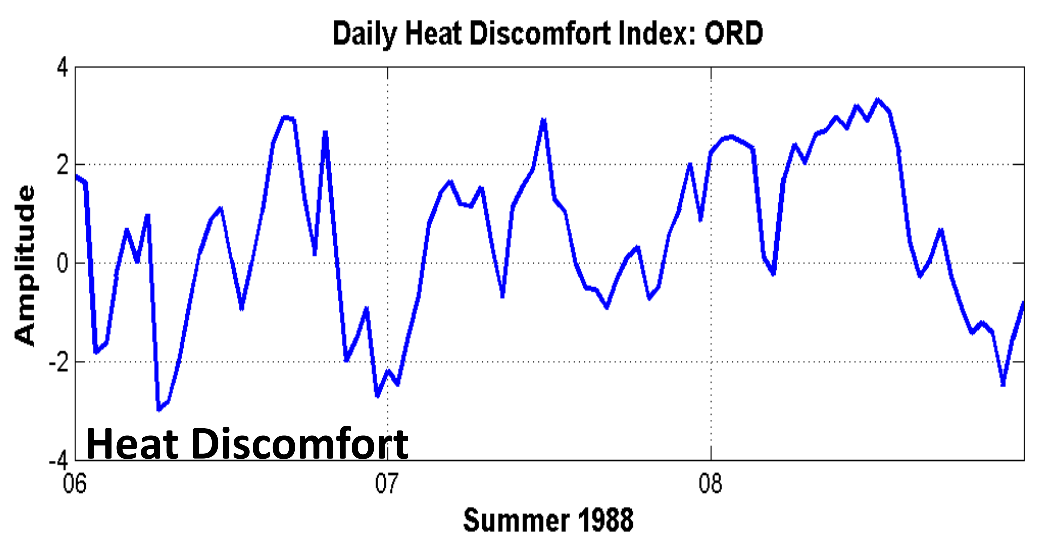
Excessive Heat Event Intensity. We define a EHE as two consecutive days with $P_{I_d} > 0.9$

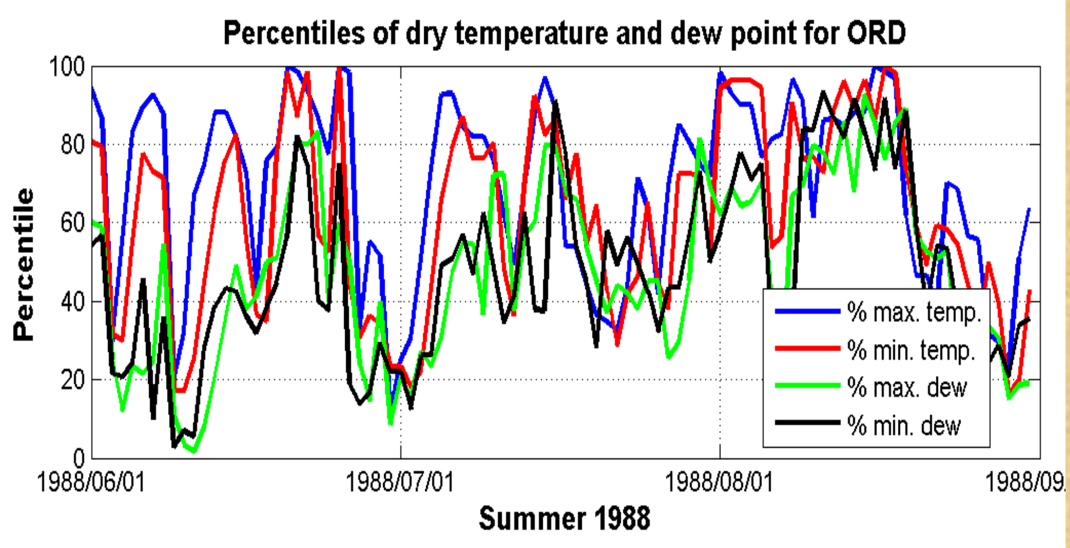
$$EHEI = \sum_{d=1}^{N} \gamma_d \cdot I_d$$

Coefficients $\boldsymbol{\gamma_d}$ account for mortality displacement. At this stage of the research we set $\boldsymbol{\gamma_d = 1}$

