Sustainable and Resilient Pavements – Research in West Virginia

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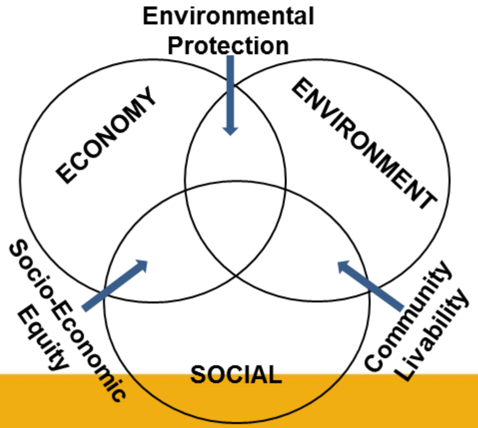
West Virginia University

Asphalt Pavements Research at WVU

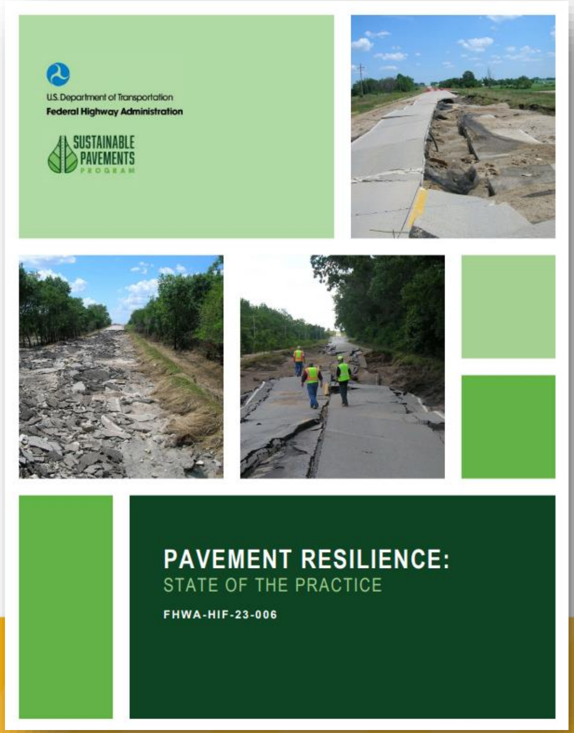
West

Today’s Discussion

- **Sustainability**
  - Impact of pavements on the environment



- **Resilience**
  - Impact of environment on pavements



Sustainability – Climate Challenge

Background / Objective

FHWA Highlights Actions to Tackle Climate Change with New Programs and Historic Funding Under President Biden's Bipartisan Infrastructure Law

Friday, April 22, 2022

FHWA 13-22
Contact: FHWA.PressOffice@dot.gov
Tel.: (202) 366-0660

- Pavements contribute significant environmental impacts
  - Lifecycle assessment (LCA)
  - Product category rules (PCRs)
  - Environmental product declarations (EPDs)
- Objective is to use LCA, PCRs and EPDs to investigate activities to **improve the overall environmental sustainability of asphalt mixes in WV**.

Process

Product Category Rule (PCR)

"Set of specific rules, requirements, and guidelines for developing Type III environmental product declarations for one or more categories" (ISO 14025)

→

Life Cycle Assessment (LCA)

"A compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle." (ISO 14040)

→

Environmental Product Declaration (EPD)

"Providing quantified environmental data using predetermined parameters and, where relevant, additional environmental information" (ISO 14025)

Source: FHWA Sustainable Pavements Program

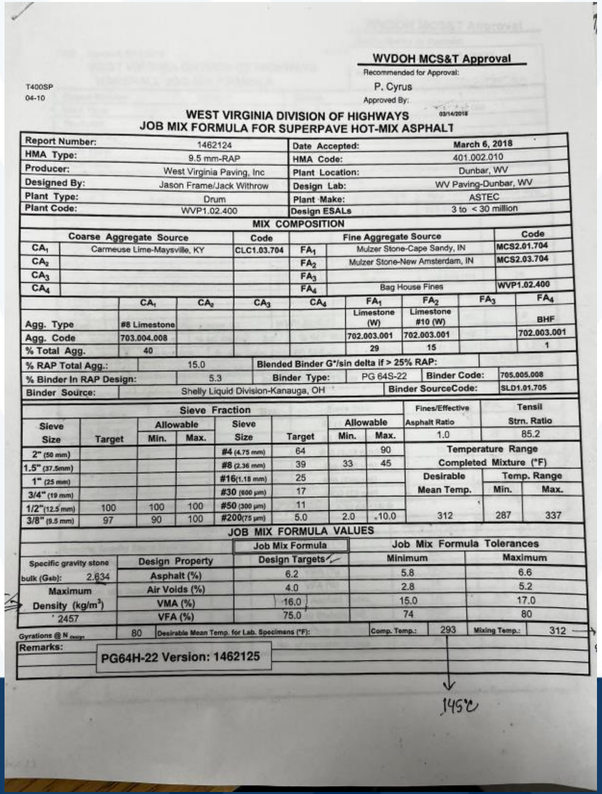
Sustainable Pavements:

- Achieve the engineering goals.
- Preserve and (ideally) restore surrounding ecosystems.
- Use financial, human, and environmental resources wisely.
- Meet basic human needs such as health, safety, equity, employment, comfort, and happiness.

