Elements of a subseasonal-to-seasonal excessive heat outlook system (SEHOS)

Augustin Vintzileos

University of Maryland – ESSIC/CICS

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Outline:

- Motivation & Background

- The elements of a SEHOS

Forecast model (GEFS, CFS, ECMWF, JMA etc) → Bias correction → Bio-meteorological core → Calibration → Interface to health sector and climate forecasters

- Conclusions and future work

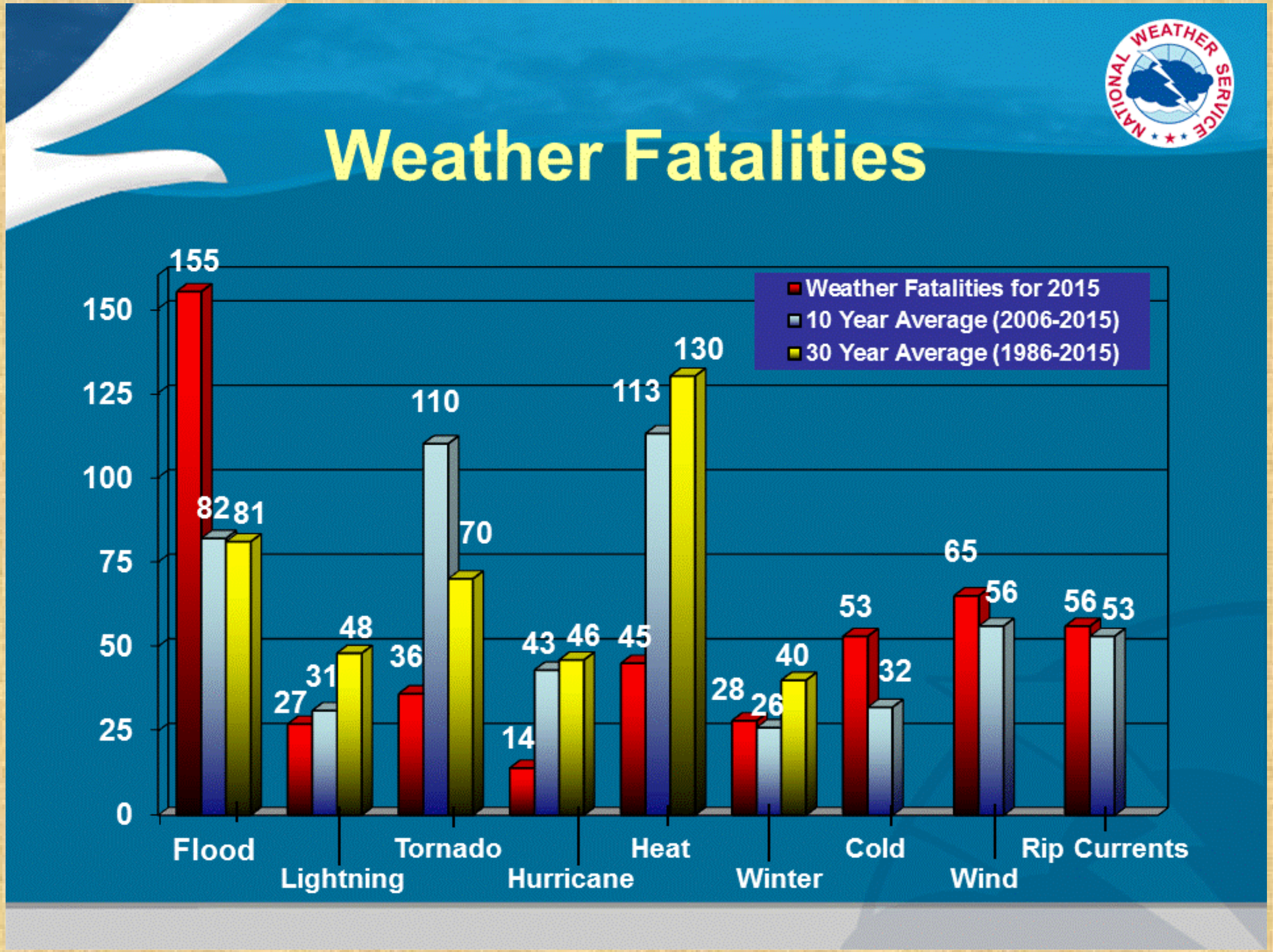
Motivation: Why develop Early Warning Systems for Excessive Heat?

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.



Measuring heat discomfort

Complexity / Utility

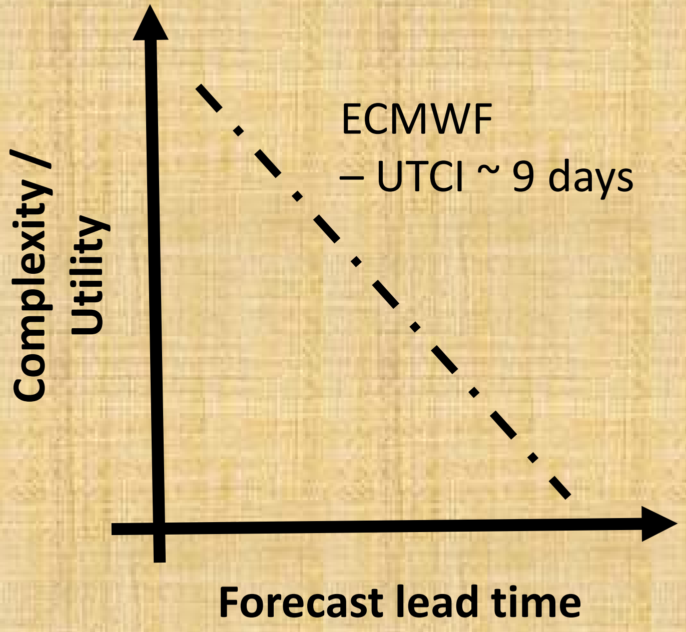
UTCI – Universal Thermal Climate Index

Environmental Parameters

- ambient temperature
- radiant temperature
- barometric pressure
- humidity
- wind speed

Personal Parameters

- subject weight
- subject surface area
- clothing insulation
- metabolic rate
- work rate – external
- exposure time



WBGT - Wet Bulb Globe Temperature - (experimental NWS)

- ambient temperature
- radiant temperature
- humidity
- wind speed

WBGT heat stress meter (~ $500)

Heat Index - (operational NWS)

- ambient temperature
- humidity

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

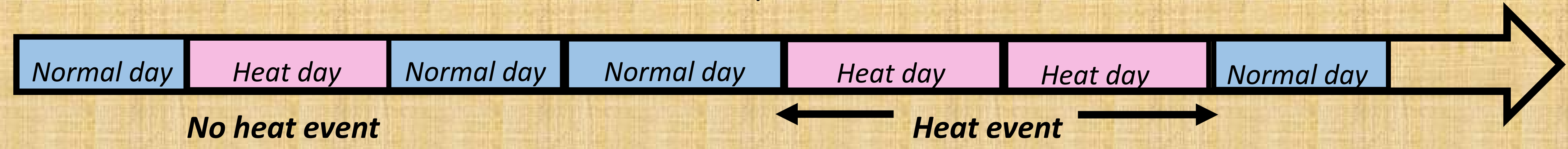
Ambient Temperature

Defining excessive heat events

- Need to be based on one of the measures of **thermal discomfort** e.g., UTCI, WBGT, **NOAA's *Heat Index***, *HUMIDEX etc*.
- Impacts of excessive heat events increase as a function of their **duration:** Need for forecasting consecutive days with high thermal discomfort.
- Impacts of excessive heat depend on **geographical location** e.g., Seattle *versus* Atlanta *versus* Tropics**.** Requirement for a definition of what is high thermal discomfort as a function of location.
- Account for gradual **acclimatization** of the human body to high thermal discomfort (however there are limits to acclimatization that also need to be taken into account)**.**

Baseline Subseasonal Excessive Heat Outlooks

- 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.

