Heat Stress Equation Development and Usage for Dryden Flight Research Center (DFRC)

Franzeska Houtas

TYBRIN Corporation

Edward H. Teets Jr.

NASA Dryden Flight Research Center

Outline

- Heat Stress Intro

- Background

- Development

- Implementation/Automation

Leading causes of weather fatalities
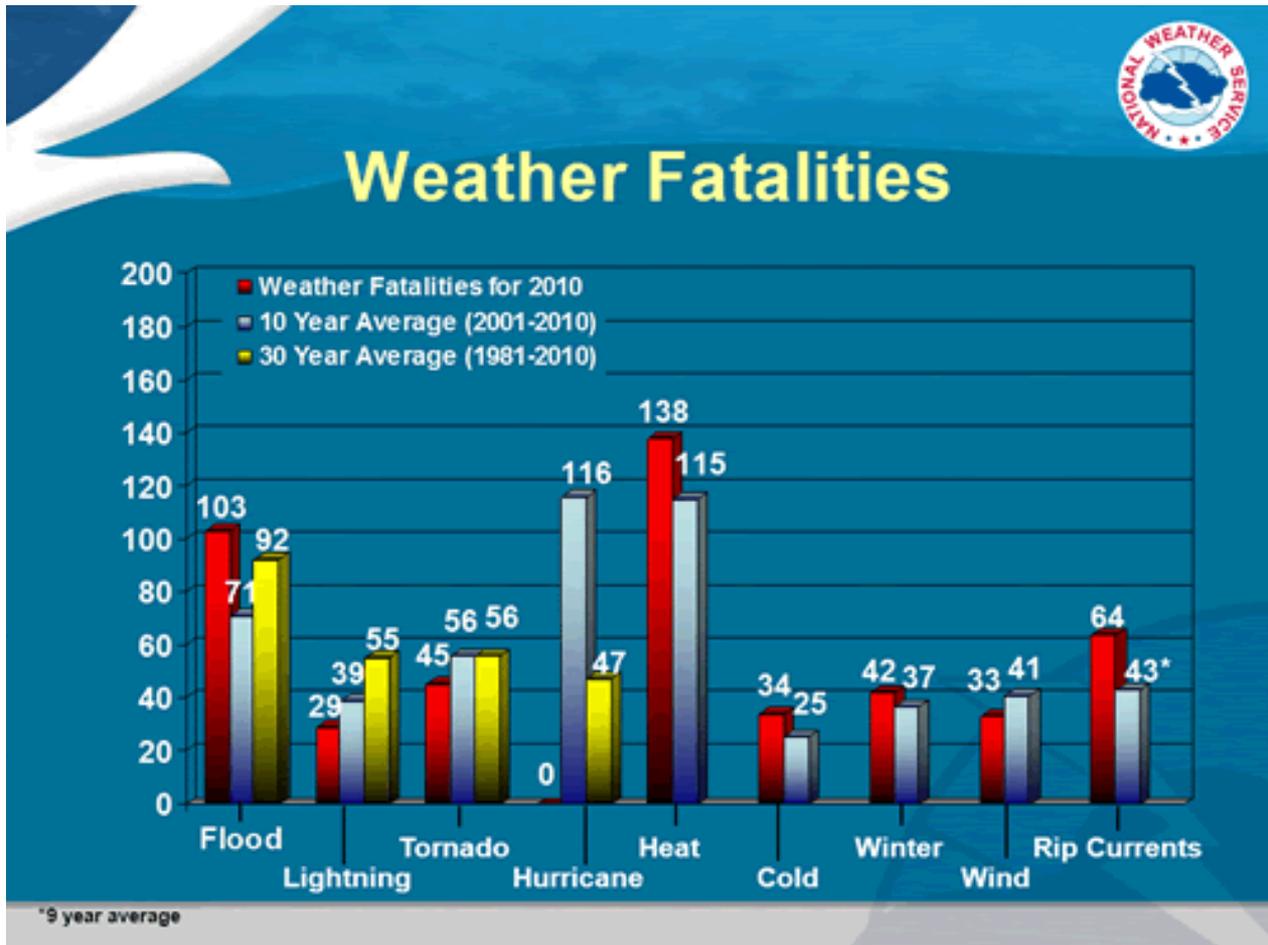
Heat Stress

