Development of a Wet Bulb Globe Temperature (WBGT) Approximation Equation from Standard Meteorological Variables and Implementation of an Automated Heat Stress Condition Display at the Eglin Range

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What is WBGT?

- **WBGT created in 1950s through study funded by US Office of Naval Research**
  - **Derived measurement to provide objective measure of risk of heat related injury**
  - **Categorical thresholds developed to reduce likelihood of heat injuries to workforce during periods of warm weather/high humidity**
  - **Still widely used by US military and other organizations**
  - **US Air Force defines four heat stress categories based on WBGT**

- **Through June of 2014; WBGT measured at a single site every hour or two by Eglin AFB Bioenvironmental Personnel and applied to entire 724 square mile Eglin Range**

$$\text{WBGT} = 0.7 \, (T_{NWB}) + 0.2 \, (T_{BG}) + 0.1 \, (T_{DB})$$

T_{BG} 20% T_{NWB} 70% T_{DB} 10%

WBGT Range (°F)	WBGT Range (°C)	Severity	Flag Color
82.0 – 84.9	27.8 – 29.4	Low	Green
85.0 – 87.9	29.4 – 31.1	Moderate	Yellow
88.0 – 89.9	31.1 – 32.2	Severe	Red
90.0+	32.2+	Extreme	Black

Heat Stress Notifications
# at Eglin Range – History (Cont.)

- **Summer 2014 and May/June 2015; USAF weather observers took over measurements to ensure accuracy and higher frequency to build dataset for research and algorithm development; single measurement still applied to entire Eglin Range**

- **June 2015; Automated WBGT measurement and dissemination process on Eglin AFB's local weather dissemination system begins. Tailored heat stress data provided for 16 sites on Eglin Range**

Size of Eglin Land Range

Eglin Range
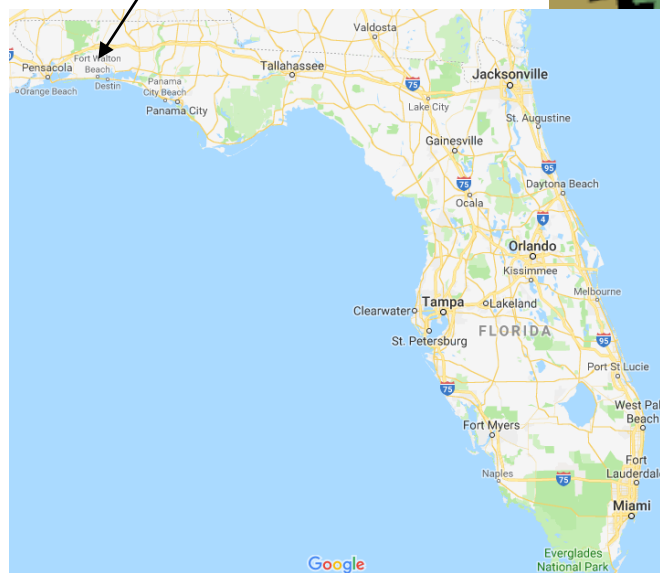
Size of Eglin Land Range

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Slide Notes from Previous Slide:
Location of Eglin Range within Florida and proportional size of DC Beltway shown next to Eglin land range map to help illustrate size of Eglin Test and Training Complex (referred to as "Eglin Range" in presentation). The land portion of the ETTR is a 724 square mile area.

Developing a Formula for WBGT Using Standard Weather Data

- **Reviewed various journal articles on subject**

  - **Hunter and Minyard (1999)**
  - **Houtas and Teets (2012)**
  - **Liljegren (2008)**
  - **Sauter (2013)**

- **Tested WBGT formula from a paper by Bernard and Barrow (Industrial Health, 2013)**

Bernard and Barrow WBGT Formula:

$$WBGT = 1.1 + 0.66\ T_{DB} + 2.9\ P_{v\text{-}Met} - 1.8\ SUN$$

T_{DB} = Temperature (deg C)

$P_{v\text{-}Met}$ = Water Vapor Pressure

$\quad = 0.6107 e^{(17.27 * T_{DP})/(T_{DP} + 237.3)}$ where T_{DP} = dew point temp

SUN = 0 for direct sun and 1 for shade

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Slide Notes from Previous Slide:

Bernard T. E., and C. A. Barrow, 2013, Empirical approach to outdoor WBGT from meteorological data and performance of two different instrument designs. *Ind Health*., **51**, 79-85.