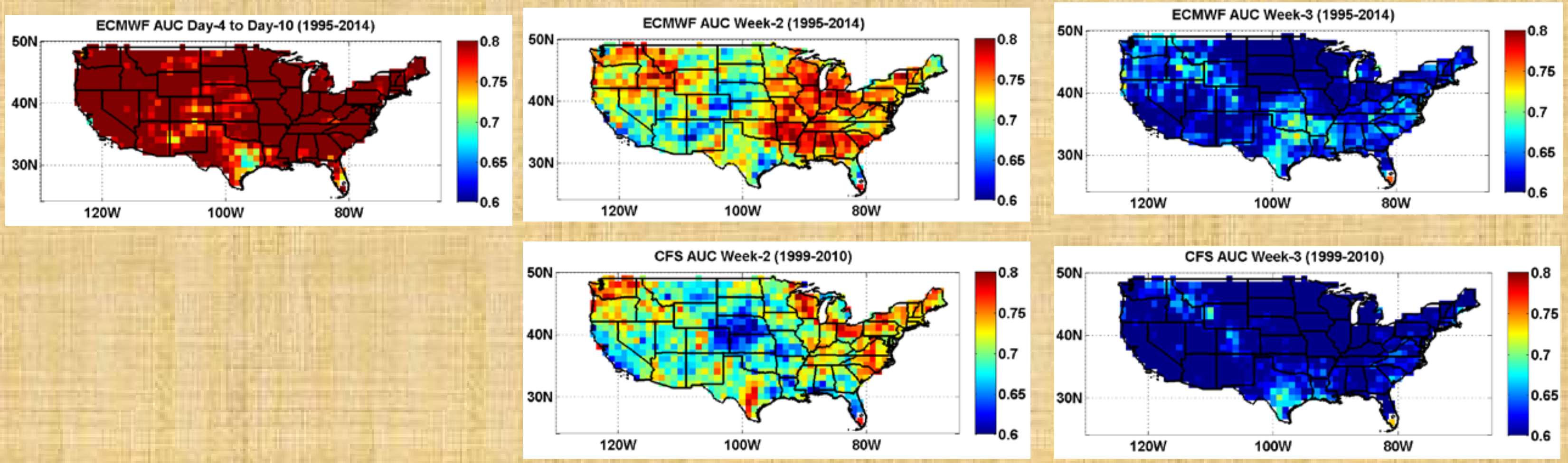


Measure of predictability of excessive heat events: Area under the ROC Curve (AUC)

Week-1 | Week-2 | Week-3

ECMWF

CFSv2



The baseline version of the SEHOS shows there is predictability at Week-2 (also that multi-model combinations are beneficial)

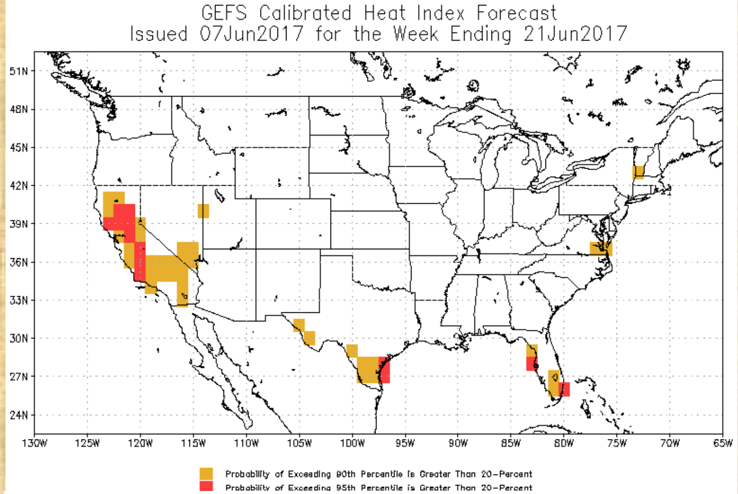
Realtime subseasonal excessive heat outlooks

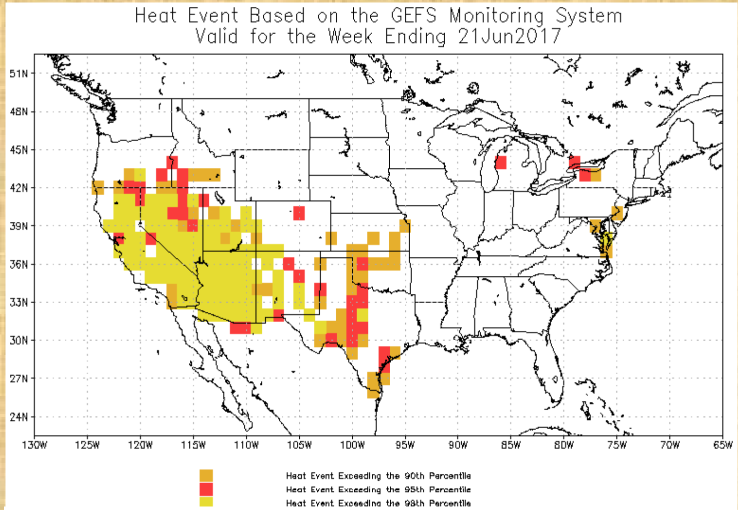
During the summers of 2016/17 daily realtime forecasts from the baseline system were provided to CPC forecasters:

Forecast

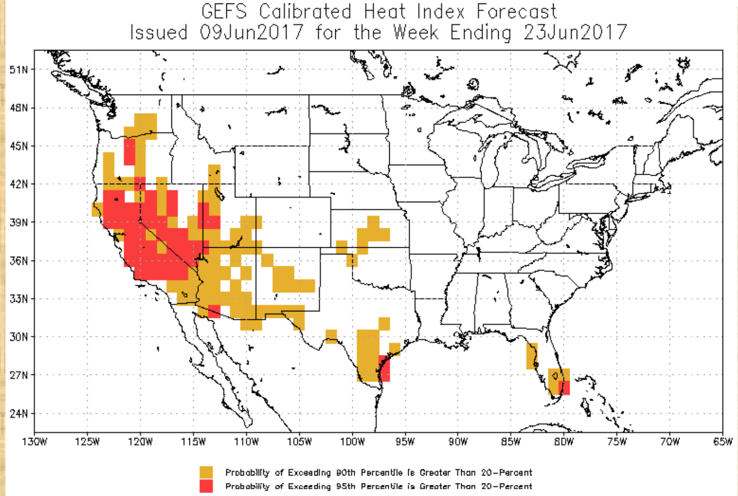
Verification

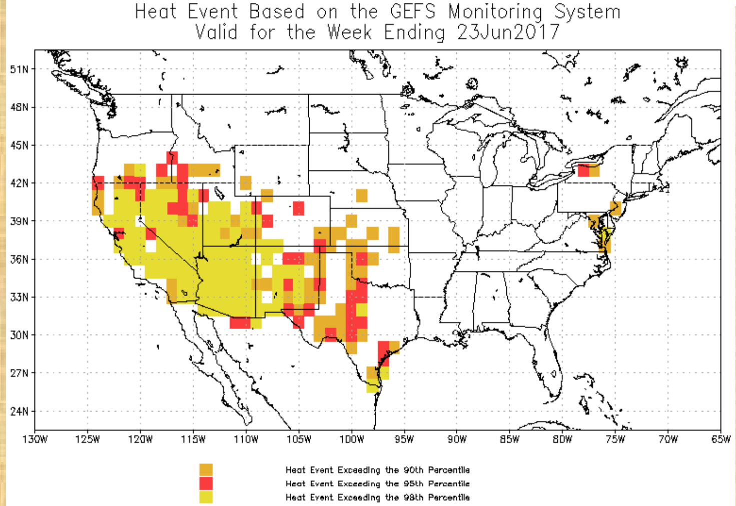
Week-2 ending 21 June 2017





Week-2 ending 23 June 2017

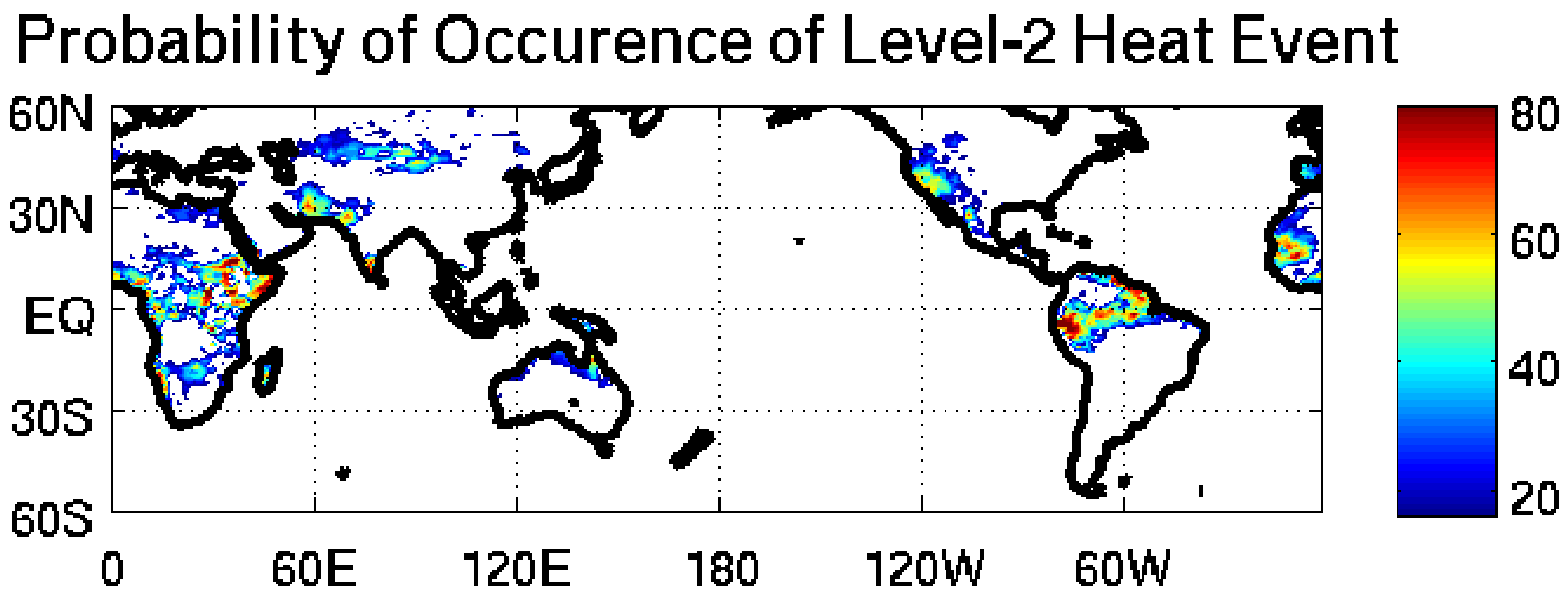




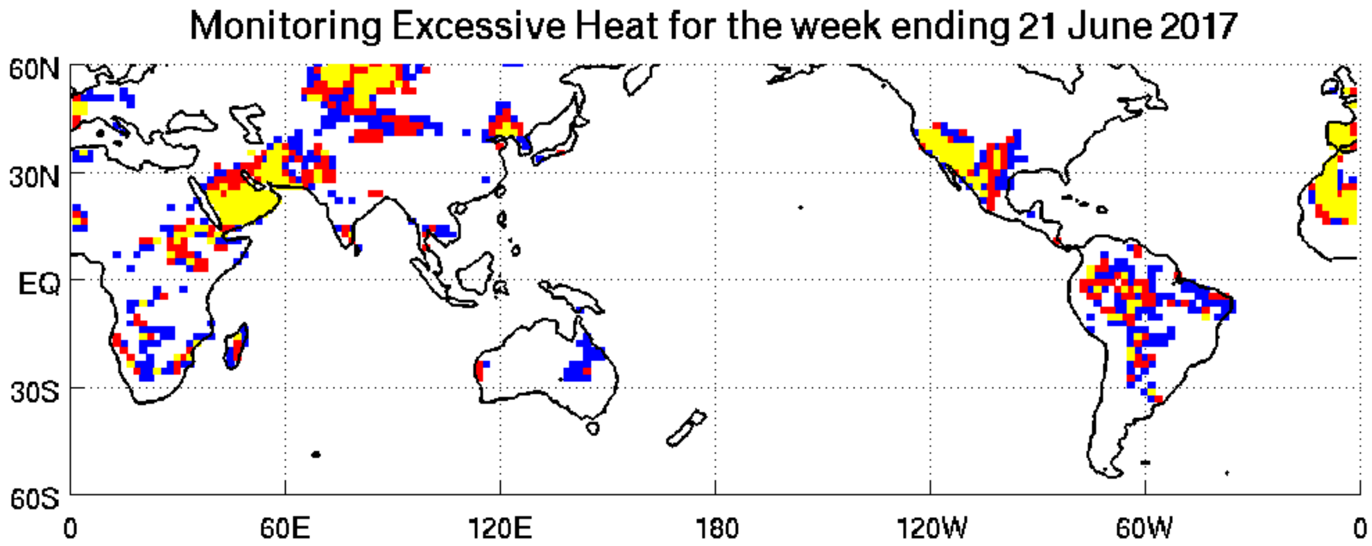
Acknowledgment to CPC collaborators for technical support.

