Towards Improved Worldwide Forecasts of Excessive Heat Events at Subseasonal Lead Times

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This study is supported by NOAA grants:

NA15OAR4310081
NA14NES4320003
NA16OAR4310147

Outline:

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

- **Discussion on the complexity of the task**

- **Current quasi-operational status:**
  - Defining heat events
  - Monitoring/Forecasting Heat Events
  - Verification of the system over the CONUS – importance of MME methods
  - The Global Excessive Heat Outlook System (SEHOS-GLOB)

  Research conducted by the PI. Transition to quasi-operational status in coordination with the CPC collaborators

- **Current development status:**
  - Revisiting the definition of Excessive Heat Events
  - Excessive Heat Event definition versus mortality

  Research conducted by the PI

- **Future**
  - Quasi-operational use of the CFS and other models based on the new EHE definitions
  - Feedback to modelers on model issues during EHE
  - Monitoring and verification based on direct observations

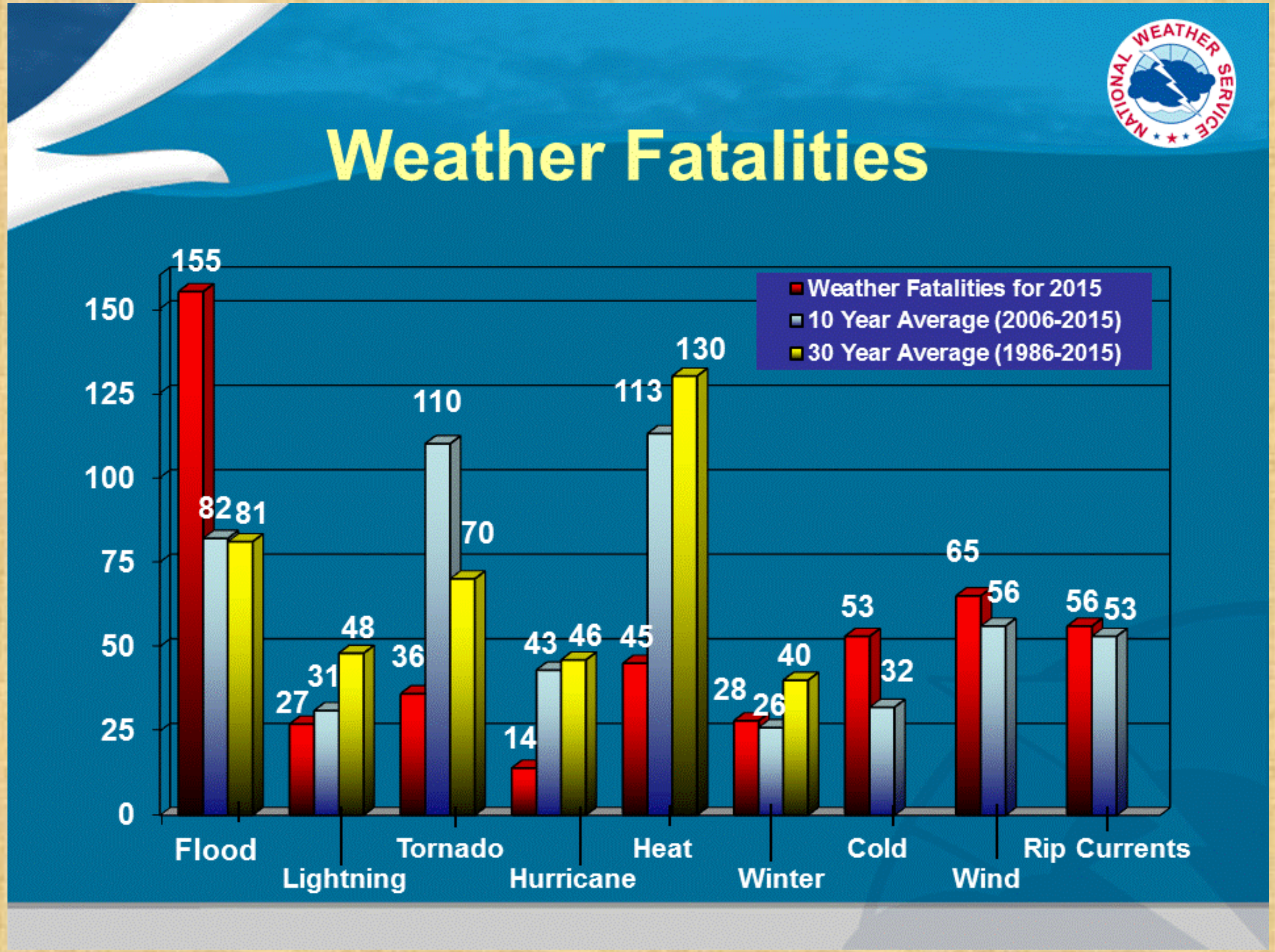
Motivation: Why develop Early Warning Systems for Excessive Heat?

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:

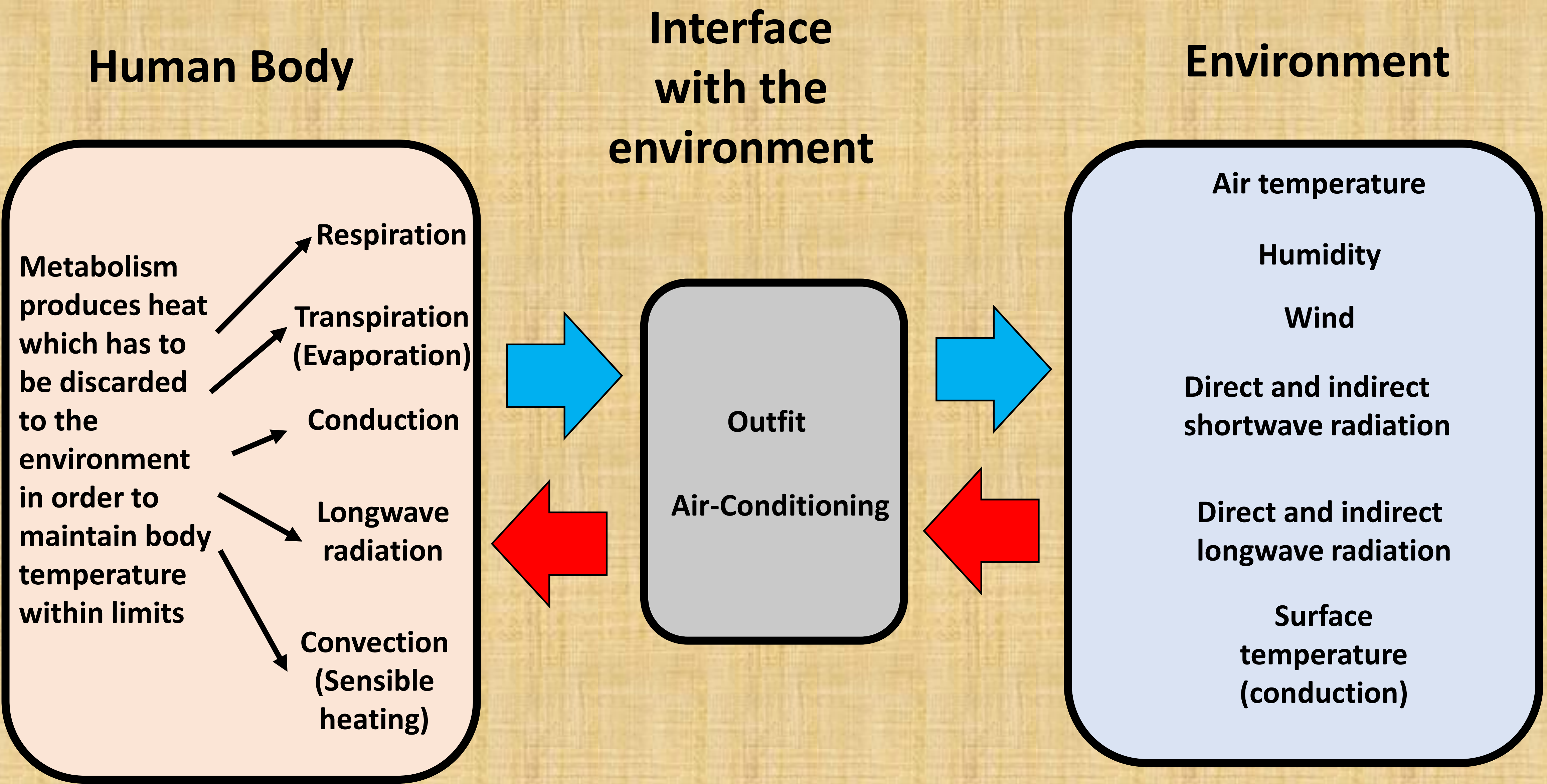
Heat = 130
Flood = 81
Tornado = 70
Lightning = 48
Hurricane = 46

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 warning to relief agencies will help to build resilience.



The Complexity of Subseasonal Excessive Heat Outlook Systems (SEHOS)



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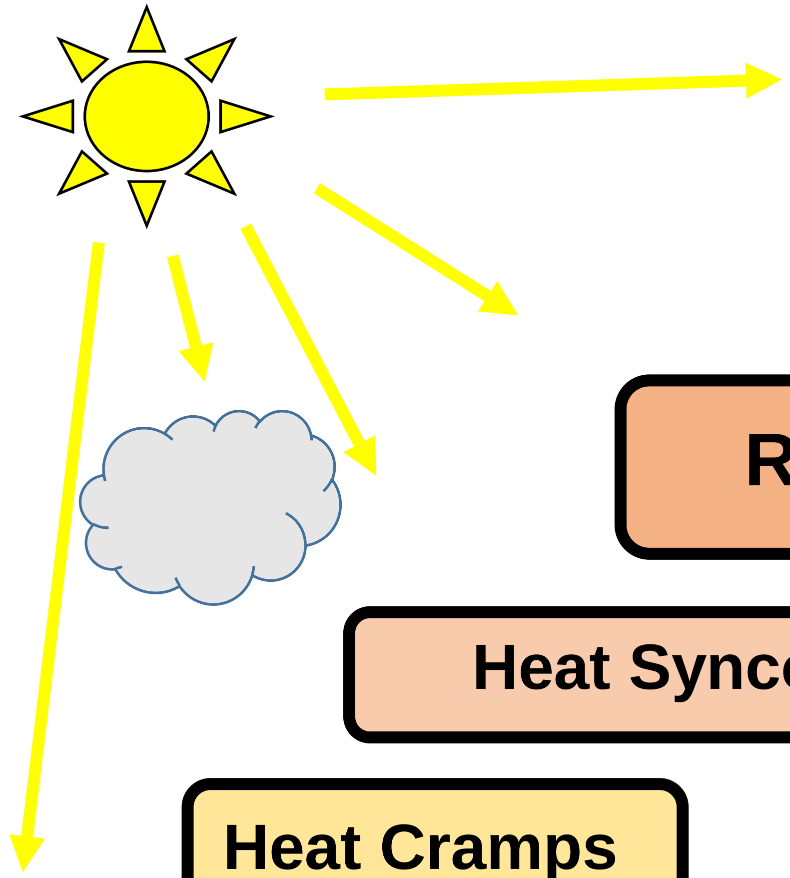


Heat Stroke

It occurs when the body becomes unable to control its temperature: the body's temperature rises rapidly, the sweating mechanism fails, and the body is unable to cool down. When heat stroke occurs, the body temperature can rise to 106°F or higher within 10 to 15 minutes. Heat stroke can cause death or permanent disability if emergency treatment is not given. CALL 911

Heat Exhaustion

Rhabdomyolysis

Heat Syncope

Heat Cramps

Heat Rash

The Complexity of Subseasonal Excessive Heat Outlook Systems (SEHOS)

Models of the effects of atmospheric conditions on thermal discomfort:

(1) NOAA Heat Index – Valid under shade and light breeze:

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

Where *T* is the dry temperature, *R* is the relative humidity and the coefficients are empirically derived

(2) Universal Thermal Climate Index (UTCI)

(3) Wet Bulb Globe Temperature (WBGT)

(4) A myriad more definitions…

The Complexity of Subseasonal Excessive Heat Outlook Systems (SEHOS)

- **Thermal discomfort** and not just temperature is the basis of any SEHOS, in this work we initially use **NOAA's *Heat Index*** (temperature and humidity).

- **Effects of heat waves increase as a function of their duration:** Requirement for consecutive days of high thermal discomfort.

- **The definition of heat waves depends on geographical location:** Requirement for a definition of what is high apparent temperature as a function of location.

- **Effects of heat waves vary as a function of time within the warm season (acclimatization):** Requirement for definition of what is high apparent temperature as function of time within the warm season.

