U.S. ARMY TEST AND EVALUATION COMMAND
WHITE SANDS TEST CENTER

Exploring the Subtleties in Measuring Wet Bulb Globe Temperature (WBGT)

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What is Wet Bulb Globe Temperature (WBGT)?

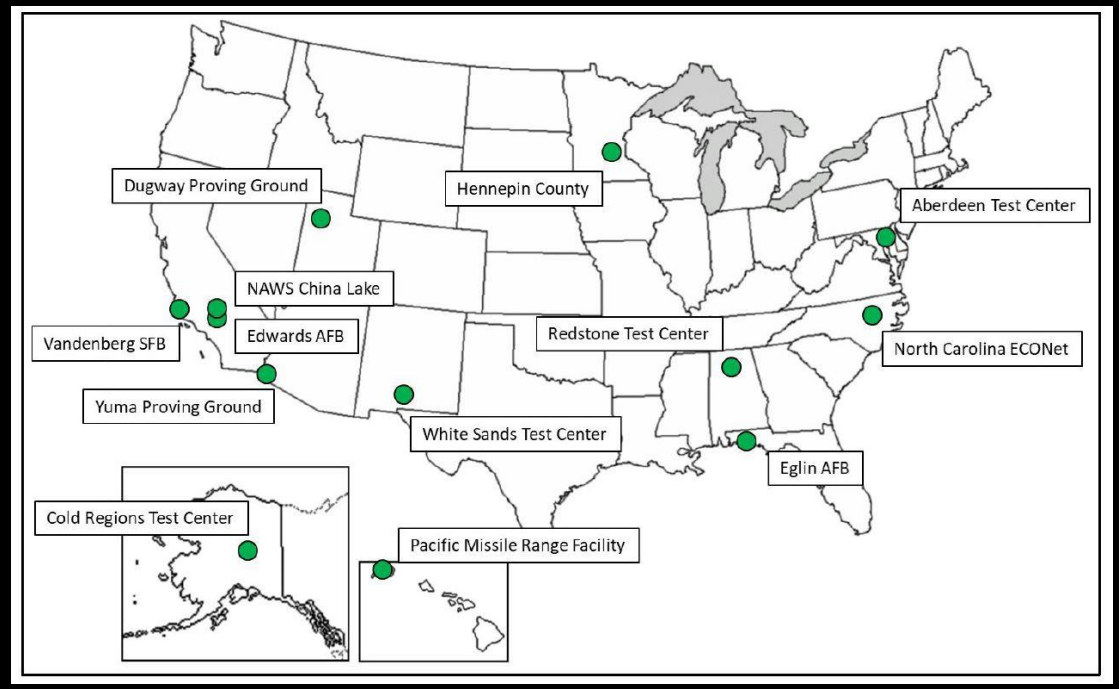
- Measure of heat stress accounting for air temperature, humidity, radiant heat, and air movement
- Developed in the mid-1950s by the US military and remains its standard heat stress metric
- Increasing use by workplaces and activities associations; recently operational in the US National Weather Service

$$\mathbf{WBGT = 0.1T_a + 0.2T_{bg} + 0.7T_{nwb}}$$

T_a = air temperature
T_{bg} = black globe temperature
T_{nwb} = natural wet-bulb temperature

Range Commanders Council Meteorology Group (RCC-MG) WBGT Project

- Take observations of WBGT-related variables over an extended period (several months) at as many different climatic sites as possible using a standard set of instrumentation
  - Data collected at 13 locations from 15 May-15 Oct 2021
- From these observations, develop algorithms applicable to all locations that provide quickly calculated and reasonably accurate estimates using standard meteorological variables from weather observations and models
  - Work in progress!



RCC-MG Project Participants

Challenges with WBGT Measurements

Malchaire (1976)

- "It must be concluded that ***apparently insignificant design factors may notably influence the results***."
- "***Very detailed specifications*** must be given for the design of this instrument ***if these readings are to be reproducible and comparable***."

Alfano et al. (2012)

- Natural wet-bulb temperature can be influenced by such ***odd factors as the length, thickness, capillarity, and tightness of the wick***

- WBGT platforms for the RCC-MG project were configured as similar as possible using ISO 7243 guidelines to minimize impacts of the above factors

*Malchaire, J. B., 1976: Evaluation of natural wet bulb and wet bulb thermometers. Ann. Occup Hyg., **19 (3-4)**, 251-258.*
*Alfano, F., J. Malchaire, B. Palella, and G. Riccio, 2014: WBGT index revised after 60 years of use. Ann Occup Hyd., **58** (8), 955-970.*