Source: FHWA Sustainable Pavements Program

LCA/EPD West Virginia Pavements

- Gathered materials and JMFs from 8 mixes from 5 producers around the state
- Build LCA
  - Compared to EPDs from Emerald Eco-Label
- Lab work



T400SP
04-10

WVDOH MCS&T Approval
Recommended for Approval:
P. Cyrus
Approved By:
03/14/2018

WEST VIRGINIA DIVISION OF HIGHWAYS
JOB MIX FORMULA FOR SUPERPAVE HOT-MIX ASPHALT

Report Number:	1462124	Date Accepted:	March 6, 2018
HMA Type:	9.5 mm-RAP	HMA Code:	401.002.010
Producer:	West Virginia Paving, Inc	Plant Location:	Dunbar, WV
Designed By:	Jason Frame/Jack Withrow	Design Lab:	WV Paving-Dunbar, WV
Plant Type:	Drum	Plant Make:	ASTEC
Plant Code:	WVP1.02.400	Design ESALs	3 to < 30 million

MIX COMPOSITION

	Coarse Aggregate Source	Code		Fine Aggregate Source	Code
CA_1	Carmeuse Lime-Maysville, KY	CLC1.03.704	FA_1	Mulzer Stone-Cape Sandy, IN	MCS2.01.704
CA_2			FA_2	Mulzer Stone-New Amsterdam, IN	MCS2.03.704
CA_3			FA_3		
CA_4			FA_4	Bag House Fines	WVP1.02.400

	CA_1	CA_2	CA_3	CA_4	FA_1	FA_2	FA_3	FA_4
Agg. Type	#8 Limestone				Limestone (W)	Limestone #10 (W)		BHF
Agg. Code	703.004.008				702.003.001	702.003.001		702.003.001
% Total Agg.	40				29	15		1

% RAP Total Agg.:	15.0	Blended Binder G*/sin delta if > 25% RAP:			
% Binder In RAP Design:	5.3	Binder Type:	PG 64S-22	Binder Code:	705.005.008
Binder Source:	Shelly Liquid Division-Kanauga, OH			Binder SourceCode:	SLD1.01.705

Sieve Fraction

Sieve Size	Target	Allowable Min.	Allowable Max.	Sieve Size	Target	Allowable Min.	Allowable Max.
2" (50 mm)				#4 (4.75 mm)	64		90
1.5" (37.5mm)				#8 (2.36 mm)	39	33	45
1" (25 mm)				#16 (1.18 mm)	25		
3/4" (19 mm)				#30 (600 µm)	17		
1/2" (12.5 mm)	100	100	100	#50 (300 µm)	11		
3/8" (9.5 mm)	97	90	100	#200 (75 µm)	5.0	2.0	.10.0

Fines/Effective Asphalt Ratio	Tensil Strn. Ratio
1.0	85.2

Temperature Range Completed Mixture (°F)

Desirable Mean Temp.	Temp. Range Min.	Temp. Range Max.
312	287	337

JOB MIX FORMULA VALUES

	Design Property	Job Mix Formula Design Targets	Job Mix Formula Tolerances Minimum	Job Mix Formula Tolerances Maximum
Specific gravity stone bulk (Gsb): 2.634	Asphalt (%)	6.2	5.8	6.6
Maximum	Air Voids (%)	4.0	2.8	5.2
Density (kg/m^3)	VMA (%)	16.0	15.0	17.0
2457	VFA (%)	75.0	74	80

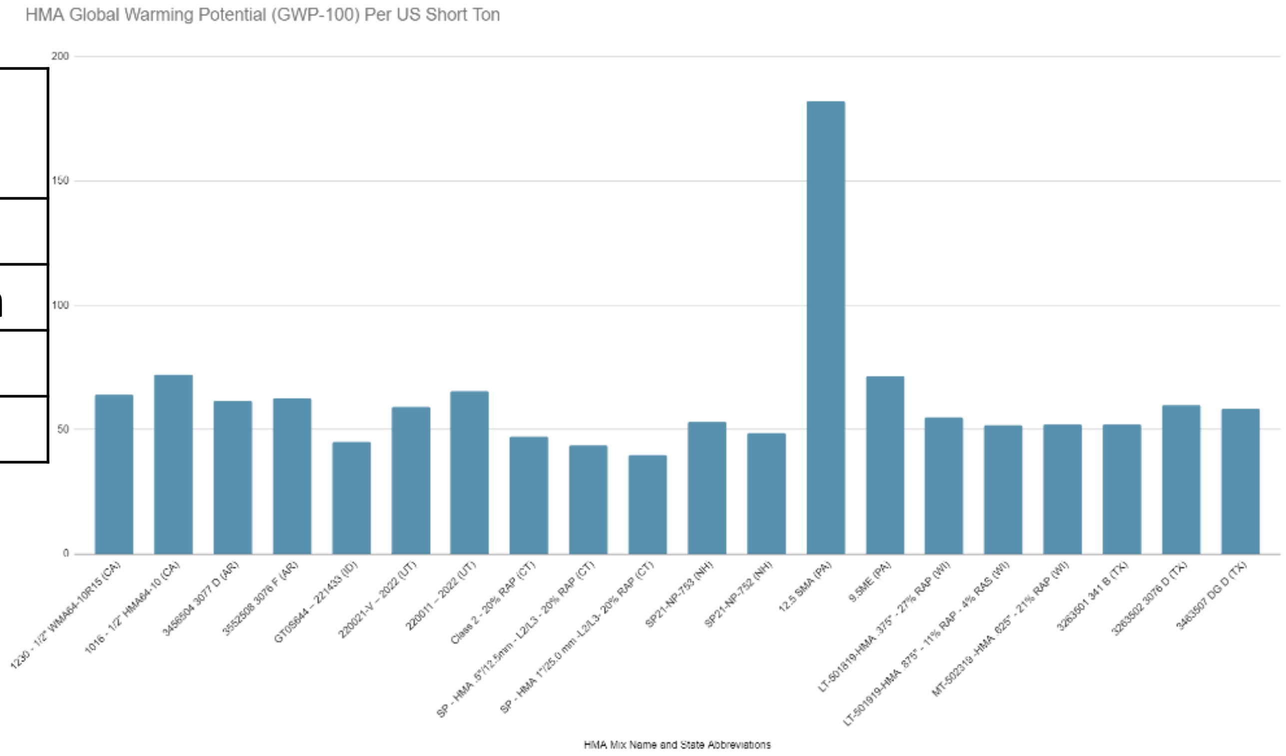
Gyrations @ N_{design}	80	Desirable Mean Temp. for Lab. Specimens (°F):		Comp. Temp.:	293	Mixing Temp.:	312