The Complexity of Subseasonal Excessive Heat Outlook Systems (SEHOS)

Numerical Model

Initial Conditions →  → **Forecast**

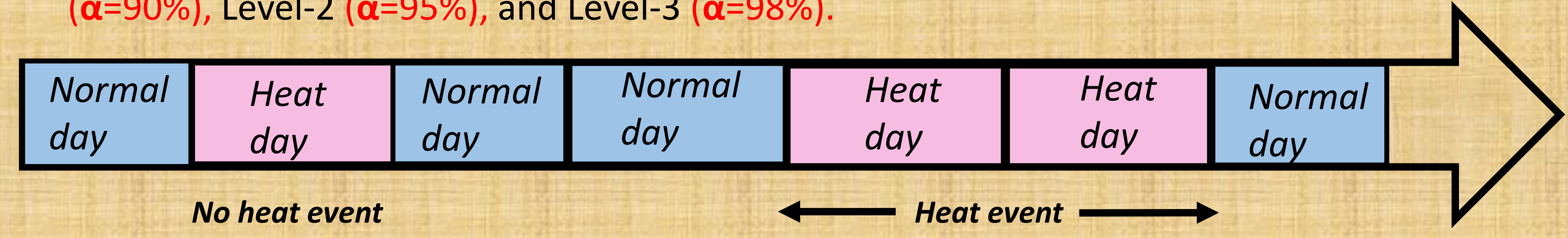
Issues:

- **Lead time dependent systematic model drifts and errors**
- **At the height of 2 meters there is no data assimilation and no direct model calculation – interpolation from other levels, sometimes even horizontal interpolation is needed.**
- **Different forecast errors for each of the components of a Thermal Discomfort ⇒** $T = T_{Real} + \mathcal{E}rror$ **and** $R = R_{Real} + \mathcal{E}rror$ **to:** $HI = a + b \cdot T + c \cdot R + d \cdot T \cdot R + e \cdot T^2 + f \cdot R^2 + g \cdot T^2 \cdot R + h \cdot T \cdot R^2 + w \cdot T^2 \cdot R^2$.
- **Necessary atmospheric fields (especially 6-hourly or higher output) are sometimes difficult to access from reforecast databases.**

Marrying Complexities…

Based on the above considerations we define heat events using **percentiles of apparent temperature:**

- A 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.
- A Heat Event 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%).



Benefits from this definition: Addressing physiological effects of heat AND 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)

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

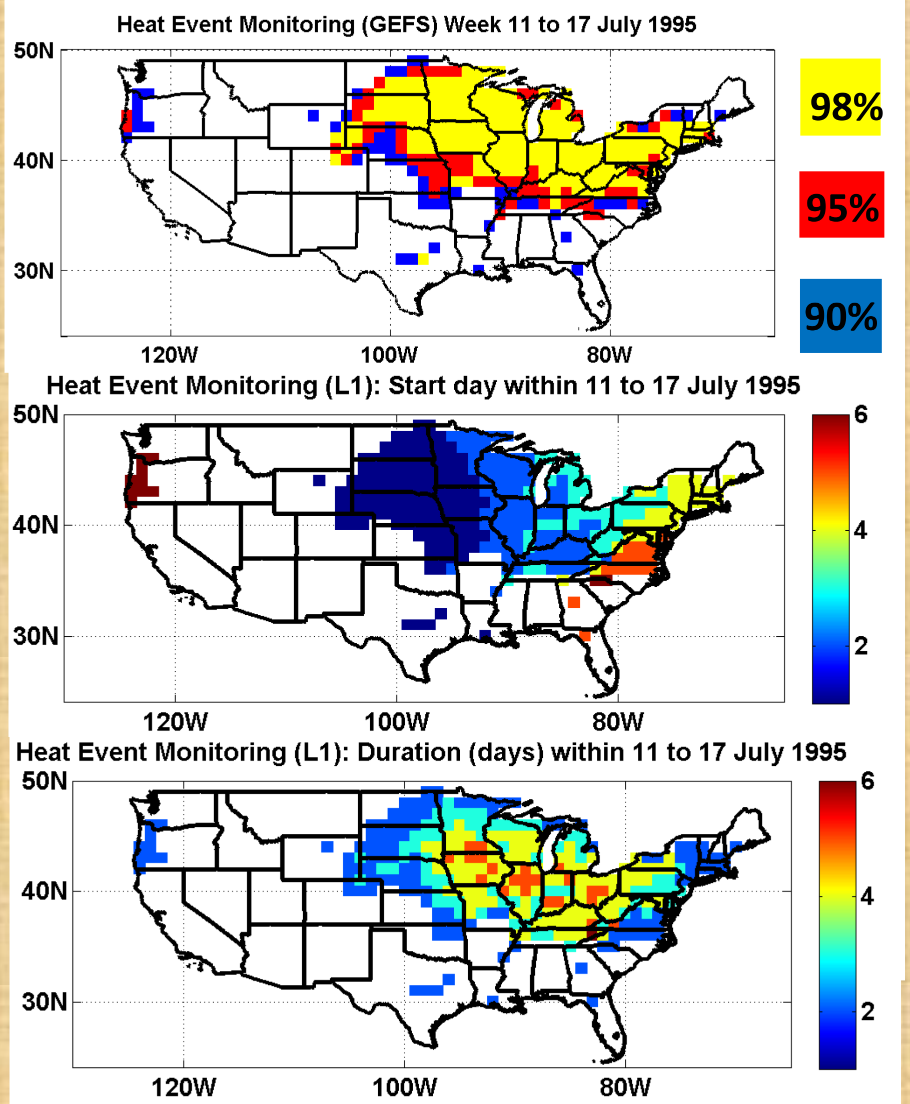
- During the week of 11-17 July 1995 a Level-3 Heat Event (98% - yellow) was covering an extended area from the Upper Midwest to the Northeast and Mid-Atlantic.
- This heat event progressed from west to east during this week.
- The event lasted 5 days (for Level-1 intensity) in the Chicago area.

Week of 11-17 July 1995

Occurrence

Start day (90%)

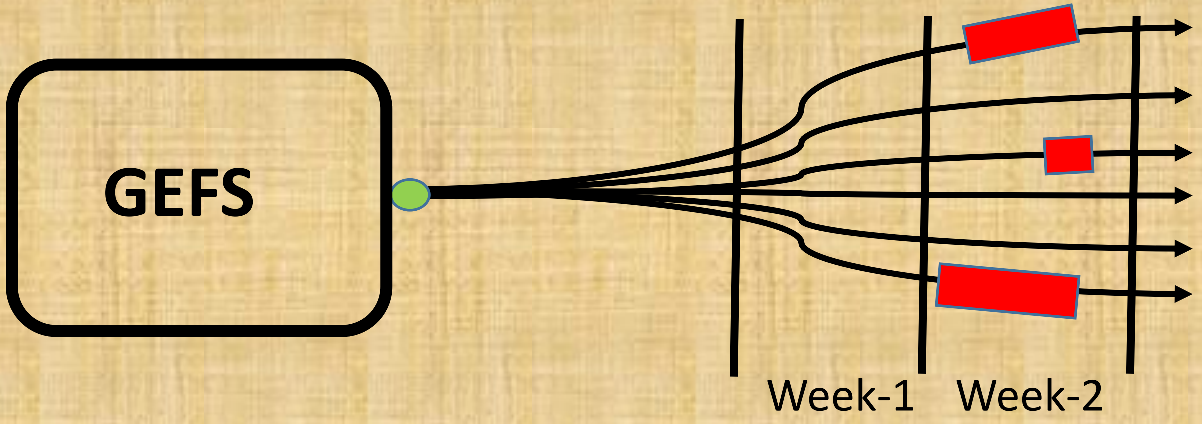
Duration (90%)



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.

