OFFICE OF RESEARCH & DEVELOPMENT

2012 R&D REVIEW

# Development of a Rail Temperature Prediction Model Based on Heat Transfer Principles

U.S. Department of Transportation

Federal Railroad Administration

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# Program Area & Risk Matrix

**Development of Rail Temperature Prediction Model Based on Heat Transfer Principles**

| Program Areas \ Risk Factors | Trespass | Grade Crossing | Derailment | Train Collision | All Other Safety Hazards |
|---|---|---|---|---|---|
| Railroad Systems Issues | | | | | |
| Human Factors | | | | | |
| **Track & Structures** | | | X | | |
| Track & Train Interaction | | | | | |
| Facilities & Equipment | | | | | |
| Rolling Stock & Components | | | | | |
| Hazardous Materials | | | | | |
| Train Occupant Protection | | | | | |
| Train Control & Communications | | | | | |
| Grade Crossings & Trespass | | | | | |

# Outline

- Background
  - Current industry practices
- Research motivation and objectives
- Research approach and implementation
- Lessons Learned
- Current status
  - Web-based application

# Background

- Due to thermal expansion, risk of buckling exists on track with continuously welded rail (CWR)
- 2005 to 2009:  124 incidents, $43 million in damages
- Railroads issue slow speed orders on hot days in order to prevent and minimize damages due to buckling incidents

# Background

# Current Industry Practice

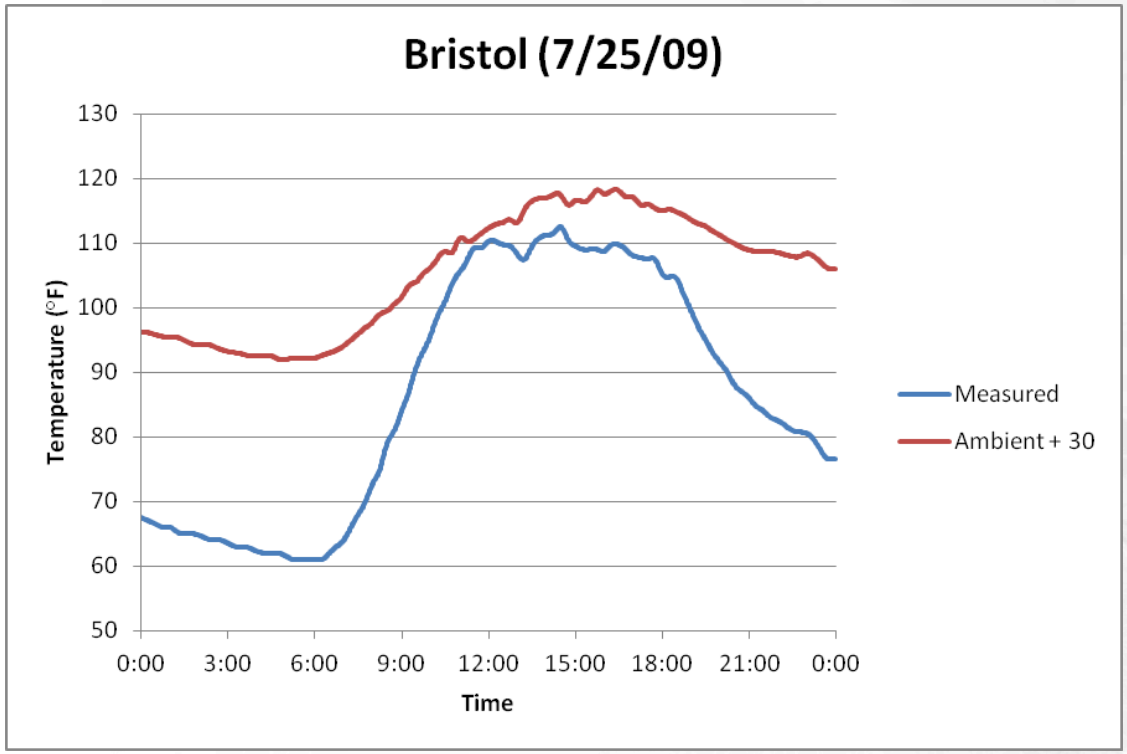
- Empirical model currently used by railroad industry to predict maximum daily rail temperature:

$$\left(\begin{array}{c}\text{Max Forceasted}\\ \text{Rail Temp.}\end{array}\right)°\text{F} = \left(\begin{array}{c}\text{Max Forecasted}\\ \text{Ambient Temp.}\end{array}\right)°\text{F} + \text{Constant}$$