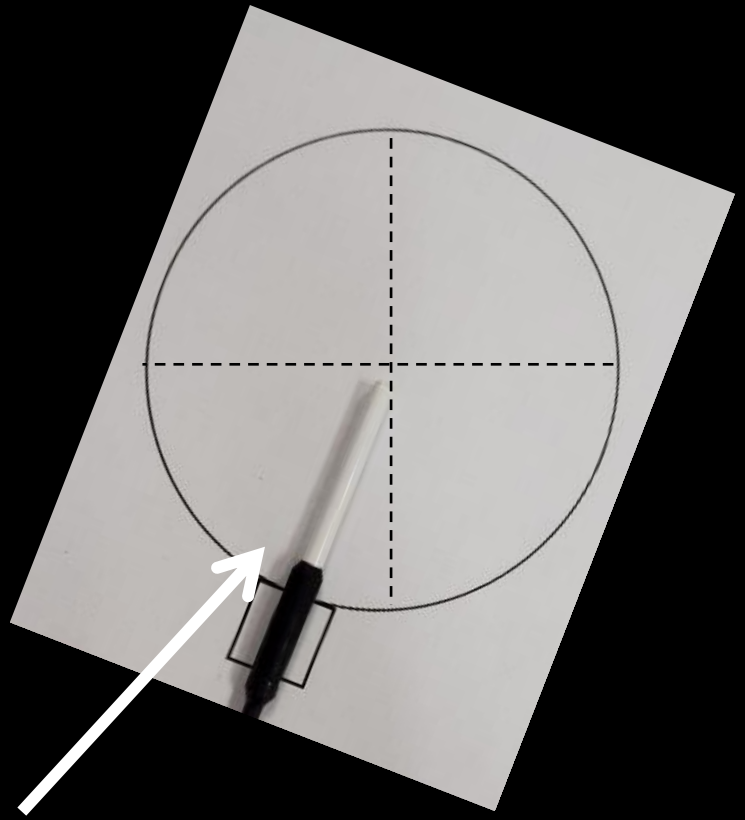
2021 RCC-MG WBGT Project Sensors

Campbell Scientific BLACKGLOBE-L with CS109 probe

Custom NWB fixture from Vandenberg TDDEC

BLACKGLOBE-L Standard Installation

FIGURE 6-3. BlackGlobe fitting and cable alignment



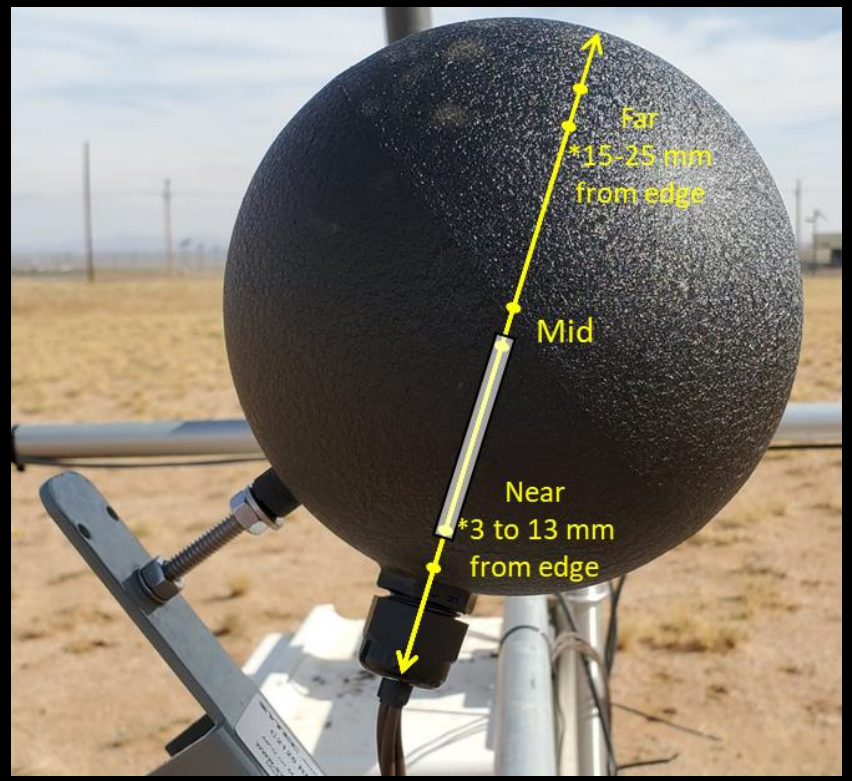
- Probe in the lower half of the globe
- Probe tends to measure the average temperature over its length

FIGURE 6-4. BlackGlobe mounted to a crossarm (front view)

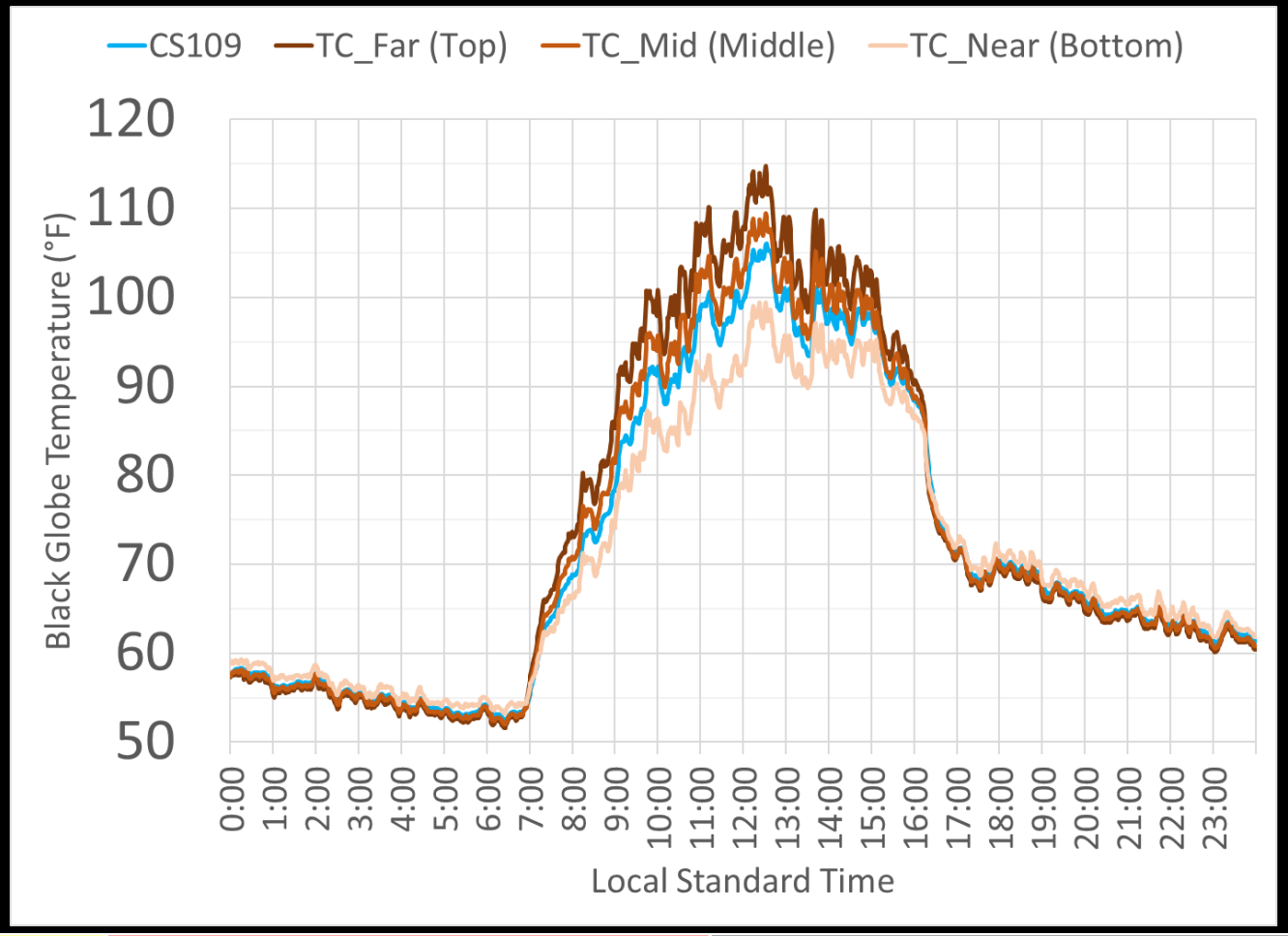
FIGURE 6-5. BlackGlobe mounted to a crossarm (back view)

Temperatures Differences Inside the Black Globe

Two adjacent Campbell Scientific black globes:
1) CS109 angled and standard position
2) Type-T thermocouples at top ("far"), middle ("mid"), and bottom ("near")



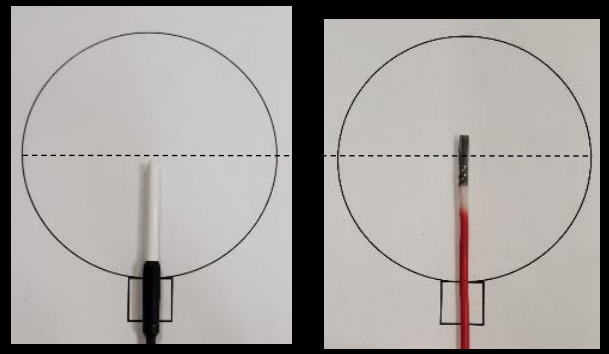
Temperature (°F) inside black globes with CS109 & thermocouples
White Sands Missile Range (WSMR) - 19 November 2020



