Excessive Heat Events and Health: Health-Impact Oriented Subseasonal Excessive Heat Outlook System

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Excessive heat research supported by NOAA grants:
NA15OAR4310081
NA14NES4320003
NA16OAR4310147
Outlook:

• Motivation for this work.

• Definitions of excessive heat events.

• Physics of heat events

• Is subseasonal forecasting of excessive heat events possible?

• A health-impact oriented excessive heat early warning system.

• Next steps.
Currently 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 thus more sensitive to heat 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.

Source: http://www.nws.noaa.gov/om/hazstats.shtml
Anatomy of the Chicago July 1995 event which resulted to more than 700 deaths

(METAR from O’Hare airport; mortality data courtesy Scott Sheridan)

Dry temperature anomalies were high but within the 35-40°C range. However the dew point was elevated.

The resulting Heat Index remained above 90°F for over 3 days with maximum reaching 119°F (49°C !!)

Abnormal mortality started increasing at the beginning of the heatwave reaching a maximum 2.5 days after
Impacts of heat:

• **Grow non-linearly as temperature and humidity increase.** Therefore we need to use thermal discomfort indices that are based on models of the physiological effects of heat on the human body e.g., the Heat Index, HUMIDEX, WBGT, UTCI, rather than just dry temperature.

• **Increase as a function of their duration.** Therefore we need to consider consecutive days with high thermal discomfort rather than just weekly, monthly, or seasonally averaged temperature.

• **Depend on geographical location.** Therefore we need to consider a definition of heat waves that varies as a function of location. This can be done by considering temperature thresholds (absolute values or quantiles).

• **Depend on earlier periods of colder or warmer than average weather due to acclimatization.** Therefore we need to take in consideration environmental conditions before the heat wave in order to assess possible impacts on health.
Heat waves result from quasi-stationary wavenumber 5-8 Rossby waves (e.g., Teng et al., 2013; McKinnon et al., 2016; Mann et al., 2017, Frangoulidis et al., 2018). It has been suggested that extra-tropical sea surface temperature forcing has an impact on these Rossby waves and that tropical variability is irrelevant.

To test the impact of high wavenumber Rossby waves on excessive heat we:
- Choose a baseline definition for heat waves (at least two consecutive days with maximum heat index exceeding the 90th percentile).
- Create a list of heat events similar to the Chicago 1995 event.

We composite weekly anomalies of geopotential at 500 hPa for the week of the events and the week prior to these events. Results show a quasi-stationary wave train indicative of subseasonal (Week-2) predictability.

We need to underline that impacts of the tropospheric forcing to human health will depend on the reaction of the coupled PBL – land-surface system to the individual tropospheric forcing from the cluster of similar events.
Are excessive heat events predictable at subseasonal lead times?

• Use the simplified definition of excessive heat events: At least two consecutive days of maximum heat index exceeding the 90th percentile

• Use reforecasts data from the S2S database to calculate the probability of occurrence of a heat event within a given week

• Verify reforecasts using the Receiver Operating Characteristics (ROC) and Area Under the ROC Curve (AUC):
  
  ➢ Map probabilistic forecasts to categorical for different thresholds of probability of occurrence
  ➢ For each threshold compare the hit rate to the false alarm rate, generate the ROC curve, and calculate the Area Under the Curve (AUC). A non-useful forecast system has AUC=0.5 (hit rates and false alarms are equal). A perfect forecast system has AUC=1
Predictability of Excess Heat Events: Area Under the ROC Curve for 90% – events

Week~1: We have not compute AUC for Week-1

Week-2: No Week-3 GEFS (for the moment)

Week-3: We have not compute AUC for Week-1

Multi-Model Ensemble Forecasting of Heat Events
There are two drawbacks in the baseline definition of excessive heat events:

(1) No acclimatization is factored in.
(2) The intensity of heat events is not well defined (extremely important for quantifying possible health impacts).

The Excess Heat Factor (Nairn and Fawcett, 2014) resolves both of these issues.