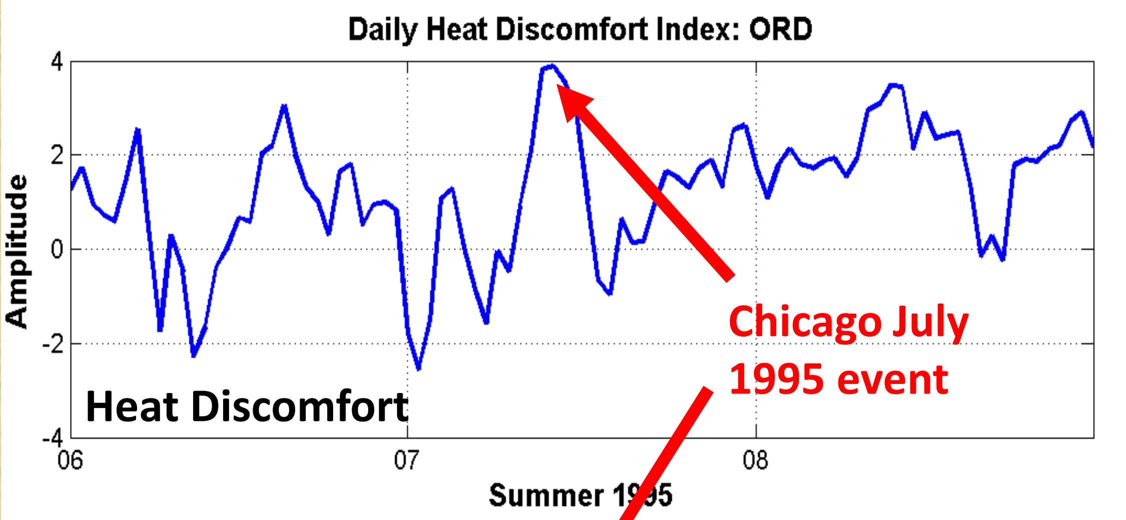
Intensity and components of the simplified Thermal Discomfort Index (HadISD)

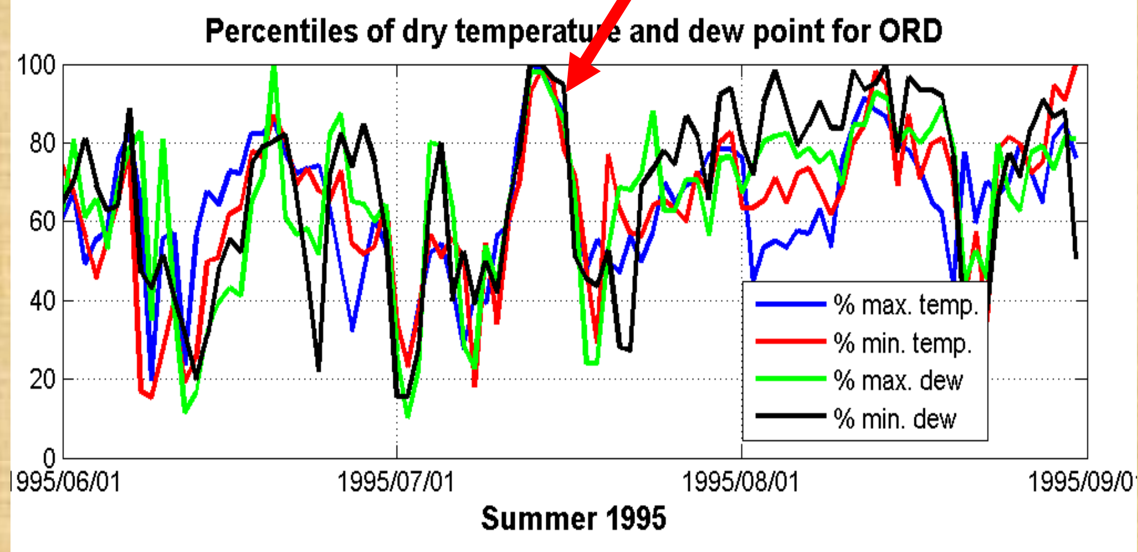
Chicago summer 1988





Chicago summer 1995





Definition of Excessive Heat Event (EHE)

- A **Heat Day** is a day with **Thermal discomfort index** exceeding 90% percentile computed from the historical record for the geographical location and time-frame within the warm season.
- A **Heat Event** is a succession of at least two heat days.
- The EHE Intensity is the sum of the daily discomfort index for the duration of the EHE.