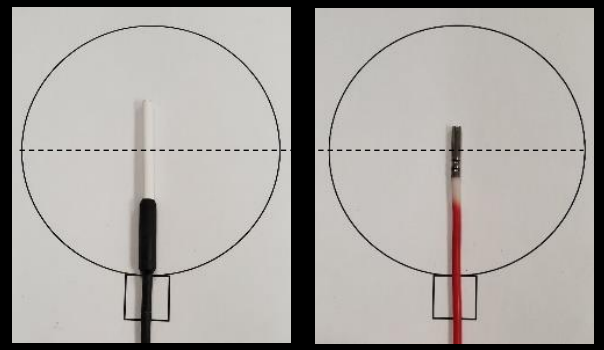
Probe Positioning Inside the Black Globe

Two adjacent Campbell Scientific black globes at WSMR:
1) 04-14 Jan 2021: CS109 vertical & standard position vs Atlas Scientific PT-1000 centered
2) 14-19 Jan 2021: CS109 & Atlas Scientific PT-1000 both centered

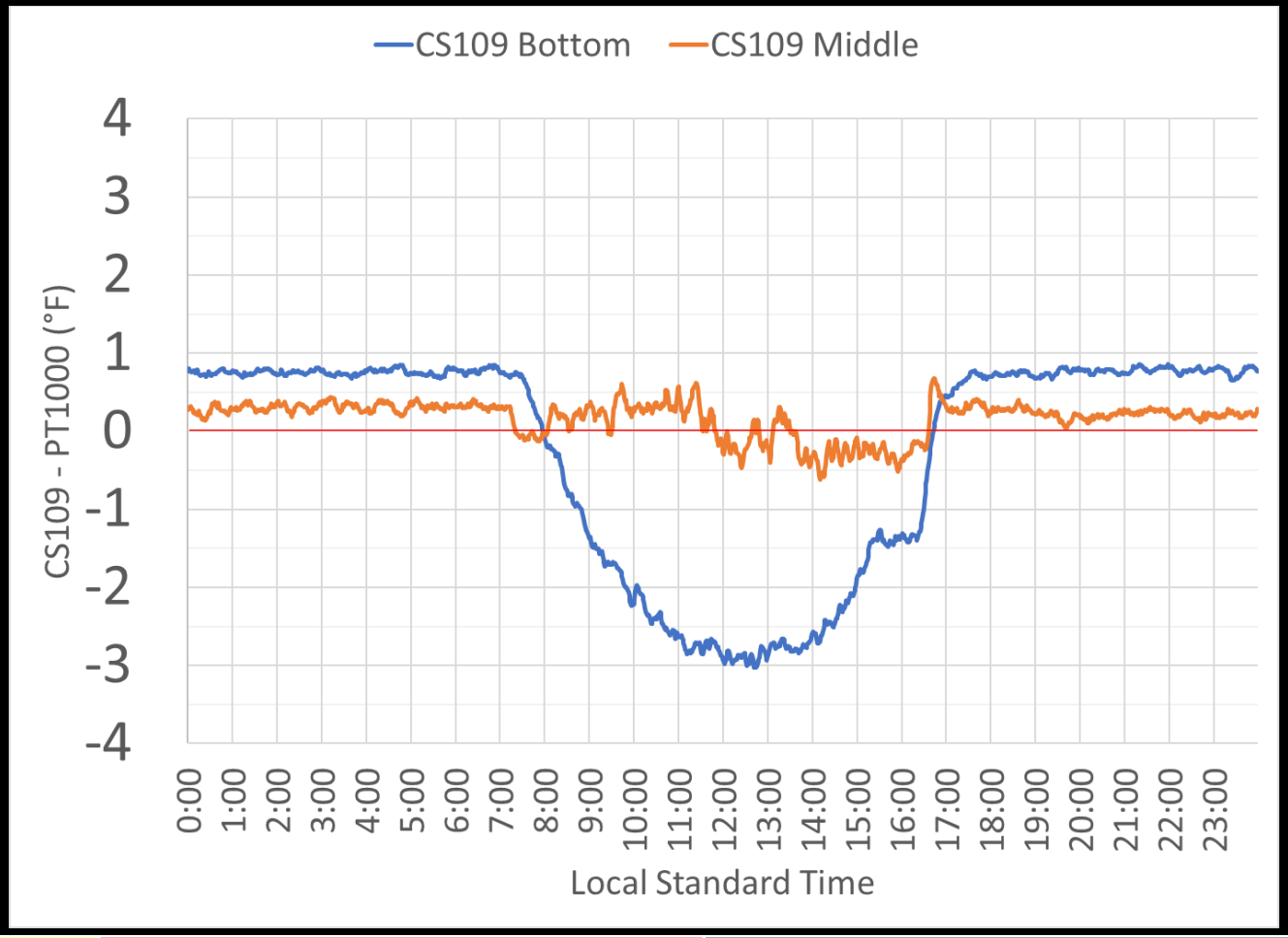
1



2



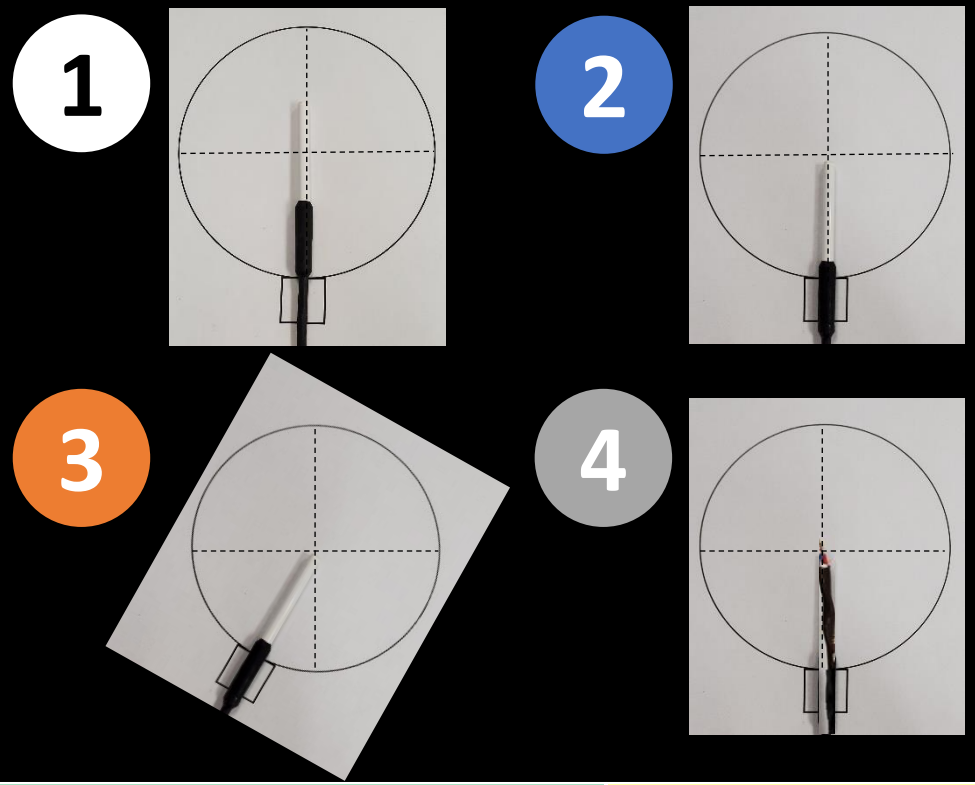
Average temperature difference (°F) between CS109 and PT-1000 probes