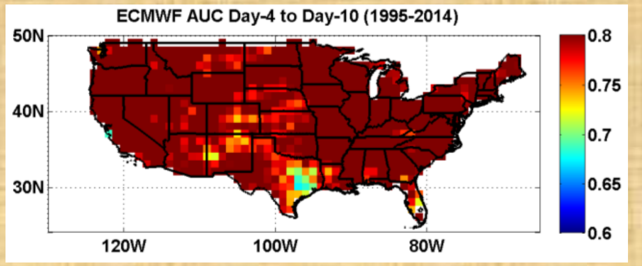


- Verification of reforecasts based on the Receiver Operating Characteristics (ROC) method and Area Under Curve (AUC)

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

Week~1

ECMWF



GEFS

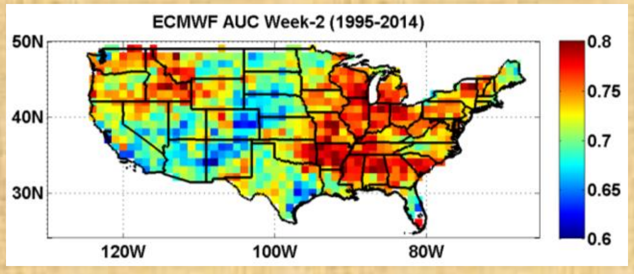
We have not compute AUC for Week-1

CFS

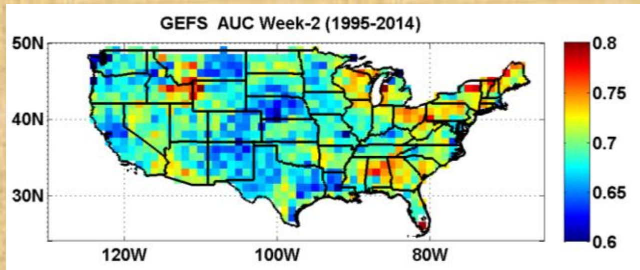
We have not compute AUC for Week-1

Week-2

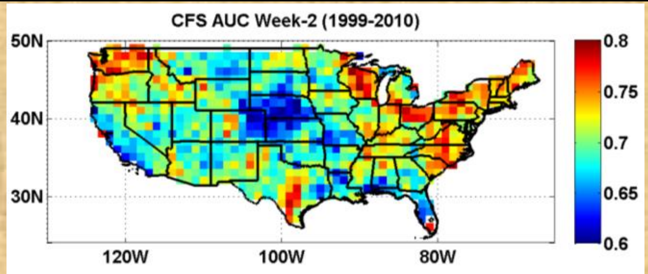
ECMWF



GEFS

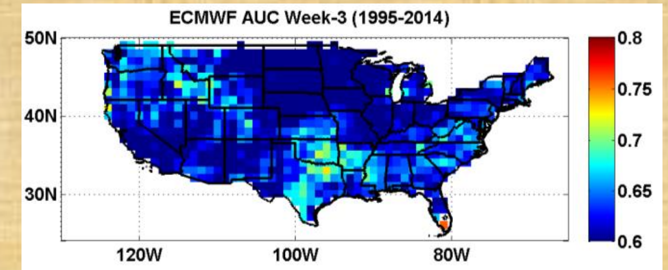


CFS



Week-3

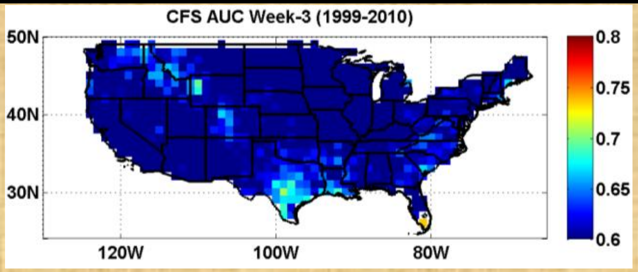
ECMWF



GEFS

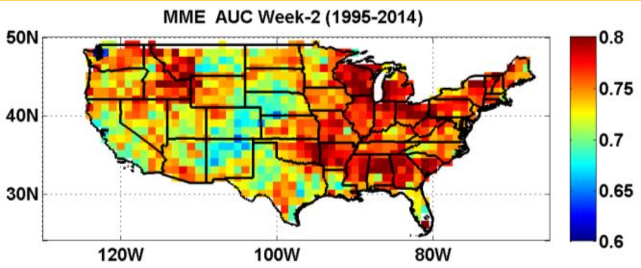
No Week-3 GEFS
(for the moment)

CFS

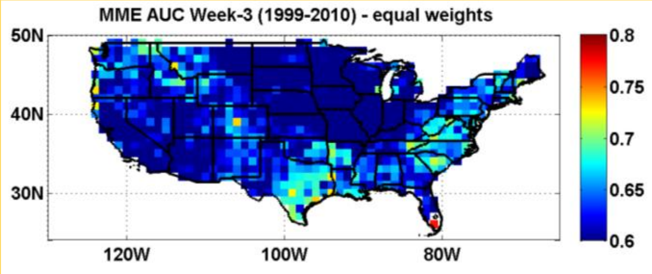


Multi-Model Ensemble Forecasting of Heat Events

GEFS + ECMWF



CFS + ECMWF



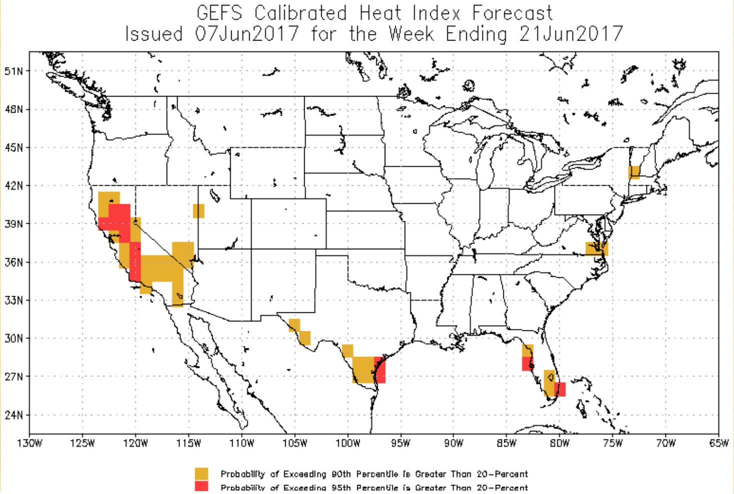
Realtime subseasonal excessive heat outlooks