Global Subseasonal Excessive Heat Outlooks (SEHOS-GLOB)

SEHOS-GLOB for Week-2 ending 21 June 2017



Verification for week ending 21 June 2017



Improving the Baseline SEHOS: Bias correction

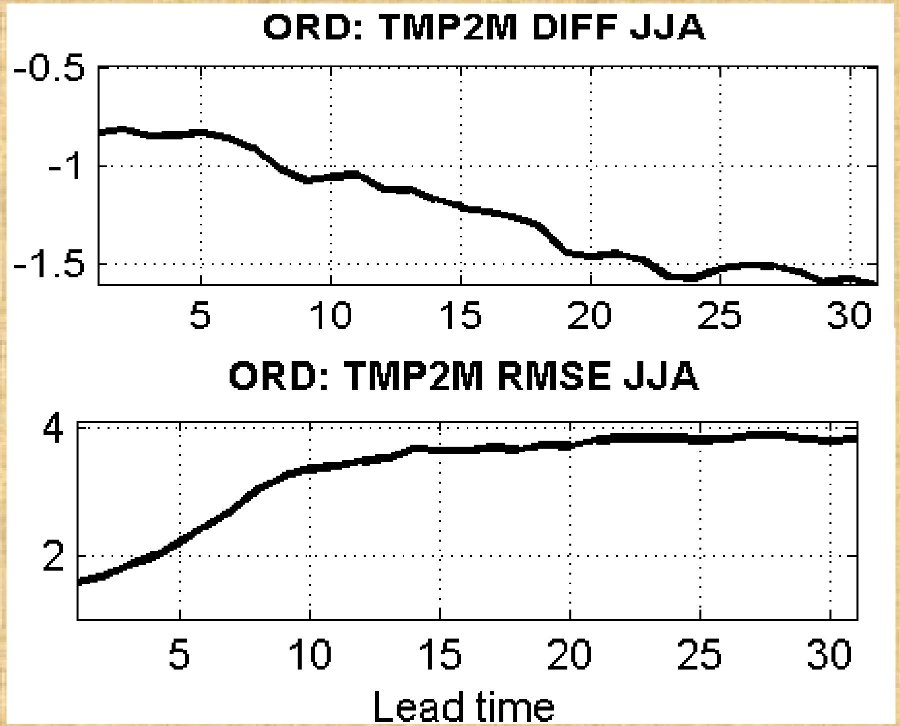
- Forecast models present systematic biases and forecast errors that depend on forecast lead time.
- An example of systematic bias and forecast error as a function of daily forecast lead time with the CFSv2 for Chicago, Illinois. 'Observations' are from the ERA-Interim product that assimilates both temperature and humidity at 2-meters.

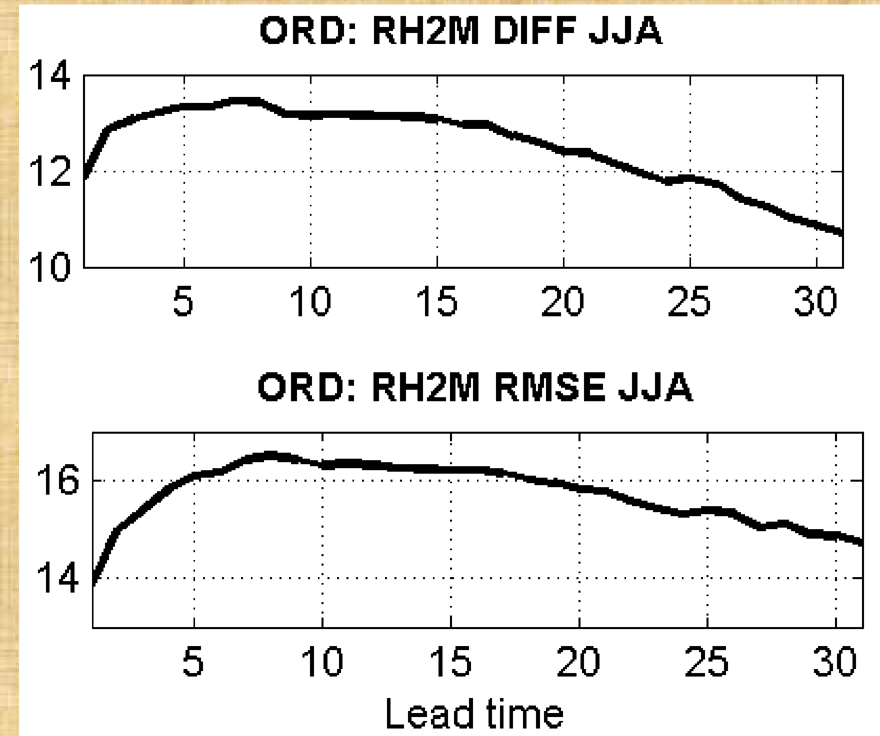
Dry temperature

Relative humidity

DRIFT

RMSE

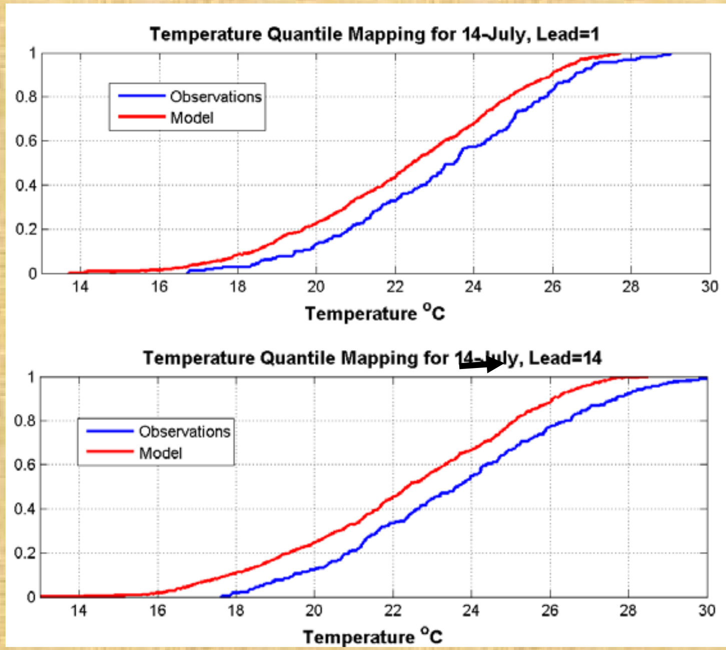




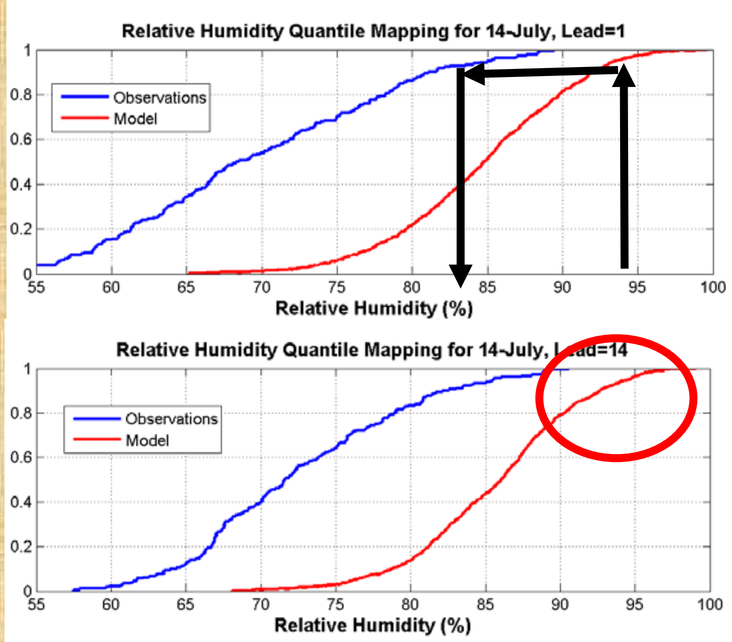
Improving the Baseline SEHOS: Bias correction through Quantile Mapping

- Bias correction of the SEHOS is based on the quantile mapping (QM) method: Example of QM for model forecasts (red) and observations (blue) Cumulative Distribution Functions calculated for 14 July in Chicago, Illinois for 1-, 14-day forecast lead times

Temperature



Relative Humidity



Definition of Quantile Mapping

Quantile Mapping for extreme values

- In the case of the SEHOS, Quantile Mapping is performed for extreme values. A parametric approach which fits Generalized Pareto Distributions to the data is used (for each grid point, initialization day and forecast lead time).