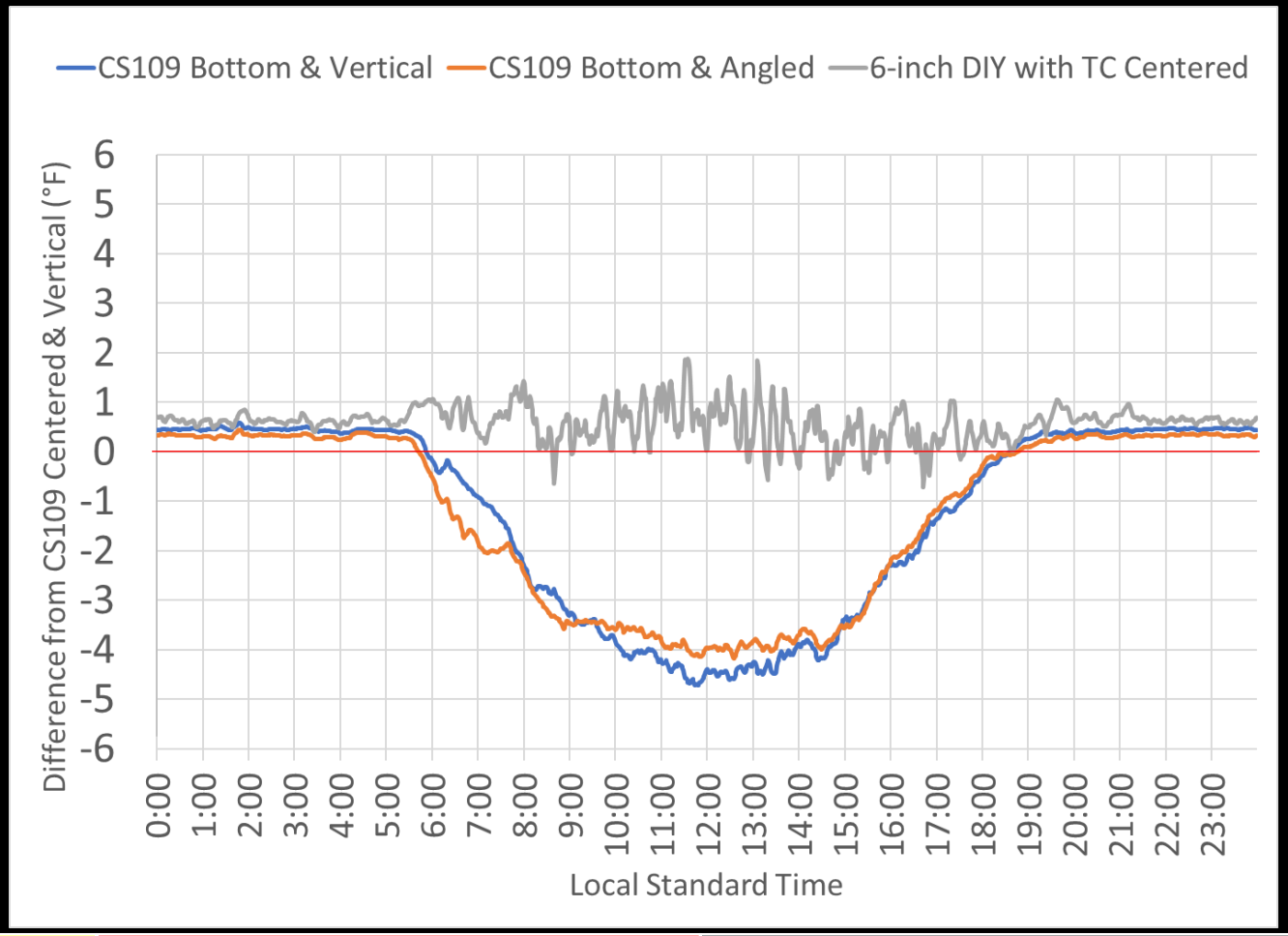
Black Globes with Different Probe Positions

1) CS109 vertical & centered
2) CS109 vertical & "standard" (lower half)
3) CS109 angled & "standard" (lower half)
4) Thermocouple centered in 6-inch "DIY" BG

- *Measurements taken at WSMR 26 Jul-15 Aug 2023*



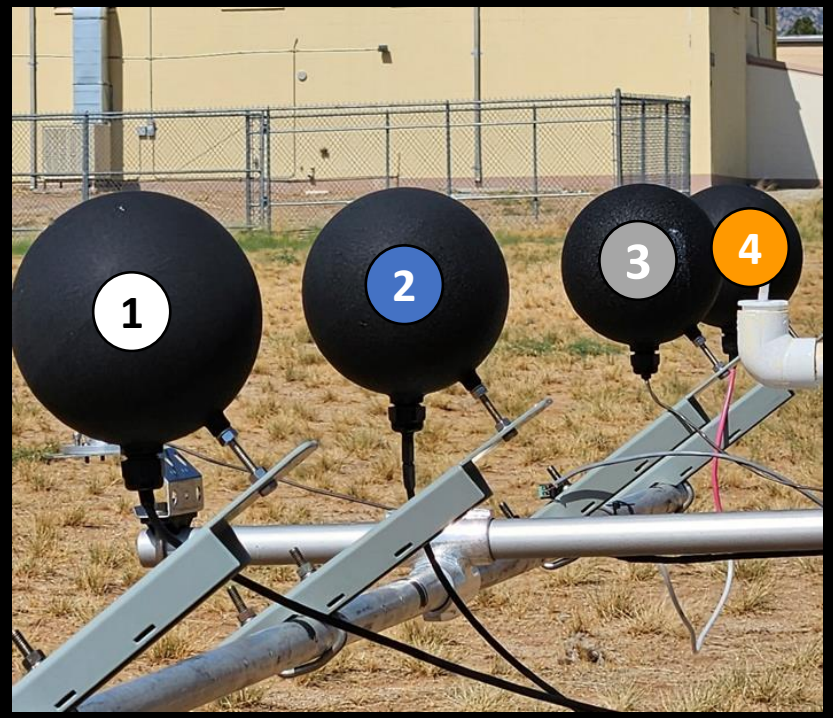
Average temperature difference (°F) from CS109 vertical & centered (#1)



