Practical Considerations of Geospatial Interpolation of Road Surface Temperature for Winter Weather Road Management

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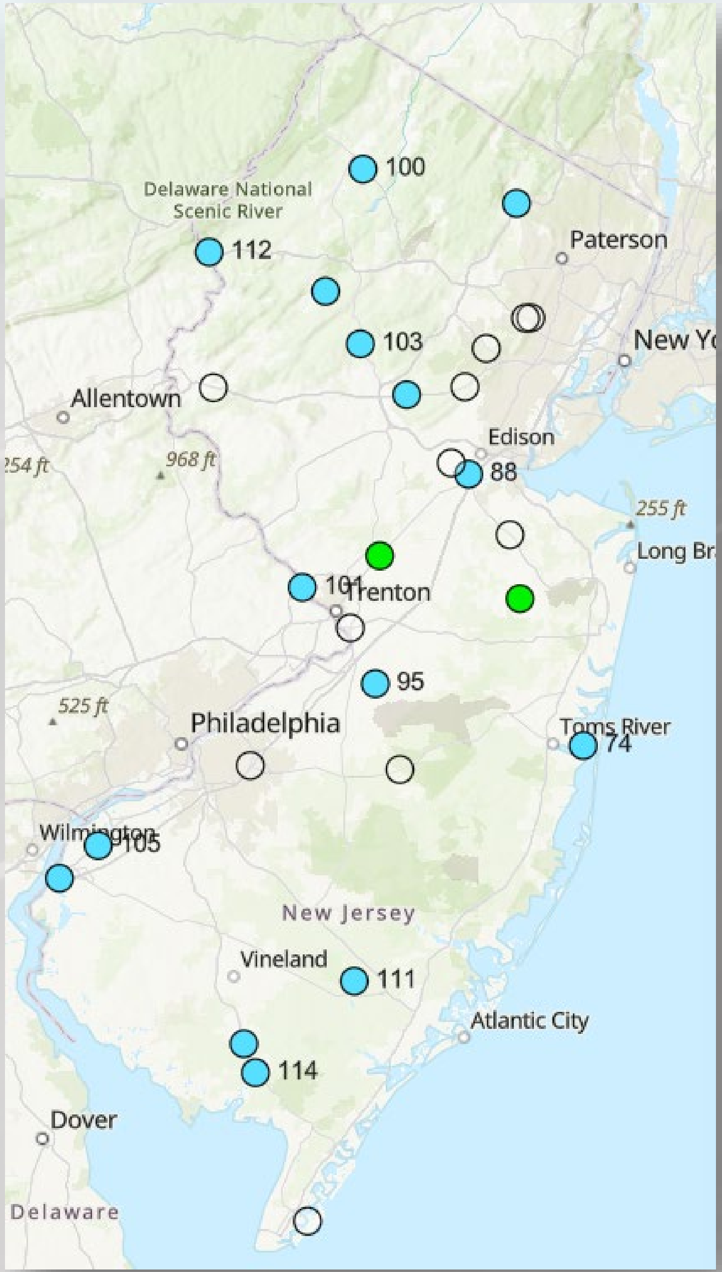
NJDOT Bureau of Research ***Tech Talk***
Research Showcase Lunchtime Edition
April 26, 2023

Background

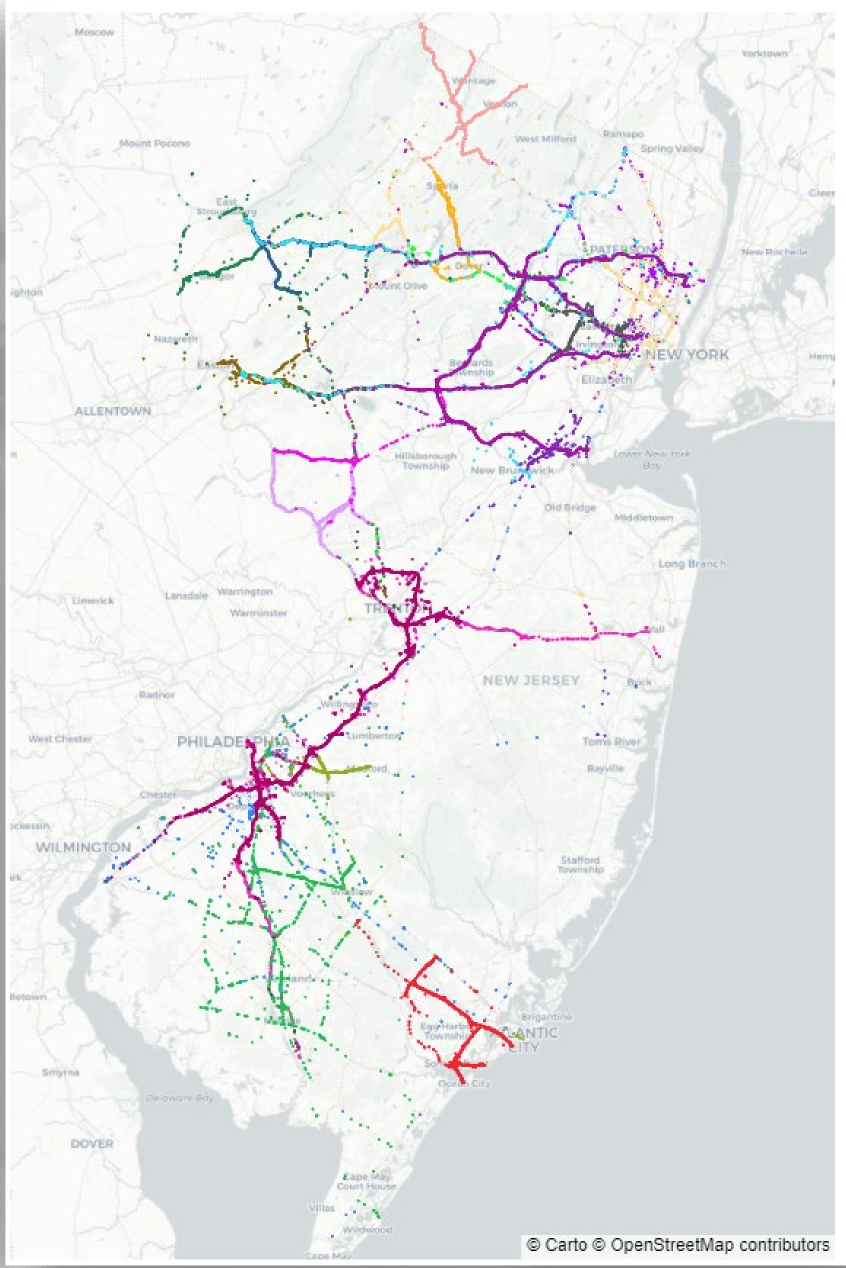
- Need for proactive winter road maintenance
- Large variation in weather conditions across the roadway network
- Limited coverage of roadside RWIS stations
- EDC-4: Weather Savvy Roads concepts and innovative technologies
- Integration of stationary and mobile RWIS data for improved coverage, awareness, and management decision support

RWIS Stations in NJ



Example of an RWIS Station (NJ 24)

Mobile RWIS Coverage



Weather Savvy Roads – Pilot Project

- **Objective**: Deploy IoT and CV technology to assist in road weather management:
  - Collect road weather and condition data in real time.
  - Provide data visualization to operators, for situational awareness and decision support.
  - Assist in analysis and planning of road weather management.
- Sponsored by the USDOT Accelerated Innovation Deployment (AID) Program, as implementation of EDC 4 “Weather Savvy Roads Integrating Mobile Observations (IMO)” innovation.