Let \( T_{\downarrow i} \) be the mean temperature of day \( i \), then

\[
\text{Significance of the Heat Event:} \quad \text{EHI}_{\downarrow \text{sig}} = \frac{1}{3} \left( T_{\downarrow i} + T_{\downarrow i-1} + T_{\downarrow i-2} \right) - T_{\downarrow 95}\%
\]

\[
\text{Acclimatization factor:} \quad \text{EHI}_{\downarrow \text{acclim}} = \frac{1}{3} \left( T_{\downarrow i} + T_{\downarrow i-1} + T_{\downarrow i-2} \right) - \frac{1}{30} \sum_{k=i-32}^{i-3} T_{\downarrow k}
\]

\[
\text{EHF} = \max(0, \text{EHI}_{\downarrow \text{sig}}) \cdot \max(1, \text{EHI}_{\downarrow \text{accl}})
\]

However this Excess Heat Factor considers humidity only indirectly through the use of the minimum temperature of the day and thus events similar to Chicago, 1995 can be misrepresented. To resolve this issue we introduce the wet EHF which uses the maximum between heat index and dry temperature.
Revisiting the definition of excessive heat

Maps of the wet EHF index for 13 July 1995 (during the Chicago, July 1995 event)
Realtime Global Subseasonal Excessive Heat Forecasting System

• We use the Climate Forecast System (CFSv2) forecasts. This choice is based on suggested impacts of SST, real time forecast availability, and previous demonstration of forecast skill of the EHF with the CFS (Ford et al., 2018).

• ECMWF’s ERA-Interim which assimilates 2 meter temperature and humidity is used for bias correction (quantile mapping) of the CFS-Analysis and the forecasts

• Experimental real time forecast system:
  - Forecasts were issued daily and outlooks were sent bi-weekly to an e-mail list from late May 2018 to early September 2018.
  - These forecasts provided the probability of exceedance of the 50th and 85th percentile for each grid point.

• Experimental excessive heat monitoring system:
  - For each grid point we calculate the maximum EHF within a given week and plot its quantile.
Global Subseasonal Excessive Heat Outlook System

Global-SEHOS Monitoring: Northern Hemisphere Summer 2018

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Research and development supported by NOAA grants:

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Monitoring the “Scandinavian” Heat Wave

Quantile of the maximum daily EHF within the given week

Anomalous weekly mean geopotential at 500 hPa

16-Jul-2018 to 22-Jul-2018

16-Jul-2018 to 22-Jul-2018

09-Jul-2018 to 15-Jul-2018
**Forecast of the Quebec Event (July 2018 >70 casualties)**

**Observed field**

Quant. of obs. wet EHF (ECDF) for: 02-Jul-2018 to 08-Jul-2018

**Forecast Week-2**

Prob. for wet EHF > 50% perc. Week-2. Valid: 02-Jul-2018 to 08-Jul-2018

**Forecast Week-3**

Prob. for wet EHF > 50% perc. Week-3. Valid: 02-Jul-2018 to 08-Jul-2018

**Observations:** Quantile of the maximum daily EHF during a given 7-day period at each grid point

**Forecast:** Probability of exceeding the 50th or 85th quantile of daily EHF for a given 7-day period
Summary

• Subseasonal forecasting of excessive heat events is possible.

• We developed a real time forecast system which was used quasi-operationally during the summer of 2018.

• The system continues operating on a daily basis.

• Currently evaluating the skill of this system during summer 2018.
Future plans

Short term:
• Transition ‘ground truth’ from ERA-Interim to ERA-5 which will be delivered in almost real-time.
• Introduce additional forecasts from coupled models that provide freely real-time forecasts.
• Extend the system to seasonal forecasts, future projections

Medium term:
• Better understanding of boundary layer processes during heat-waves
• Better understanding of atmospheric blocking and teleconnections during summer

Longer term:
• Dynamical downscaling (~200m) in ‘hot spots’ using boundary layer parameterizations developed by the better understanding of boundary layer processes during heat events.
• Answer the question: To tailor model forecasts or tailor forecast models?
Defining excessive heat events: Apparent Temperature

- Air Temperature at 2 meters
- Humidity at 2 meters
- Solar radiation
- Infrared radiation
- Wind velocity at 2 meters

Maximum and minimum air temperature e.g. BoM

Universal Thermal Climate Index (UTCI)

• Heat Index (NOAA) and HUMIDEX (Environment Canada)

Index complexity
- High
- Intermediate
- Lower

Index predictability
- Days?
- Weeks?
- Seasons?
Mission: Develop Health Oriented Early Warning Systems (from days to seasons to future projections)

- Weather/Climate Forecast models
- Ecological Forecast models
- Health Modelling
- Feedback

Pull triggers for issuing public health alerts and initiating relief efforts

Feedback
Excessive Heat Event in Scandinavia

Natural-color image acquired by the Moderate Resolution Imaging Spectro-radiometer (MODIS) on NASA's Terra satellite

Quant. of obs. dry EHF (ECDF) for 16-Jul-2018 to 22-Jul-2018