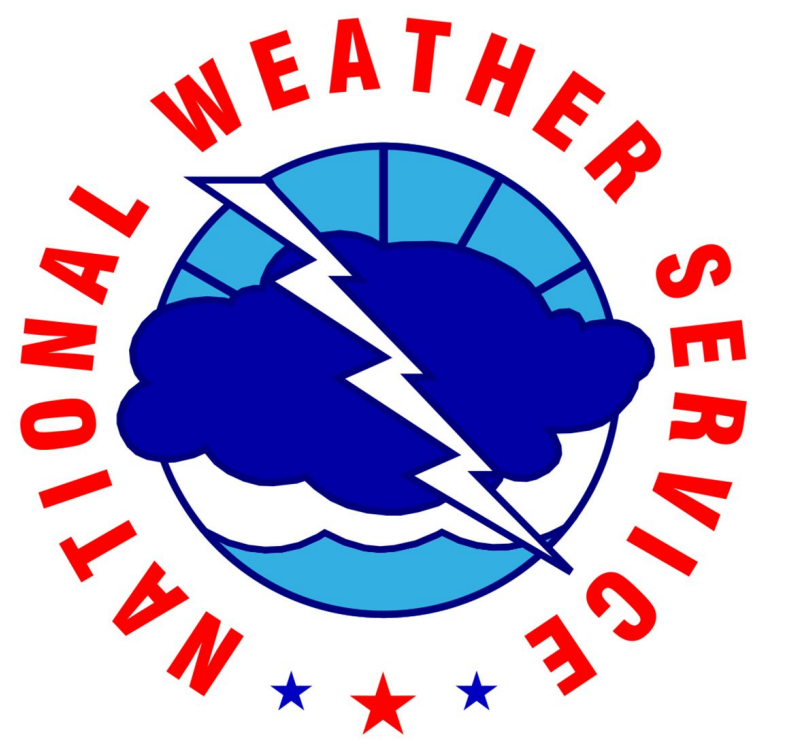


# Not Just a Number: Intra-Hour Heat Metric Variability

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<sup>1</sup>.
- 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<sup>2,3,4,5</sup>.
- 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<sup>7</sup> are used, including WBGT, solar radiation (SR), and wind speed (WS).