  - Constant is above equation, may vary but is typically 30 °F

- Model is accurate only for predicting the maximum daily rail temperature

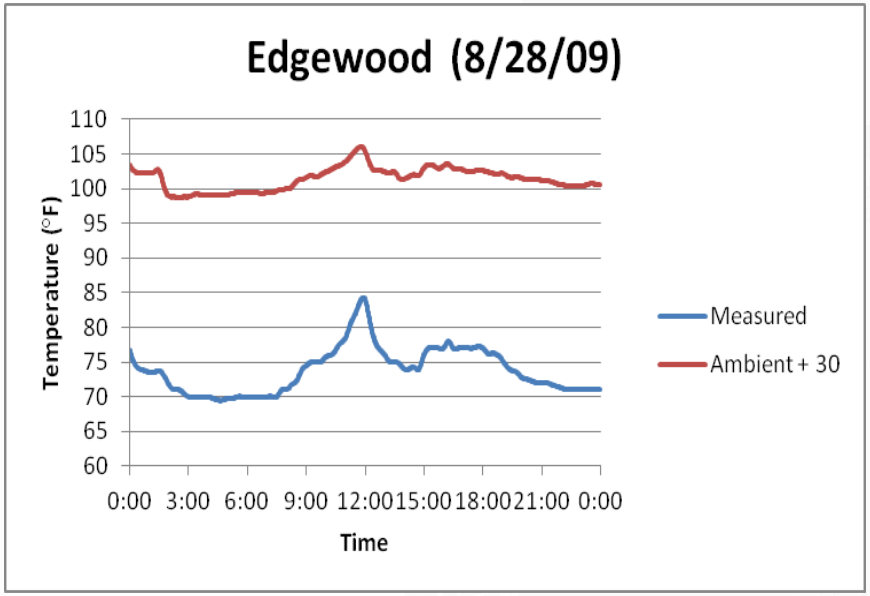
# Research Motivation

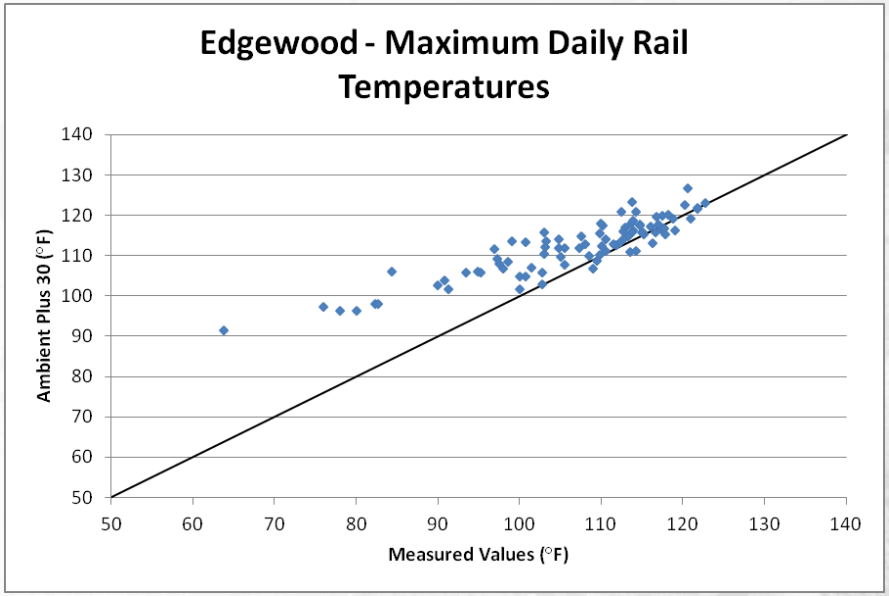



**Empirical model used by industry does not provide information on how rail temperatures change throughout an entire day**

# Research Motivation

- Empirical model used by industry is only useful for predicting the maximum daily rail temperature on hot days
- Over-predicts on cool / overcast days



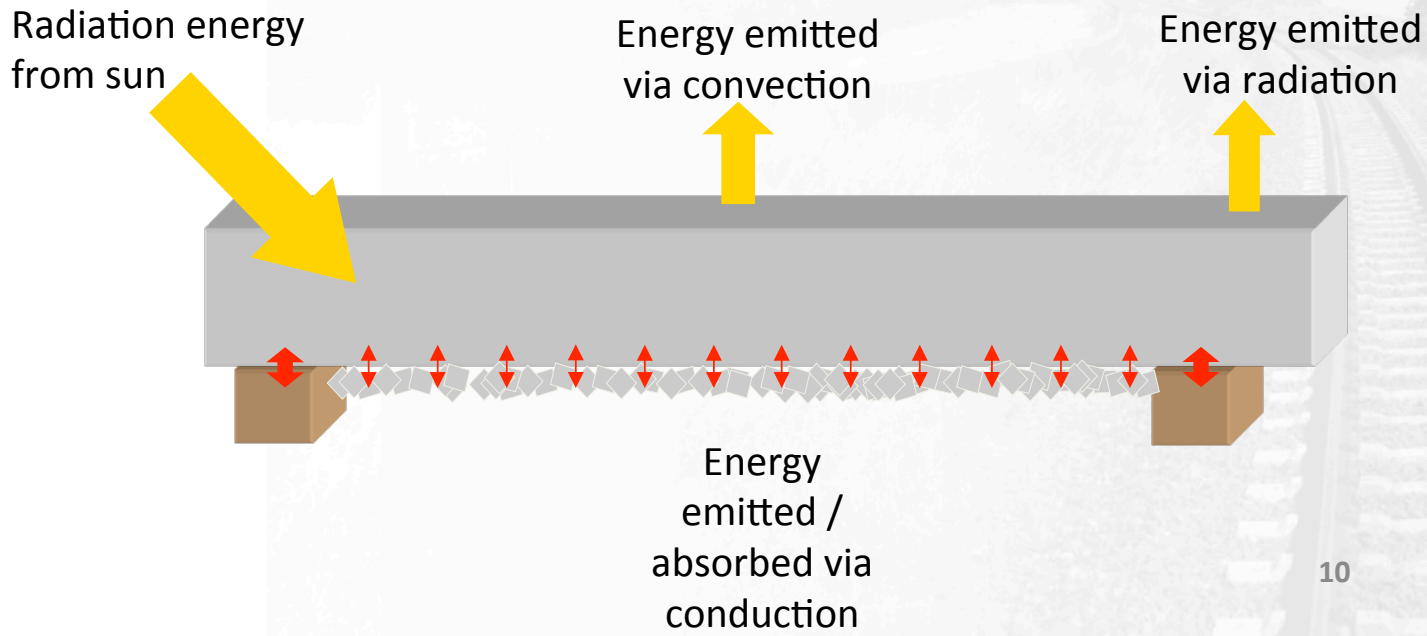



# Research Objectives

- Assist in more objective and reliable issuance of slow orders
- Develop a model that accurately predicts rail temperatures at all times throughout the day
  - Predicts rail temperatures up to nine hours in advance
- Incorporate predictions into a web-based application to be utilized by industry for operations and research purposes

# Research Approach

- Develop physical model based on heat transfer principles
- Diagram of physical heat transfer model parameters:



# Rail Temperature Model

## Heat transfer equation

$$k\alpha_s A_s G_s \cos(\theta) - \left[h_{conv} A_c (T_r - T_\infty) + \varepsilon\sigma A_r \left(T_r^{\,4} - T_{sky}^{\,4}\right)\right] = \rho c V \frac{dT_r}{dt}$$

Solar Radiation | Convection | Sky Radiation

## Qualitative explanation of equation

$$\begin{pmatrix}\text{Energy Absorbed}\\ \text{Via Solar Radiation}\end{pmatrix} - \left[\begin{pmatrix}\text{Energy Emitted}\\ \text{Via Convection}\end{pmatrix} + \begin{pmatrix}\text{Energy Emitted}\\ \text{Via Sky Radiation}\end{pmatrix}\right] = \begin{pmatrix}\text{Rate of Change}\\ \text{of Rail Temperature}\end{pmatrix}$$

# Data Collection

- Set up weather station with short section of rail (including ties and ballast)
  - Verify accuracy of predicted weather data (solar radiation, ambient temperature, and wind speed)
  - Verify accuracy of rail temperature model predictions