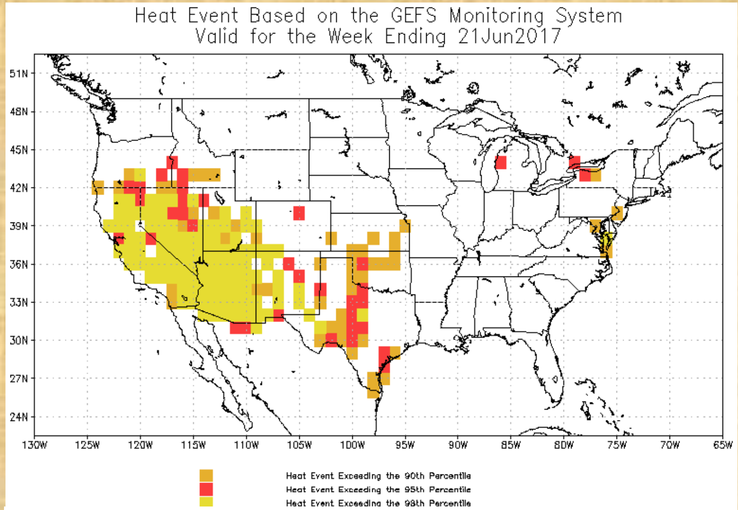
During Summers of 2016/17 we were providing daily realtime forecasts from the baseline system to CPC forecasters:

Forecast

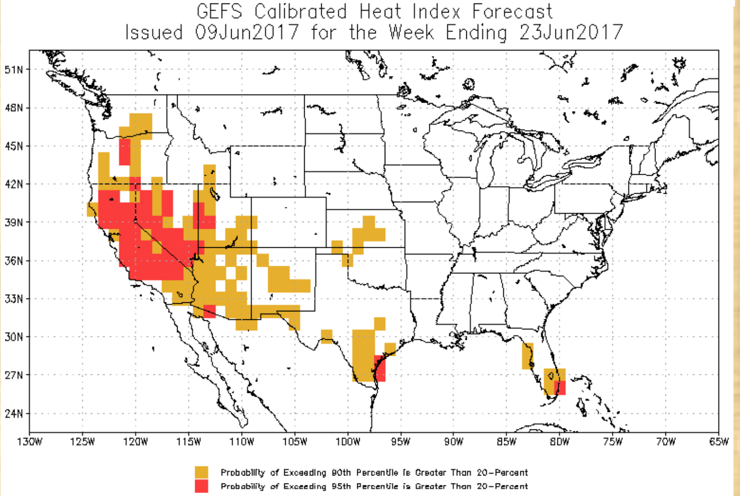
Verification

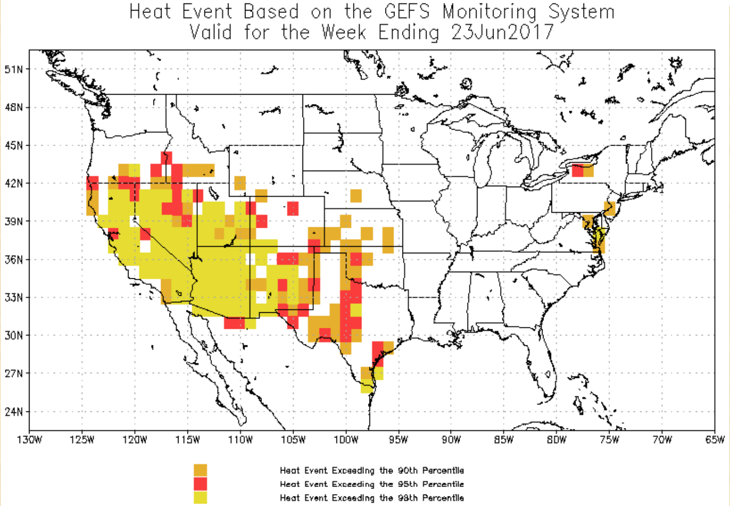
Week-2 ending 21 June 2017



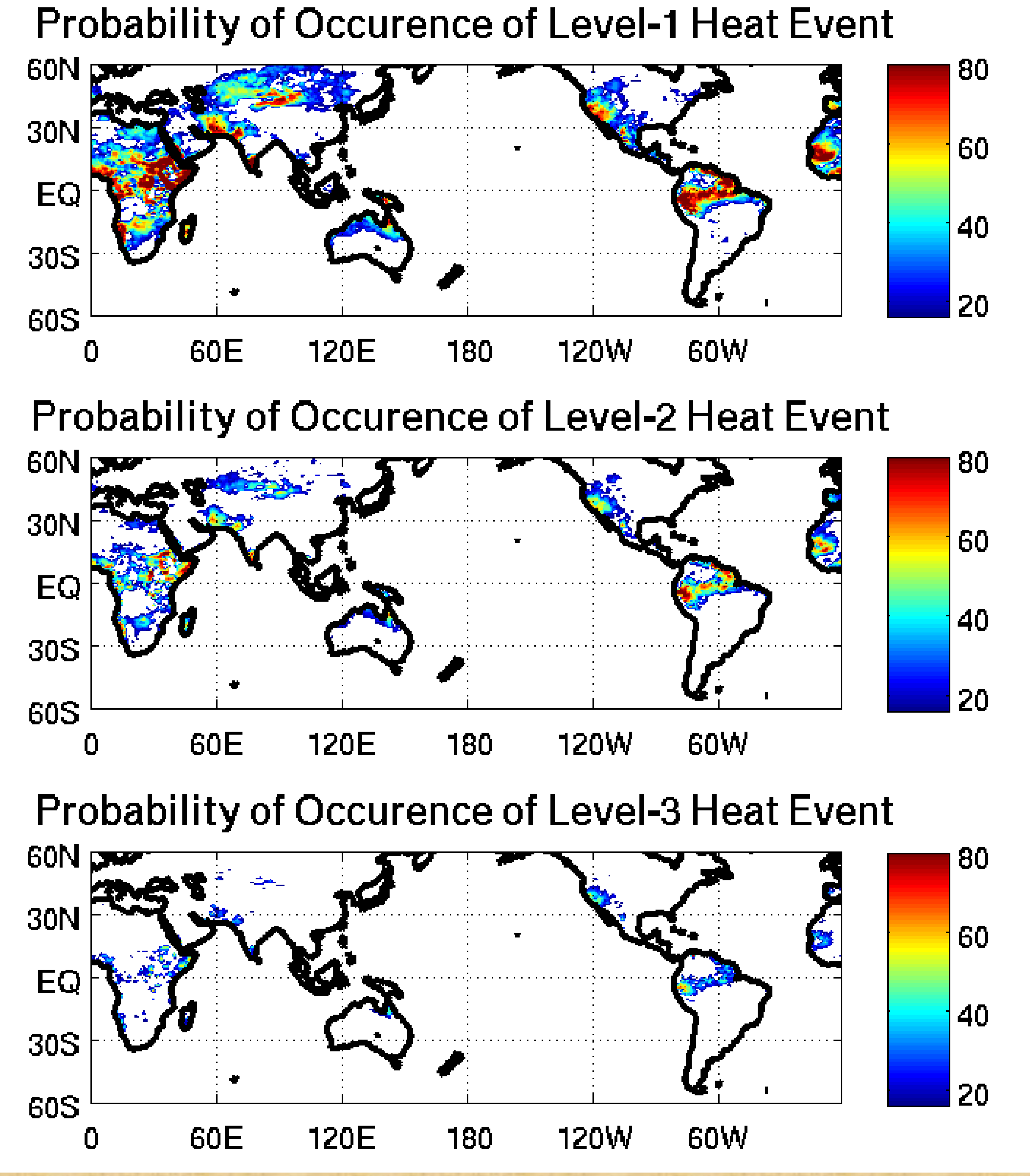


Week-2 ending 23 June 2017



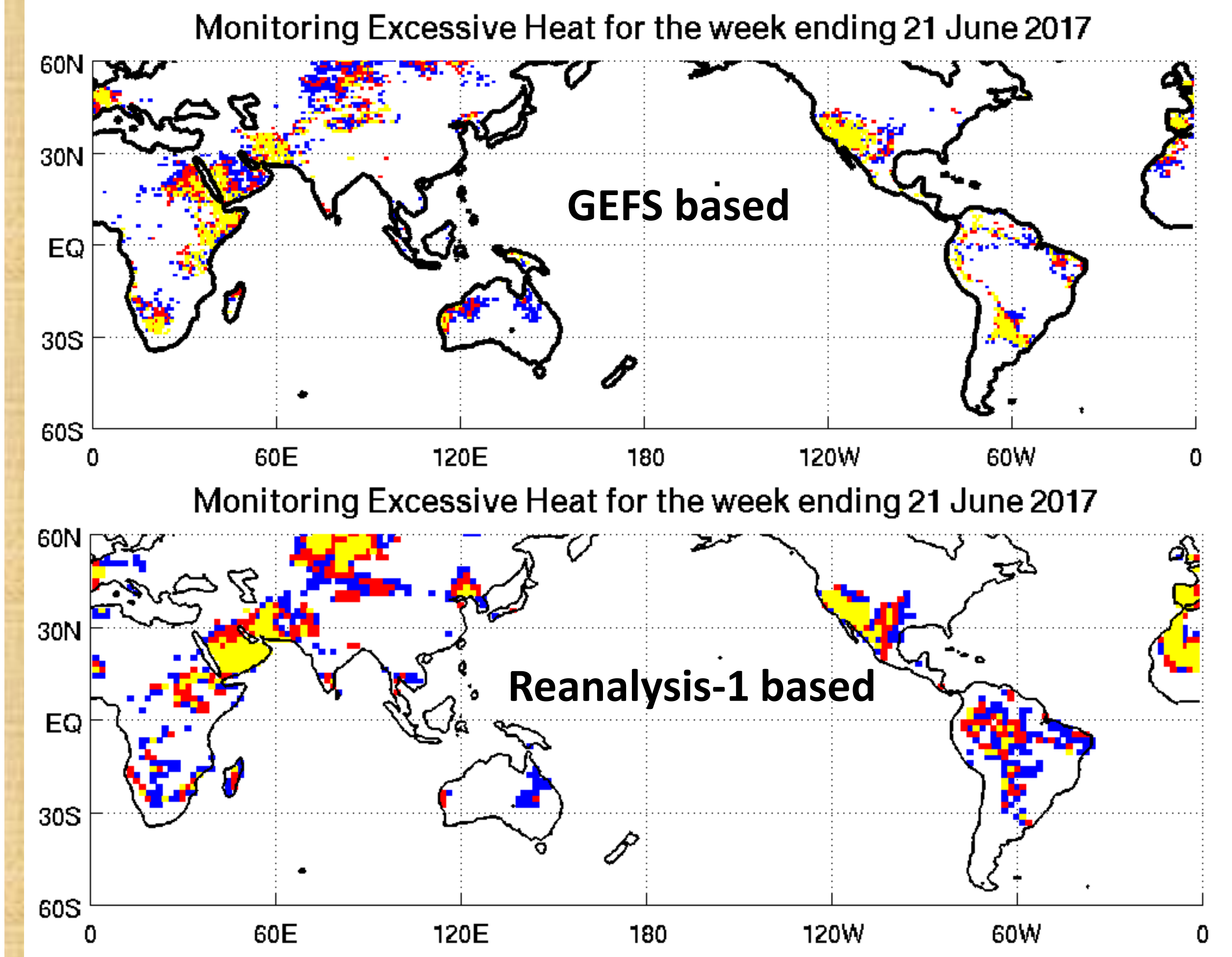


SEHOS-GLOB for Week-2 ending 21 June 2017



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. Heat events in India that made the news were not captured by the monitoring system. Need to revisit definitions of Excessive Heat Events

Scenario 0

Based on the above considerations we define heat events using **percentiles of apparent temperature:**

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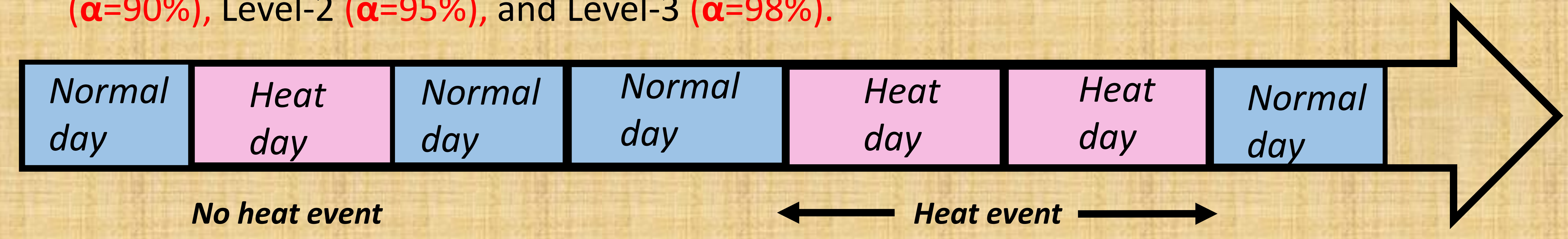