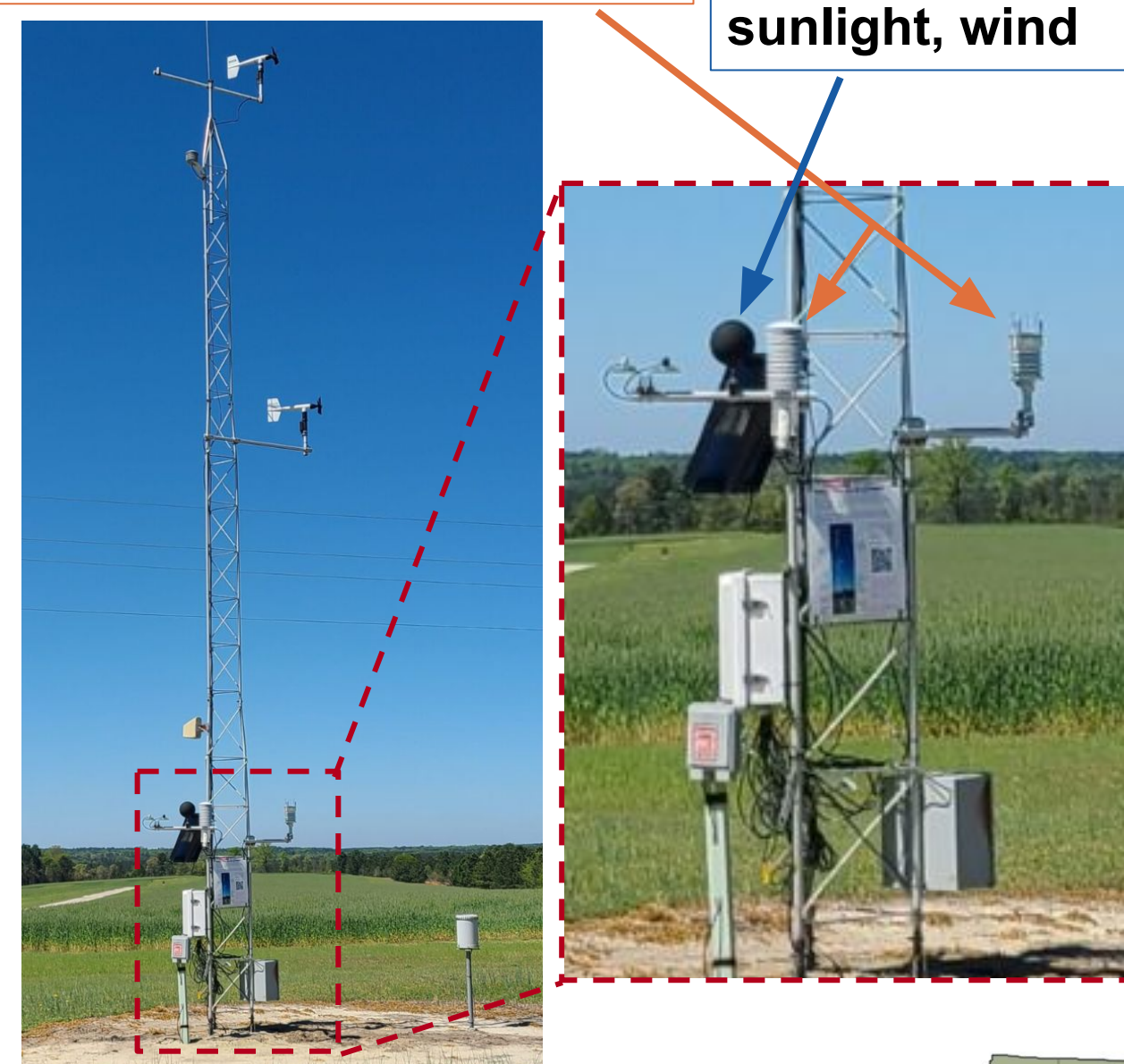
- WBGT is a **calculated** heat metric from three measurements<sup>6</sup>:

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

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

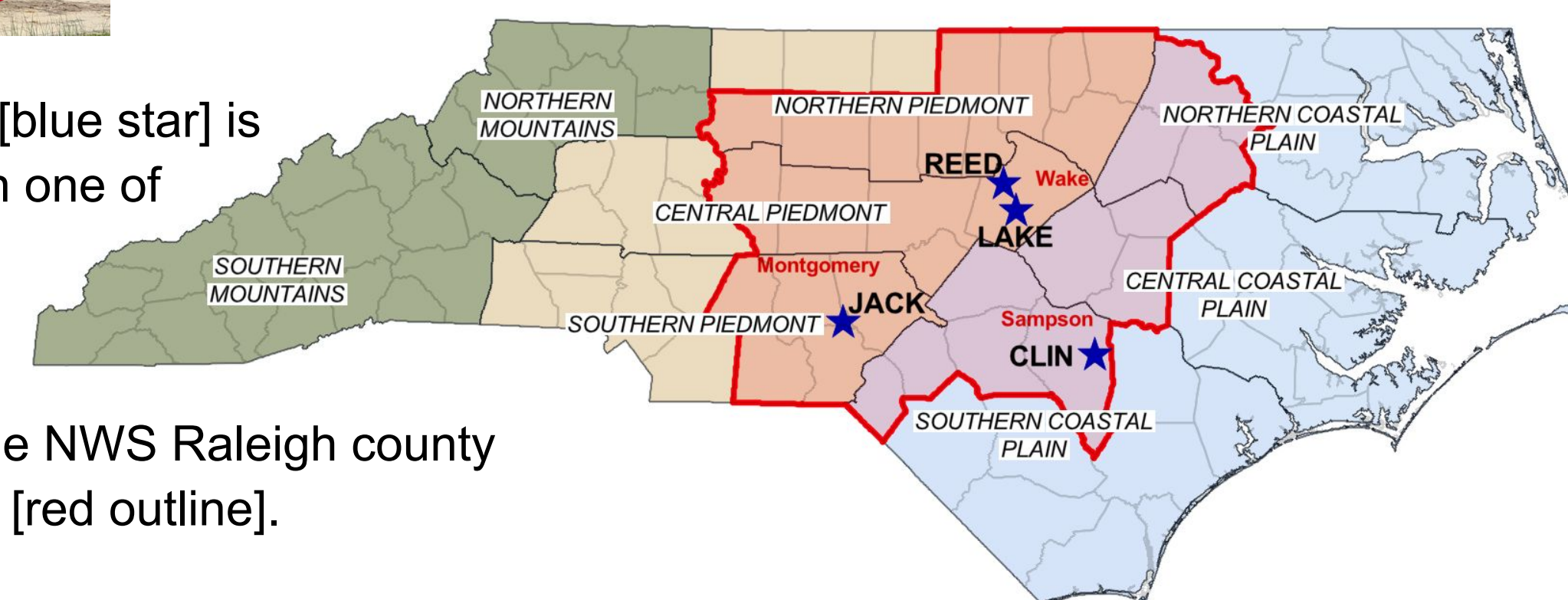
**Black Globe temperature (GT)**  
-thermometer covered in copper black globe  
-measured: **air temp., sunlight, wind**