- Net heat load of metabolic and environmental factors
- Four methods of heat loss: conduction, convection, radiation, evaporation
  - Normal: convection and radiation
  - Heat stress: evaporation (up to 80%)
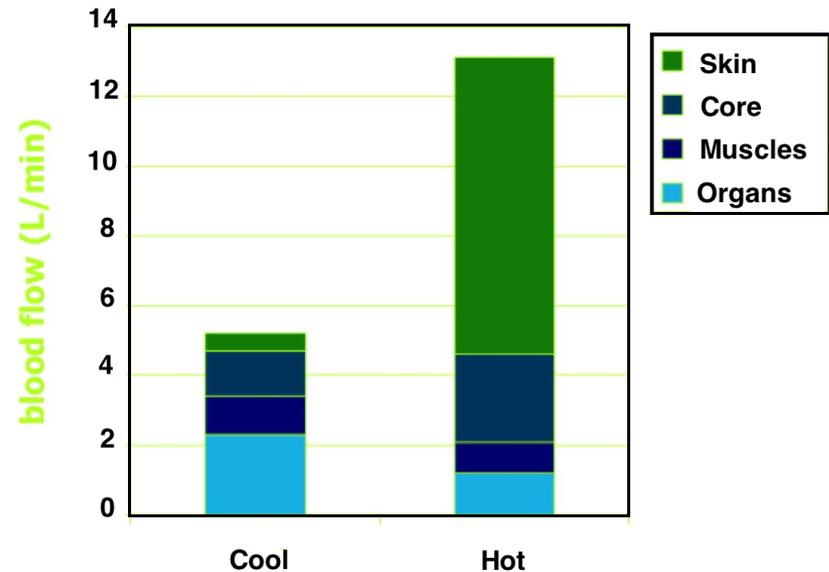
Illnesses

- Heat rash
- Heat Syncope
- Heat cramps
- Heat exhaustion
- Heat stroke

Predisposing Factors

- Certain Medications
- Very small body size
- Poor nutrition
- Overweight
- Over 40 years old (the older the more sensitive)
- Previous heat illness
- Heart disease
- High blood pressure
- Diabetes
- Skin disease
- Liver, kidney, and lung problems

Predisposing Factors (cont.)

- Physical activity
- Poor physical condition
- Fatigue
- Excessive clothing
- Dehydration
- Being female
- Being pregnant
- Alcohol, caffeine, nicotine intake
- Sunbathing

Vehicle Temperatures

- Previous studies have examined the internal environment of motor vehicles.

- One study showed that with an outdoor ambient temperature of 98.2°F, 75% of the maximum temperature rise in the vehicle occurred within 5 minutes of closing the doors and maximized within 15 minutes to 124 –153°F

- Opening the windows 20 cm (8 inches) had minimal effect on the temperature rise and maximum temperature attained.