Bernard and Barrow WBGT Formula Info

- **Advantages:**
  - **Easy calculation with only standard temp and dew point temperature required**

- **Disadvantages:**
  - **Differences in the "black globe" temp component (20%) of instrumented WBGT calculation, not accounted for (black globe temp affected by sun angle and clouds)**
  - **Water vapor pressure (derived from dew point) does not take into account cooling effect of wind.**

Developing a WBGT Formula at Eglin Range

- **In summer of 2014 and 2015, total of 2210 WBGT measurements collected, along with associated temp, dew point temp, wind speed, and solar elevation angle data.**

- **Multi-variate regression analysis was conducted on meteorological and solar parameters to develop the optimal WBGT equation.**

Best-Fit WBGT Formulas for Various Parameters

(1) $\textbf{WBGT} = \textbf{4.18} + \textbf{0.59 T}_{\textbf{DB}} + \textbf{0.32 T}_{\textbf{DP}}$

(2) $\textbf{WBGT} = \textbf{5.16} + \textbf{0.49 T}_{\textbf{DB}} + \textbf{0.34 T}_{\textbf{DP}} + \textbf{2.46 sine (SEA)}$

(3) $\textbf{WBGT} = \textbf{4.50} + \textbf{0.52 T}_{\textbf{DB}} + \textbf{0.35 T}_{\textbf{DP}} + \textbf{2.68 sine (SEA)} - \textbf{0.10 WS}$

$\textbf{T}_{\textbf{DB}}$ = Temperature (deg C)

$\textbf{T}_{\textbf{DP}}$ = Dew Point Temperature (deg C)

$\textbf{SEA}$ = Solar Elevation Angle in degrees

$\textbf{WS}$ = Wind Speed in kts

Statistics for Regression Equations	Equation (1)	Equation (2)	Equation (3)
R^2	0.57	0.65	0.68
Standard Error	1.23 deg C	1.12 deg C	1.07 deg C

# Best-Fit WBGT Formulas for Various Parameters

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R^2 is the coefficient of determination. It is a measure of how close the data are to the fitted regression line. A value of 1.0 would be a perfect fit. A value of 0.0 would mean there was no fit of the data to the regression line. Standard error is the standard deviation of its sampling distribution (or an estimate of the standard deviation).   The lower the standard error, the more accurately the data fits the regression line.
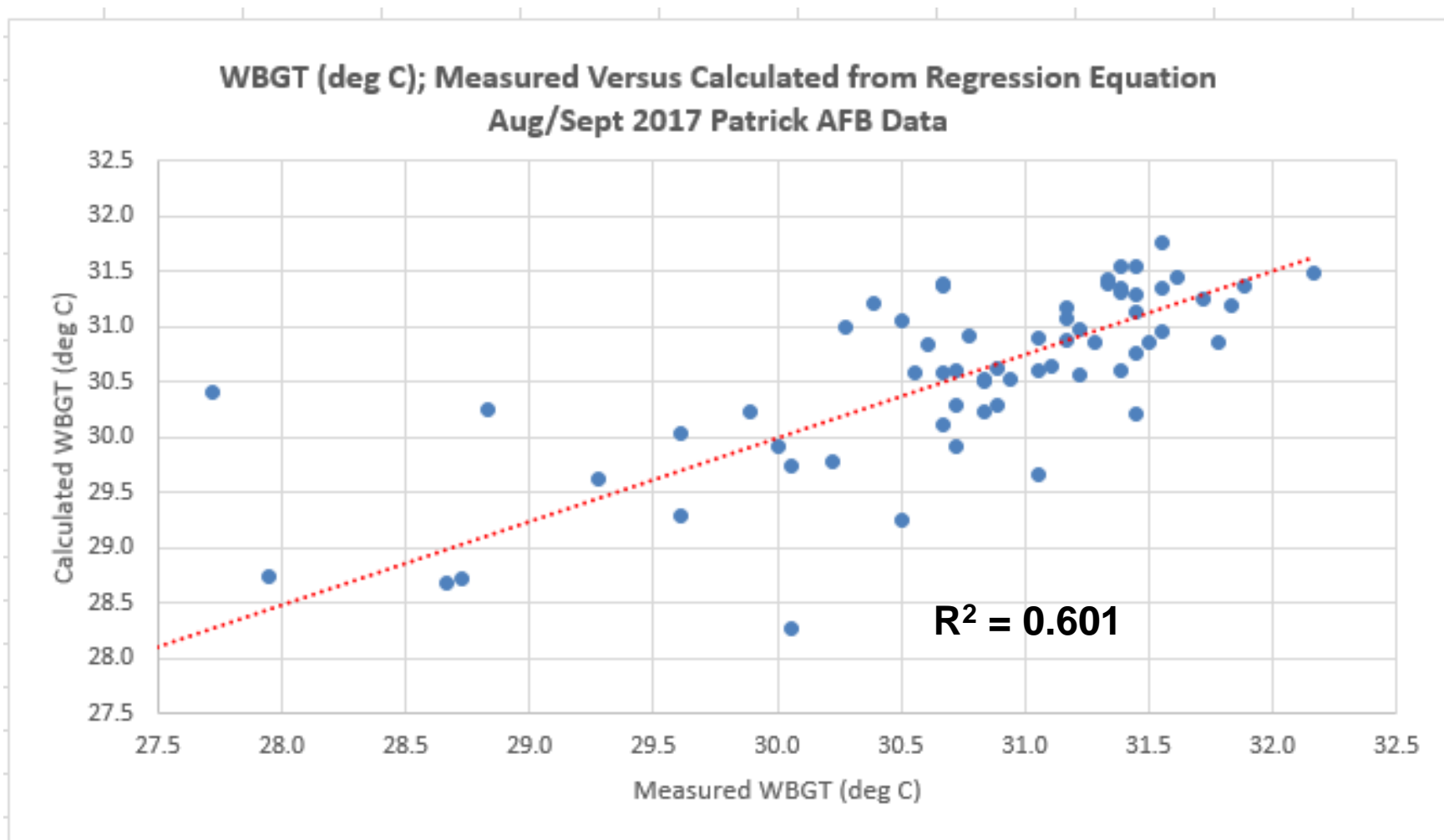
Results; Measured WBGT Versus Calculated (2210 Eglin AFB Observations)