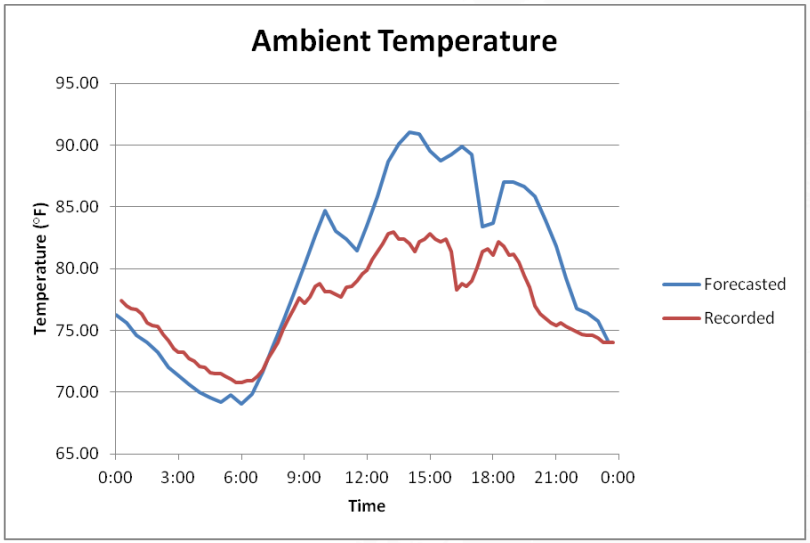
# Data Collection

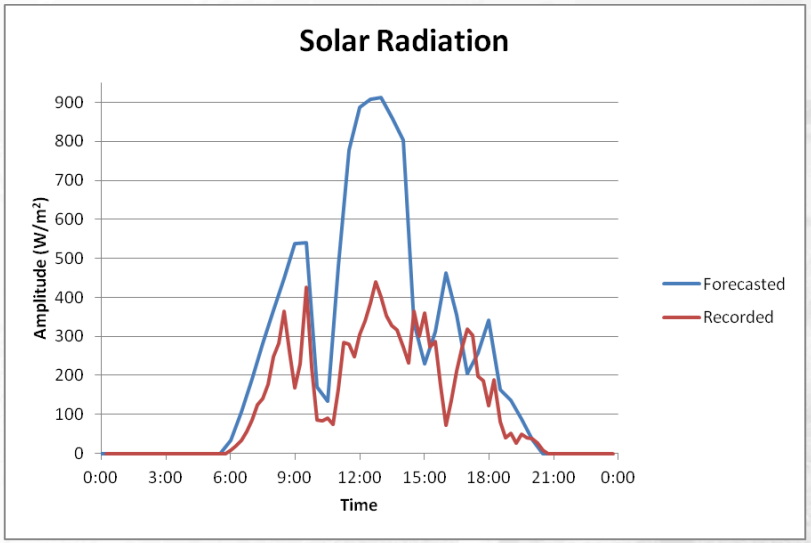
Received recorded weather data and rail temperatures from several wayside weather stations on Amtrak's Northeast Corridor

- Data collected at 15 minute intervals
- Stations installed approximately 30 feet above ground

# Initial Lessons Learned

- Forecast weather data sometimes is not accurate
- Example of inaccurate ambient temperature and solar radiation forecast



# Model Modifications and Improvements

- Utilized measured weather data as inputs into model
  - Allows for isolation of model errors by eliminating input uncertainties due to weather forecast errors

- Based on this approach, several improvements were made to the model
  - Rail orientation / Solar angle

# Data Collection

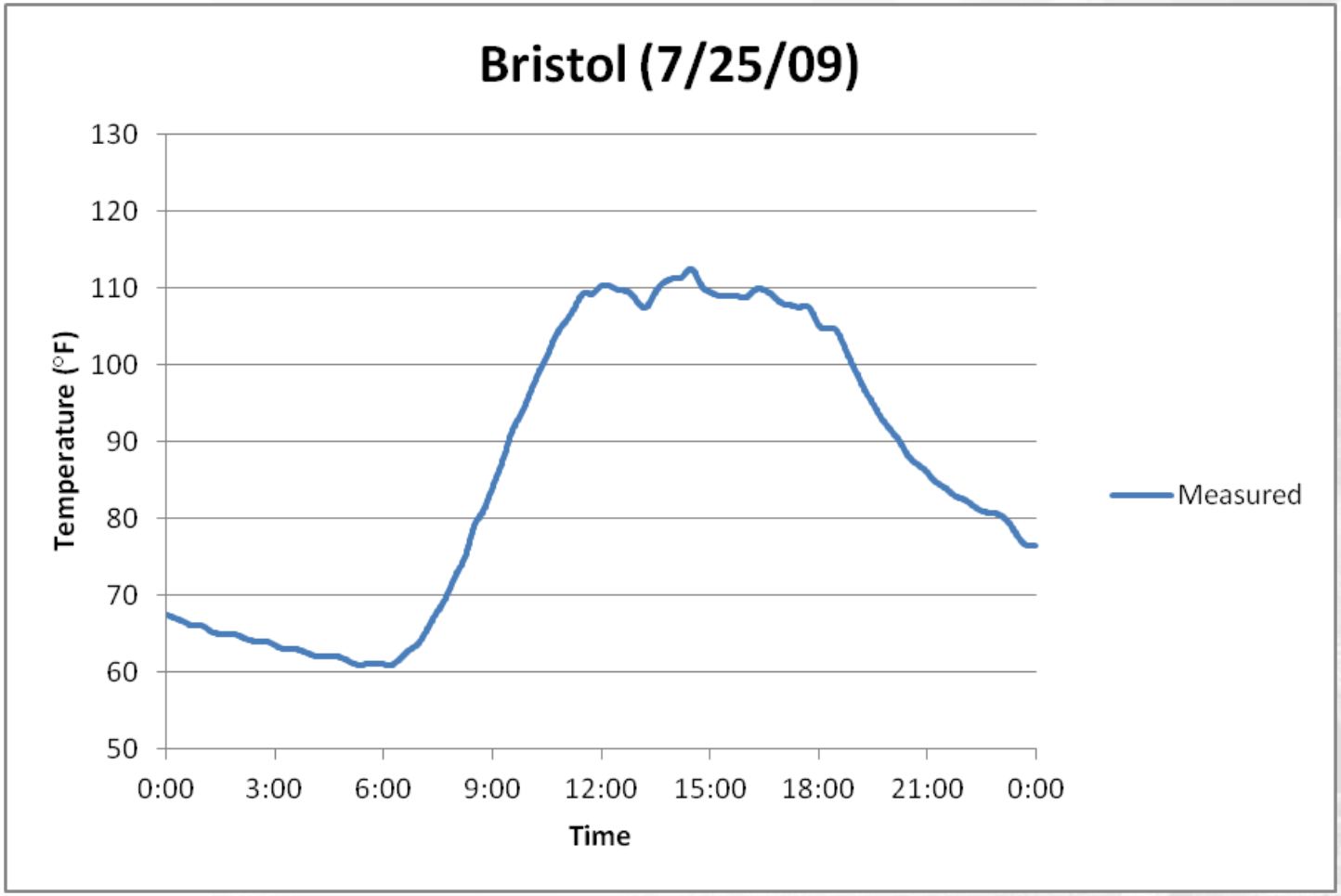
Installed two ground-level weather stations at a couple locations on Amtrak's Northeast Corridor

