Verification of Wet Bulb Globe Temperature Index for the North Carolina ECONet

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Background

Wet-bulb globe temperature (WBGT) is a widely used index of heat stress. The metric is used in sports, industry, the military, and other areas to indicate the level of heat stress on humans and animals.

Similar to heat index, WBGT is used to determine safe levels of heat stress on humans. However, WBGT adds in effects of wind and solar activity to its calculation.

WBGT can be easily measured by a black globe (BG) thermometer, which consists of a copper sphere, painted black with a thermometer inside. This sensor, however, is expensive and may require more power and resources at a given weather station.

However, WBGT may be calculated using weather parameters already measured at research weather stations. The National Weather Service in Tulsa, OK has derived an equation to measure black globe temperature. The purpose of this study is to validate this equation under a different climate regime with sensors for the NC ECONet.

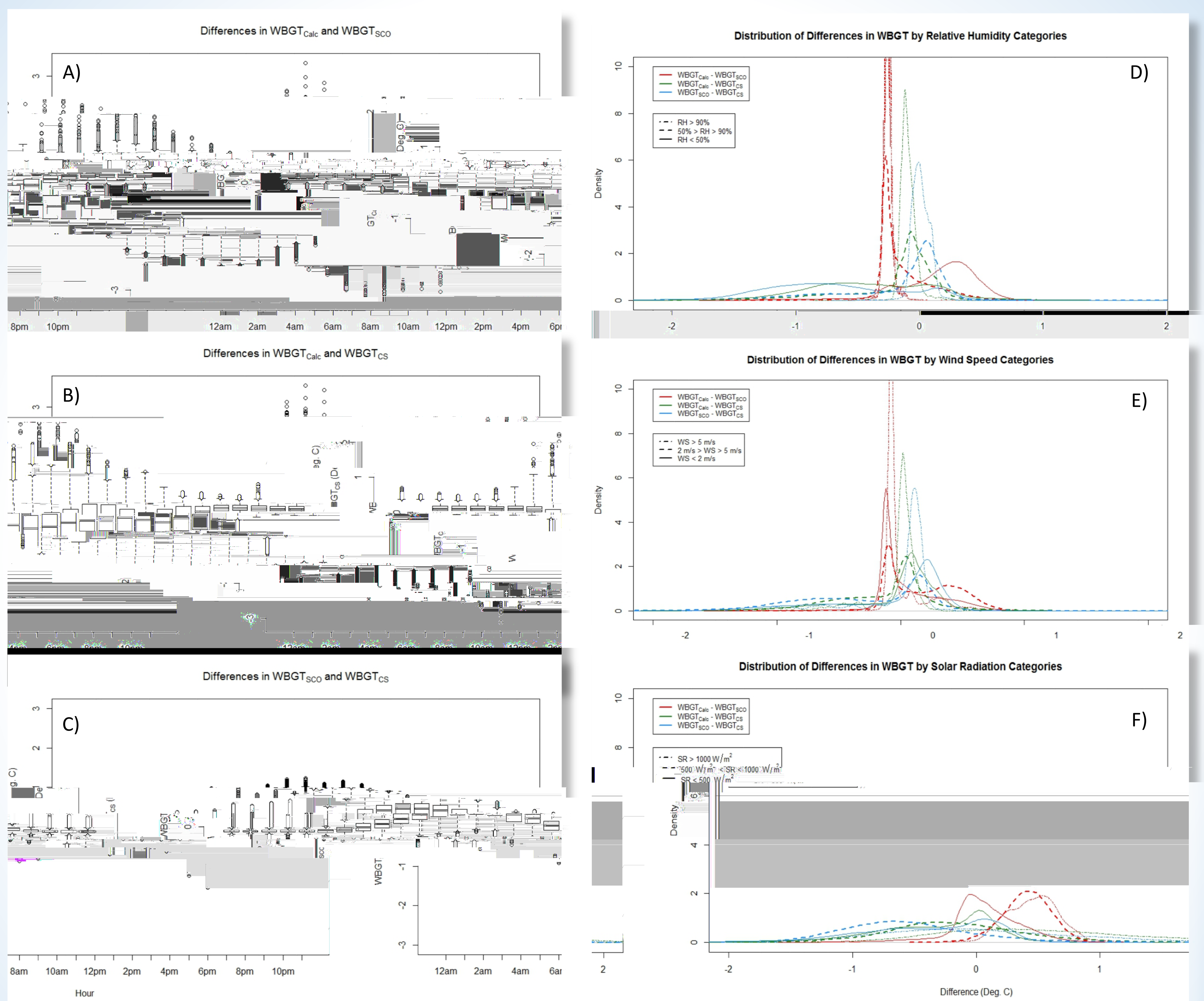
Data and Methods

Two BG thermometers were installed at a testing facility in Raleigh, NC. One was a commercial BG thermometer from Campbell Scientific. Another BG thermometer was designed in-house at the State Climate Office of North Carolina (SCO).