Remarks: PG64H-22 Version: 1462125

145°C

GWP from reviewed Emerald Eco-Label HMA mix EPDs

GWP (kg CO2 eq/ US short ton)	
62	Mean
57	Median
40	Min
182	Max



LCA Benchmarking Tool

- Publicly available LCA tool
  - Training videos
  - Documentation

Available at: https://www.fhwa.dot.gov/pavement/lcatool/

Also used OpenLCA as comparison – results were similar and not discussed here

Paving Contractor Wearing 1

- Hand calculations for GWP values from materials based on their impact indicators:
  - Binder with no additives: (578*0.051) = **29.5 kg CO2 eq**
  - RAP: (1.26*0.14235) = **0.18 kg CO2 eq**
  - Aggregates: (#8 2.06*0.4745)= 0.98 (Natural 4.2 *0.14235)= 0.59787 (Manufactured 4.2*0.18031)= 0.757 (BHF 4.2*0.00949)= 0.0399 = **2.37 kg CO2 eq**
- Which makes the total GWP for materials: **32.03 kg CO2 eq** per short ton

Paving Contractor Wearing 1

- Adjusted transportation calculations:
  - #8 (0.4745*307.44)= 145.88 & (0.0189*0.4745)= 0.00897
    GWP: (145.88*0.0538)+(0.00897*0.1008)=**7.85 kg CO2 eq**
  - (M) (0.1803*307.44)= 55.43 & (0. 1803*0.0189)= 0.00341
    GWP: (55.43*0.0538)+(0.00341*0.1008)= **2.99 kg CO2 eq**
  - (N) (0.14235*635.31)= 90.44 & (0.14235*0.0189)= 0.0027
    GWP: (90.44*0.0538)+(0.0027*0.1008)= **4.87 kg CO2 eq**
- Binder (0.051*19.6)= 0.9996 GWP: (0.9996*0.2264)= **0.23 kg CO2 eq**
- Total GWP for (A2) = **15.93 kg CO2 eq**

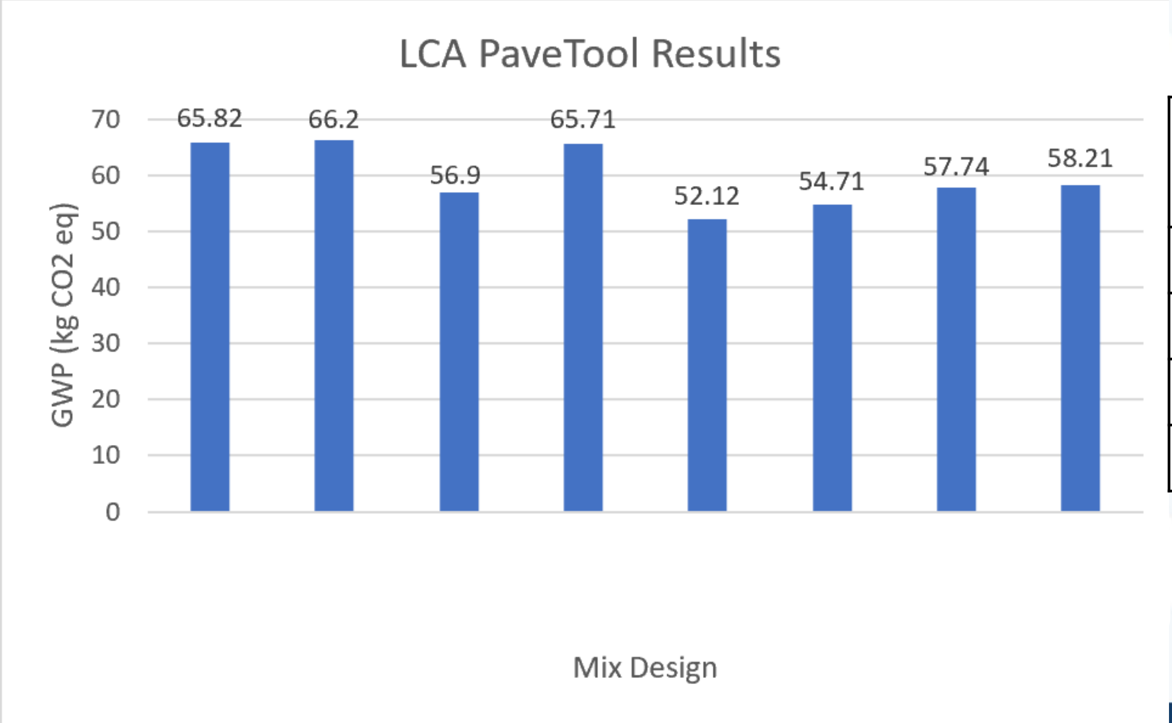
Paving Contractor Wearing 1

- Energy and mixing operations
  - Broken down into energy consumption, natural gas combusted in an industrial boiler, and diesel combusted in industrial equipment
- This makes the total hand calculation GWP **3.8742 kg CO_2 eq + 13.527 kg CO_2 eq + 0.442 kg CO_2 eq = 17.84 kg CO_2 eq**

Paving Contractor Wearing 1

- Using the LCA Pave Tool library impact indicators for hand calculations the overall GWP is **65.8 kg CO_2 eq (151 lbs)**
- A1 materials **32.03 kg CO_2 eq**; A2 Transportation **15.93 kg CO_2 eq**; A3 Production **17.84 kg CO_2 eq**

LCA Results – WV Mixes



GWP (WV Mixes)	GWP (EPDs)	
60	62	Mean
58	57	Median
52	40	Min
66	182	Max

Issue with mixing operations

- In LCA Pave Tool…
  - Assuming same mix, but classifying it as “Marshall” vs “Superpave” results in significantly different results
  - e.g., from 47 to 35 kg CO2 eq/US short ton
- According to FHWA, “Marshall” vs “Superpave” was intended to be a classifier…not to be used with different mixes at the same plant