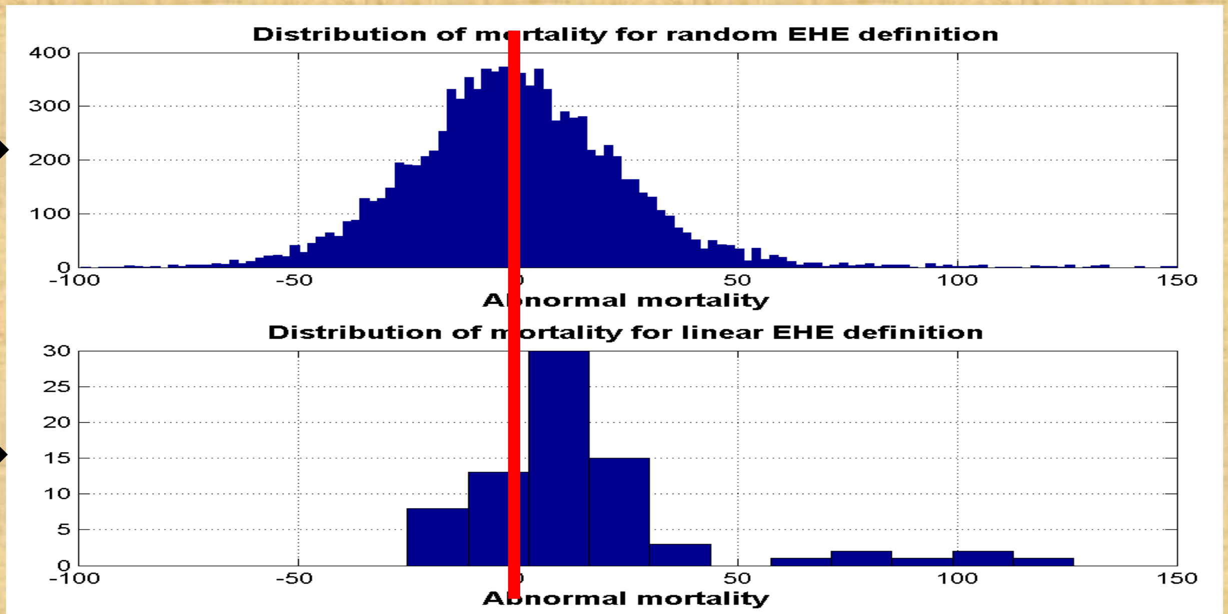
Normal day	Heat day	Normal day	Normal day	Heat day	Heat day	Normal day

No heat event

Heat event

We sum abnormal mortality data from 1975-2010 (courtesy Scott Sheridan) from day 2 to the end of the EHE defined randomly: initial day in JJA and duration (Gaussian) from 2-12 days

We sum abnormal mortality data from 1975-2010 (courtesy Scott Sheridan) from day 2 to the end of the EHE defined by the thermal discomfort index based criterion



Summary and R&D directions

- Subseasonal forecasting of excessive heat events is feasible.
- Multi-model approaches are fruitful.
- We developed the baseline Week-2 Subseasonal Excessive Heat Outlook System (SEHOS) which now runs quasi-operationally at CPC.

- The short path to account for forecast model errors at S2S timescales is to simplify heat discomfort indices. We are introducing such and index and validate it based on abnormal mortality
- We will compute the forecast skill using reforecasts from the S2S database and the newly developed SubX database.
- We will be producing experimental real-time global EHE forecasts based on the simplified definition which we will be distributing weekly by e-mail. This will accelerate improvements of the system as a function of user feedback (please let me know if interested to be on the e-mail list).
- The longer path to better predictions of EHE is to understand and resolve model errors i.e., improve parameterizations of physical processes.
- Any improvements in understanding, modelling and forecasting of EHE can only be based on some common global historical EHE database which we proposed to develop in collaboration with CDC and NCEI (drawing a parallel to lessons learned from adopting the RMM-index).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