**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<sup>6</sup>

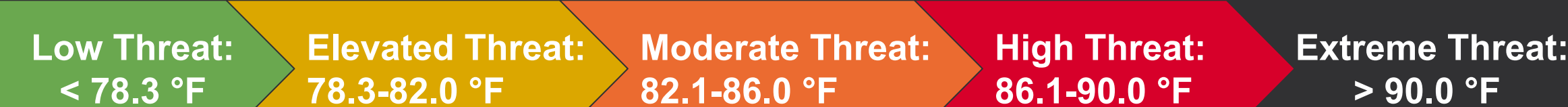


The NC State Climate Office ECONet<sup>7</sup> stations (JACK Station pictured) directly measure GT and DB, and calculate WB<sup>6</sup>. The zoomed in photo [dashed red outline] shows the black globe and air temperature instruments.  
IMAGE: NC State Climate Office, JACK - Sandhills Research Station

- 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<sup>9</sup>. These are from Region 3, which includes NC:

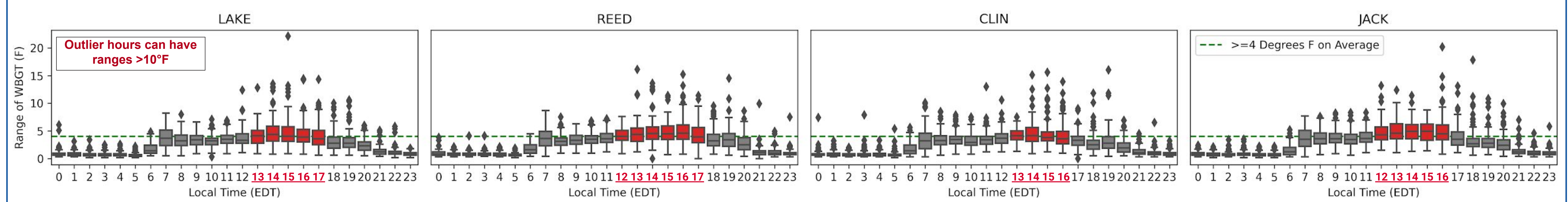


## Results

### 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<sup>9</sup> (see Methodology). Hours with red boxes and labels indicate that the mean range for that hour of the day is  $\geq 4^\circ\text{F}$ , 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.