Binder with Polymer vs. None

- From LCA Pave tool, GWP per 1 short ton using asphalt binder with no additives is **86.16** kg CO2 eq
- GWP per 1 short ton with polymer additives is **75.89** kg CO2 eq

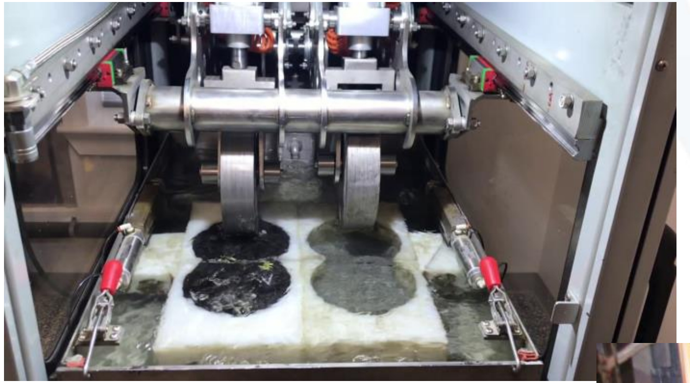
Sensitivity to Using Polymer-Modified Binder

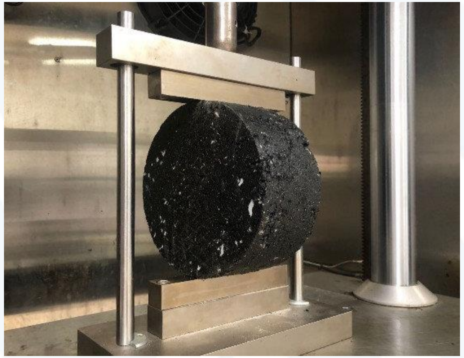
For the sensitivity analysis, SBS was used as a polymer. The inventory used (Boustead & Cooper, 1998) does not meet the any data quality requirements, as it is more than 5 years old, and the source is not publicly available for use. However, the inventory was used to test the sensitivity of the asphalt binder impacts when modified by polymers such as styrene-butadiene-styrene (SBS) and polybutadiene. The differences in the GWP indicator for the different polymer-modified binders are illustrated in Table 8. It is expected that as the Asphalt Institute develops a detailed LCI for asphalt binder, this LCA will be modified to reflect the most recent outcomes, including the impacts of polymer modification.

Table 8: Difference in GWP for Polymer-Modified Binder and Mix (per ton)

	GWP (kg of CO_2eq)	Difference
Liquid Binder in Refinery	390.20	
Polymer-Modified: SBS	494.81	27%
Polymer-Modified: Polybutadiene	498.40	28%
Mix 1: Virgin materials, 5% Binder	58.59	
Polymer-Modified Mix 1	63.82	9%
Mix 2: 15% RAP, 3% RAS, 4.2% Binder	35.89	
Polymer-Modified Mix 2	40.29	12%

Upcoming Tasks





Resilience – Modeling Future Temperatures

Definition: Resilience

1. Ability to anticipate, prepare for, and adapt to changing conditions
    - Gradual changes in frequency and intensity of climate stressors
2. Withstand, respond to, and recover rapidly from disruptions
    - Extreme events that are very disruptive

Source: Adapted from FHWA Order 5520

Stationary vs. Non-stationary

- Stationary:
  - Observed data = future climate

- Non-stationary:
  - Observed data ≠ future climate

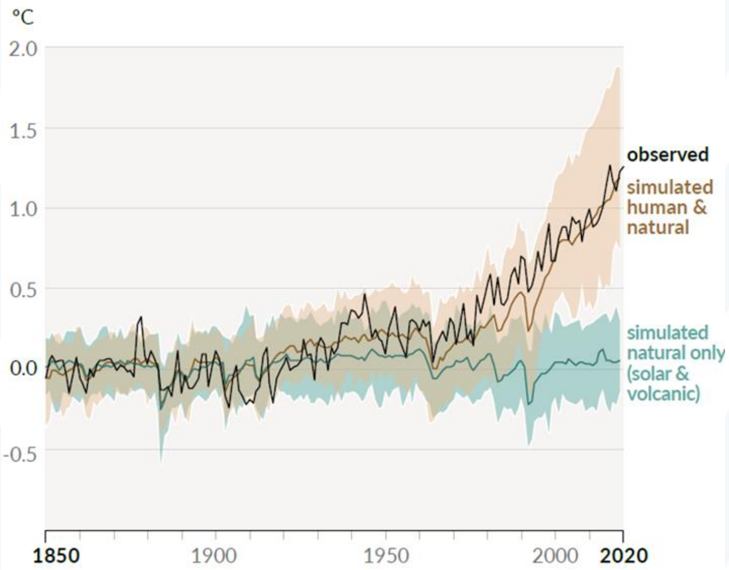


Image Source: IPCC AR6 WG1

MEPDG & LTPP Bind Climate Consideration

- MEPDG predicts *temperature* and moisture content in pavement layers

- *Method:* Built-in EICM
  1. Energy balance – pavement surface
  2. Heat transfer – pavement profile

