Not Just a Number: Intra-Hour Heat Metric Variability

Why does it matter? Heat kills - accurate heat metrics can save lives.

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Introduction

- According to the National Weather Service (NWS), heat is the #1 cause of weather-related fatalities in the US[1].
- **Wet bulb globe temperature (WBGT)**, chosen because of its robustness, is used by military, athletic, and outdoor labor settings, but is not the primary metric used by NWS for Heat Advisories and Warnings.
- WBGT is subject to **rapid variation** both spatially and temporally because of its incorporation of solar radiation and wind. Literature suggests application of smoothing or averaging on 5, 15, 30, and 60 minute timeframes[2,3,4,5].
- An evaluation of sub-hourly WBGT is important for **establishing heat alert thresholds** and danger levels. This project investigates the intra-hour variation in WBGT, seeking to inform best practices in using WBGT for NWS heat alerts.

Research Question:

How is the intra-hour variability of wet bulb globe temperature characterized, and how does this impact its utility as a heat metric for use by NWS?

Methodology

- Based on ***(A) the variable input into WBGT, (B) spatial WBGT variability,*** and ***(C) the current county-wide resolution of NWS heat alerts***, a **4 station case study analysis** is utilized to explore WBGT intra-hour variability. Data from the NC State Climate Office ECONet Stations[7] are used, including WBGT, solar radiation (SR), and wind speed (WS).
- WBGT is a calculated heat metric from three measurements[6]:

WBGT = 0.1(DB) + 0.20(GT) + 0.70(WB)

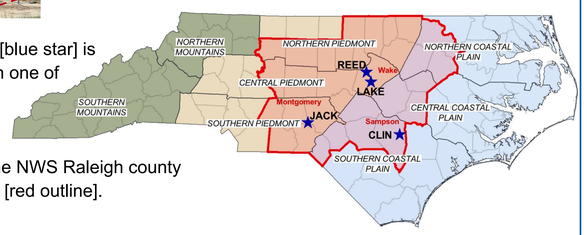
Dry bulb temperature (DB)
-typical outdoor thermometer
-measured: **air temp. (shade)**

Black Globe temperature (GT)
-thermometer covered in copper black globe
-measured: **air temp., sunlight, wind**

Wet bulb temperature (WB)
-typically thermometer covered in wet cloth, simulates sweat
-measured: **air temp., humidity, wind, sunlight**
-this is calculated from other measurements at ECONet using methodology from NWS[6]

The NC State Climate Office ECONet[7] stations (JACK Station pictured) directly measure GT and DB, and calculate WB[6]. The zoomed in photo [dashed red outline] shows the black globe and air temperature instruments.
IMAGE: NC State Climate Office, JACK - Sandhills Research Station

- Each station [blue star] is located within one of three climate regions, in one of three counties in the NWS Raleigh county warning area [red outline].



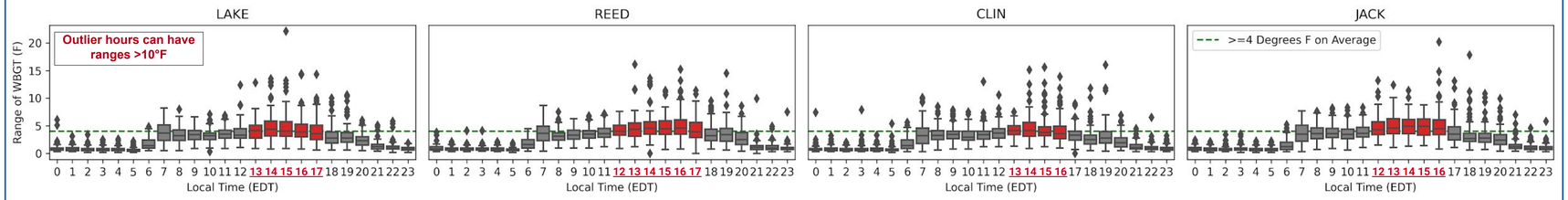
- NWS WBGT threat guidelines differ across the US[9]. These are from Region 3, which includes NC:

Low Threat:	Elevated Threat:	Moderate Threat:	High Threat:	Extreme Threat:
< 78.3 °F	78.3-82.0 °F	82.1-86.0 °F	86.1-90.0 °F	> 90.0 °F

Results

Average Temporal Variance

Fig.1: WBGT Hourly Range across all hours in July 2019-2022
Each box plot shows all hourly ranges across all days in July and all years 2019-2022. The green, dashed line indicates 4°F, which is the magnitude between two WBGT thresholds for the NWS WBGT guidelines[9] (see Methodology). Hours with red boxes and labels indicate that the mean range for that hour of the day is ≥ 4°F, indicating multiple thresholds could be reached in an hour despite one hourly average. The 4 panels also indicate that across Central NC and even across 1 county (Wake) these ranges vary. **Intra-hour WBGT at peak heating hours can move between multiple thresholds across an hour and a county, suggesting a need for more refined and detailed heat alerts.**