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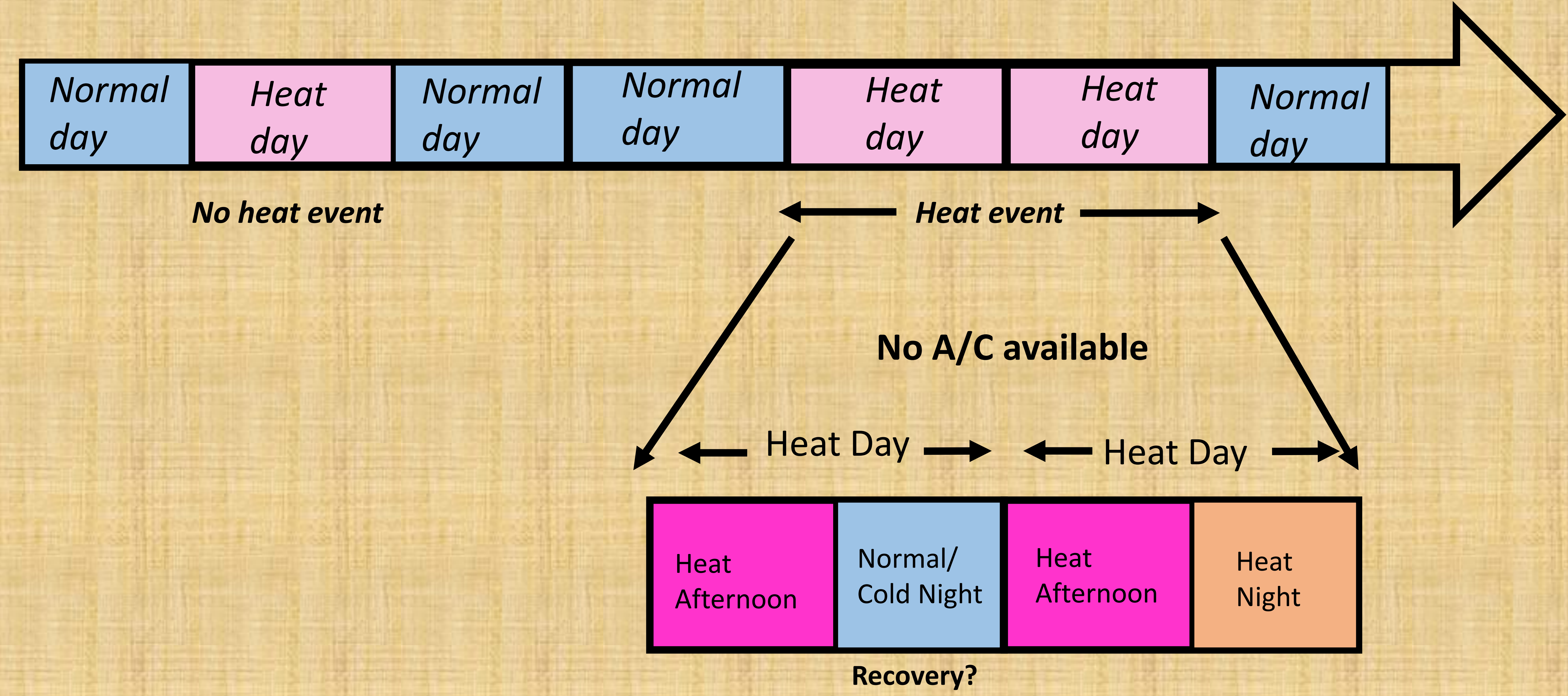
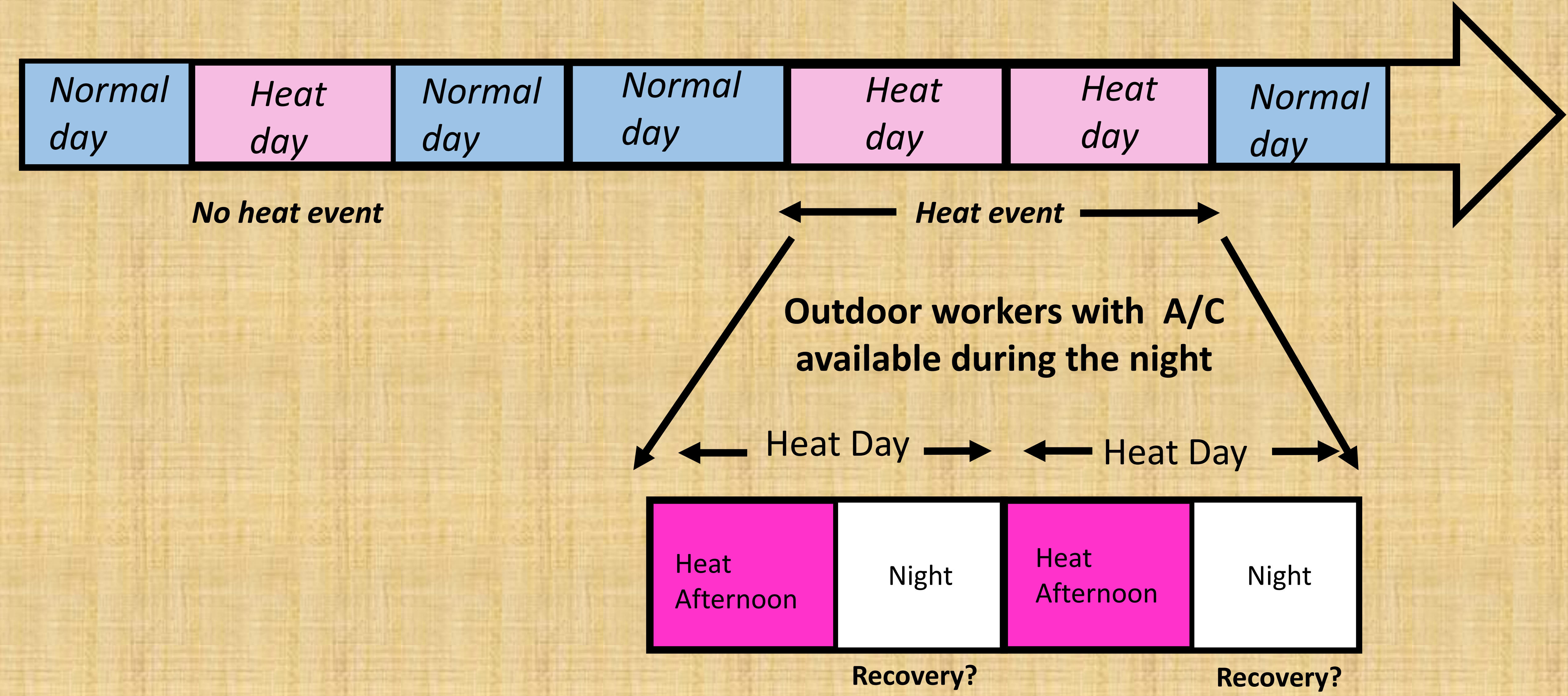
Inconveniences of this definition: Based on expensive reforecasts