# Data Collection

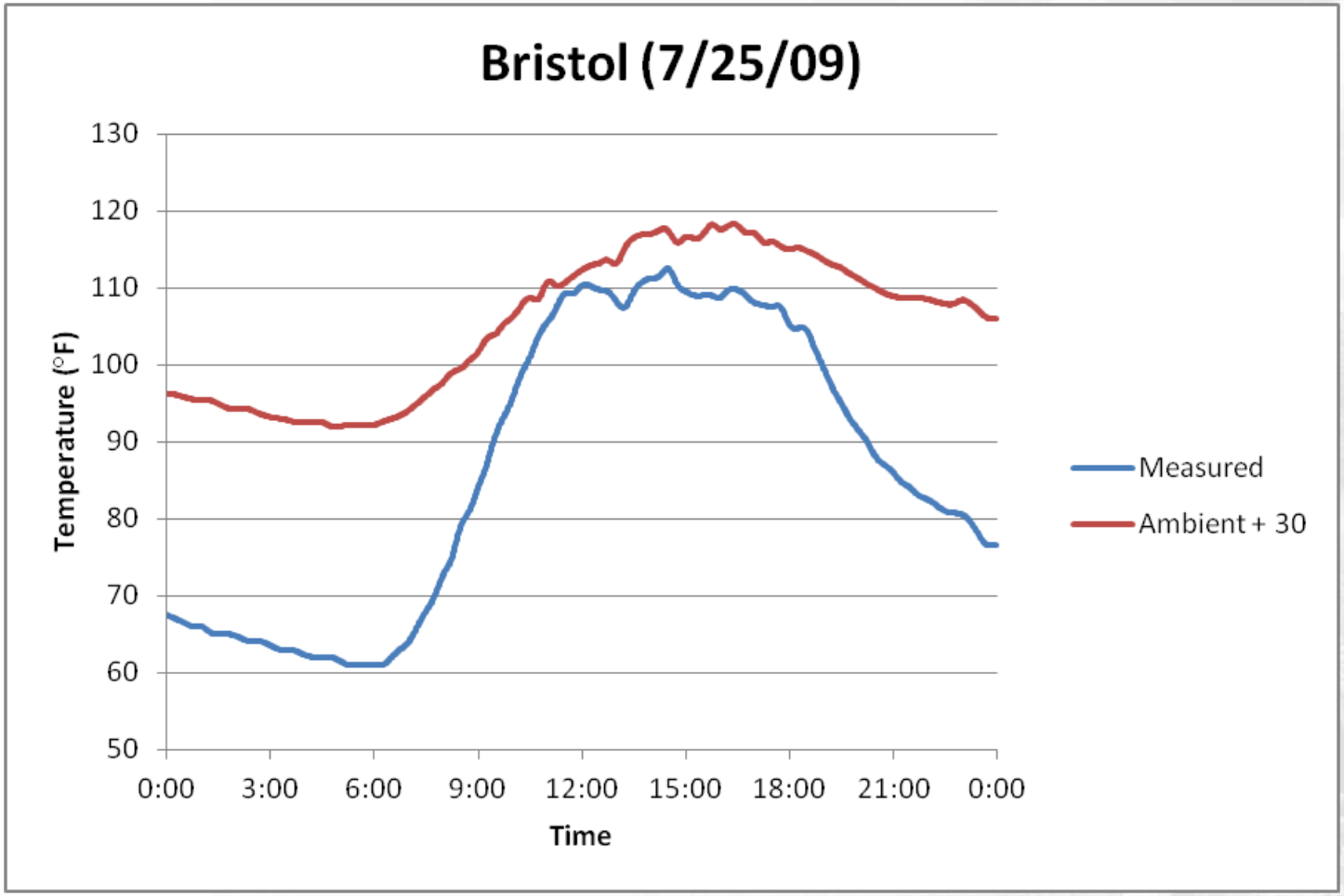
- Ambient temperature at ground level typically 1 – 2 °F higher than ambient temperature measured 30 feet above ground level

- Wind speed at ground level typically 25% - 50% less than wind speed measured 30 feet above ground level