Improving the Baseline SEHOS: The bio-meteorological core

- **Definition of the intensity of an excessive heat event**

A simple linear approach

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

Normalized departure of the percentile from its median.

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

Thermal discomfort index for day ***d***

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

Excessive Heat Event Intensity.

A probabilistic approach based on the rarity of a heat event

$$\mathrm{K}_n^i(\alpha, M_{min}) = -\log\left(\prod_{d=1}^{M} p_d^i\right)$$

The Excessive Heat Factor approach (Nairn and Fawcett, 2015)

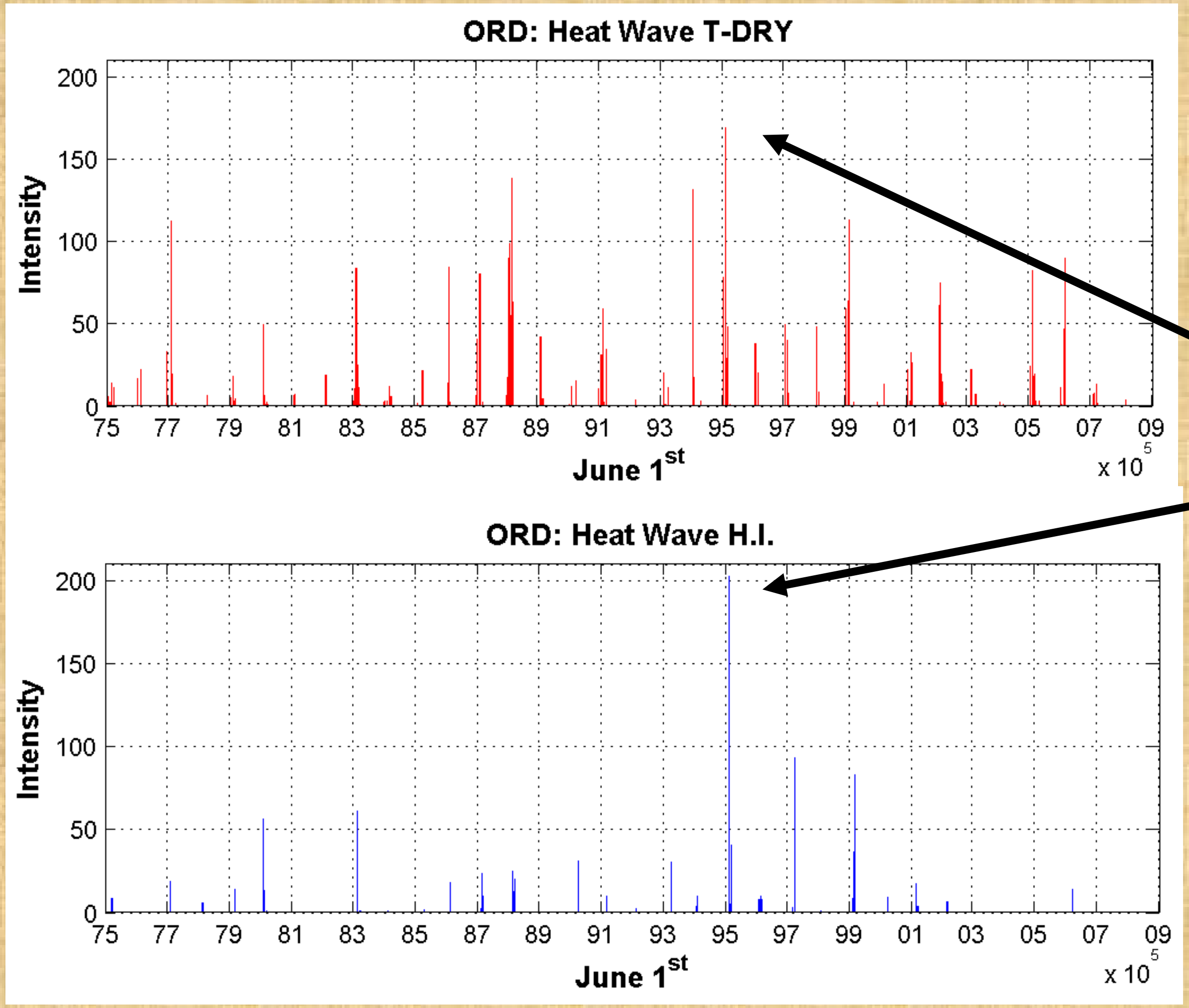
$$\boldsymbol{EHI_{sig} = \frac{1}{3}(T_i + T_{i+1} + T_{i+2}) - T_{95}}$$

$$\boldsymbol{EHI_{accl} = \frac{1}{3}(T_i + T_{i+1} + T_{i+2}) - \frac{1}{30}(T_{i-1} + \cdots + T_{i-30}),}$$

$$\boldsymbol{EHF_i = EHI_{sig} \cdot max(1, EHI_{accl})}$$

Intensity of heat waves based on the Excessive Heat Factor

Excessive heat factor based on dry temperature



Excessive heat factor based on the heat index

The Chicago July 1995 heat event is captured by both approaches. However, the intensity of this event is much higher when the heat index is used

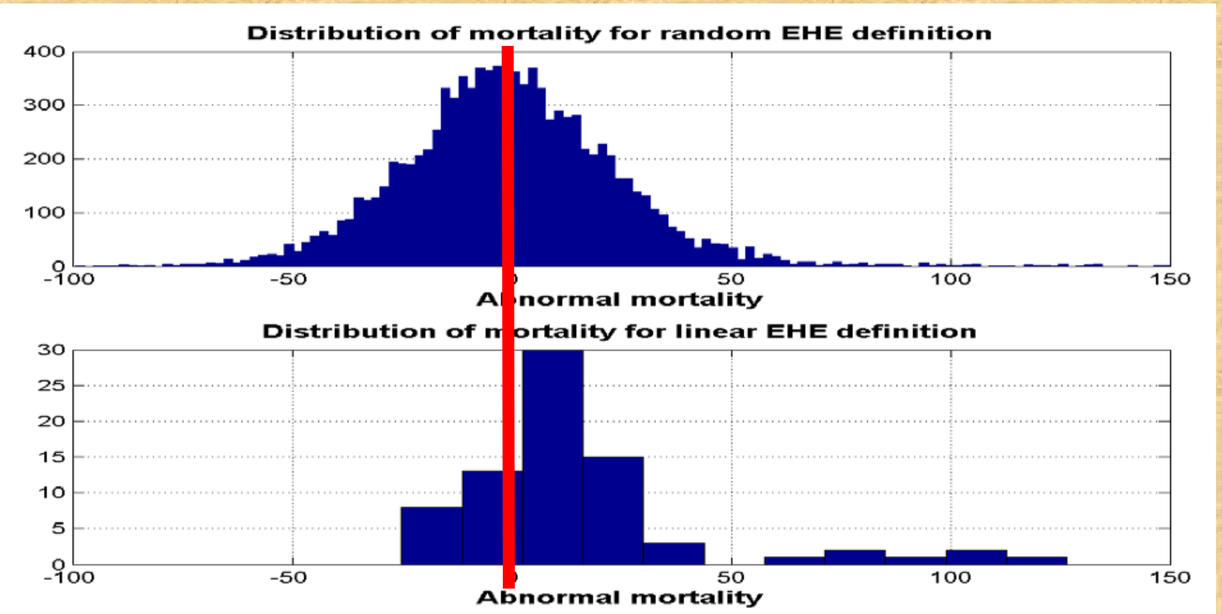
Improving the Baseline SEHOS: Validating the bio-meteorological core

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

$$\mathrm{K}_n^i(\alpha, M_{min}) = -\log\left(\prod_{d=1}^{M} p_d^i\right)$$

$$\boldsymbol{EHF_i = EHI_{sig} \cdot max(1, EHI_{accl})}$$

Shift of integrated abnormal mortality distribution from randomly defined excessive heat events in Chicago, Illinois when the simple linear method is used.