Vehicle Temperatures
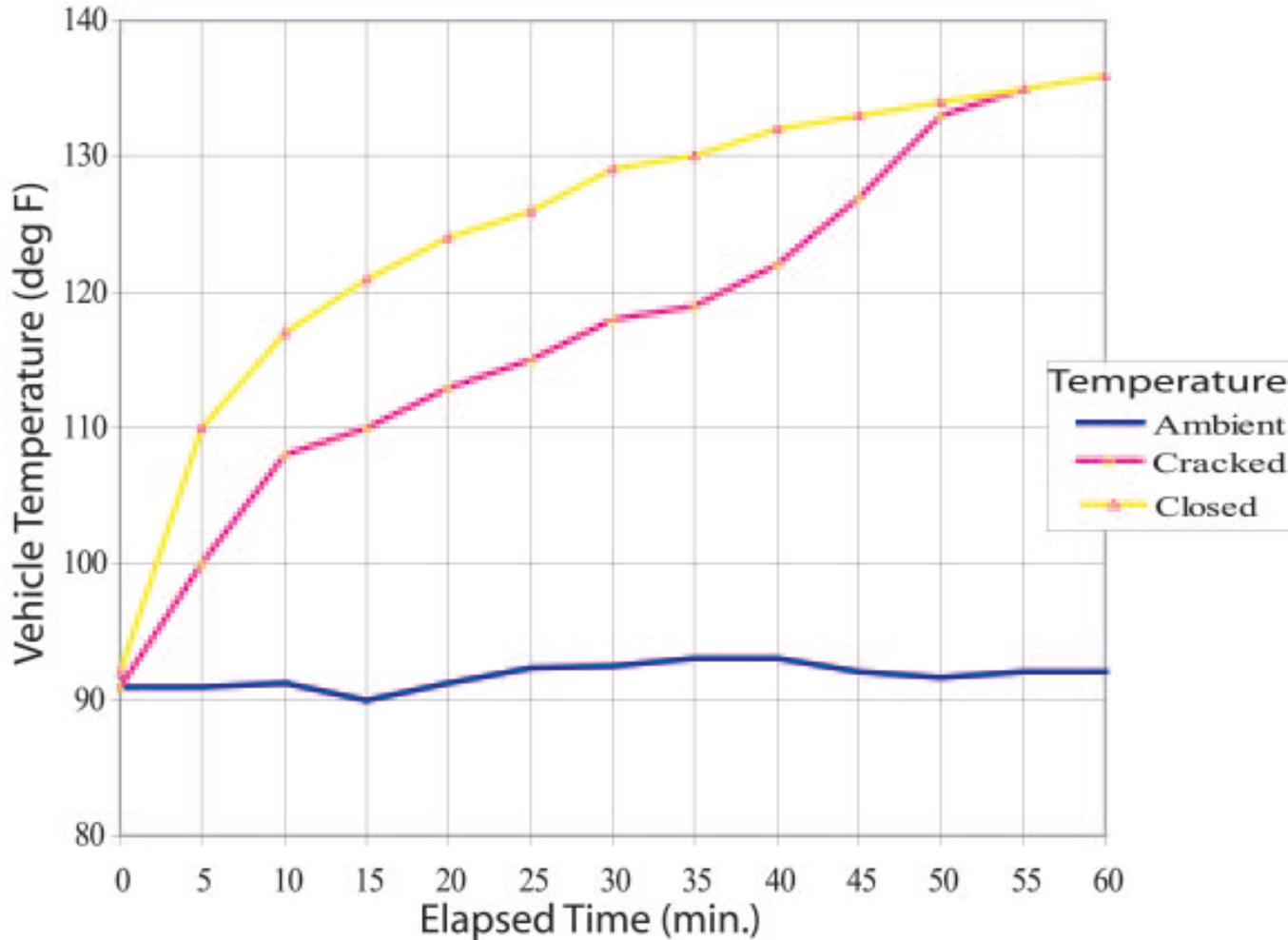
Vehicle Temperatures

- A study done at Dryden has shown that using a sunshade and having windows cracked is the best method of reducing the temperature inside a parked vehicle

- [Legend: NS – No sun shade, SS – sun shade]

White Car Dry Bulb

Temperature (C)

Legend:
- NS, Windows Up (red)
- NS, Windows Cracked (green)
- SS, Windows Up (blue)
- SS, Windows Cracked (orange)
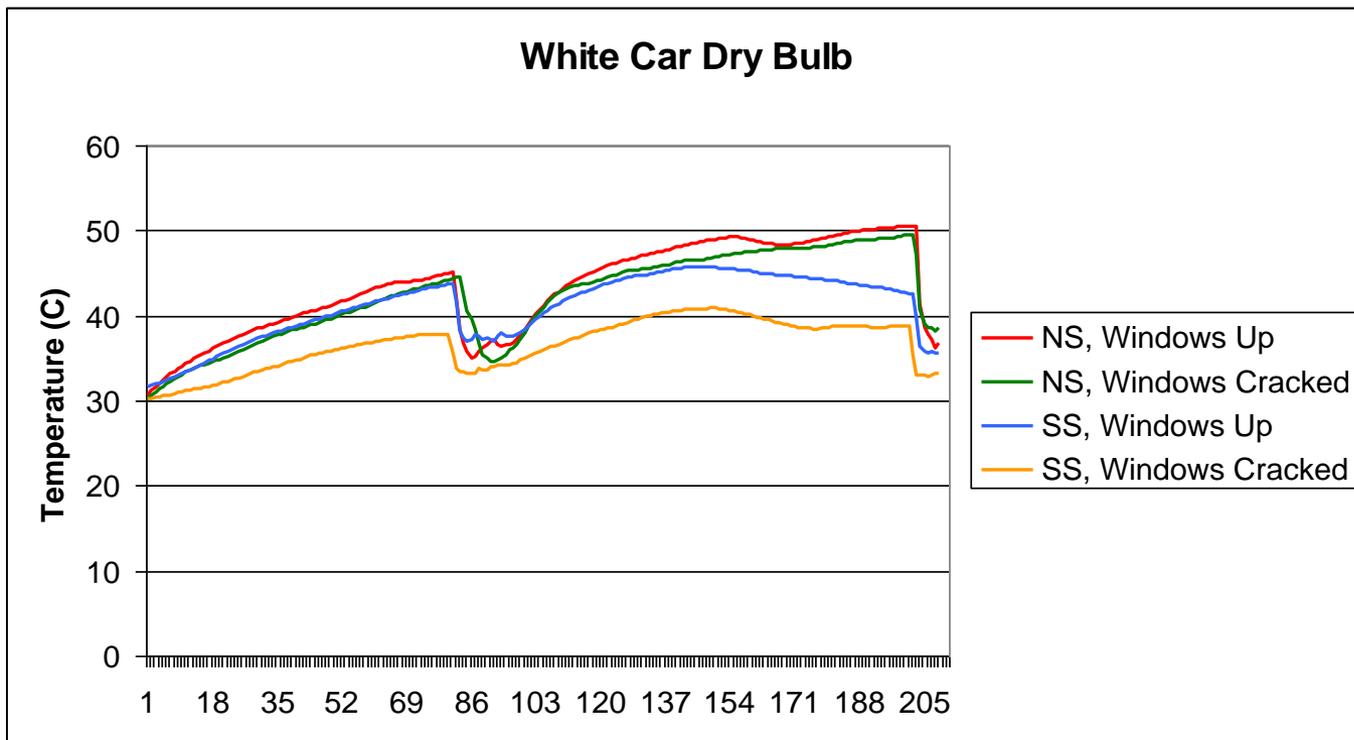
Vehicle Temperatures