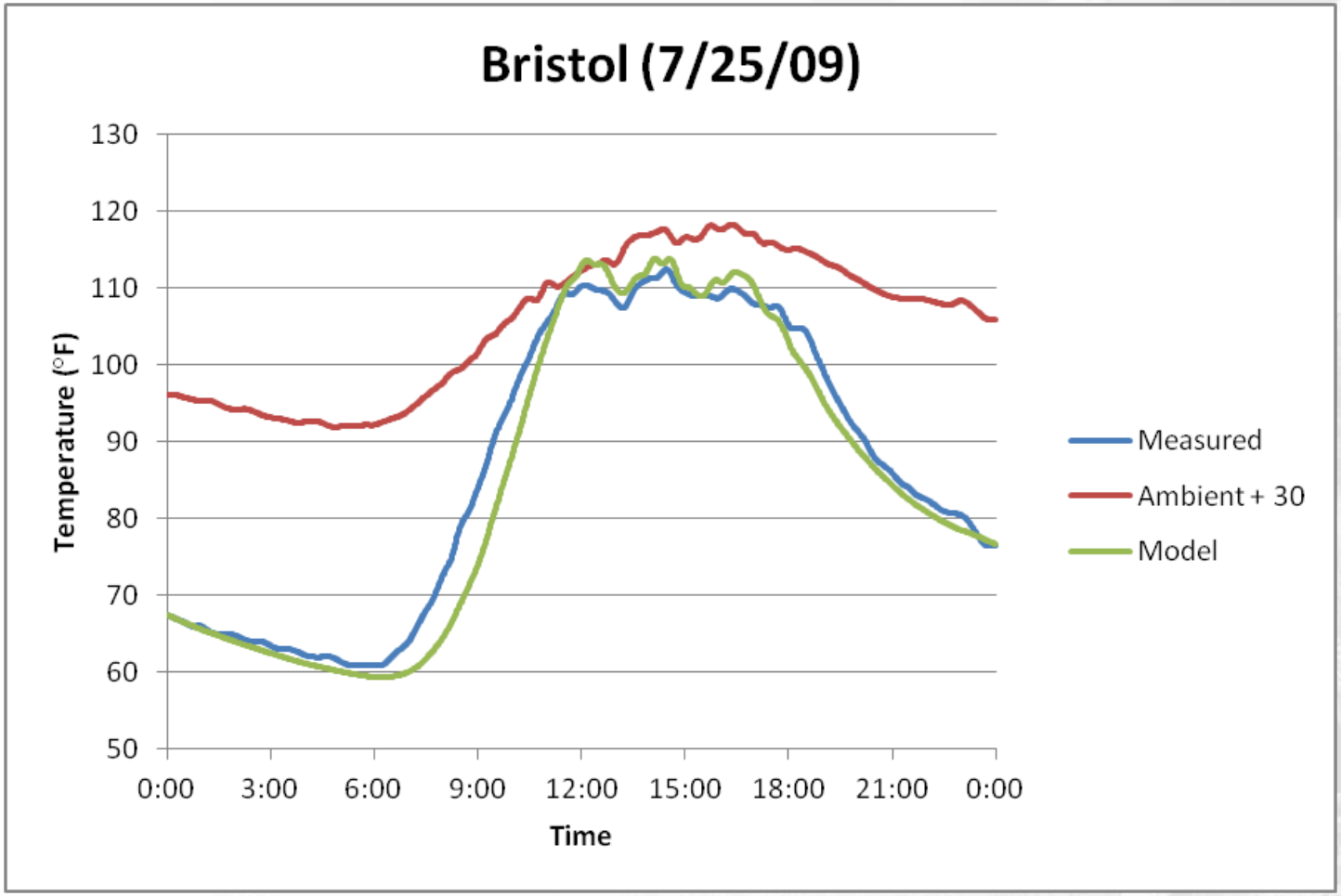
# Example of Model Output



# Example of Model Output

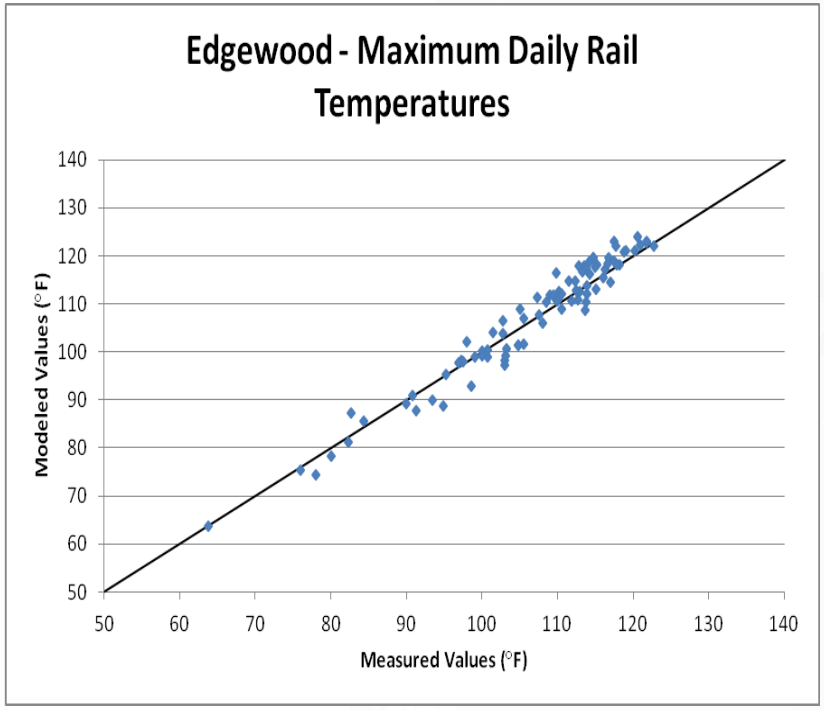


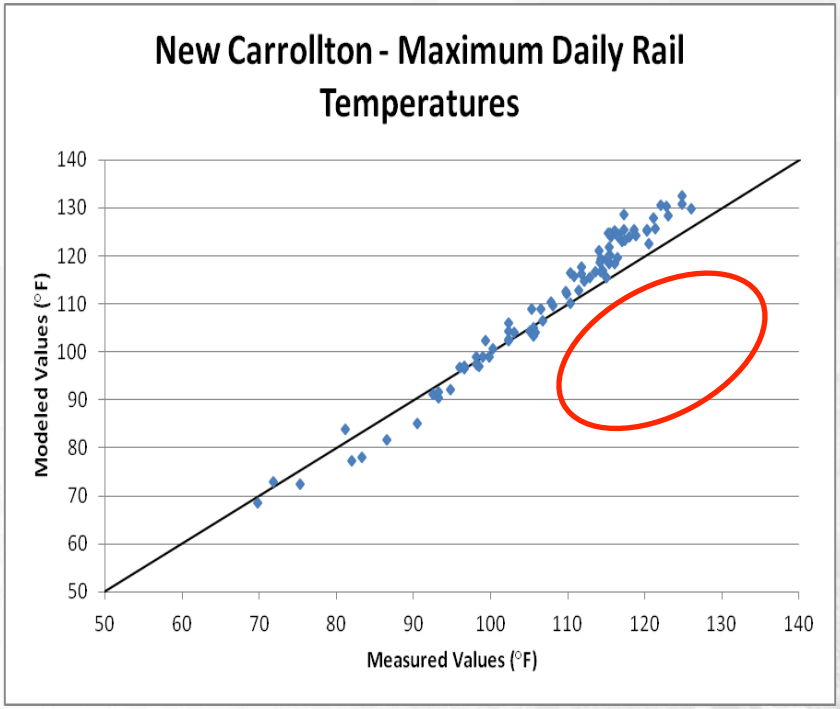
# Example of Model Output



# Lessons Learned – Role of Local Conditions

## Local conditions affect rail temperature

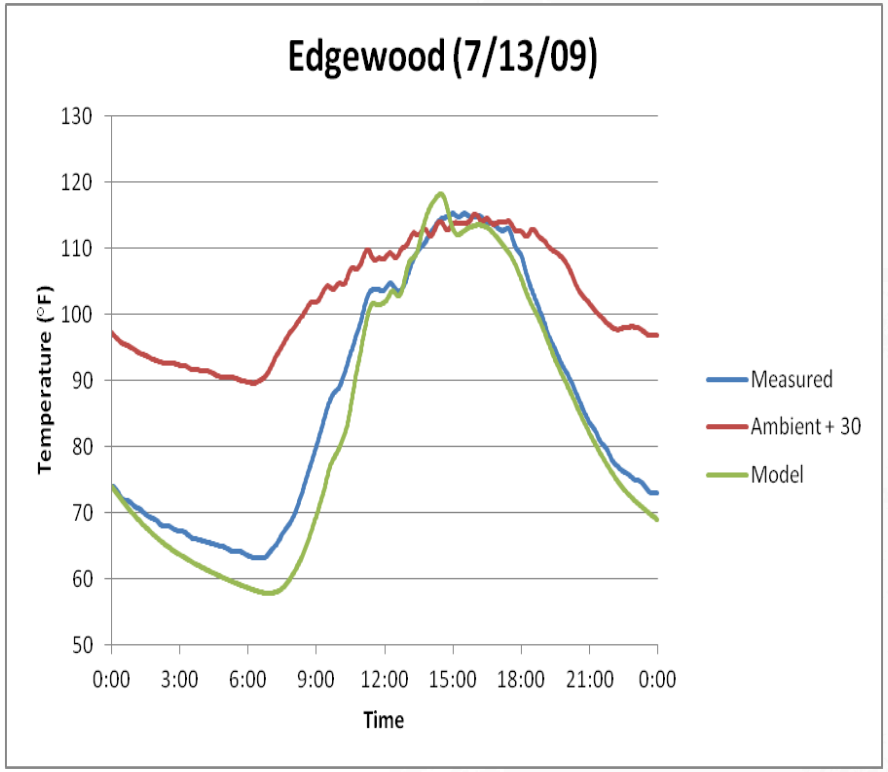


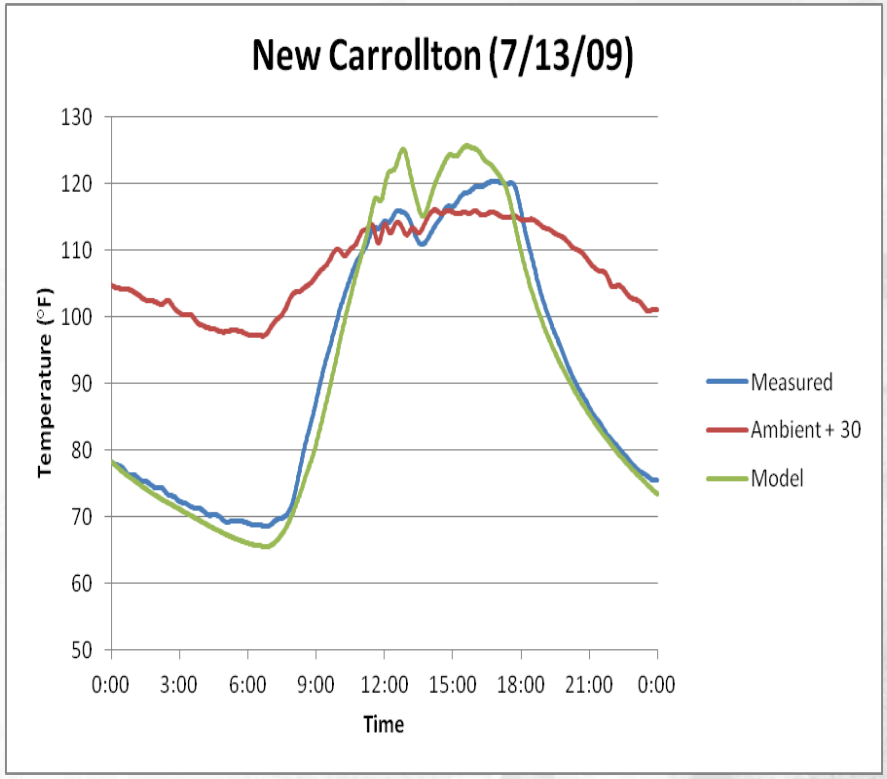