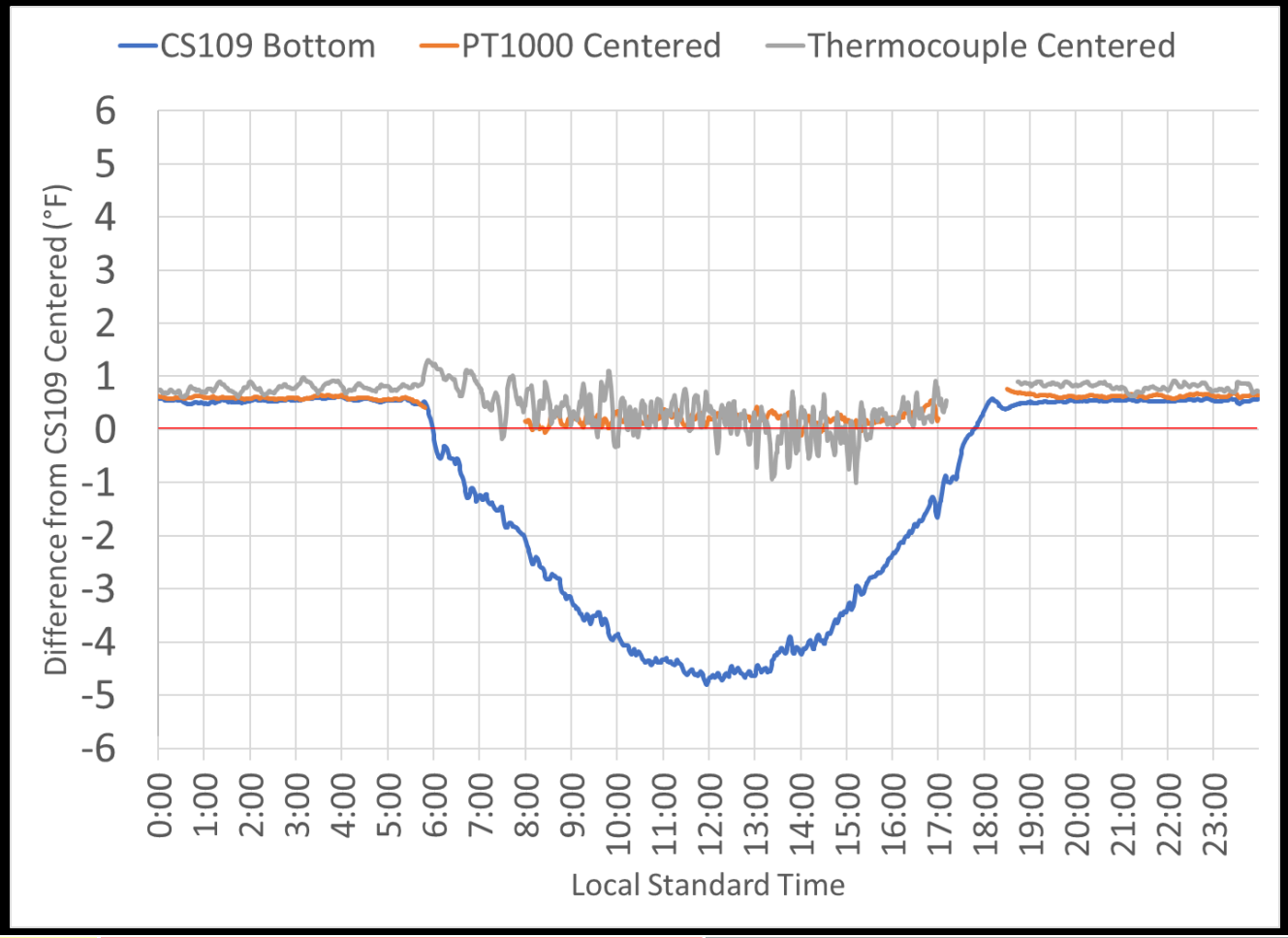
Black Globes with Different Probes

1) CS109 vertical & centered
2) CS109 vertical & "standard" (lower half)
3) Type-T thermocouple vertical & centered
4) Atlas Scientific PT-1000 vertical & centered

- *Measurements taken at WSMR 16 Aug-07 Sep 2023*



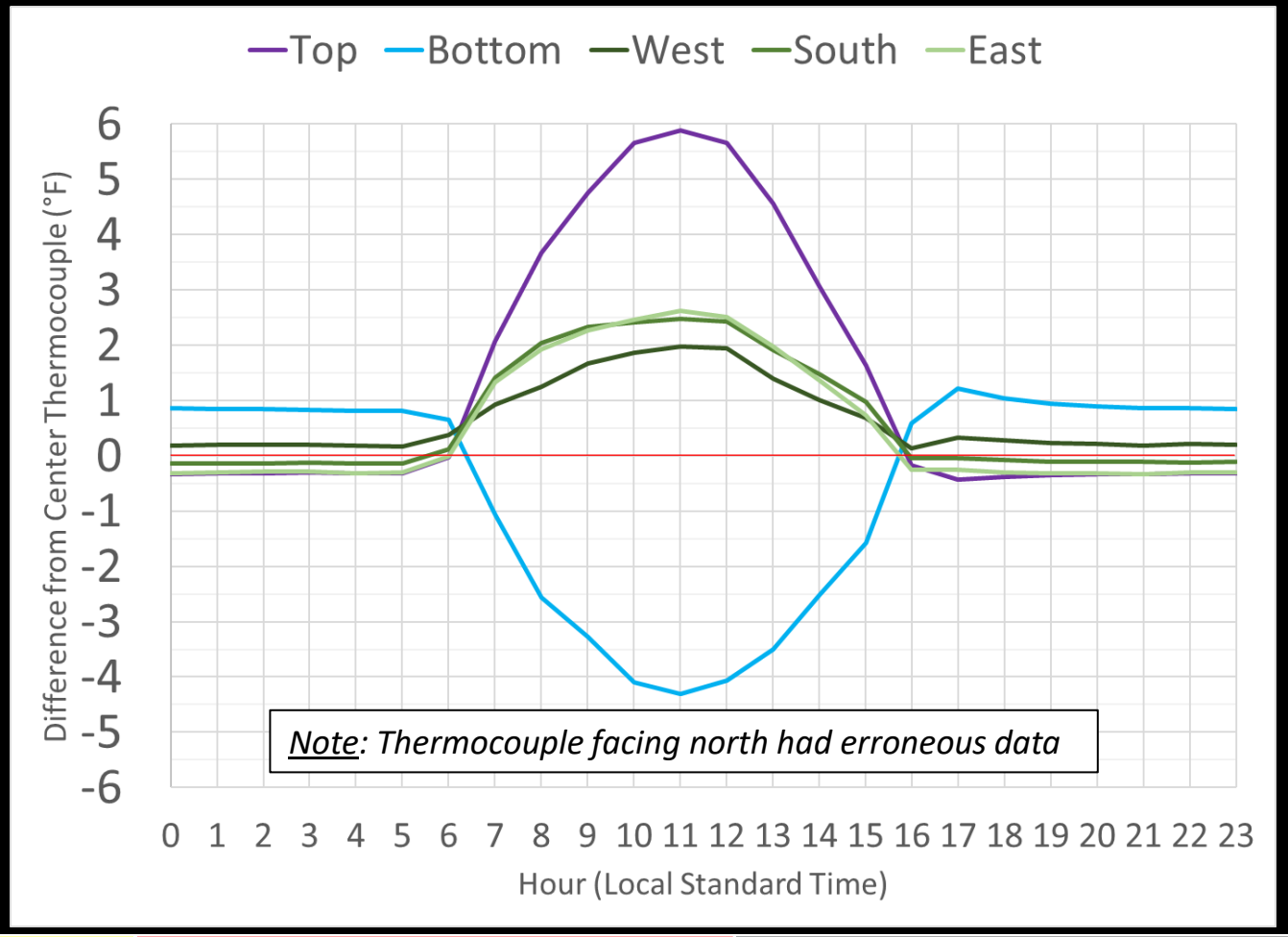
One-minute average temperature (°C) difference from CS109 vertical & centered (#1)