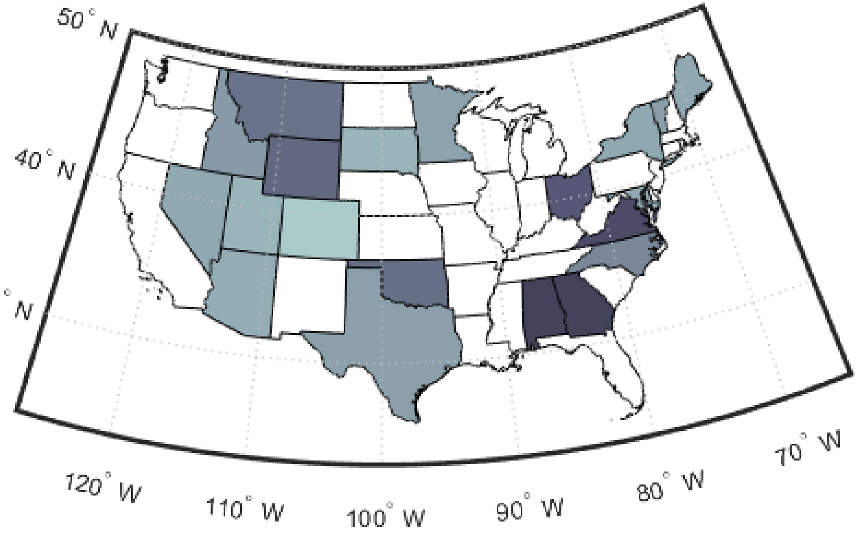
Given uncertainties in pavement temperature prediction, are changes in temperature due to climate change statistically significant?

Given those same uncertainties, are the differences between two downscaling methods statistically significant?

Data and Sites

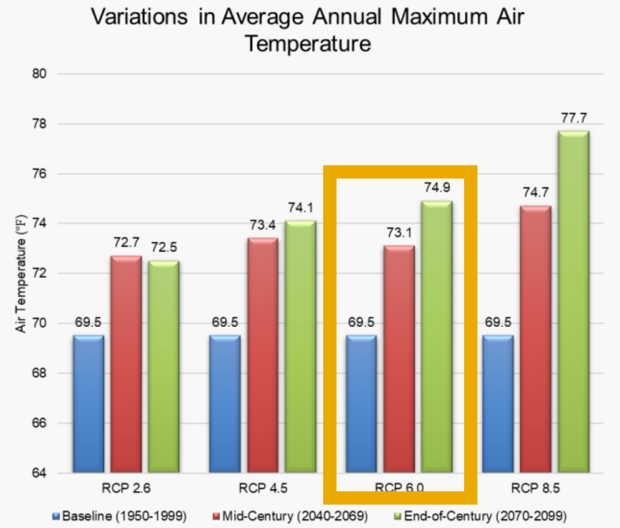
- 20 LTPP SMP sites from around continental US
  - Selected because measured temperatures available

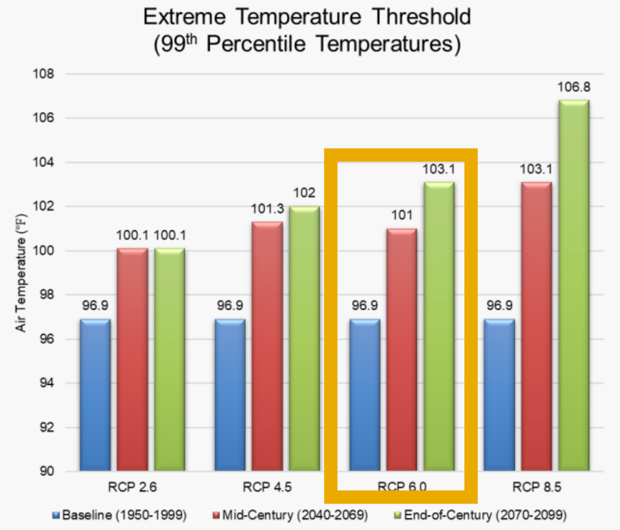
State	SHRP-ID	Thermistor Range	Future Projection Period
AL	01-0101	11/17/1997 - 11/17/1998	11/17/2042 - 11/17/2043
ME	23-1026	10/15/1996 - 10/15/1997	10/15/2041 - 10/15/2042
NV	32-0101	1/1/2000 - 1/1/2001	1/1/2045 - 1/1/2046
OK	40-4165	3/29/1994 - 3/29/1995	3/29/2039 - 3/29/2040
TX	48-1060	1/1/2000 - 1/1/2001	1/1/2045 - 1/1/2046



Future Climate

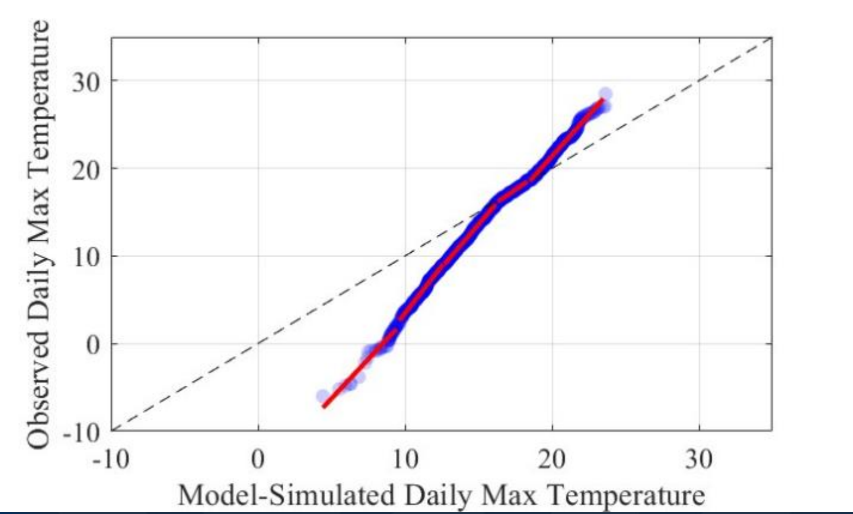
- CMIP RCP 6.0 (VA example →)
- 20-year hourly temperature predictions
  - Historical and historical plus 45 years
- Two downscaling methods
  - Delta Method (Meagher et al. (2012))
  - Asynchronous Regional Regression Model (ARRM) (2019)





