Towards Multi-Model Ensemble Forecasting of Excessive Heat Events at Subseasonal Lead Times (Week-2 to Week-4)

Augustin Vintzileos
University of Maryland – ESSIC/CICS

and

Jon Gottschalck, Mike Halpert
NOAA/CPC

This study was supported by NOAA grants: NA15OAR4310081 and NA14NES4320003.
Outline:

• A definition of excessive heat events
• Monitoring heat events
• The baseline forecasting system
• Preliminary forecast verification
• Towards multi-model ensemble forecasting
• Summary and future work
Heat kills: The example of the July 1995 Heat Event

From the NOAA study of the event (published December 1995)
Defining excessive heat events (I)

In comparison with other natural disasters heat is a silent (invisible) killer

An extreme heat wave in India May 2015

Defining adequately Heat Events is a necessary step for their monitoring and forecasting:
Impacts of Heat Events:

• **Grow non-linearly as temperature and humidity increase:** Requirement for using apparent temperatures (these are based on models of the physiological effects of heat on the human body). In this work we use NOAA’s *Heat Index*.

• **Increase as a function of their duration:** Requirement for consecutive days with high apparent temperature.

• **Depend on geographical location:** Requirement for a definition of what is high apparent temperature as a function of location.

• **High apparent temperatures are felt differently as a function of time within the warm season due to acclimatization:** Requirement for definition of what is high apparent temperature as function of timing within the warm season.
Defining excessive heat events (III)

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 $\alpha$ 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 ($\alpha=90\%$), Level-2 ($\alpha=95\%$), and Level-3 ($\alpha=98\%$).

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

**Inconveniences of this definition:** Based on expensive reforecasts.
Based on the above definition we introduce a criterion for Weekly Heat Events. For each grid point:

- 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.

Monitoring system data source:
- GEFS Day-1 forecasts.
- NCAR/NCEP Reanalysis (comparison in backup slides)
- Working towards monitoring systems based on direct observations of temperature and humidity

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.
Investigating sources of subseasonal predictability for Heat Events:

Composites of anomalies of 500mb geopotential for L1 – Heat Events similar to the Chicago 1995 event

**Composite heat event of Chicago 1995 type based on 42 cases (1948-2015):**

- **Composite weekly mean geopotential anomalies:**
  - during the week of the Chicago 1995 type of events
  - during the week prior to Chicago 1995 type of events
  - two weeks prior to Chicago 1995 type of events

This diagnostic shows a midlatitude high wavenumber structure in 500 hPa geopotential similar to recent reports (Teng et al., 2013; McKinnon et al. 2016)
Baseline system: The NCEP GEFS.
- Initialized daily at 00Z, 06Z, 12Z and 18Z
- 20 perturbed forecasts per cycle resulting to 84-member ensemble per day
- For each ensemble member we compute whether Week-2 is a Heat Week, the starting day and the duration.
- Compute the statistics: Probability of occurrence, mean start day, mean duration (CDFs as a function of lead time)


**Verification**

**Probability of Occurrence of Heat Event**

**Climatological Heat Day for Week: 06/26 to 07/02 (Red line = 100°F)**
Verification of the baseline forecasting system (1985-2014)

Receiver Operating Characteristic (ROC) and Area Under Curve (AUC)

<table>
<thead>
<tr>
<th>Contingency table</th>
<th>OBS Yes</th>
<th>OBS No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forecast Yes</td>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>Forecast No</td>
<td>c</td>
<td>d</td>
</tr>
</tbody>
</table>

Forecast **YES** when Probability of Occurrence > P.

ROC: POD vs. POFD for different values of P.

AUC provides a measure of the predictive capacity of the system.

(aall CONUS grid points)
Ways for improving the baseline system:

(1) Investigate physical reasons for successes and drawbacks in forecasting specific heat events.

(2) Use statistical post-processing to bias correct and calibrate the probabilistic forecasts:

(3) Use multi-model ensemble forecasting approaches:
Multi-model Ensemble forecasts: AUC for L1 – events

**Week~1**

- Multi-model Ensemble Forecasting of Heat Events
- 11 ensemble members
- ECMWF

**Week-2**

- 1995-2015 twice per week to accommodate the ECMWF reforecast design.
- Caveat: GEFS is initialized by CFS-R and not GDAS

**Week-3**

- No Week-3 GEFS (for the moment)
- 8 ensemble members constructed by combining forecasts initialized from two consecutive days (1999-2010)
Summary

• We quantified heat waves using a definition that takes into account human physiology and the constraints of probabilistic subseasonal forecasting (Week-2 to Week-3&4).

• We developed a monitoring systems for excessive heat events.

• We developed a baseline forecast system using the NCEP-GEFS and presented preliminary verification:
  • The system is capable of detecting heat events two weeks in advance (depending on the geographical area).

• We investigated multi-model approaches:
  • Combining the GEFS and ECMWF models provides better forecasts of heat events (better AUC) for forecast Week-2.
  • Combining the CFS and ECMWF models results to better forecasts of heat events along the northeast corridor and the mid-Atlantic for forecast Week-3.
Current/Future Work

• Daily experimental forecasts of Week-2 Heat Events with the GEFS (based on 84 ensemble members) will start during the week 2-6 May 2016.

• These forecasts will be available to Climate Prediction Center forecasters for evaluation which will allow to improve the system.

• Augment forecast capacity of the system by including predictions based on the ECMWF Week-2 forecasts.

• Augment forecast capacity by including CFS and other NMME operational models.

• Extend the system to Week3@4 and to the global subtropics and tropics.