New Carrollton data shows offset on hot days

# Lessons Learned – Role of Local Conditions

## Local conditions affect rail temperature



# Lessons Learned – Role of Local Conditions

Solar absorptivity coefficient

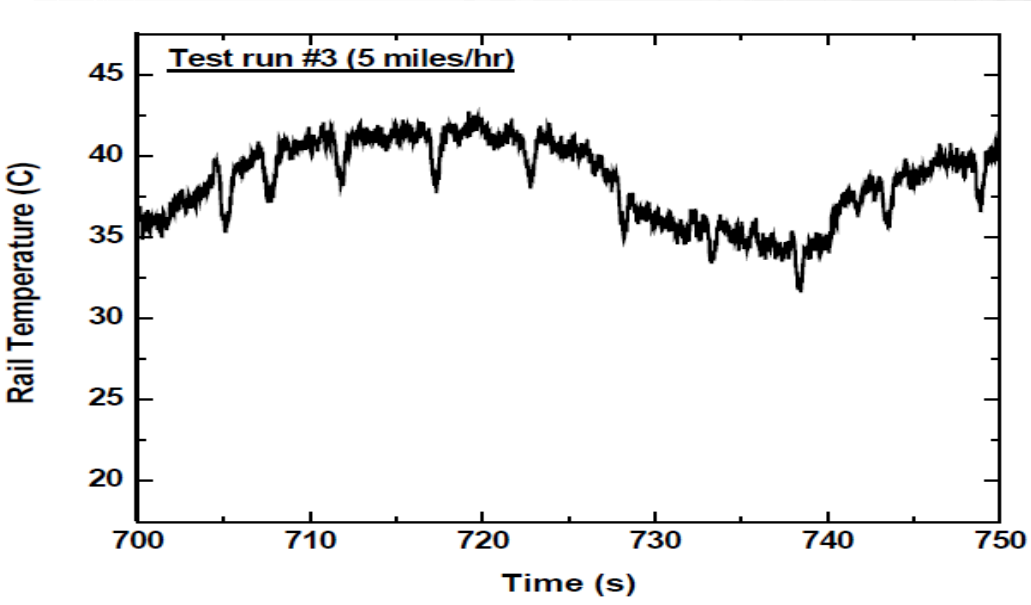
$$k\,\alpha_s\,A_s G_s \cos(\theta) - \left[h_{conv} A_c (T_r - T_\infty) + \varepsilon\sigma A_r \left(T_r^{\,4} - T_{sky}^{\,4}\right)\right] = \rho c V \frac{dT_r}{dt}$$