For our calculated BG temperature (Calc), air temperature (T_a; °C), station pressure (P; hPa), and relative humidity (RH; %) were obtained from a Vaisala WXT-520. Wind speed (u; converted to m/hr) was collected from RM Young 05103 and solar radiation (S; W/m^2) was obtained from an Apogee SP-110 pyranometer. All measurements were recorded on a CR1000 datalogger at one minute intervals. Calculated parameters include dew point temperature (T_d; °C) and zenith angle (z; radians).

Data was obtained from May 1 through November 30, 2016. The warm season was chosen to verify the heat stress, since this is the purpose of WBGT. Automated and manual quality control was done on the data to eliminate any erroneous values required for the calculated BG temperature.

Results



Conclusions

- WBGT calculated from weather parameters were routinely within 1°C of WBGT using the globe thermometers.
- Biggest differences between the calculations occur during peak sunlight hours as noticed by Figure F.
- Calculations are closest to observed when wind speeds are light (Figure E) and humidity is high (Figure D). This result may be heavily influenced by nighttime observations, where these conditions are more common.
- Averaging out data to 5 minute, 10 minute, or even 15 minute intervals produced similar distributions of WBGT differences.

Future Work

- Validate that calculations work for multiple sites across the North Carolina ECONet. This will be done through different regions.
- Verify that the main source of variability in the calculated version of WBGT is solar radiation. Explore solutions to the issue.
- Create a map of WBGT indices to spatially determine areas of potentially hazardous conditions.
- Create an alert system for stakeholders to warn of potentially hazardous conditions through e-mail or text.

Calculating WBGT

WBGT is calculated by the following equations:
If outdoors with no solar load:

$$WBGT = 0.7NWB + 0.3GT$$

If outdoors with a solar load:

$$WBGT = 0.7NWB + 0.2GT + 0.1DB$$

where:
NWB = Nature Wet-Bulb Temperature
GT = Black Globe Temperature
DB = Dry Bulb Temperature

Wet bulb temperature is calculated using the following algorithm:

$$\begin{aligned} NWB &= T\tan^{-1}\left[0.151977(RH + 8.313659)^{1/2}\right] \\ &+ \tan^{-1}(T + RH) - \tan^{-1}(RH - 1.676331) \\ &+ 0.00391838(RH)^{\frac{3}{2}}\tan^{-1}(0.023101RH) \\ &- 4.686035 \end{aligned}$$

Calculating GT:
The estimate of globe temperature for a calculated example is:

$$GT = \frac{B + CT_a + 7680000}{C + 256000}$$

where:

$$B = S\left(\frac{f_{db}}{4\sigma\cos(z)} + \left(\frac{1.2}{\sigma}\right)f_{dif}\right) + (\varepsilon_a)T_a^4$$

$$C = \frac{0.315u^{0.58}}{(5.3865 * 10^{-8})}$$

$$\varepsilon_a = 0.575(e_a)^{1/7}$$

$$\begin{aligned} e_a &= exp\left(\frac{17.67(T_d - T_a)}{T_d + 243.5}\right) * (1.007 + 3.46 * 10^{-6}P) \\ &* 6.112exp\left(\frac{17.502T_a}{240.97 + T_a}\right) \end{aligned}$$

$$\sigma = 5.67 * 10^{-8}$$

References

Budd, Grahame M, 2008. Wet-bulb globe temperature (WBGT) – its history and its limitations. *Journal of Science and Medicine in Sport*. **11**, 20-32.

Dimiceli, Vincent E. and S. F. Piltz. "Estimation of Black Globe Temperature for Calculations of the WBGT Index." http://www.weather.gov/media/tsa/pdf/WBGTpaper2.pdf