The bio-core is further validated by computing the forecast skill at different lead times

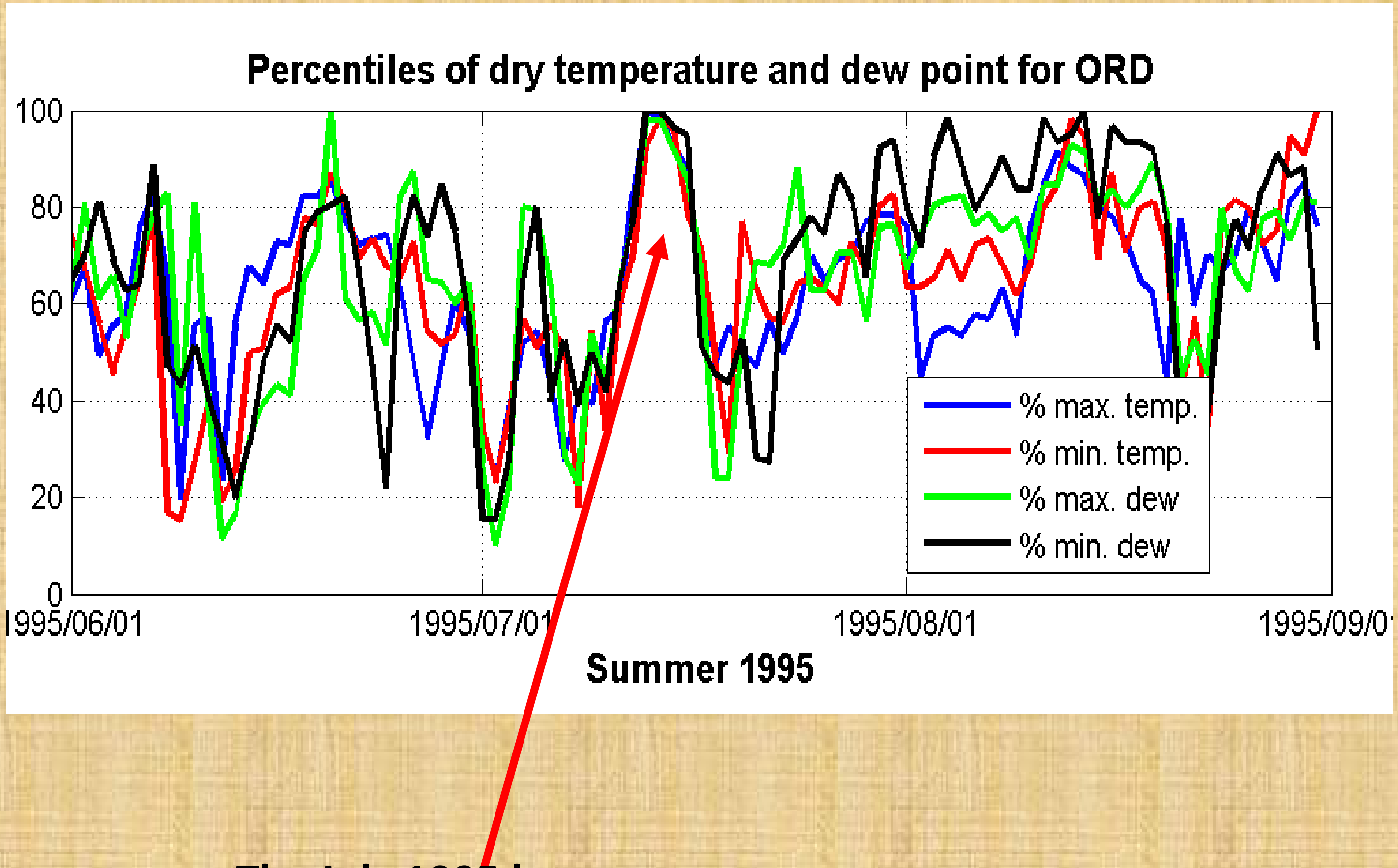
Improving the Baseline SEHOS: The interface to the Health Sector

- There is additional forecast information that can be provided to the health sector.

Percentiles of max and min temperature and dew point for the summer of 1995 in Chicago

- There is a vast amount of research work (especially within the social sciences) on the reasons for the extremely high mortality during the Chicago 1995 heat event.

- HadISD observations show that this was an exceptional event from the environmental point of view.



The July 1995 heat event

Summary and R&D directions

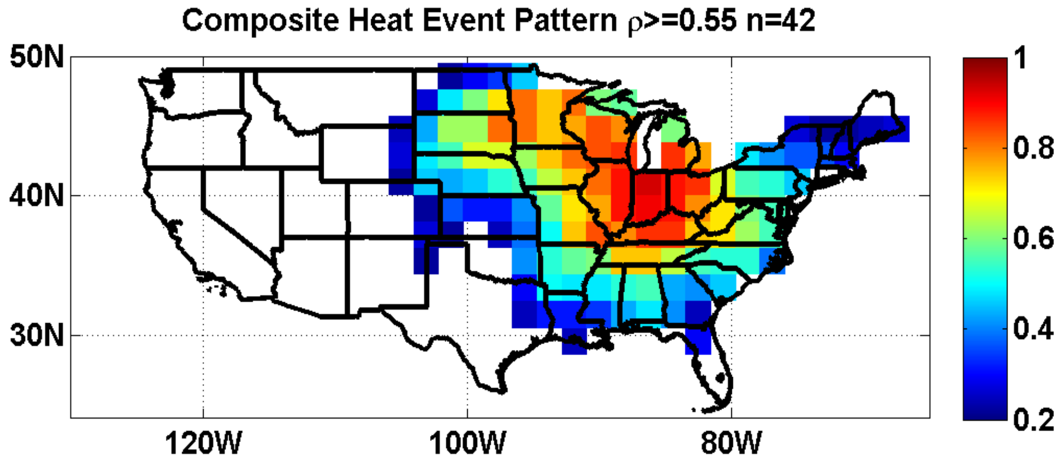
- Subseasonal forecasting of excessive heat events is feasible.
- A quasi-operational baseline Week-2 Subseasonal Excessive Heat Outlook System (SEHOS) was provided to the Climate Prediction Center during summers 2016/17.
- A new version of the SEHOS is under development and will be used for subseasonal-to-seasonal forecasts. Forecast model: CFSv2, bias correction using quantile mapping of extremes, bio-meteorological core that will provide a multitude of fields relevant to the health sector, and calibration based on Bayesian approaches.
- Real time global quasi-operational subseasonal-to-seasonal forecasts will be provided to climate forecasters and the health sector (please send me e-mail if interested on these forecasts).
- It is crucial to improve parameterizations of models based on extreme-heat-process oriented metrics
- Further improvements in understanding, modelling and forecasting of extreme heat events will be facilitated by the development of a common global historical database.