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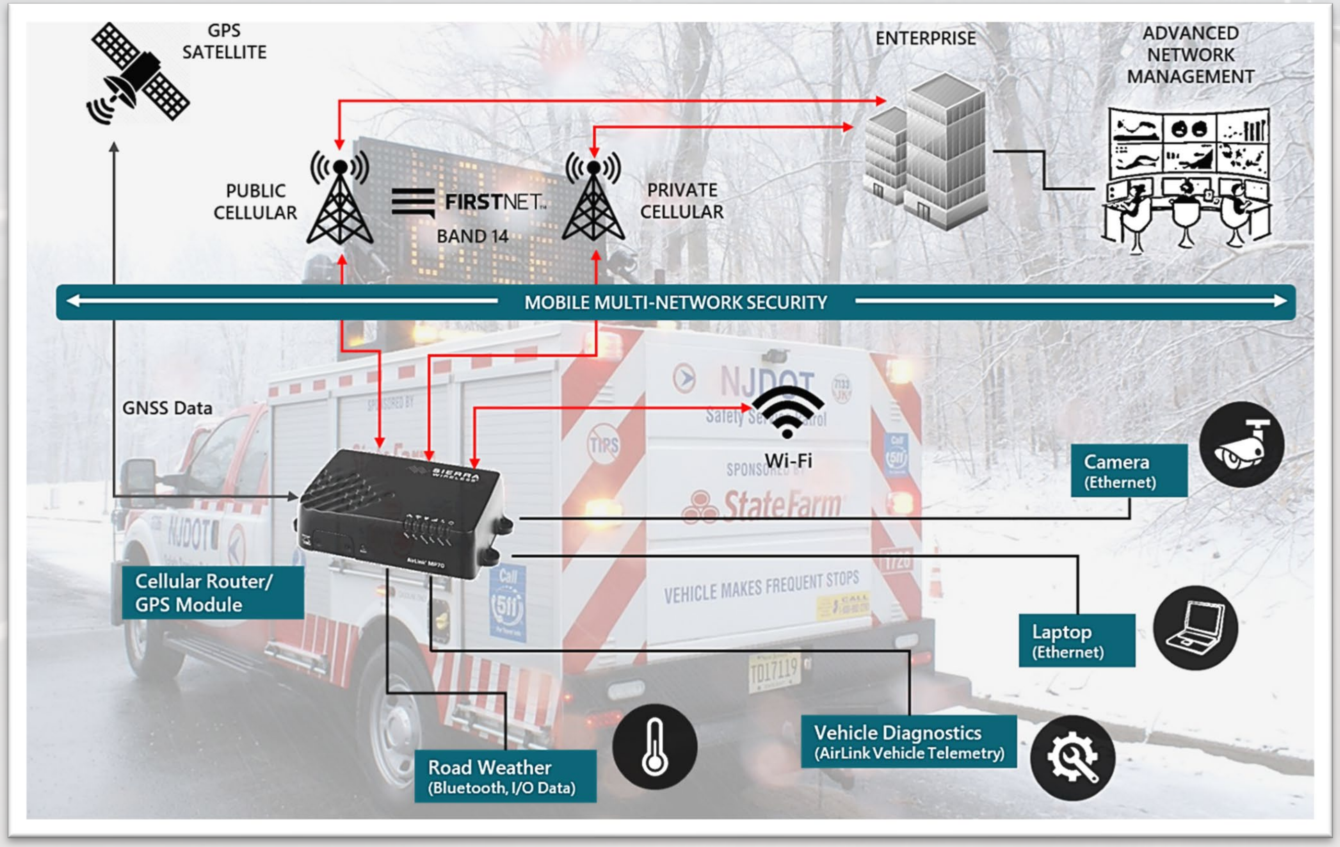
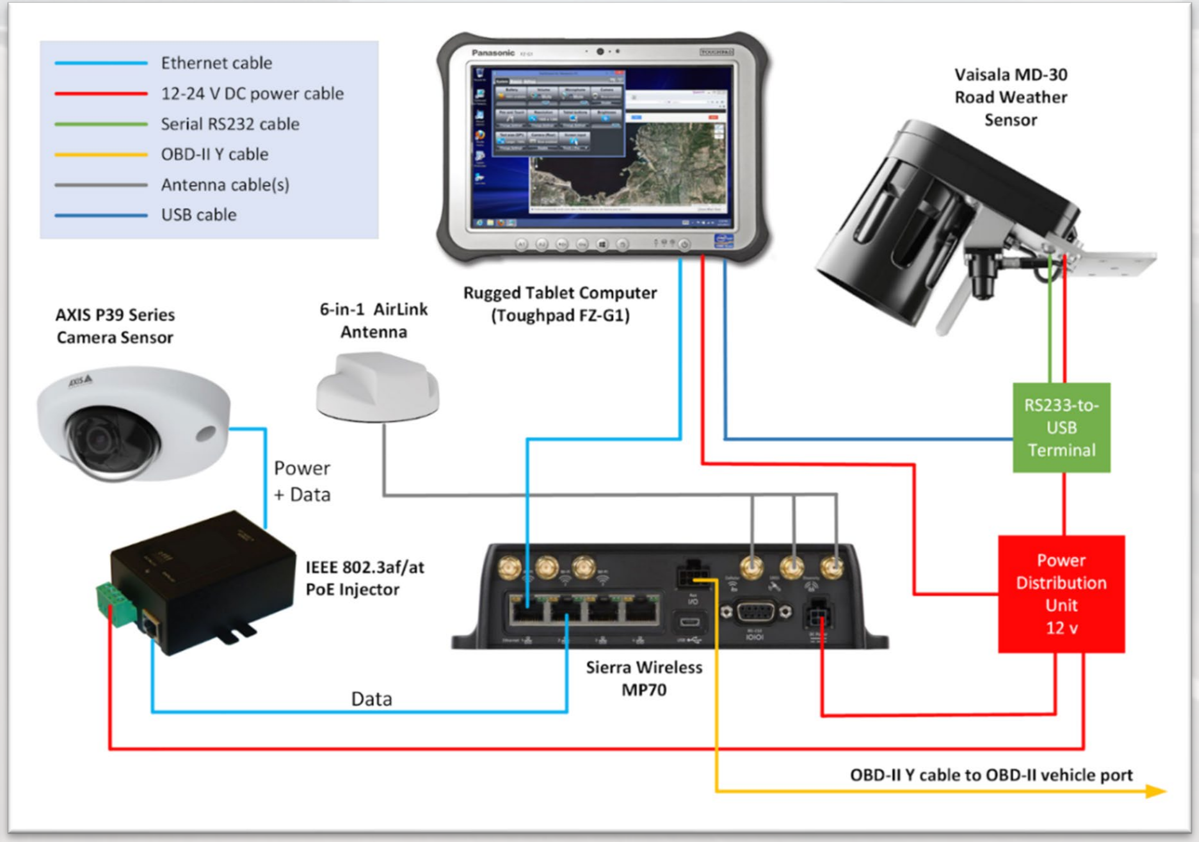
Weather Savvy Roads IMO: Concept