Differences in Downscaling Methods

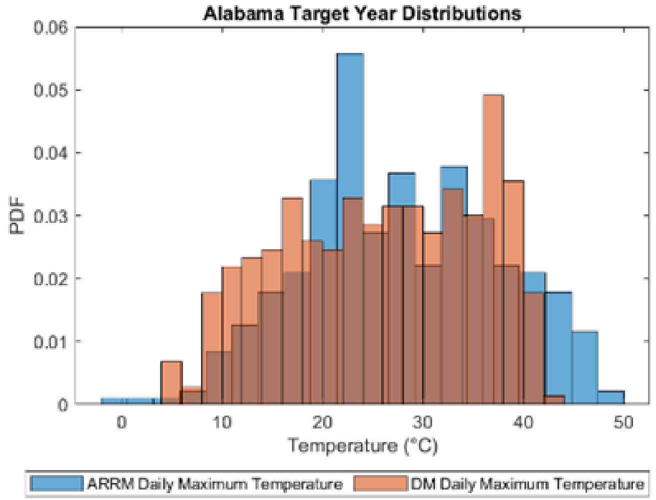
- Delta method
  - Scale daily minimum and maximum temperatures using CMIP data and calculate intermediate temperatures
- ARRM
  - Sophisticated approach that minimizes biases inherent in other approaches

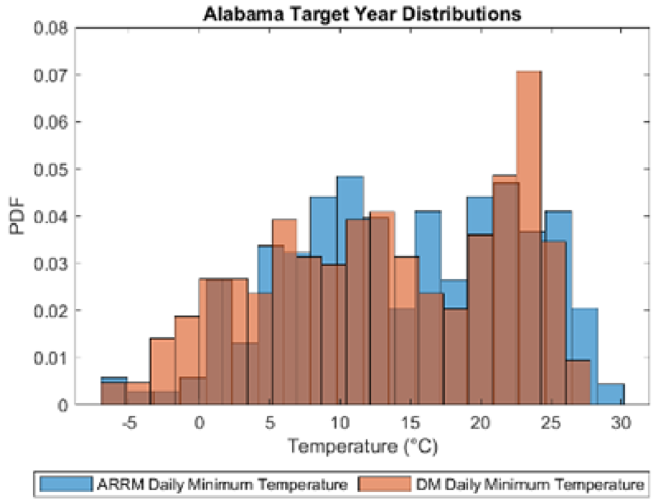


Comparing Downscaling Methods

State	Daily Maximum Temperature	Daily Minimum Temperature
AL	h=1	h=0
ME	h=1	h=1
MN	h=0	h=0
NV	h=1	h=1
OK	h=1	h=1
TX	h=1	h=1
VA	h=0	h=0
WY	h=1	h=1

h=1 means likely from different distributions





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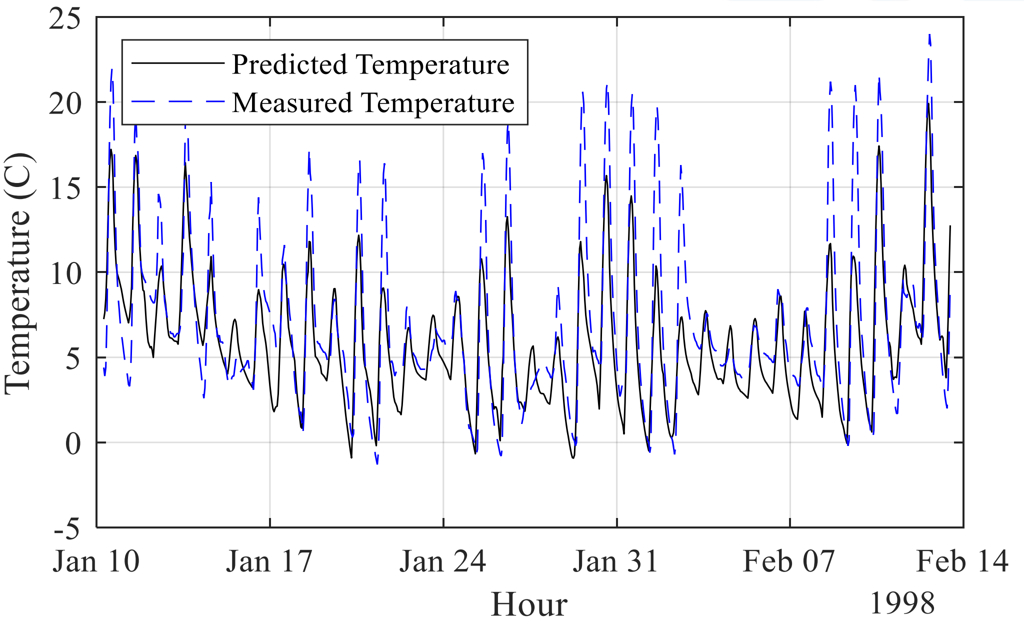
Predicting Current and Future Temps

$$\rho C_p \frac{\partial}{\partial t} u(x,t) = \frac{\partial}{\partial x} k \left(\frac{\partial u(x,t)}{\partial x} \right)$$