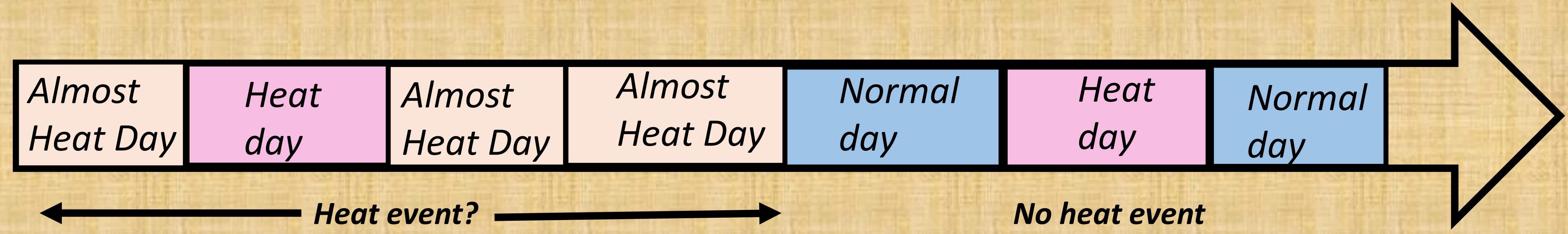
Scenario 1


Normal day
Heat day
Normal day
Normal day
Heat day
Heat day
Normal day
No heat event
Heat event
No A/C available
Heat Day
Heat Day
Heat Afternoon
Normal/ Cold Night
Heat Afternoon
Heat Night
Recovery?

Scenario 2


Normal day
Heat day
Normal day
Normal day
Heat day
Heat day
Normal day
No heat event
Heat event
Outdoor workers with A/C available during the night
Heat Day
Heat Day
Heat Afternoon
Night
Heat Afternoon
Night
Recovery?
Recovery?

Scenario 3



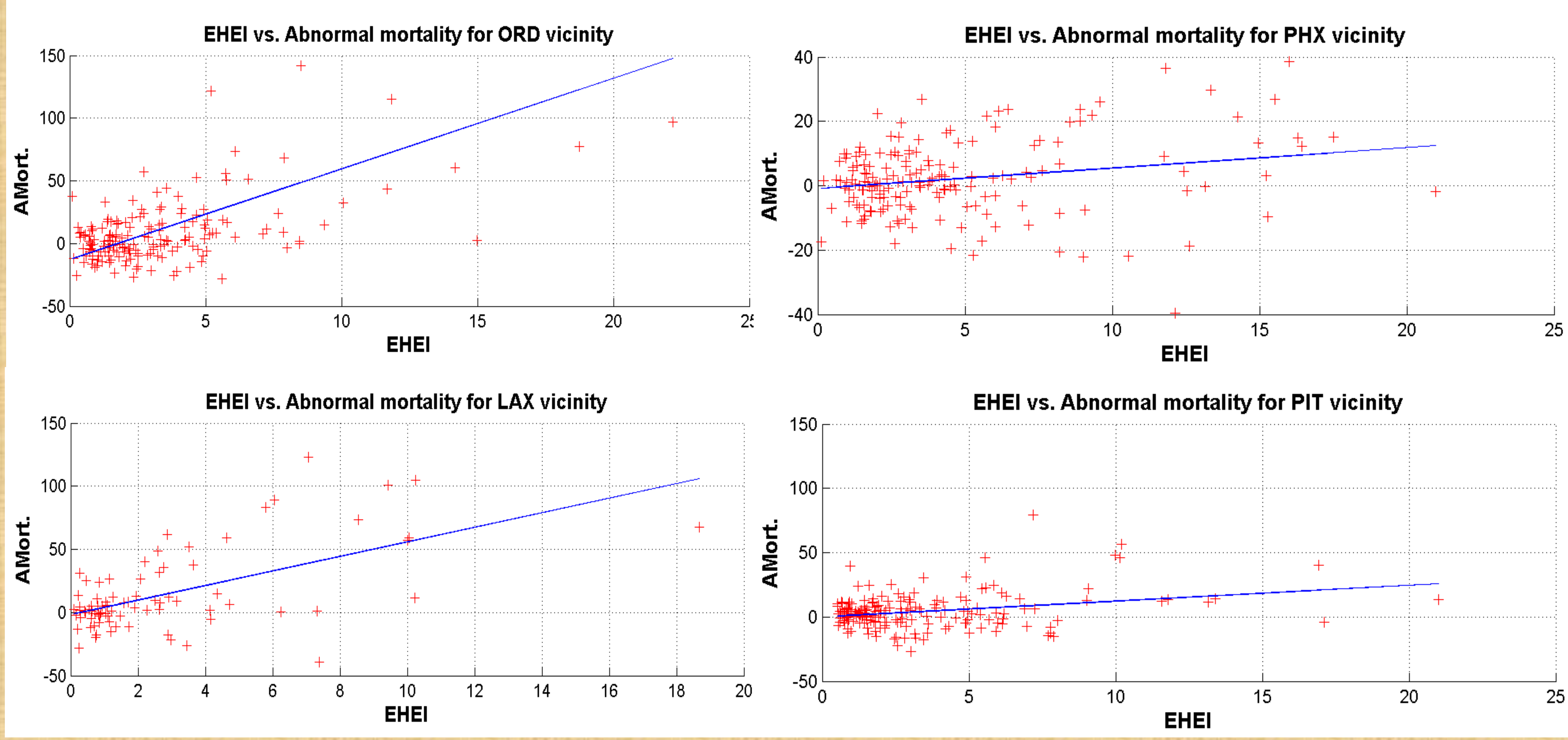
- There is a myriad of scenaria leading to heat related illness and many possible forecast solutions to drive each one of these: A double probabilistic forecast problem.

- A first step towards resolving this problem is to investigate whether any definition of the intensity of excessive heat events we introduce is related to abnormal mortality.

- We use aggregated all cause of death mortality data for ages 65+ (courtesy Scott Sheridan) and hourly data of temperature and dew point from the HadISD dataset (Hadley Center).

- For this presentation we use the simplest possible definition: adding the daily relative standardized amplitude of maximum and minimum heat index and dry temperature for the duration of a heat wave.

Excessive Heat Event Intensity vs. Abnormal Mortality



Summary and R&D directions

- Subseasonal forecasting of excessive heat events is feasible.
- Multi-model approaches are fruitful.
- We developed the baseline quasi-operational Week-2 SEHOS-GLOB/CONUS which runs daily at CPC. Realtime SEHOS forecasts can also be executed on any modern PC connected to the internet.
- We introduced a 'scenario' based approach for forecasting EHE which in its simplest form was shown to explain part of abnormal mortality (depending on the CONUS city).

- GEFS, CFS and other model forecast skill will be evaluated based on the 'scenario' excessive heat event approach. Quasi-operational multi-model forecasts will be updated daily and extended to Week 3&4.
- We will conduct research on model deficiencies during excessive heat events and provide feedback to modelers.
- We will be working towards a common flexible historical EHE database.

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