- Maximum Ambient Temperature 106 °F
- Inside Vehicle Max temp: 157.6 °F
- WBGT: 117.32 °C

Before   After

Measured Surface Temperature of Vehicles at Dryden (Direct Sunlight)

Time (PDT)	*1145*	*1300*	*1330*	*1400*
Ambient Air Temp (°F)	100	102-104	107	109
Wind (Knots)	<10	10+	<5	<5
Black Car (2 cars) °F	175	166-172		185
White Car °F	136	129		138
Red Car °F		153	151-154	
Charcoal Grey Car °F		161	165	

- Conclusion: Black surfaces, when exposed to direct sunlight typical at Dryden, will exceed 180°F on a hot summer day. This is true for graphite/epoxy laminates, either gloss or flat finish. White surfaces are typically 40+°F cooler than black.

Heat Stress Indices

- Principles of heat exchange
  - HIS ('Belding and Hatch')
- Subjective impressions (comfort)
  - HI (NWS Heat Index)
- Empirical observations/Physiological Experiments
  - Wet Bulb Globe Temperature (WBGT)

WBGT

- Three temperature measurements
  - Natural Wet-Bulb Temperature
    - Not 'Wet-bulb'
  - Globe Temperature
  - Shielded Dry-Bulb Temperature

WBGT Equations

- Direct Sunlight Exposure

$$\text{WBGT} = 0.7T_{NWB} + 0.2T_G + 0.1T_{DB}$$

- Indoor or Shaded Environments

$$\text{WBGT} = 0.7T_{NWB} + 0.3T_G$$

- T_{NWB} = Natural Wet Bulb Temperature
- T_G = Globe Temperature
- T_{DB} = Dry Bulb Temperature.

WBGT Flag Definitions (°F)

No Flag - Wet Bulb Globe Thermometer (WBGT) index 81.9 or below. Normal activity can proceed.

Green - WBGT index of 82 - 84.9. Discretion is required in planning heavy exercise for non-acclimatized personnel. This is a marginal heat stress limit for all personnel. Water intake: 1 quart per hour.

Yellow - WBGT index of 85 - 87.9. Strenuous activity must be curtailed for new and non-acclimatized personnel during the first 3 weeks of heat exposure. Avoid work in direct sunlight, if possible. Rest periods of 15 minutes per hour. Encourage water consumption at least every 30 minutes, 1 quart in an hour.

Red - WBGT index of 88 - 89.90. Avoid work in direct sunlight, if possible. Rest periods of 30 minutes per hour. Encourage water consumption at least every 15 minutes, 1 quart in an hour.