Temperatures Differences in a Black Globe

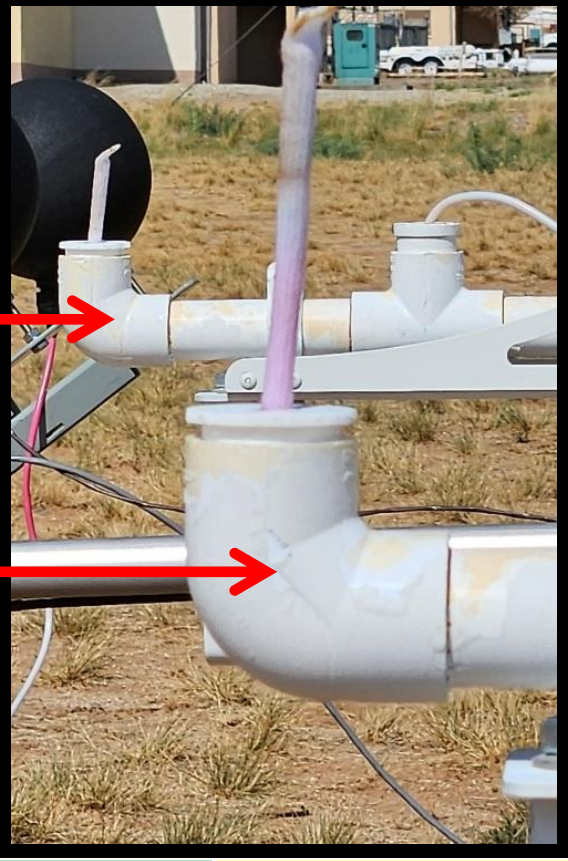
- *Type-T thermocouples inside a 6-inch copper sphere*
- *Measurements taken at WSMR 26 Oct-15 Dec 2023*

One-minute average temperature difference from center thermocouple (°F) grouped by hour

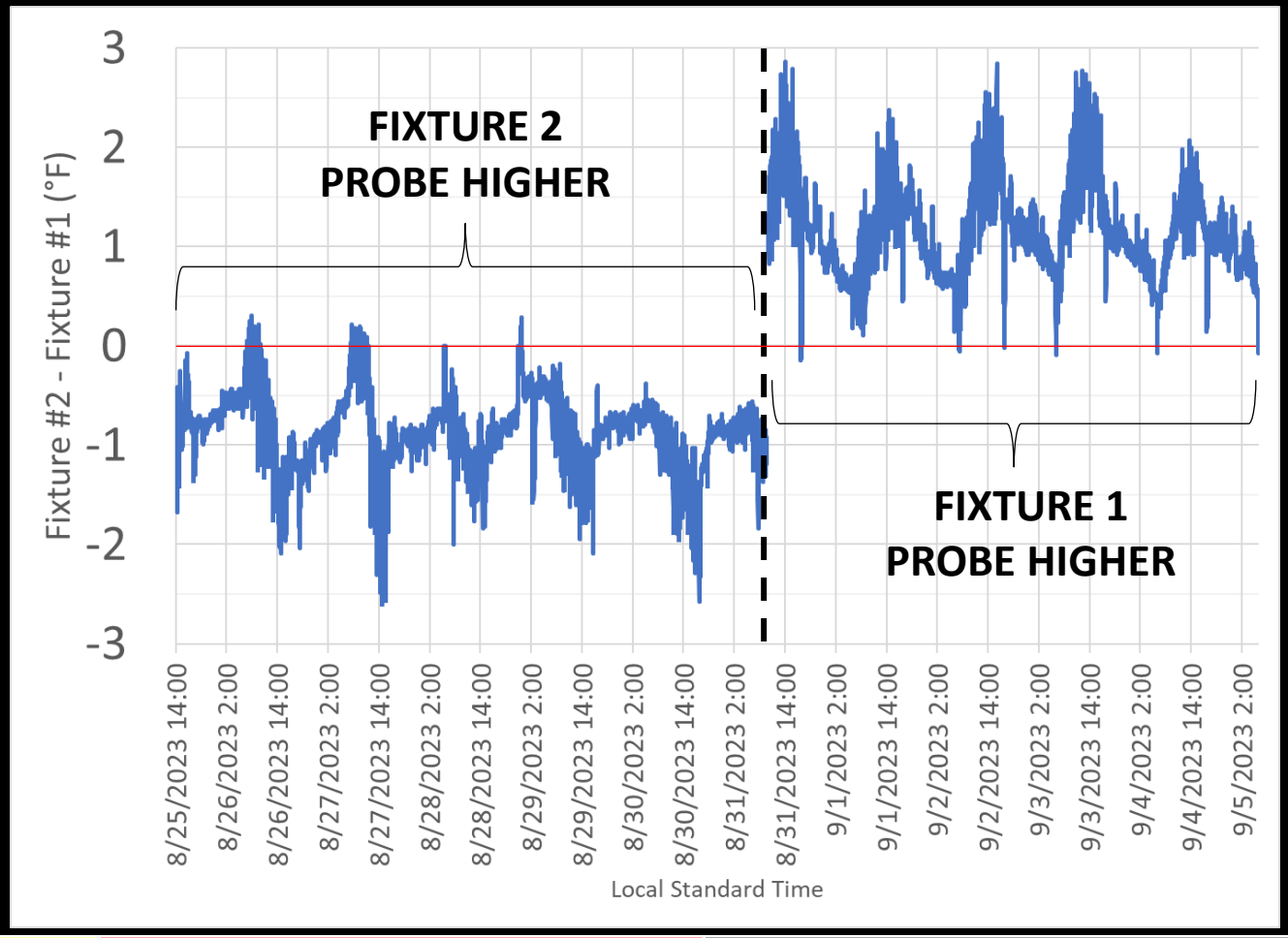


Positioning of Natural Wet Bulb Wick

- *Adjusted probe level in one fixture two inches higher than standard height*
- *Measurements taken at WSMR 25 Aug-05 Sep 2023*