Case Study Hours

1 min. vs Hourly Avg. WBGT
Sub-hourly variation can be ±5°F from the avg. **There is the potential for multiple WBGT thresholds to be reached in an hour.**

Influence of Conditions
Quick changes in wind and sun appear in 1 min. WBGT, indicating sensitivity and importance of these factors. **This may not be reflective of ambient conditions.**

Importance of Clouds
Observed SR drops below the Clear Sky Estimate (an estimation of optimal SR based on latitude, date, and hour) quickly and significantly with cloud coverage. **Passing clouds cause rapid drops in SR, which translates to reductions in WBGT.**

Fig. 2a: REED Station 1 min. WBGT, SR, & WS: High vs Low Range Hours

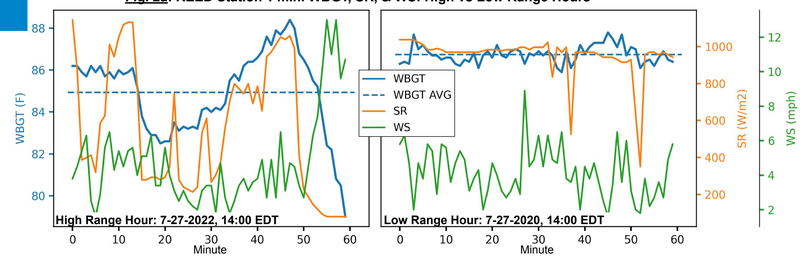
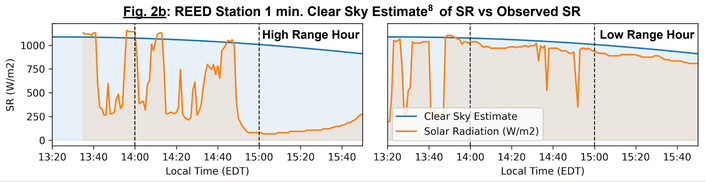


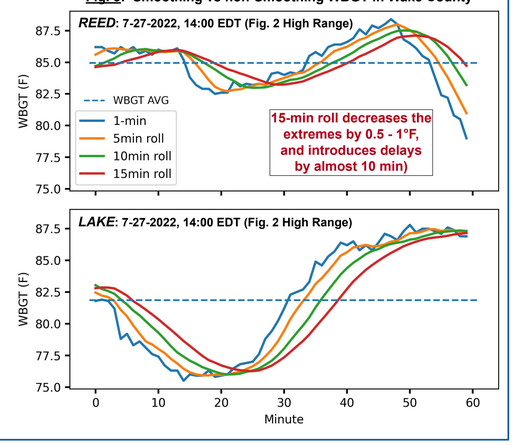
Fig. 2b: REED Station 1 min. Clear Sky Estimate[8] of SR vs Observed SR



Smoothing Differences
The 1 min. WBGT and three smoothing applications: 5 min., 10 min., and 15 min. rolling averages, show similar trends but vary. **5 min. smoothing tracks the 1 min variability the best while removing fluctuations.**

Intra-County Variations
REED and LAKE have different temporal evolutions of WBGT and hourly averages (~3°F difference), showing potential for different thresholds within same county. **WBGT can vary significantly within the same county both sub-hourly and hourly.**

Fig. 3: Smoothing vs non-Smoothing WBGT in Wake County



Conclusion

- Mid-day hours can have an **average WBGT range > 4°F**, which is larger than the magnitude between NWS thresholds. Within an hour, **multiple flag levels may be reached** that are not captured by a single hourly average.
- Max. range hours were found to be **> 10°F,** however this may be influenced by days with precipitation, where **convection forms quickly and can rapidly cool a high WBGT**, and by solar variability during sunrise and sunset hours.
- Looking at a case study hour with no convection: **SR and WS vary rapidly** minute to minute causing fluctuations in WBGT. While this may distract from general conditions, fine-scale resolution of WBGT allows for **greater understanding of threat levels** and points to the importance of **simple actions to reduce heat stress like shade and air flow**.
- The **5-min. rolling average** follows WBGT intra-hour trends closely and is in closer alignment with **instrumentation accuracy**. ECONet black globe thermometer response time is a couple of minutes, while other instrumentation is close to instantaneous.

APPLICATIONS:

- Applying the appropriate temporal smoothing is important: while it will mask the high sensitivity of instrumentation, it may temporally or magnitudinally shift maximum values.
- Spatial and temporal variation indicates an opportunity for local entities to supplement the county resolution heat guidance from NWS.

FUTURE DIRECTIONS:

- Incorporation of variability within heat-health studies
- Incorporation of the location/regional geography and the development of WBGT climatology
- Establishment of uniform thresholds with standardized smoothing based on instrumentation
- Cross comparison with other heat metric tools and integration into NWS

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