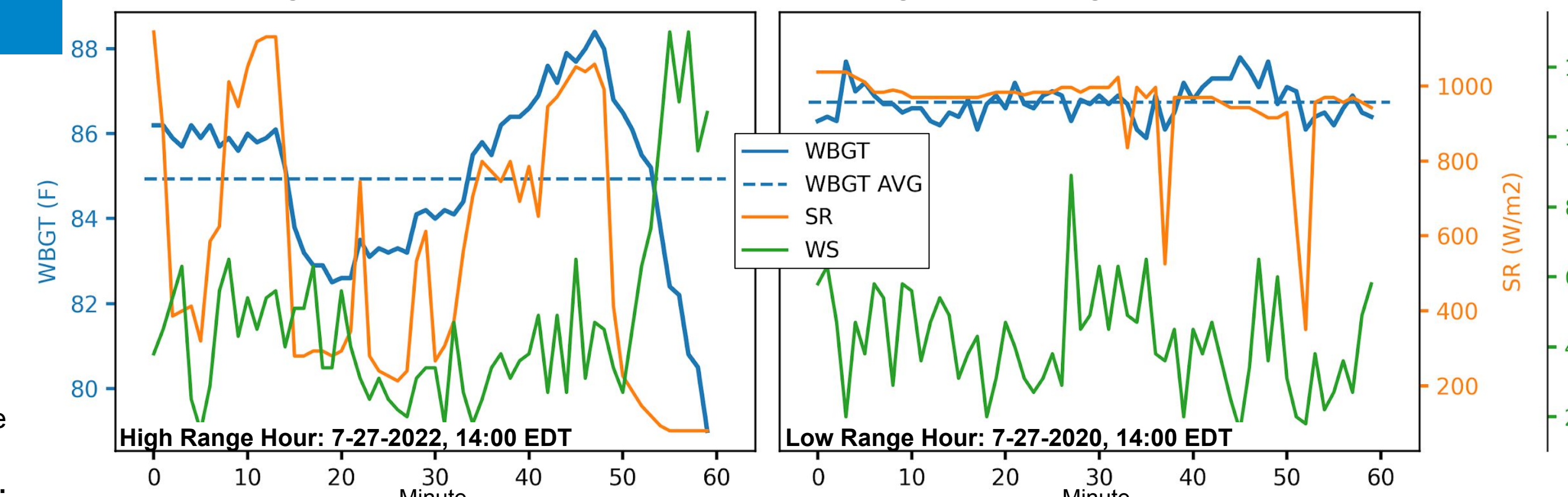
### Case Study Hours

**1 min. vs Hourly Avg. WBGT**  
Sub-hourly variation can be  $\pm 5^\circ\text{F}$  from the avg. There is the potential for multiple WBGT thresholds to be reached in an hour.

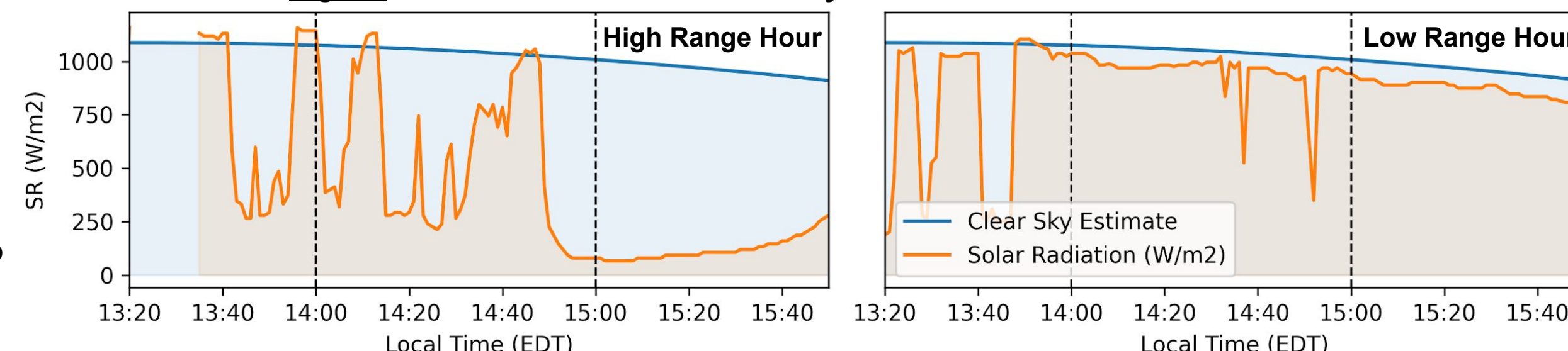
**Influence of Conditions**  
Quick changes in wind and sun appear in 1 min. WBGT, indicating sensitivity and importance of these factors. This may not be reflective of ambient conditions.