IMO = Integrated Mobile Observations





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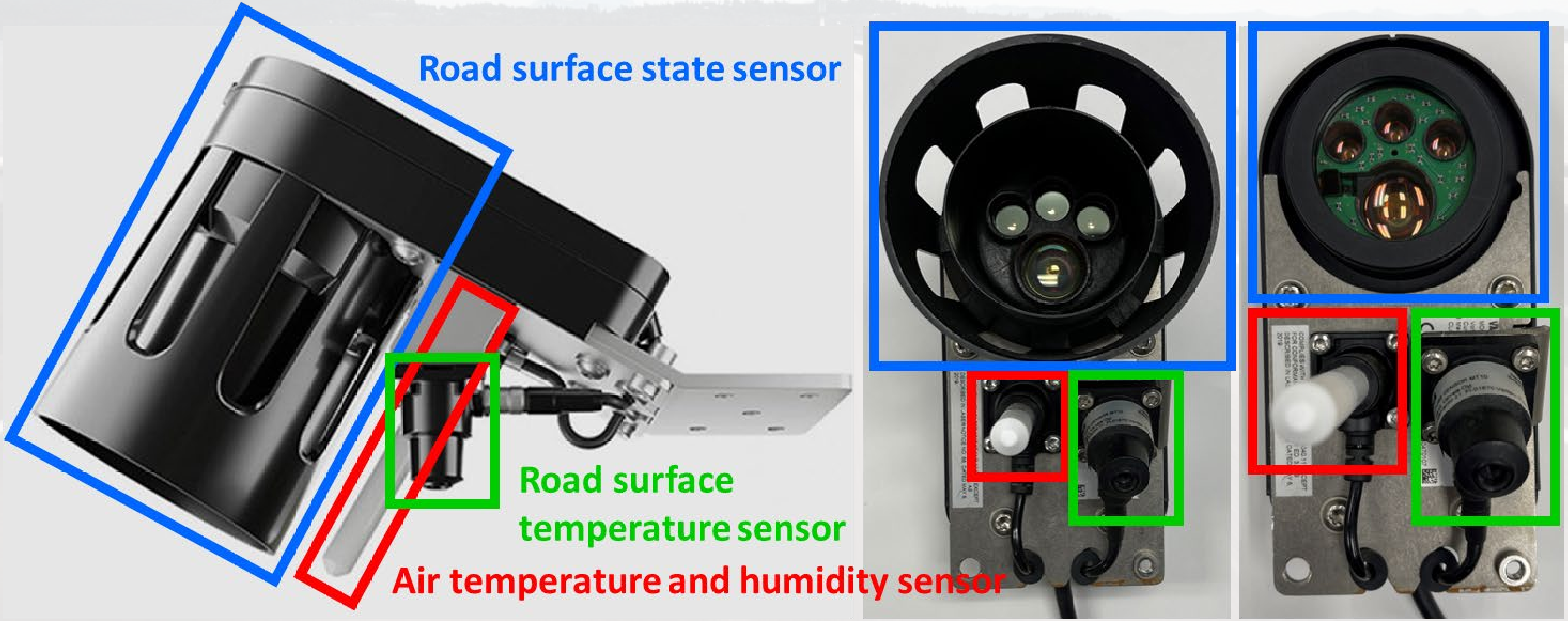
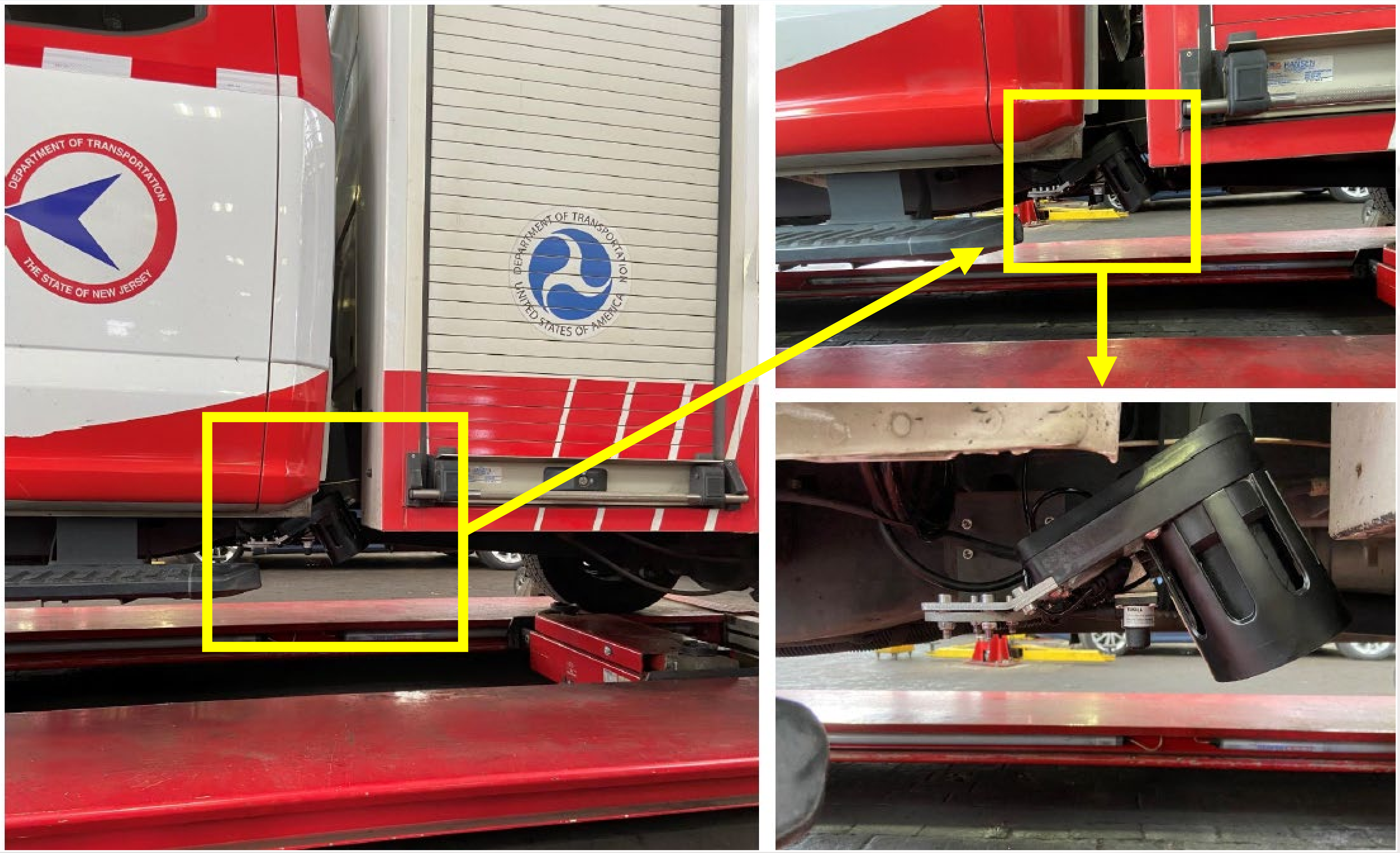
Mobile RWIS Sensor



Vehicle Instrumentation – SSP/IMRT



Mobile RWIS
Sensor Installation

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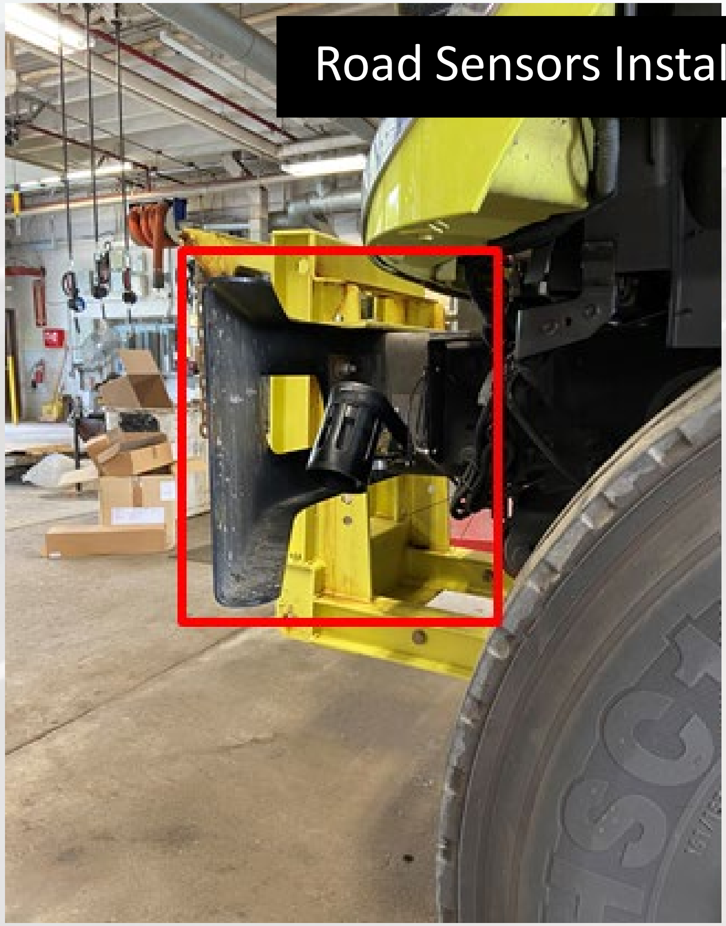
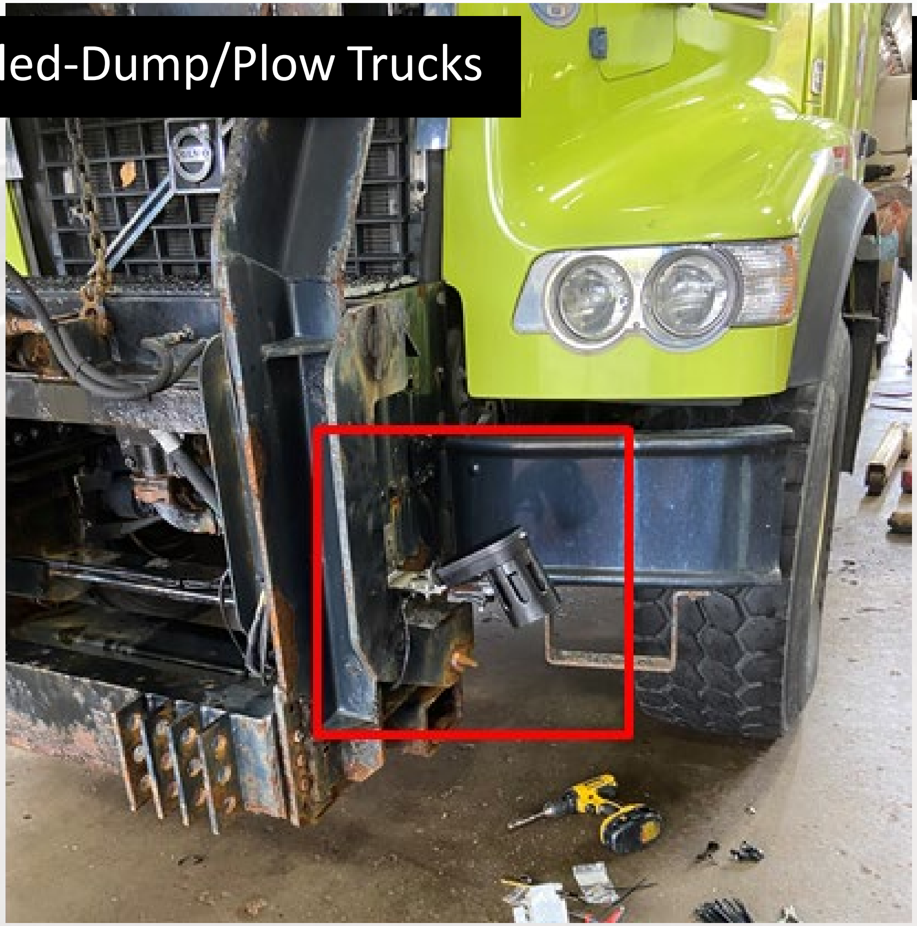
Vehicle Instrumentation – Plow Trucks