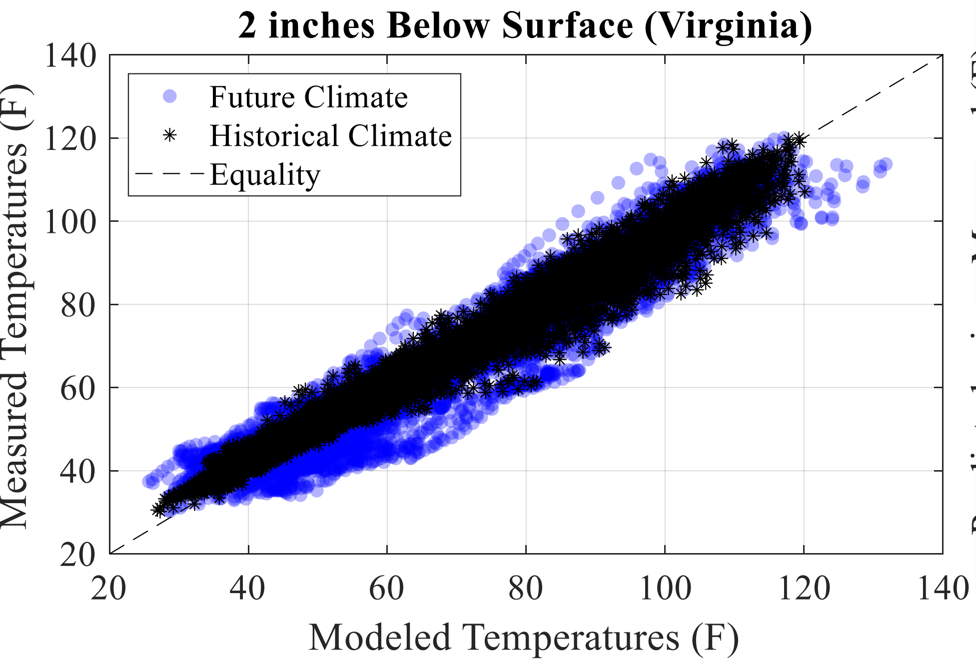
Boundary Conditions

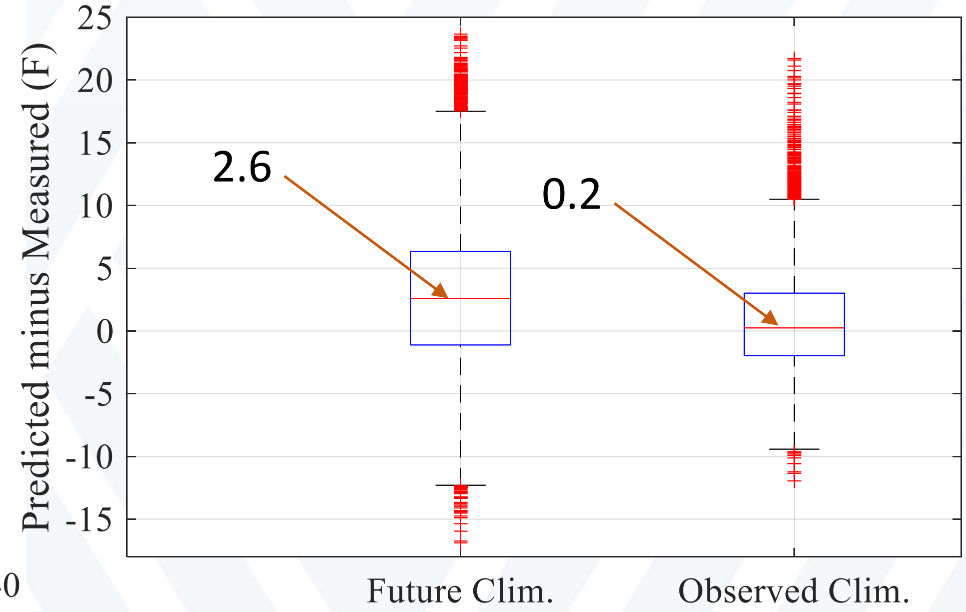
$$u(x,0) = T_i$$

$$-k \left(\frac{\partial u(0,t)}{\partial x} \right) = Q_s - Q_c - Q_R$$

$$u(L,t) = T_c$$

Observed and Future Predictions





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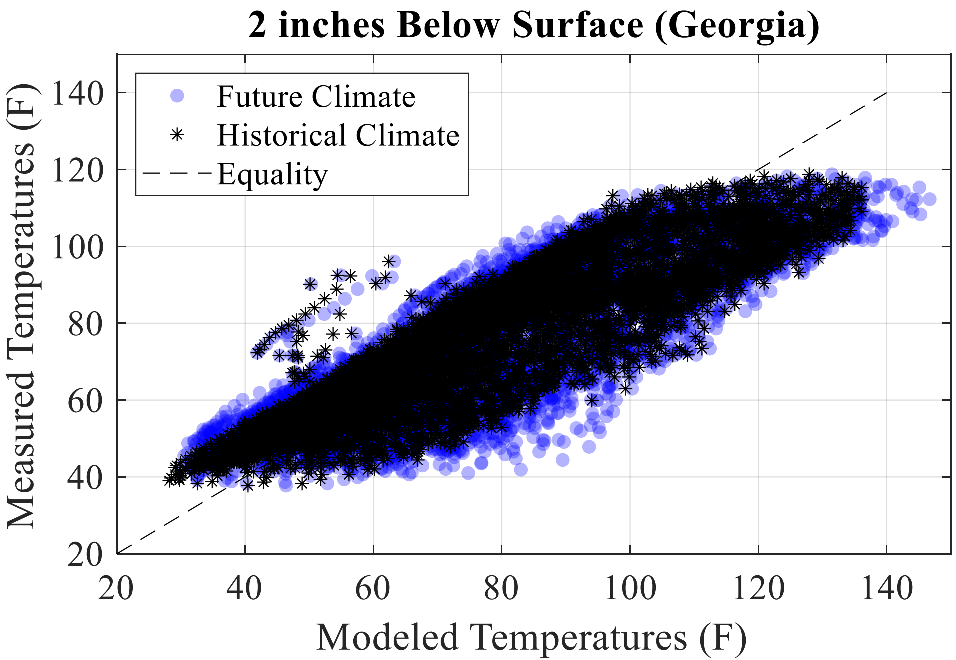