**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**



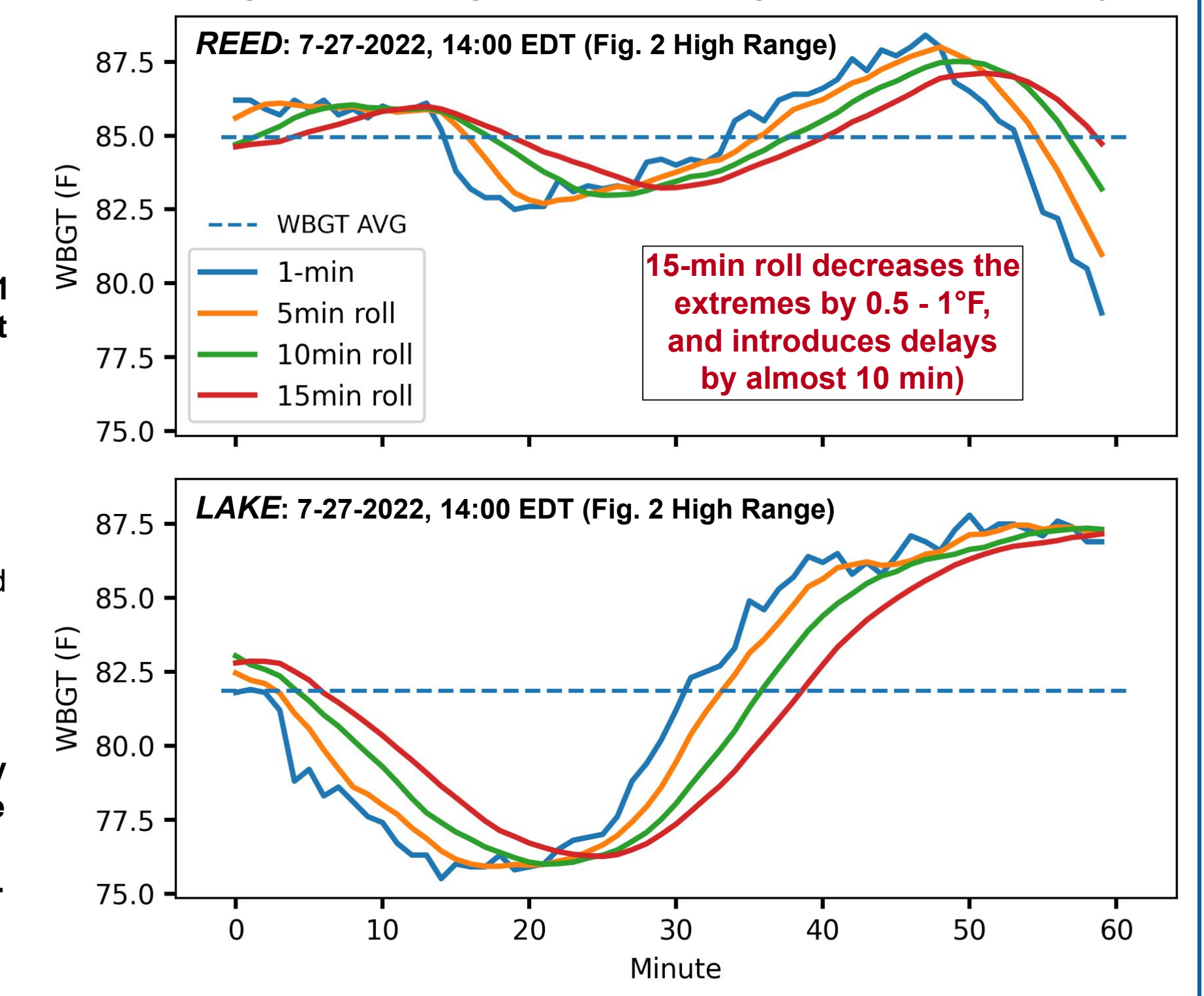
**Fig. 2b: REED Station 1 min. Clear Sky Estimate<sup>8</sup> of SR vs Observed SR**



**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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