Road Sensors Installed-Dump/Plow Trucks

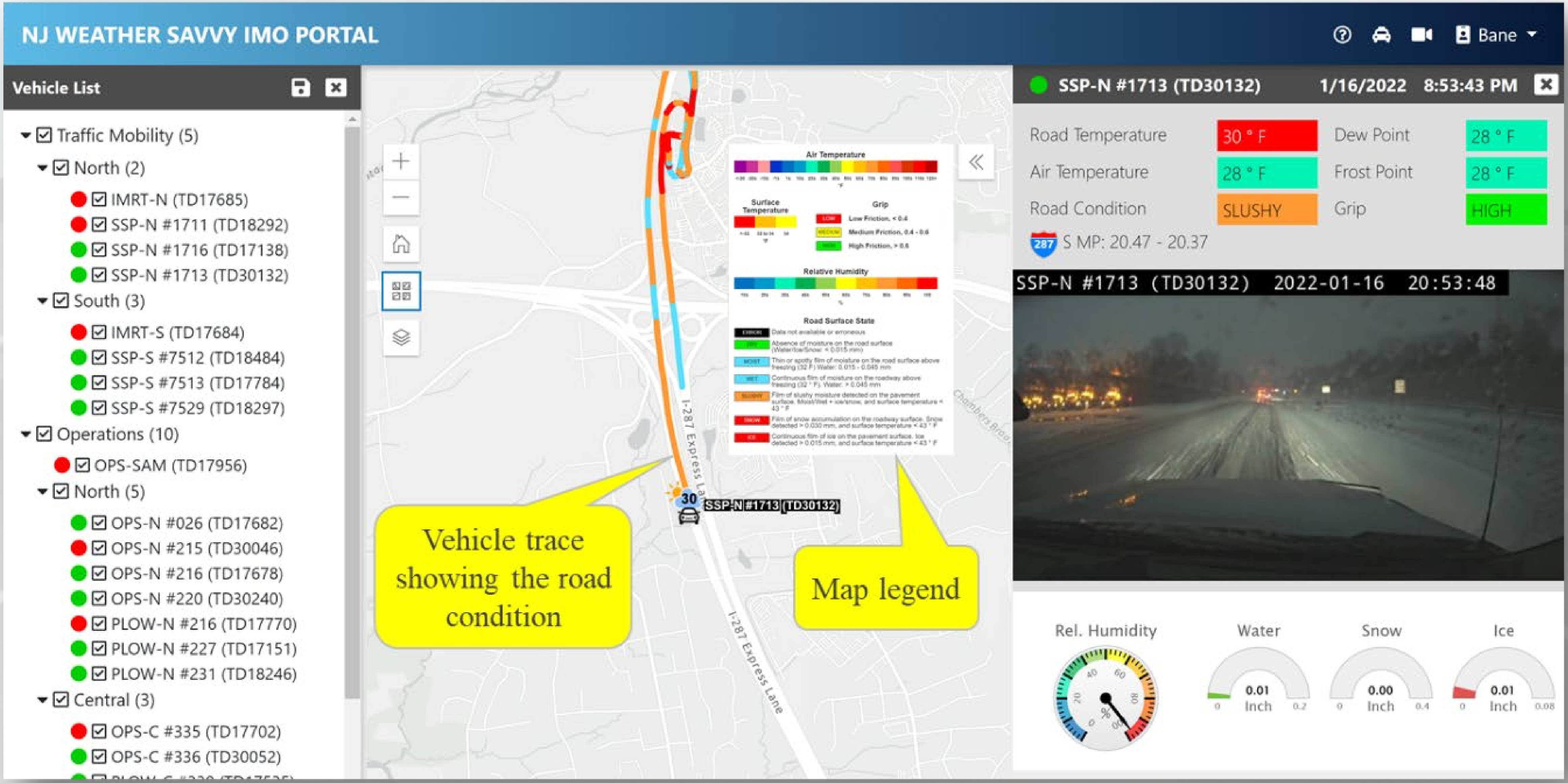




Ambient Weather Sensor Installed

Vehicle Instrumentation – Onboard PC

Cab Setup – IMRT Truck


NJ WEATHER SAVVY IMO PORTAL
Bane
Vehicle List
Traffic Mobility (5)
North (2)
IMRT-N (TD17685)
SSP-N #1711 (TD18292)
SSP-N #1716 (TD17138)
SSP-N #1713 (TD30132)
South (3)
IMRT-S (TD17684)
SSP-S #7512 (TD18484)
SSP-S #7513 (TD17784)
SSP-S #7529 (TD18297)
Operations (10)
OPS-SAM (TD17956)
North (5)
OPS-N #026 (TD17682)
OPS-N #215 (TD30046)
OPS-N #216 (TD17678)
OPS-N #220 (TD30240)
PLOW-N #216 (TD17770)
PLOW-N #227 (TD17151)
PLOW-N #231 (TD18246)
Central (3)
OPS-C #335 (TD17702)
OPS-C #336 (TD30052)
Air Temperature
Surface Temperature
Grip
Low Friction, < 0.4
Medium Friction, 0.4 - 0.6
High Friction, > 0.6
Relative Humidity
Road Surface State
I-287 Express Lane
30
SSP-N #1713 (TD30132)
Vehicle trace showing the road condition
Map legend
SSP-N #1713 (TD30132) 1/16/2022 8:53:43 PM
Road Temperature 30 ° F
Dew Point 28 ° F
Air Temperature 28 ° F
Frost Point 28 ° F
Road Condition SLUSHY
Grip HIGH
287 S MP: 20.47 - 20.37
SSP-N #1713 (TD30132) 2022-01-16 20:53:48
Rel. Humidity
Water 0.01 Inch
Snow 0.00 Inch
Ice 0.01 Inch

Weather Savvy Roads – Pilot Project

2021 Outstanding Project Award

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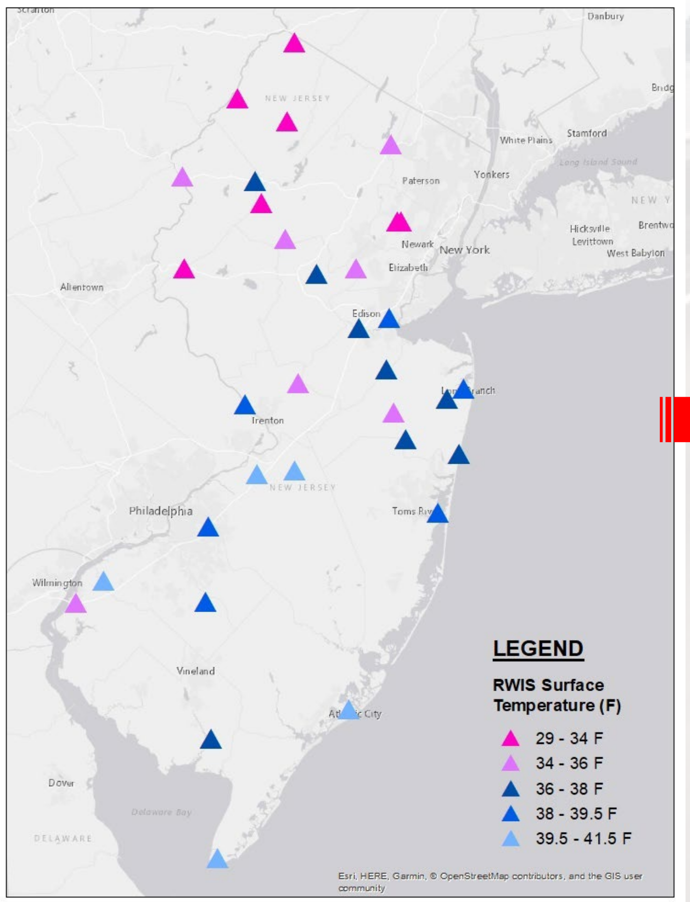
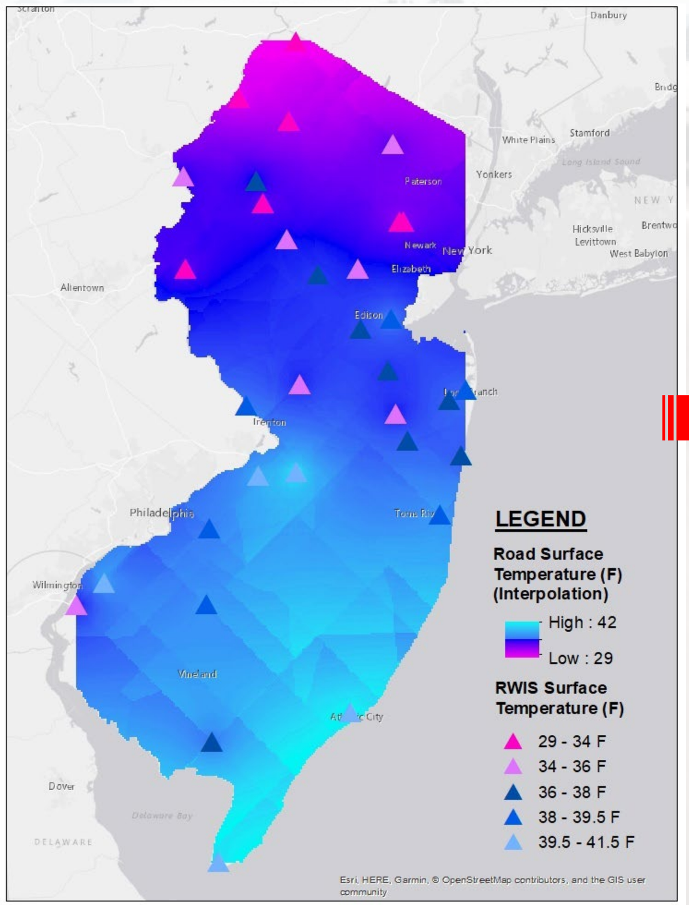
Road Surface Temperature (RST) Interpolation