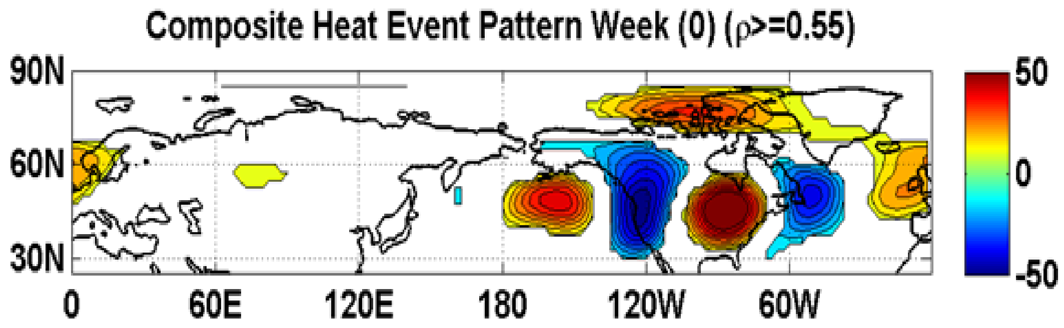

Questions: avintzil@umd.edu

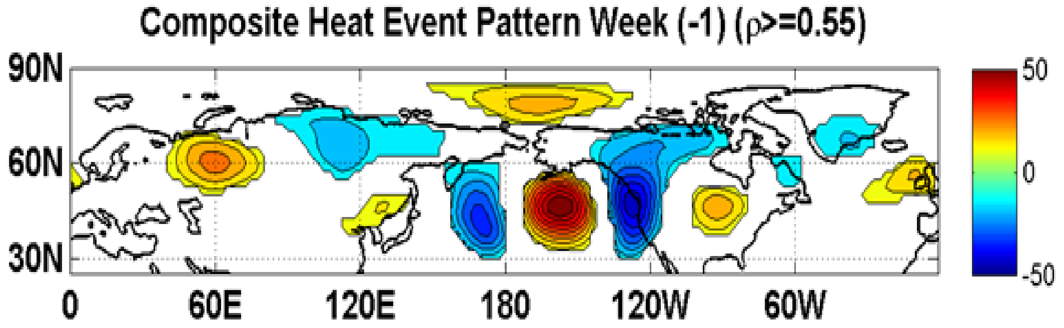
Physics of excessive heat

(b)

(a)