Black - WBGT index of 90 or Above. Terminate all outdoor tasks. Where termination is not immediately feasible, move quickly to safety after finishing activity. Avoid work in direct sunlight. Rest periods of 45 minutes per hour. Water intake: 1 quart per hour.

Reasons for Other Equations

- Absence of thermal environment monitoring system (Direct WBGT instrument)

- Large area not well enough covered by instrument

- Equations developed
  - American College of Sports Medicine (ACSM)
  - Westinghouse Savannah River Company (WSRC)

- DFRC found ACSM to be good basis for desert environment

DFRC Development

- ACSM – Equation 1

  WBGT = 0.567T_{DB} + 0.393e + 3.94

  - T_{DB} = ambient temperature

  - *e* = vapor pressure calculated from RH

Actual Wbgt and Raw ACSM WBGT Estimate
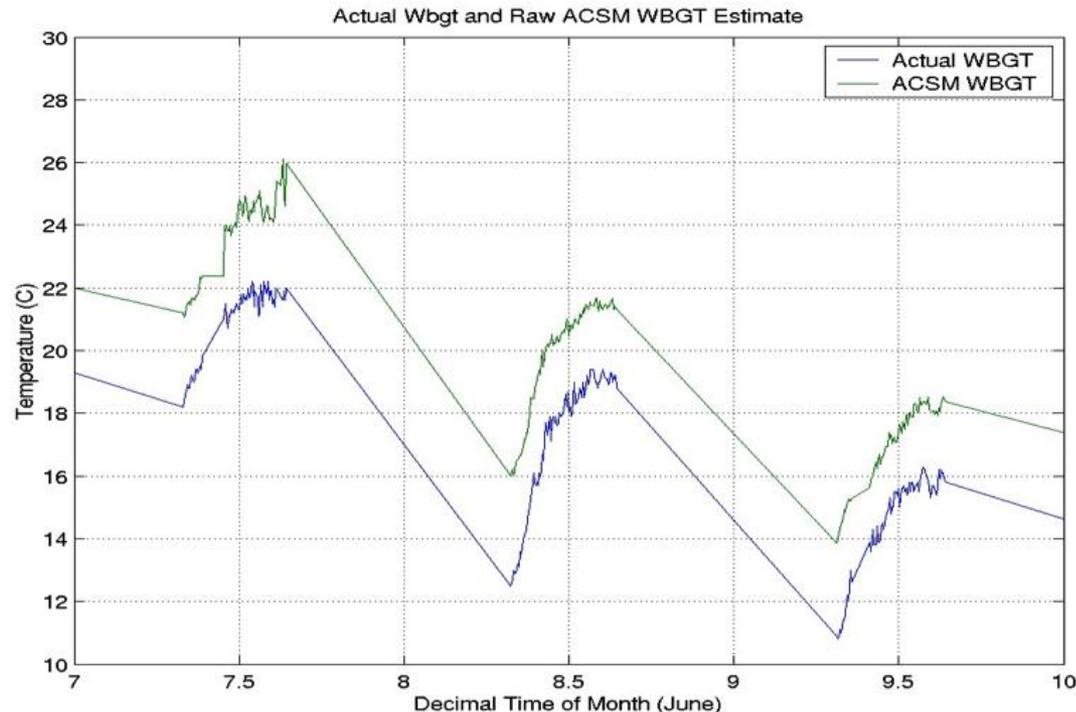
DFRC Development

- Direct relationship between wind speed and the reduction in the WBGT

- As the wind increases the difference between the two independent WBGT temperature increases

- Slope = 0.16^{o}C/kt

- Y-intercept = -0.54 deg C

June.3~July 9, 2004

temp differernce / Wind Speed (kts)