Convection coefficient

$$k\alpha_s A_s G_s \cos(\theta) - \left[h_{conv} A_c (T_r - T_\infty) + \varepsilon\sigma A_r \left(T_r^{\,4} - T_{sky}^{\,4}\right)\right] = \rho c V \frac{dT_r}{dt}$$

# Lessons Learned – Role of Local Conditions

- More mass can affect rate of increase / decrease of rail temperature
- Data from rail temperature measurement sensor is currently being developed



# Lessons Learned – Role of Local Conditions

More mass can affect rate of increase / decrease of rail

# Lessons Learned – Role of Local Conditions

Area to volume ratio can affect rate of increase of rail temperature

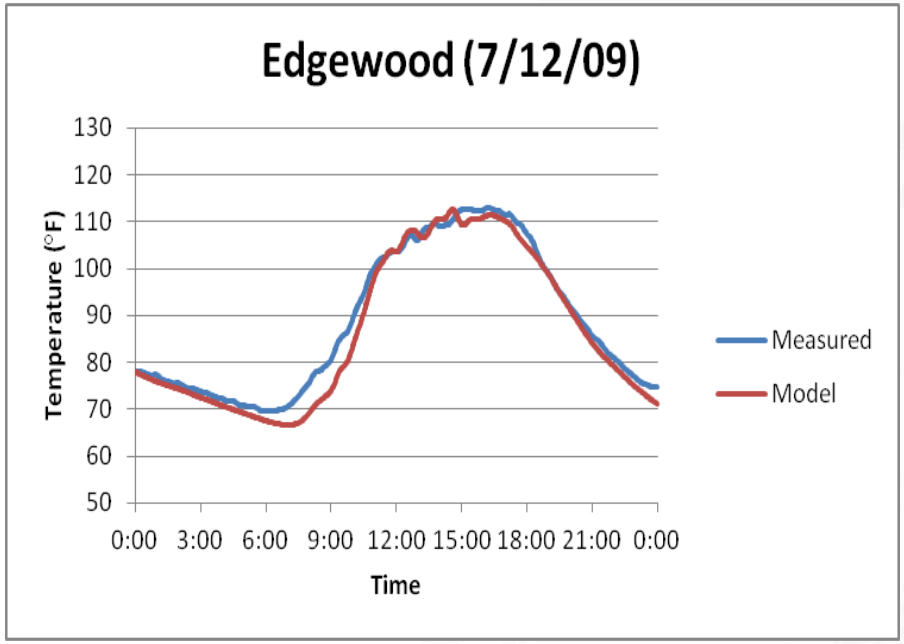
$$k\alpha_s A_s G_s \cos(\theta) - \left[h_{conv} A_c (T_r - T_\infty) + \varepsilon\sigma A_r \left(T_r^4 - T_{sky}^4\right)\right] = \rho c V \frac{dT_r}{dt}$$

As a result, rail sections with different area to volume ratios may heat up at different rates

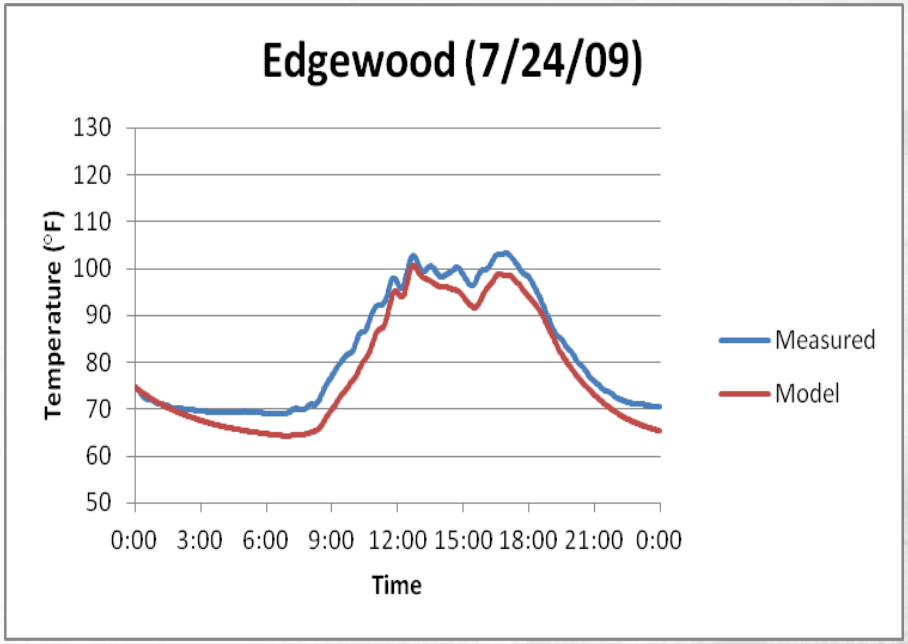
# Lessons Learned – Intermittent Offset Issue

Continuous offset is sometimes observed

**No offset**




**Continuous offset**



# Lessons Learned – Potential Role of Sky Temperature

- Offset most likely not due to local conditions
  - Only observed periodically on certain days
- May be result of the sky temperature

$$k\alpha_s A_s G_s \cos(\theta) - \left[h_{conv} A_c (T_r - T_\infty) + \varepsilon \sigma A_r \left(T_r^4 - \boxed{T_{sky}}^4\right)\right] = \rho c V \frac{dT_r}{dt}$$