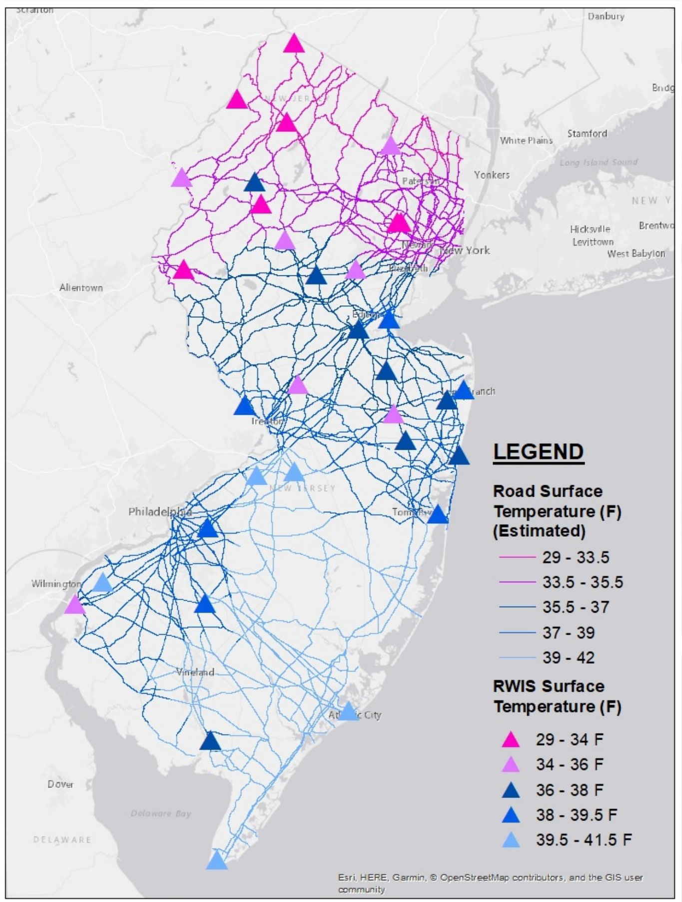
RST = commonly used measure (indicator) of the road surface condition



RWIS Readings



Kriging Interpolation



RST Interpolation Methodology

Inputs
- RWIS/MRIWS data
- Additional data layers

Model
Kriging Interpolation and Machine Learning Modeling

Outputs
Estimated RST over NJ Roadway Network

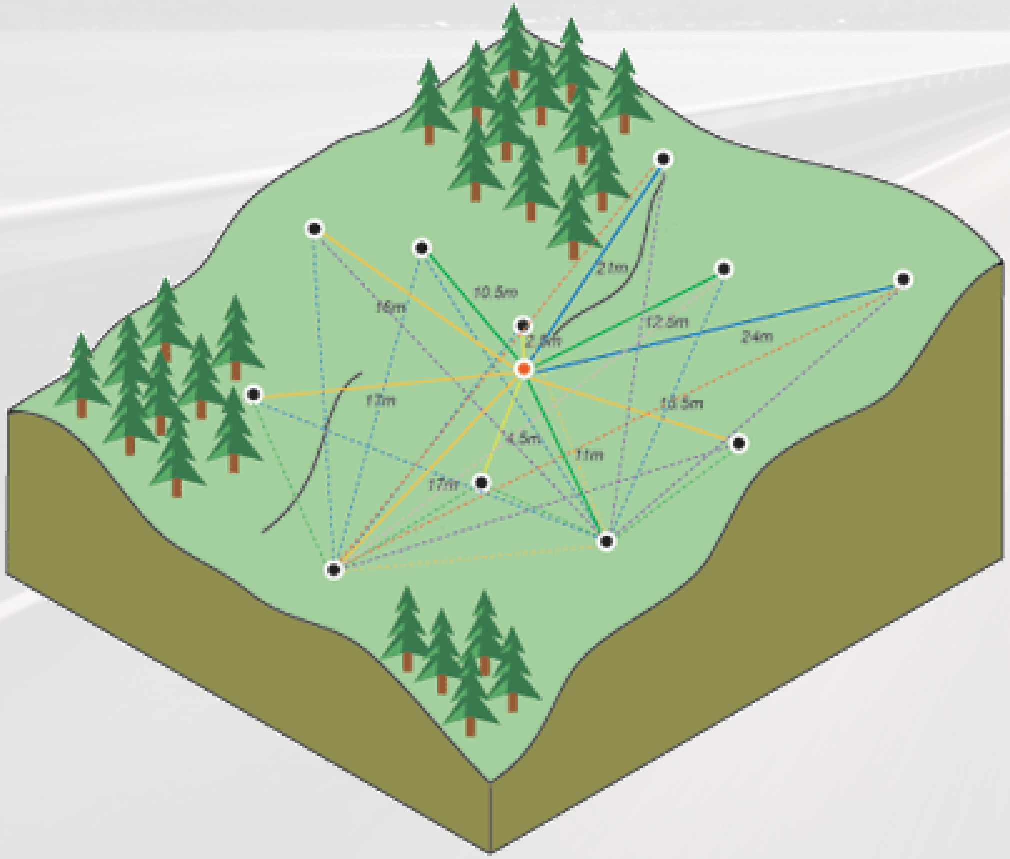
Kriging Interpolation
- Ordinary/Universal Kriging (OK)
- Regression Kriging (RK)
- Empirical Bayesian Kriging (EBK)

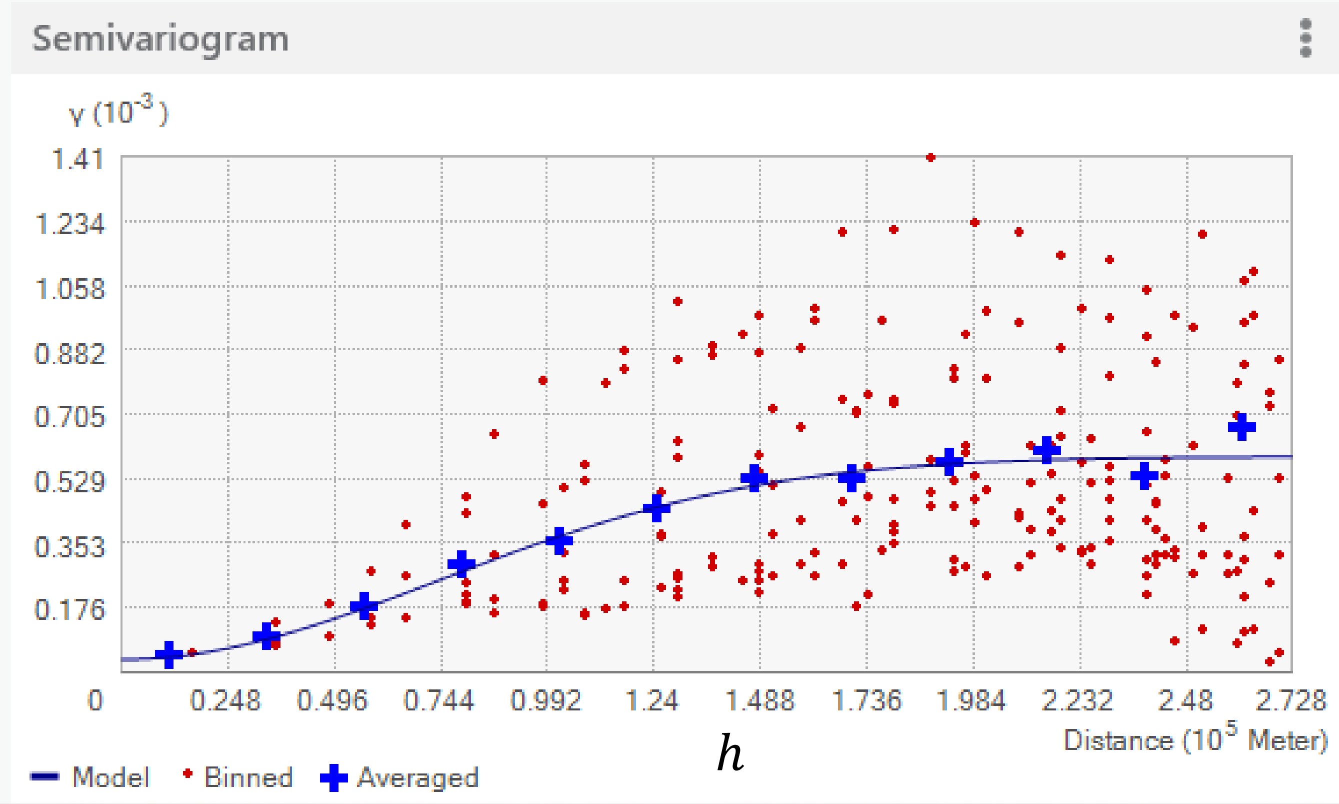
Machine Learning Regression
- Lasso Regression
- Support Vector Regression (SVR)
- Random Forest Regression