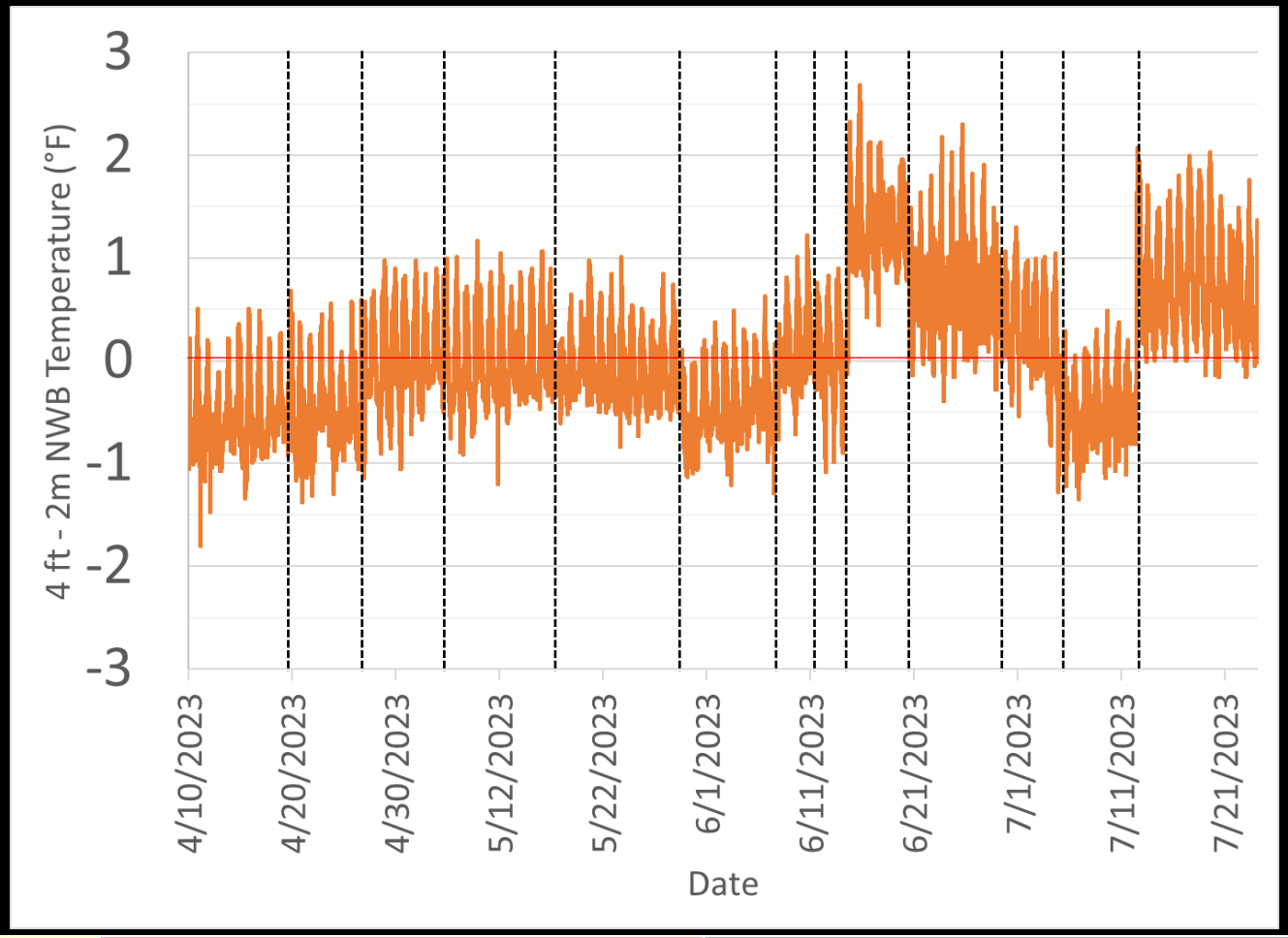
One-minute average NWB temperature difference between two adjacent fixtures (°F)



Internal Consistency of Natural Wet Bulb Measurements

- Dashed lines → Wick changes
- Large step changes in difference between 4ft and 2m NWB temperature occurring after some wick changes
- Sensor equilibrium changing with each wick change?
  - Care taken to minimize probe exposure during change, add water that is at environmental temperature, achieve same fit of wick over probe

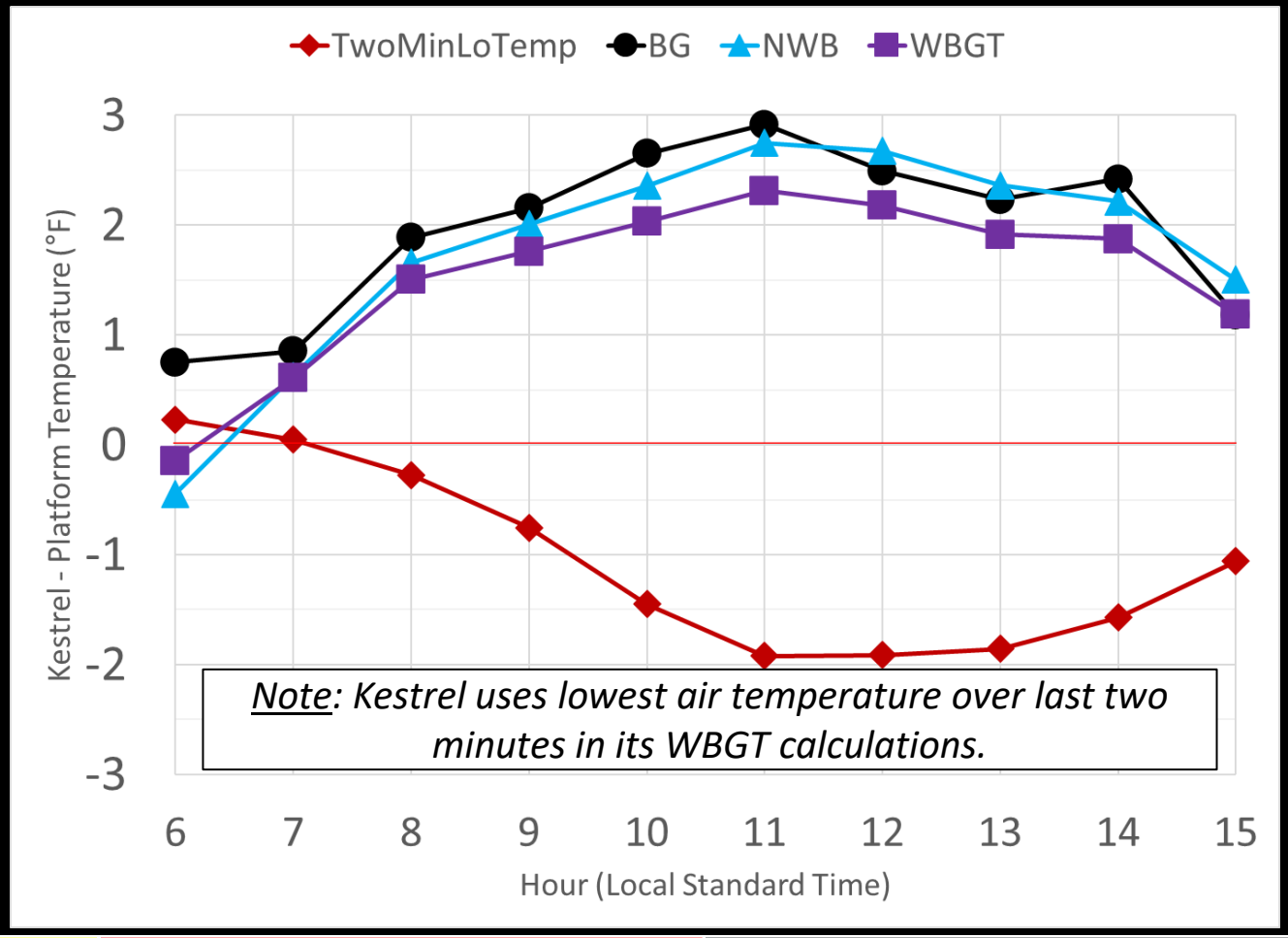
One-minute average NWB temperature difference (°F) between 4ft and 2m AGL