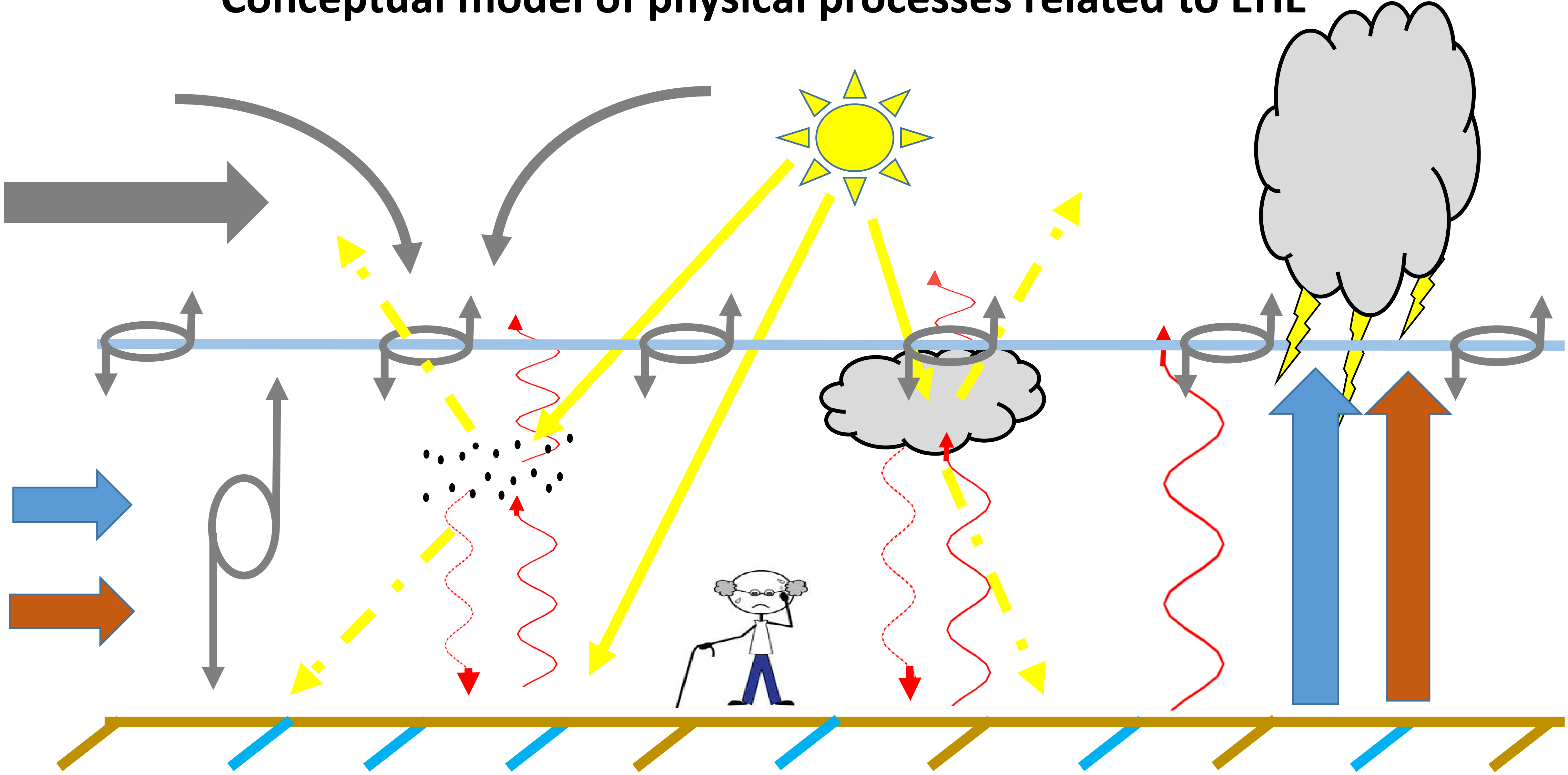


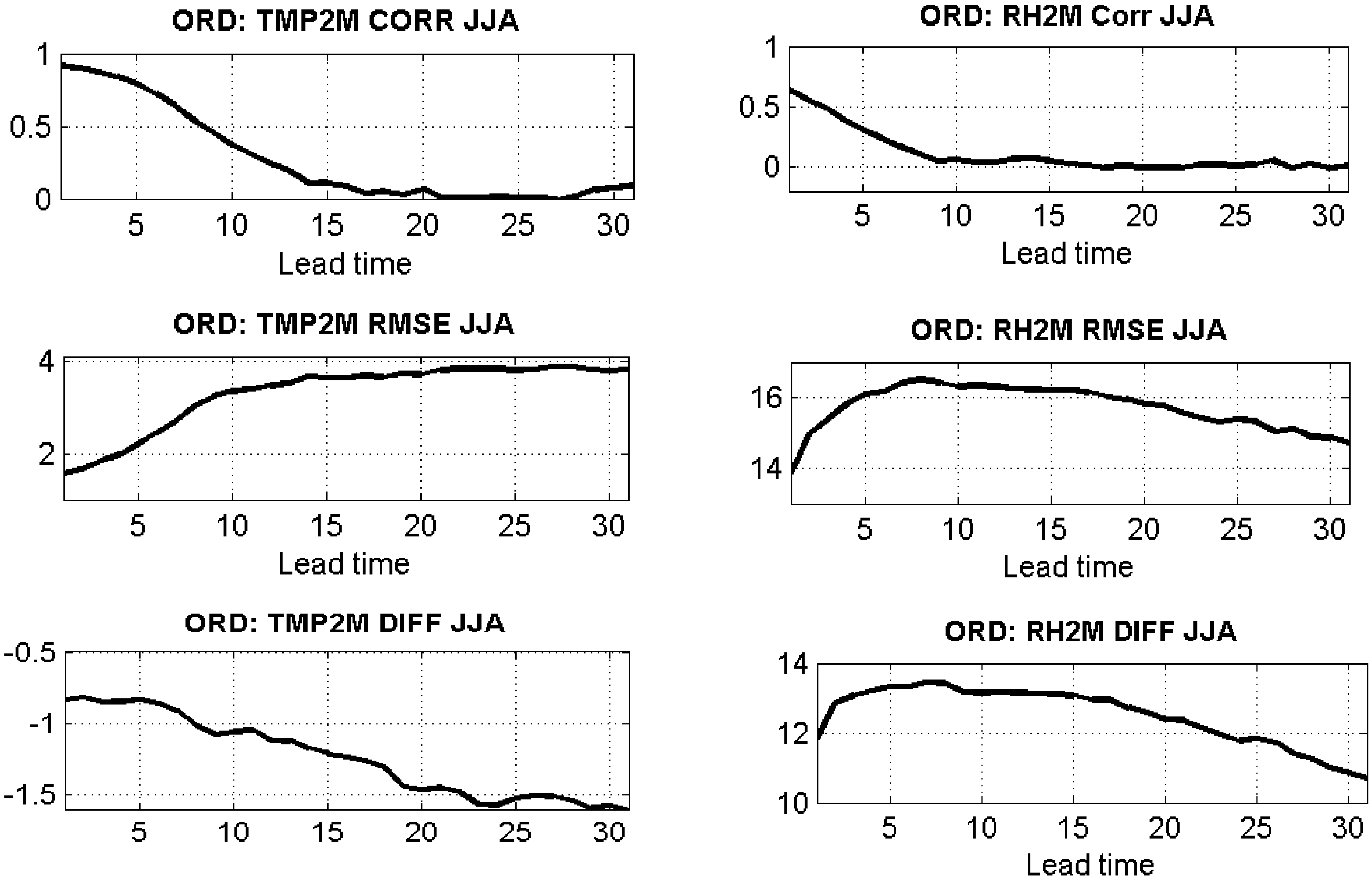




(c)

Conceptual model of physical processes related to EHE




ORD: TMP2M CORR JJA
Lead time
ORD: RH2M Corr JJA
Lead time
ORD: TMP2M RMSE JJA
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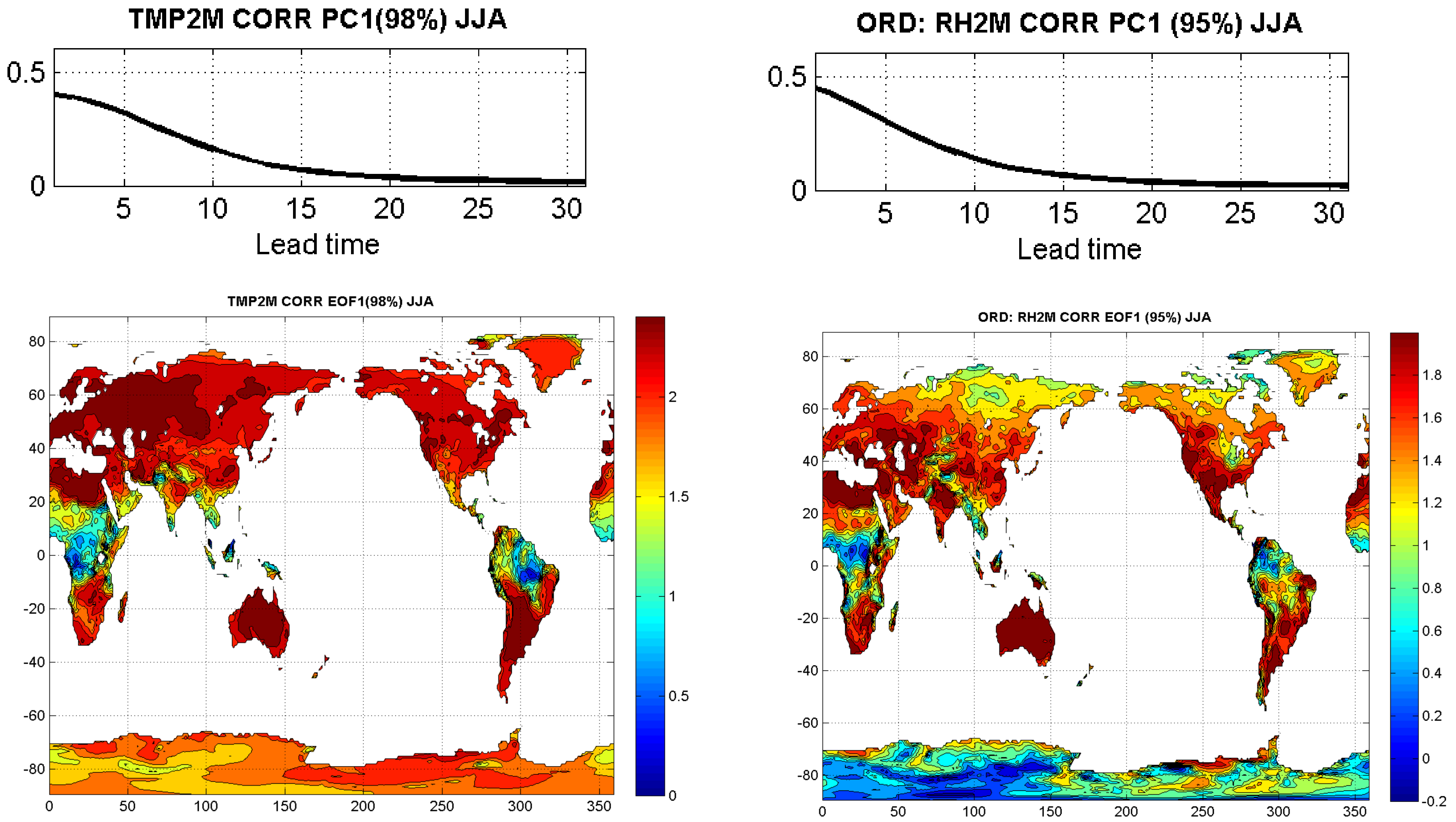
Lead time


TMP2M CORR PC1(98%) JJA
Lead time
ORD: RH2M CORR PC1 (95%) JJA
Lead time
TMP2M CORR EOF1(98%) JJA
ORD: RH2M CORR EOF1 (95%) JJA

Improving the Baseline SEHOS: Bias correction

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

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

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

Systematic bias correction

Improve the representation of the planetary boundary layer in models (especially during heat waves).