Kriging

$$\hat{Z}(x) = m(x) + \sum_{k=1}^{m} \lambda_k [Z(x_k) - m(x_k)]$$

$$\gamma(h) = \frac{1}{2n_h}\sum_{i=1}^{n_h}[Z(x_i + h) - Z(x_i)]^2) \;\; = \;\; \frac{1}{2} var(Z(x_k + h), Z(x_k))$$



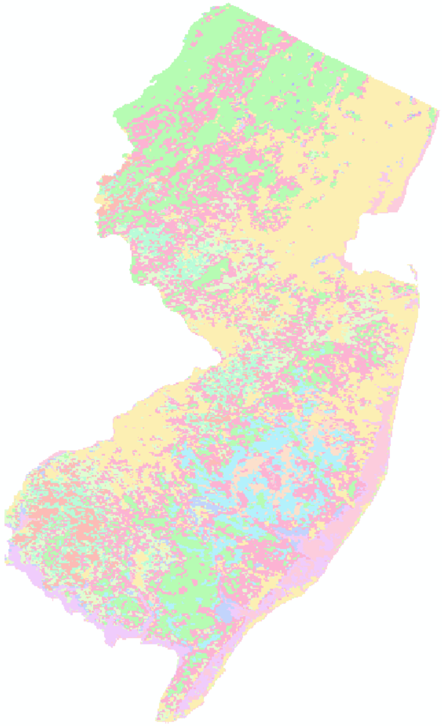


Source: ESRI (https://pro.arcgis.com/)

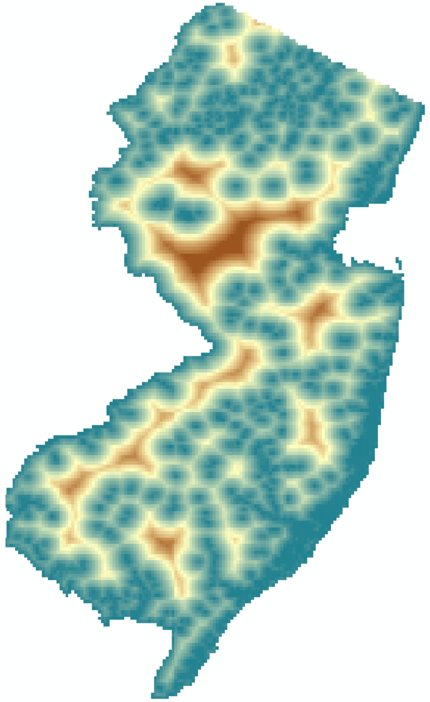
Regression Layers

Vegetation Type

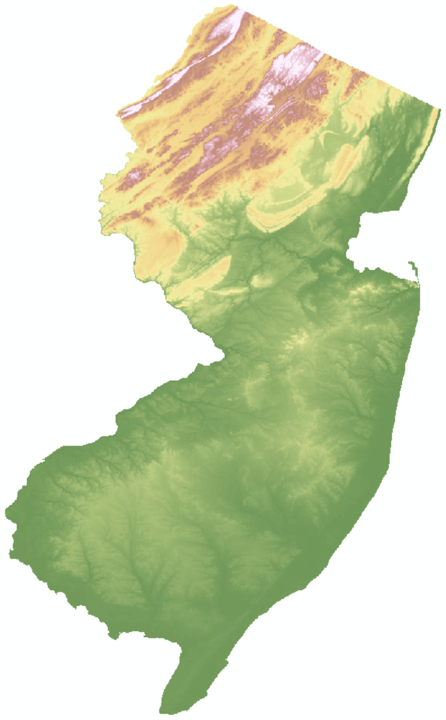
Land Cover Type

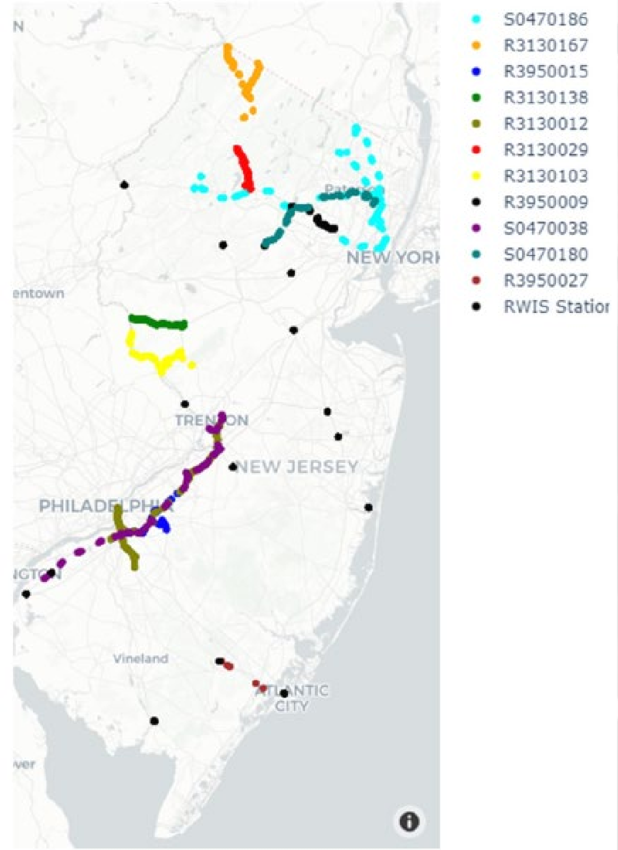


Distance to Water



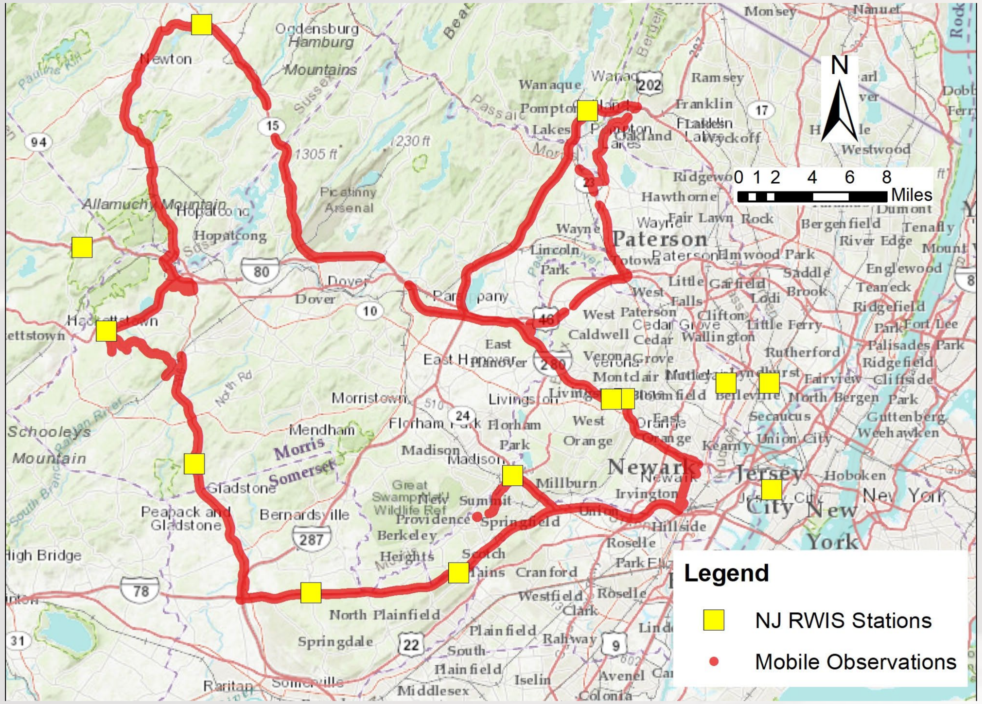
Elevation (DEM)