Comparing Portable WBGT Monitor with Full-Scale Platform

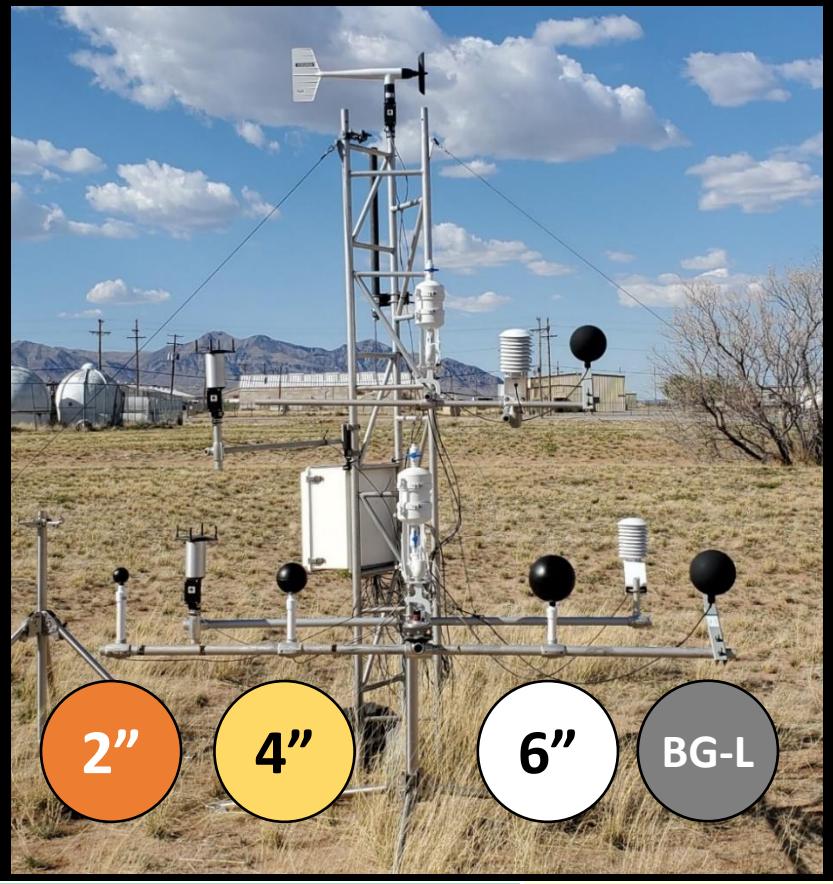
- *Data from Kestrel 5400 Heat Stress Tracker and full-scale platform over 19 separate daytime periods from 07 Aug-07 Sep 2023*

One-minute average temperature difference from full-scale platform (°F) grouped by hour

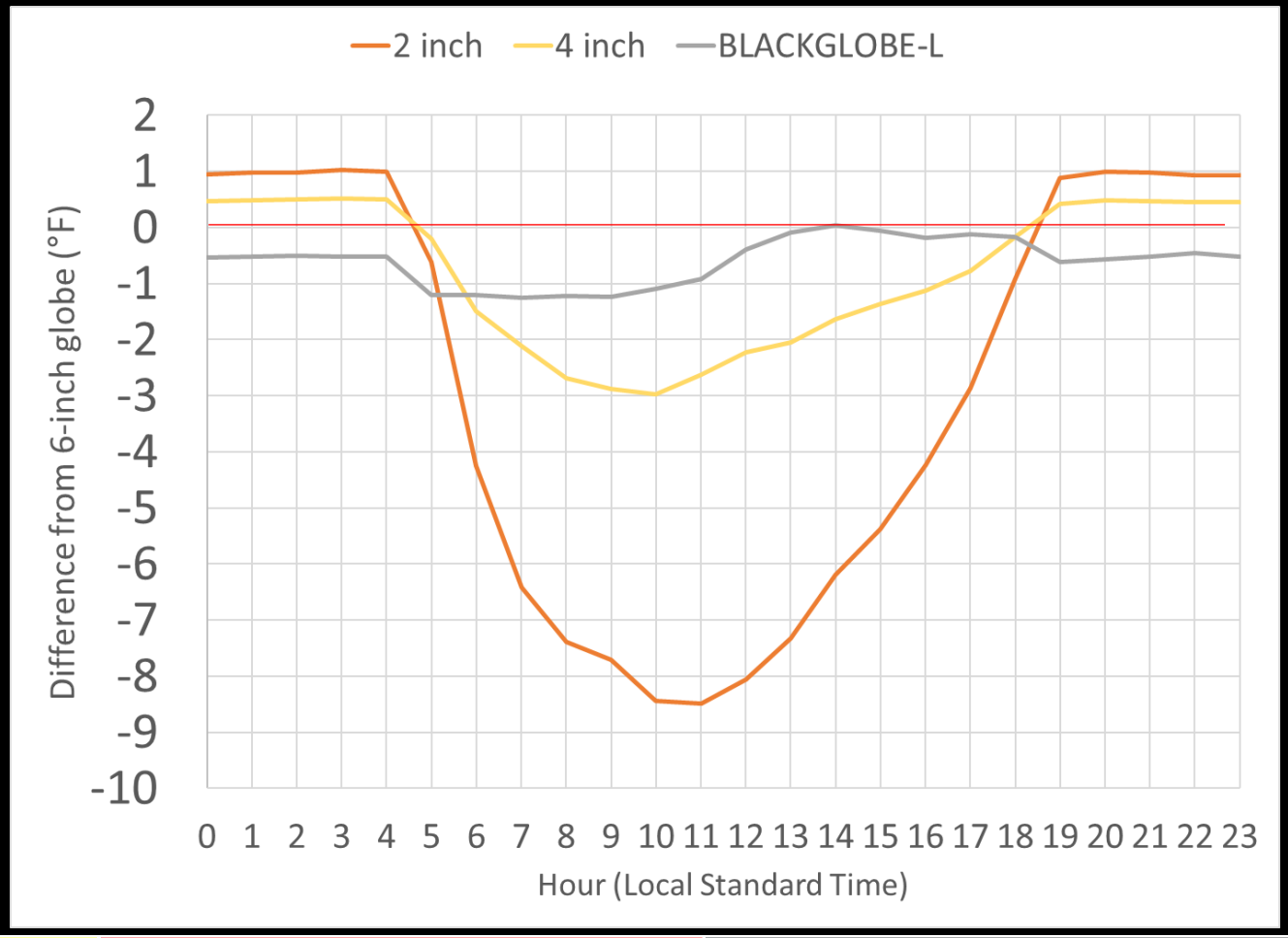


Black Globes of Different Diameter

- *Type-T thermocouples centered inside 2-inch, 4-inch, and 6-inch globes*
- *Measurements taken at WSMR 10 Apr-25 Jul 2023*



One-minute average temperature difference (°F) from 6-inch black globe (#1) grouped by hour



Why is this important?

- WBGT becoming more widely used in heat stress assessment
- Specific numerical guidelines for activity modulation
  - If instrument has a systematic bias, could increase risk
- Evaluation of estimations against measured data
  - Which algorithms really give the best estimates?

Thanks to Project Participants!

Cold Regions Test Center

Yuma Test Center

Redstone Test Center

Dugway Proving Ground

Aberdeen Test Center

White Sands Test Center

96th Test Wing (Eglin AFB)

412th Test Wing (Edwards AFB)

NAWC China Lake

Pacific Missile Range Facility

Space Launch Delta 30 (Vandenberg SFB)

North Carolina ECONet

Hennepin West Mesonet

Thanks for your attention!

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