WBGT (deg C); Measured Versus Calculated from Regression Equation

$R^2 = 0.678$
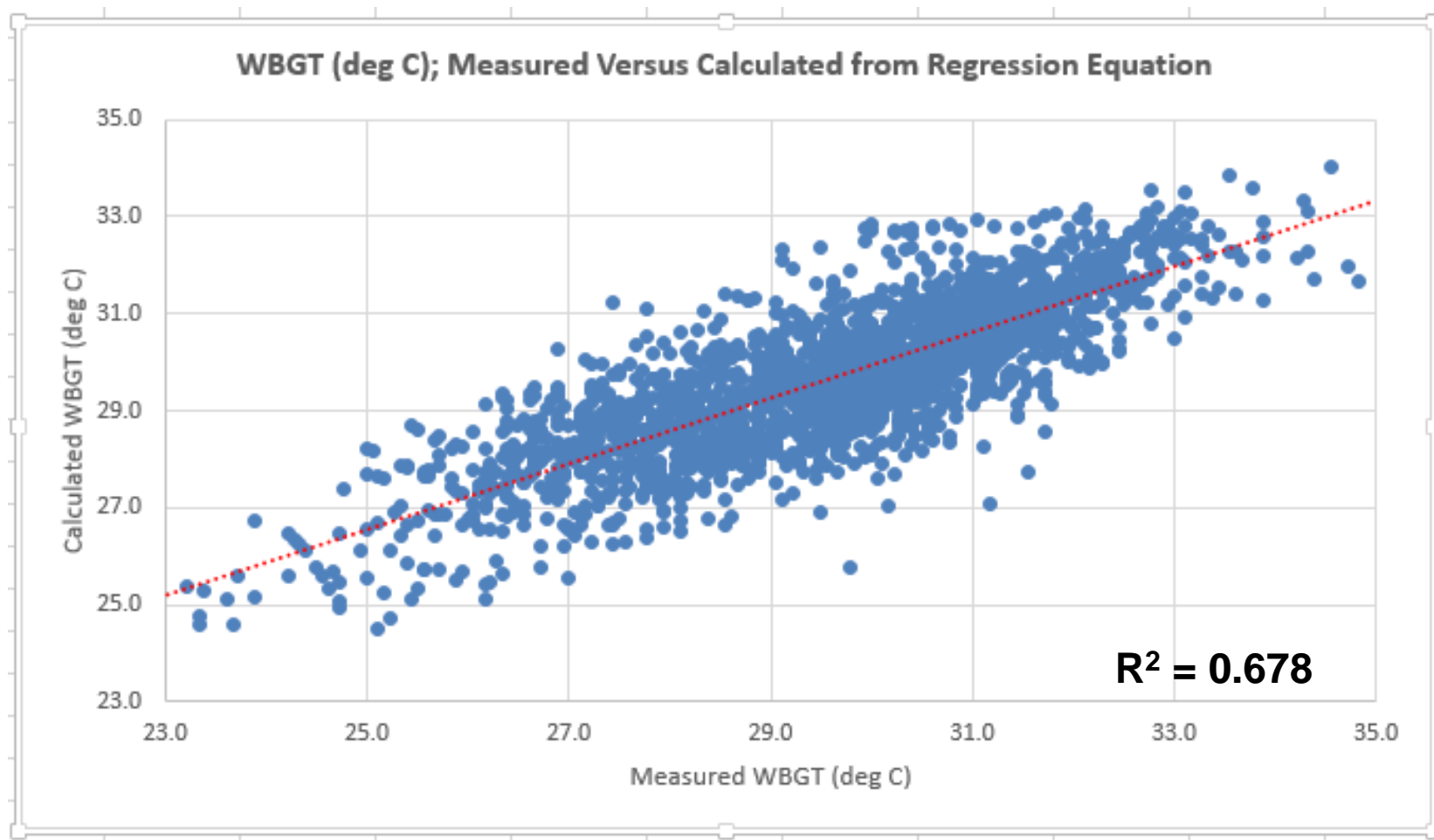
Results; Measured WBGT Versus Calculated (67 Patrick AFB Aug/Sep 2017 Observations)