Diff A & C
Linear (Diff A & C)
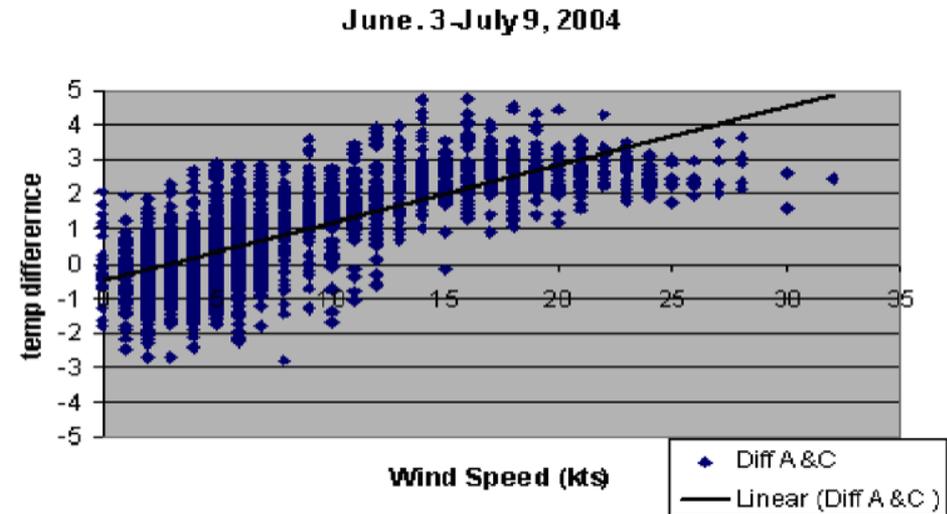
DFRC Development

- Equation 2

WBGT = 0.567T$_{DB}$ + 0.393e + 4.48 – (0.16*WS)

T$_{DB}$ = Dry-bulb temperature

Actual Wbgt and Raw ACSM WBGT Estimate w/ Wind Correction
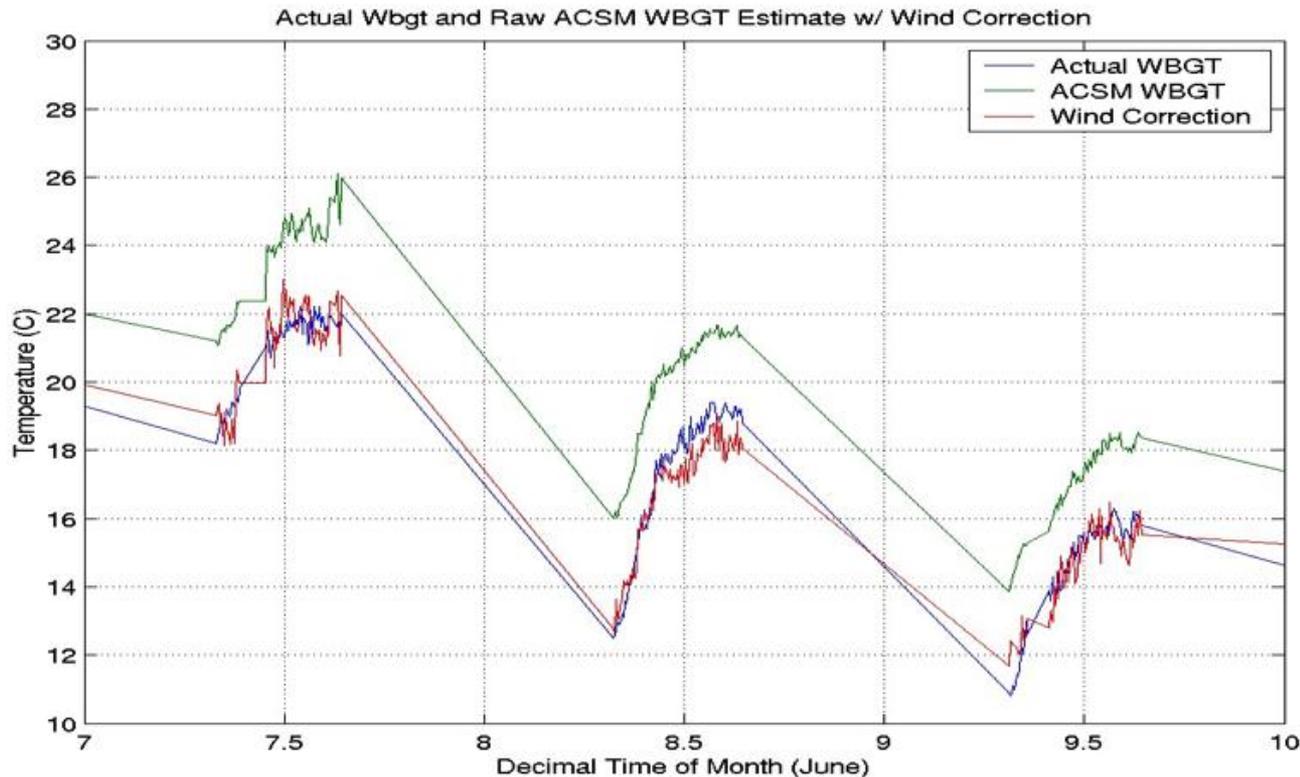
Dryden WBGT Heat Stress Equation