# Lessons Learned – Potential Role of Sky Temperature

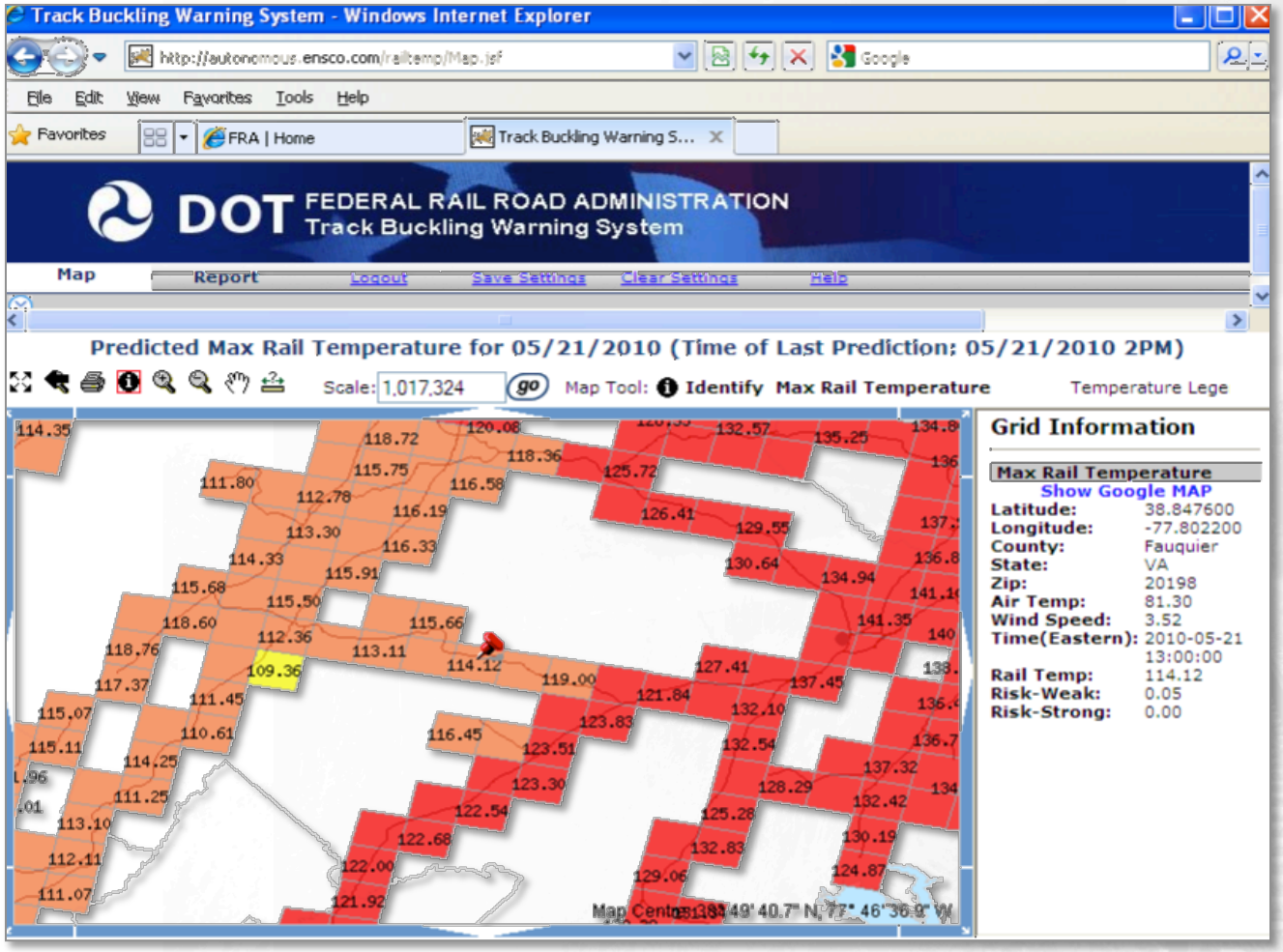
Measured and predicted sky temperatures are not readily available

- Sky temperature can vary from 0 °F to 140 °F below ambient air temperature
- Some empirical models based on dew point temperature are available but their accuracy is not known
- Currently assume a sky temperature at 68 °F (20 °C) below ambient temperature

# Web-Based Application

- Receiving real-time weather forecast data in 9x9 km grids
- Predicting rail temperature 12 hours in advance; updated at 3 hour intervals
- Only generating predictions in grids that have railroad tracks
  - Using National Transportation Atlas Data (NTAD) to determine rail line locations

# Web-Based Application




*Example screenshot

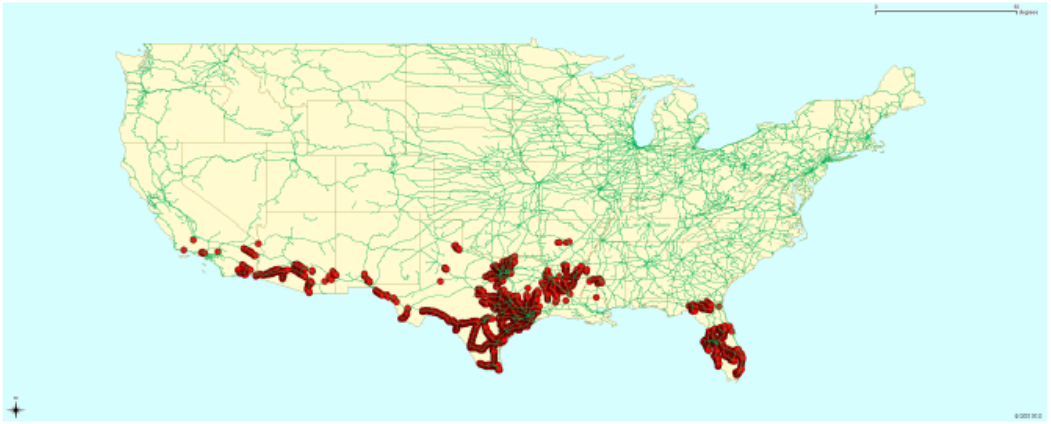
# Improvements to Web-Based Application

- Customizing user logons
  - Currently Amtrak has the only user logon, and only the Northeast Corridor is shown
- Developing automated customizable reports
  - Report can be sent directly to user's email
  - User will not have to logon to website

# Web-Based Application

**FRA High Rail Temperature Report**

**Temperature MAP**



**High Rail Temperature Safety Alert**

| Grid Id | Max Rail Temperature | Max Temperature Threshold | Start Time | End Time | Latitude | Longitude | County | State |
|---|---|---|---|---|---|---|---|---|
| 7574 | 126 | 100 | 2/1/12 12:30 PM | 2/1/12 4:00 PM | 26.20880 | -98.55190 | | |
| 7402 | 126 | 100 | 2/1/12 12:30 PM | 2/1/12 4:00 PM | 26.36320 | -98.82050 | | |
| 7461 | 126 | 100 | 2/1/12 12:30 PM | 2/1/12 4:00 PM | 26.28530 | -98.73030 | | |

**Example Report*

# Acknowledgements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