WBGT (deg C); Measured Versus Calculated from Regression Equation
Aug/Sept 2017 Patrick AFB Data

$R^2 = 0.601$

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Slide Notes from Previous Slide:
Eglin's WBGT formula was used on a small data set (67 observations) from late summer 2017 at Patrick AFB FL. The data is plotted in the graph above.

Results; Measured WBGT Versus Calculated (Eglin AFB and Patrick AFB)

Type of Measured Versus Observed Comparison	Percent (Eglin AFB FL)	Percent (Patrick AFB FL)
Same Thermal Heat Stress Category	52.7	65.7
Within one Thermal Heat Stress Category	95.8	98.5
Within two Thermal Heat Stress Categories	99.8	100
Within 1.0 °C	69.6	89.6
Within 2.0 °C	93.1	98.5

Example Eglin Range Heat Stress Display Chart (early June 2016)
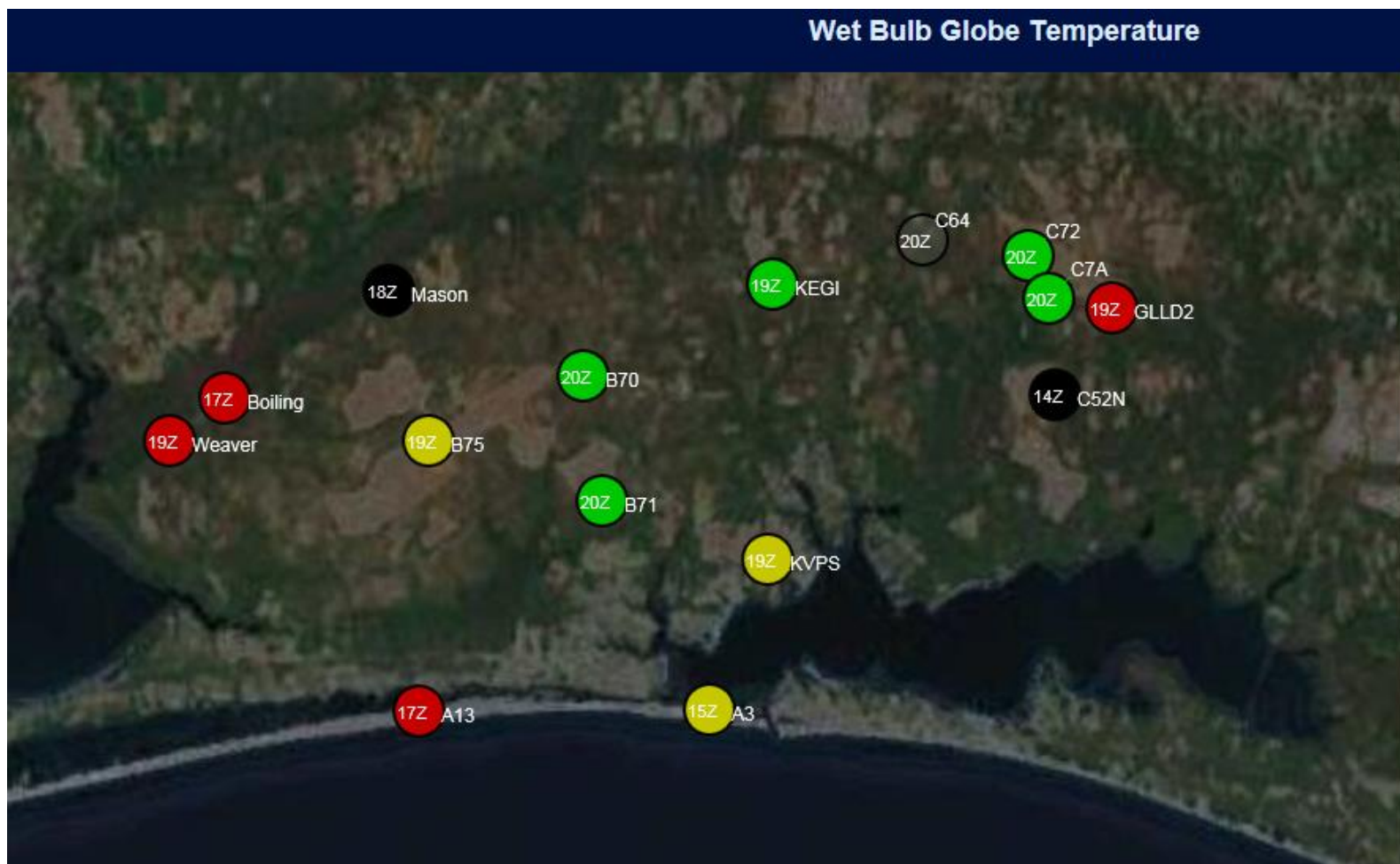
Example Eglin Range Heat Stress Display Chart (early June 2016)

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Slide Notes from Previous Slide:

Isolated convective activity over central parts of Eglin Range keeping heat stress category lower at many sites.

Example Eglin Range Heat Stress Display Chart (16 June 2016)

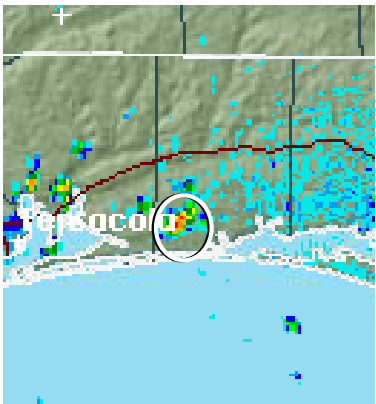# Example Eglin Range Heat Stress Display Chart (16 June 2016)

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Slide Notes from Previous Slide:

Complex of showers and thunderstorms moving in from east to west, dramatically dropped calculated heat stress levels compared to sites in western portion of range where skies were still mostly clear.
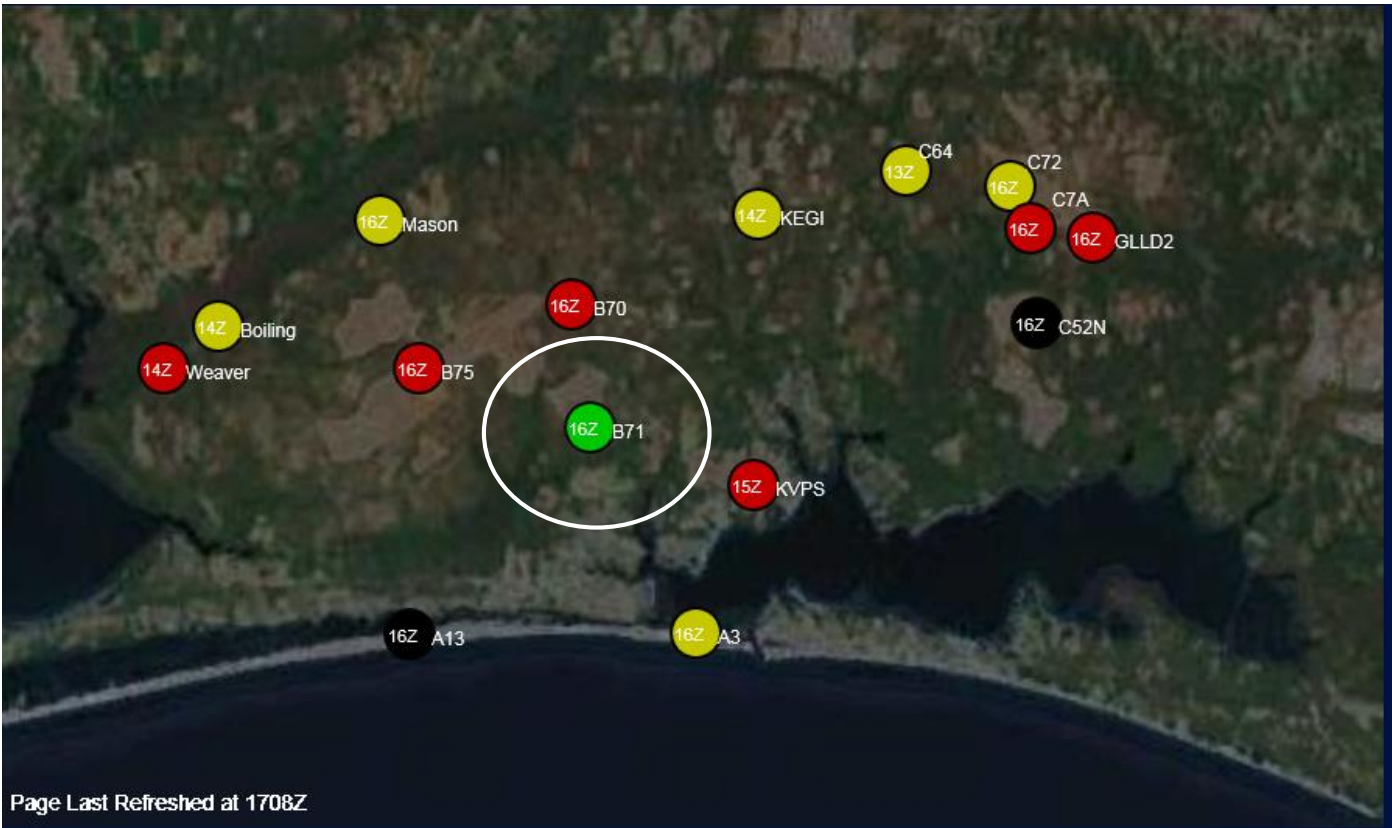
Example Eglin Range Heat Stress Display Chart (19 Aug 2016)

19 Aug 2016/1632Z

19 Aug 2016/1703Z

Page Last Refreshed at 1708Z

Example Eglin Range Heat Stress Display Chart (19 Aug 2016)

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Slide Notes from Previous Slide:
Cell develops at B71 at around 17Z; WBGT had dropped to "green" category by 16Z.

Why Automated WBGT Formula Superior to Measured for Eglin Range

- **Calculated WBGT values (and resultant heat stress category) monitored every two minutes/updated when critical thresholds are passed**

- **More frequent automated measurements smoothed anomalies in hourly measured WBGT readings**

- **More site specific readings now available via Eglin weather display system for 16 sites across Eglin Range**

- **Data still available during periods of rain/lightning (manned sensor had to be brought inside when rain was in area)**

Future Work

- **Collect measured WBGT data at site with solar radiation sensors to derive a WBGT formula including measured solar irradiance data.**

- **Determine how many observations/how long of a period of measurements necessary to derive an equation**

- **Develop different/modified equation for various weather regimes which may occur during Eglin Range summer**

- **Use model data to provide forecast WBGT capability**

- **Collect measured WBGT data at desert (low moisture) location and in other climatological areas for AF-wide application**

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Questions?

References

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