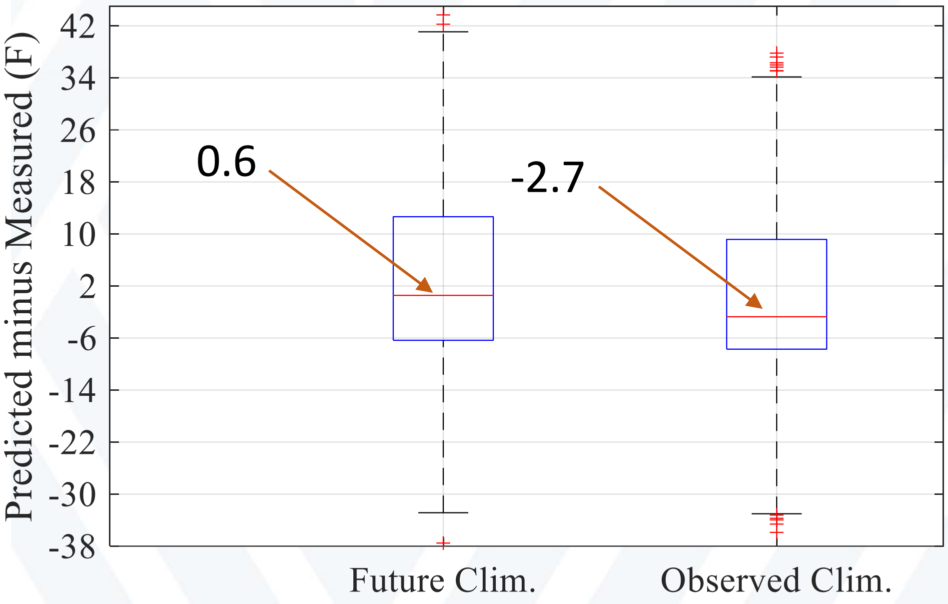

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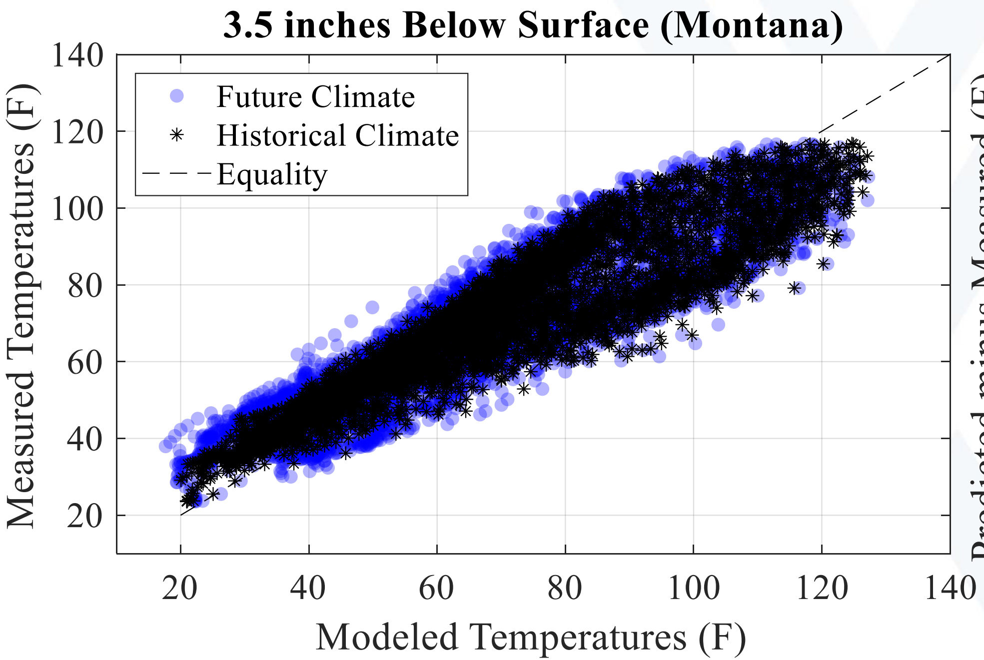

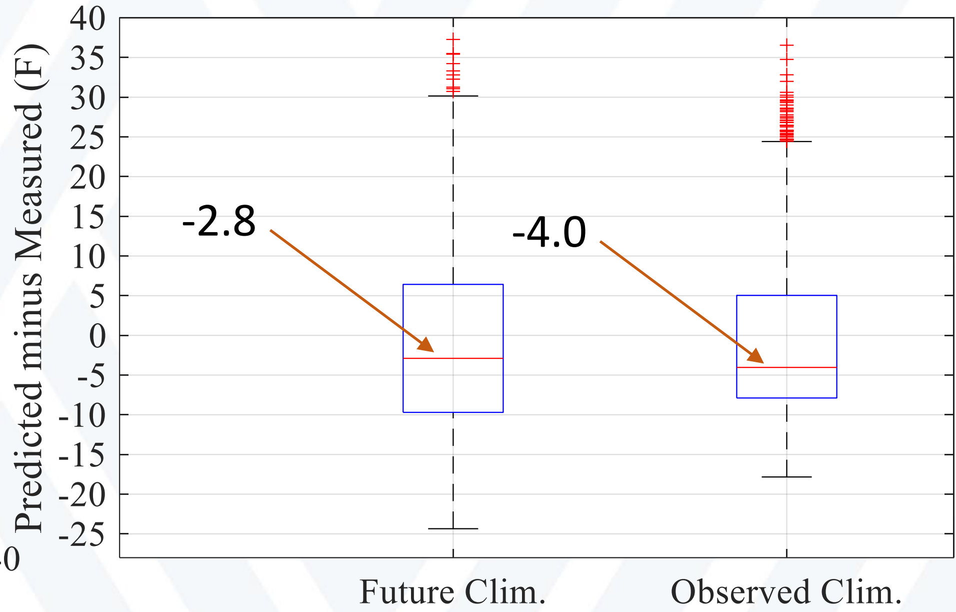

Wrap up

- Conducted LCA of several mixes in WV
  - Some unexpected results when using FHWA LCA Pave
  - Will inform recommendations for reducing carbon footprint of mixes
- Pavement resilience includes robust designs for mitigating the effects of climate change
  - How do we consider this in design and management?

Thank you for your kind attention!

Questions and Discussion?

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