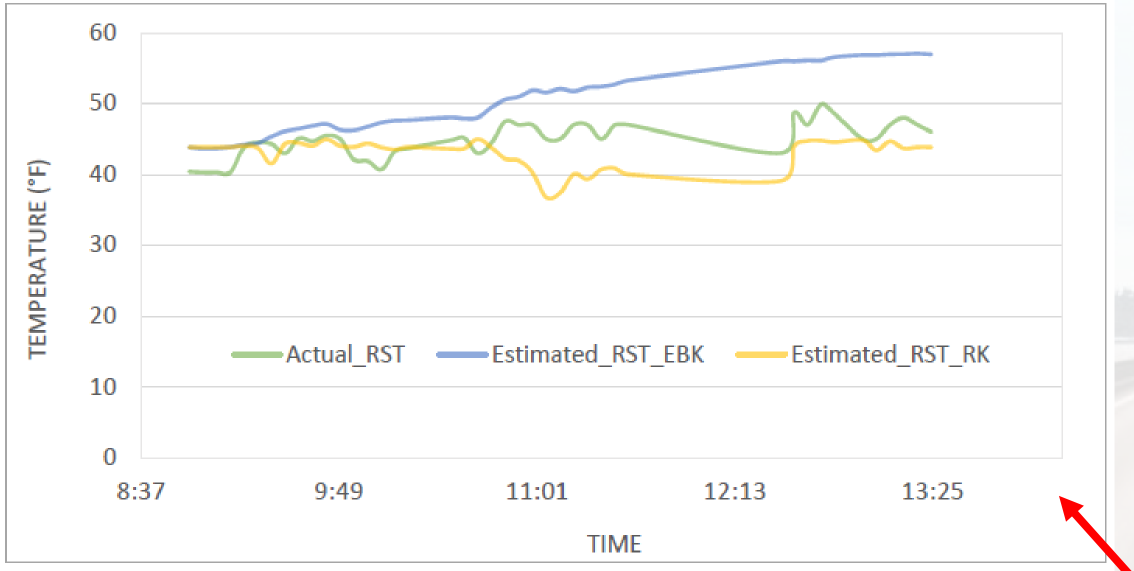


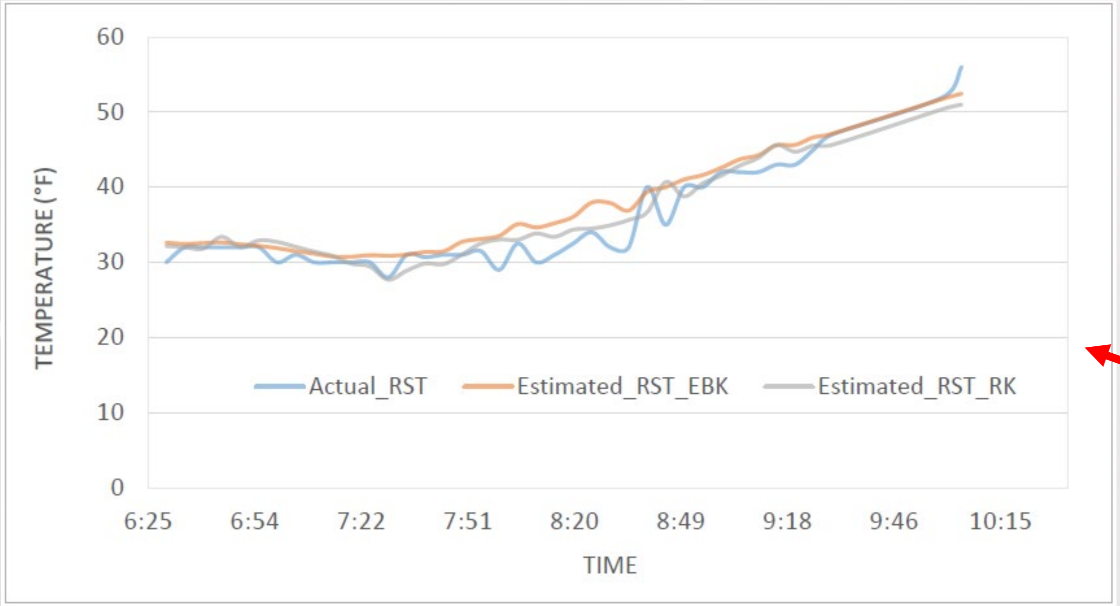


Case Study I

- RST Interpolation Stationary RWIS Data
  - Data collected from the stationary RWIS nearby a given route
  - Extrapolate the RST based on stationary RWIS readings
  - Mobile RWIS data used as a “ground truth” for comparison







Case Study I

Comparison of Kriging Models

- Regression Kriging yielded the best results among the three models
- Better performance in Trial #2 with less variability

Date	Model	MAE	RMSE
Trial #1	OK	9.22	10.26
	RK	**3.13**	**3.90**
	EBK	3.26	3.95
Trial #2	OK	15.72	17.09
	RK	**1.63**	**2.14**
	EBK	1.95	2.52