$$WBGT = 0.567T_{DB} + 0.393((RH/100) * (6.112*\exp((17.67 * T_{DB})/(T_{DB} + 243.5))) + 5.05 - (0.207*WS)$$

- T_{DB} = Dry Bulb Temperature
- RH = Relative Humidity
- WS = Wind Speed

DFRC Heat Stress History

- Safety, Health, and Environmental Branch
  - Quest Technologies® QuesTemp°10/34
  - One employee assigned to take measurements
  - Infrequent data collection
  - Not accurate for entire center

DFRC Automation

- Data
  - Official measurements made by Edwards AFB FMQ-19
  - Transferred every minute to DFRC FTP site
- Computation
  - Ingested to program every 5 minutes
  - WBGT computed
  - Values sent to DFRC intranet (Xnet)
- Display
    - Date/Time stamp
    - Flag
    - Temperature
    - Wind Direction
    - Wind Speed
    - Relative Humidity
    - WBGT

DFRC Automation (cont.)

- Dissemination
  - Frequency (three iterations/15 minutes)
  - E-mail to key personnel
  - Center-wide announcement
  - X-net banner color change
- Archive
  - DFRC archives incoming and outgoing data on FTP site for continued analysis

Xnet

Heat Stress Banner on Xnet

Heat Stress Page

The Dryden Intranet

Employee Information   Dryden Management   Organizations   Communications   Transportation

Search Xnet
Site Index
Home

Home > Heat Stress

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Note: *numbers are Wet Bulb Globe Temperature Index- not Temperature*

- 24 Hour History
- Three Day Forecast
- Heat Illnesses
- Prevention
- Work Load Requirements
- Heat Stress Measurements

Graph History/Forecasts
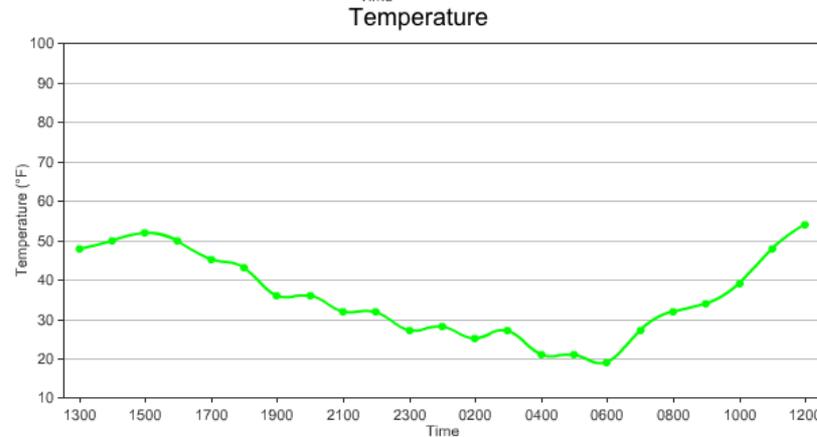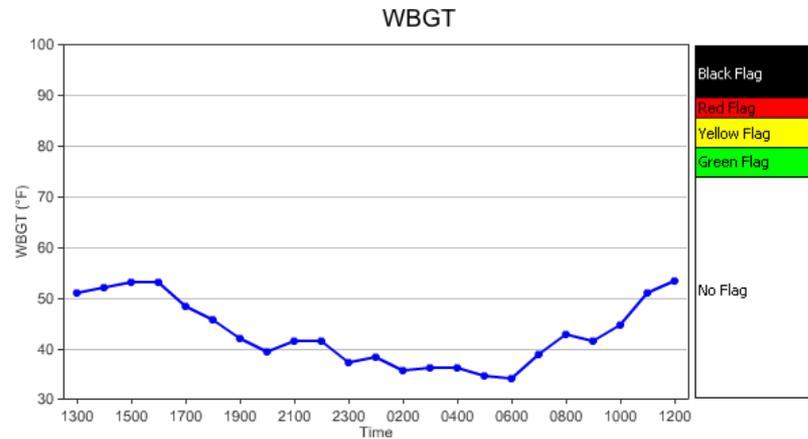
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Contact Info

- Franzeska Houtas
  - Franzeska.F.Houtas@NASA.gov
- Ed Teets
  - Edward.H.Teets@NASA.gov