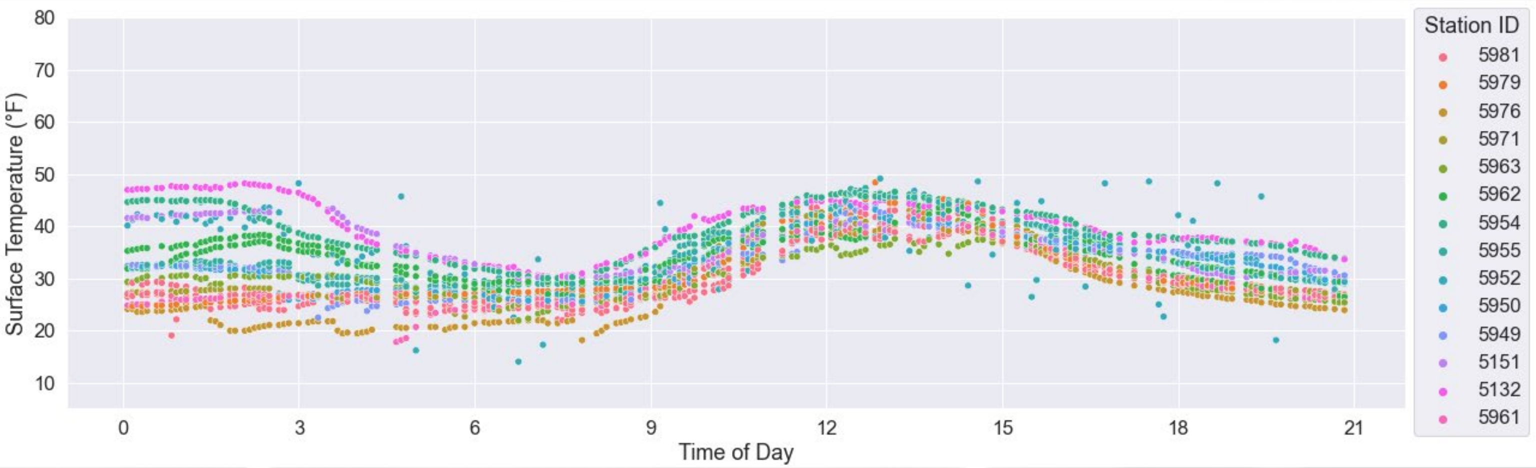
Case Study II

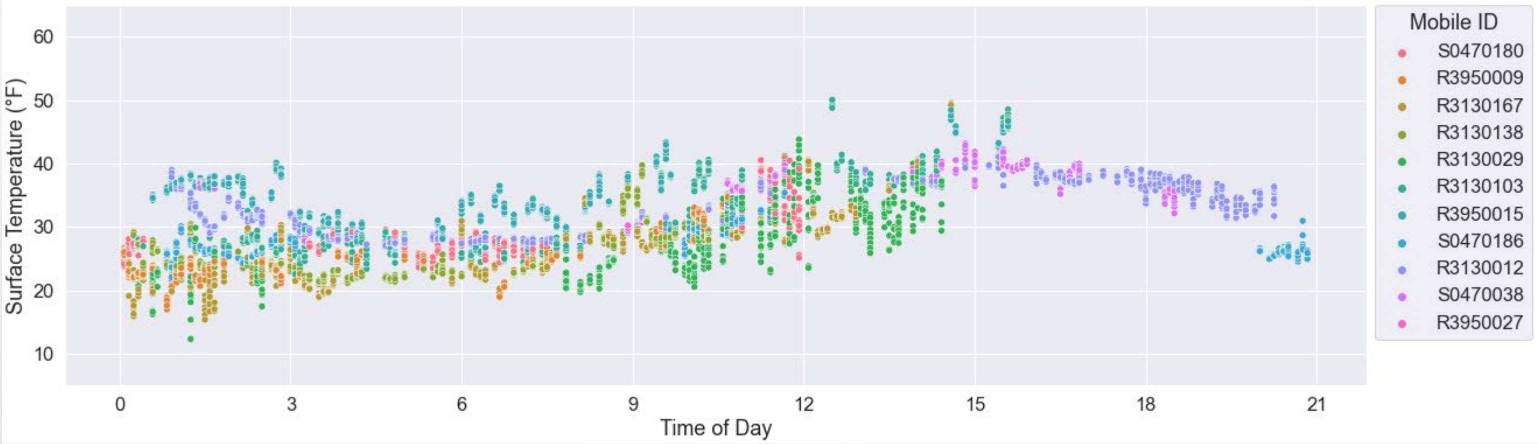
- Regional (statewide) RST estimation using stationary and mobile RWIS Data
  - Winter storm event
  - 11 active vehicles with mobile RWIS sensor
  - 20 active (reporting) RWIS stations
- Several modeling approaches used in RST model development:
  1. Ordinary/Universal Kriging Interpolation
     a) Calibration/validation using stationary RWIS, testing with mobile RWIS
     b) Calibration/validation using mobile RWIS, testing with stationary RWIS
     c) Calibration/validation using combined stationary and mobile RWIS data
  2. Regression Kriging Interpolation
     - ML regression to estimate the RST “drift” based on a set of explanatory variables
     - Kriging interpolation of the regression residuals

Exploratory RST Data Analysis

Observed RST	Stationary RWIS	Mobile RWIS
Median	28.0	28.6
Mean	33.4	29.8
Min	14.0	12.3
Max	49.1	50.1

Elevation	Stationary RWIS	Mobile RWIS
Mean	117.1 ft	358.6 ft
Min	0 ft	-75.8 ft
Max	597.1 ft	1558.1 ft





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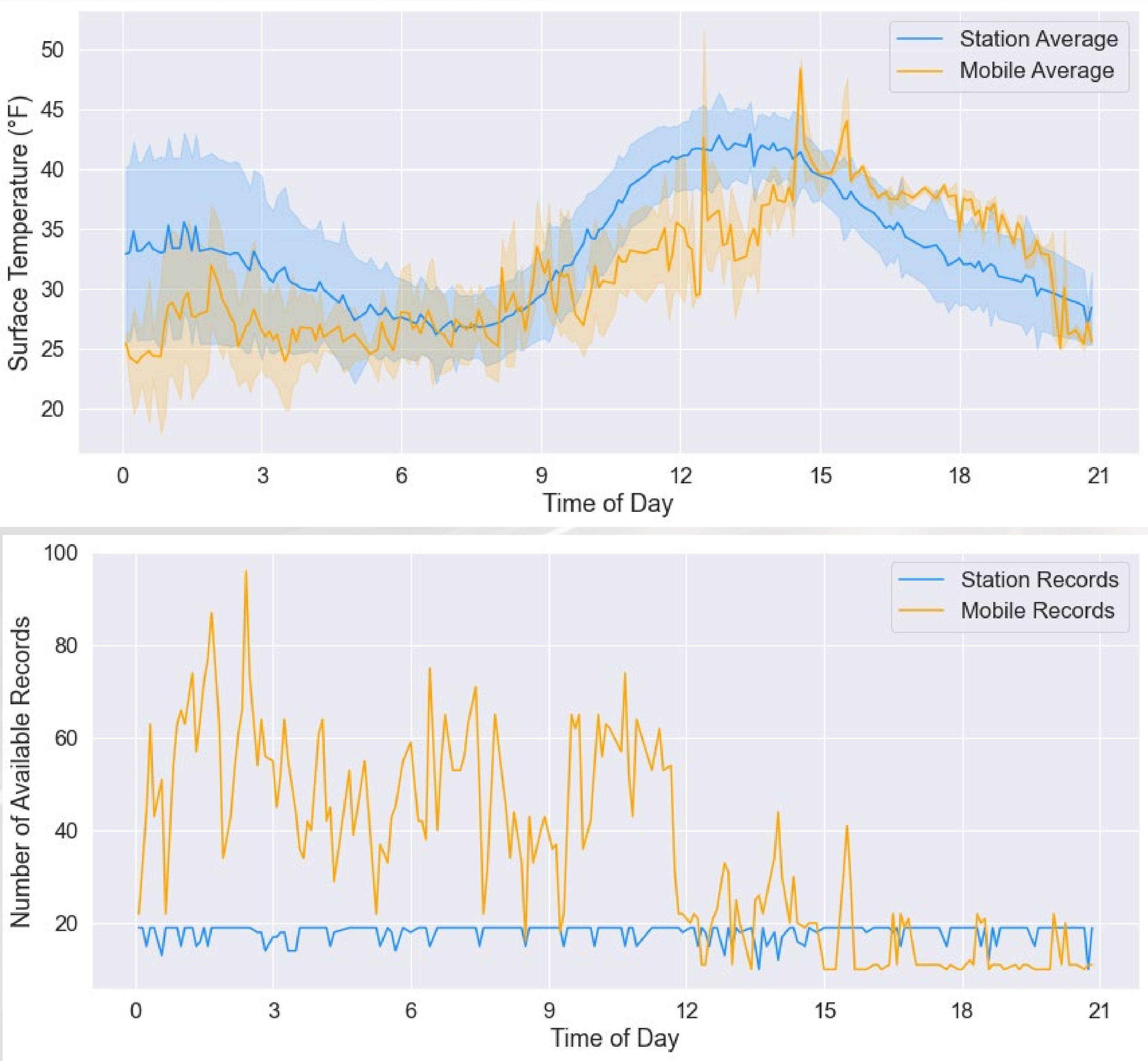


Exploratory RST Data Analysis (cont.)

- RST variation
  - Among the stations/ sensors
  - By time of day
  - Between mobile and stationary RWIS – large discrepancies observed
- Varying number of MRWIS records

Case Study II, Ordinary/Universal Kriging Interpolation

a) Calibration and validation = stationary RWIS / Testing = mobile RWIS.

Model	Validation (station data)		Test (mobile data)	
	MAE	RMSE	MAE	RMSE
Ordinary Kriging	1.96	2.74	2.98	4.01
Universal Kriging	2.02	2.94	2.92	3.91

b) Calibration and validation = mobile RWIS / Testing = stationary RWIS.

Model	Validation (mobile data)		Test (station data)	
	MAE	RMSE	MAE	RMSE
Ordinary Kriging	0.44	0.85	4.22	5.43
Universal Kriging	0.44	0.83	4.61	6.17

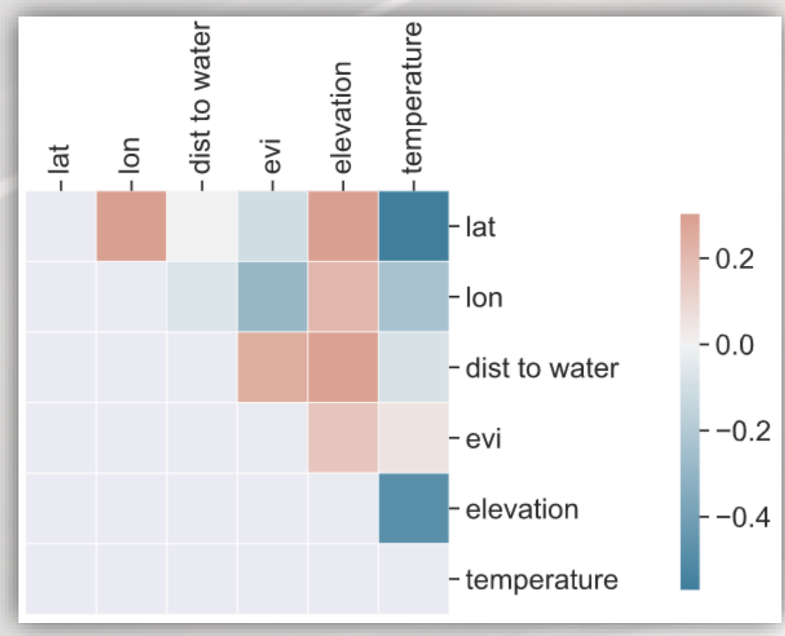
c) Calibration and validation using combined stationary and mobile RWIS data.

Model	Cross-validation (combined data)	
	MAE	RMSE
Ordinary Kriging	0.95	1.75
Universal Kriging	0.95	1.77

Case Study II, Regression Kriging

- Regression based on several explanatory variables
- Kriging applied to regression residuals to account for the spatial variance:
  - Large improvement for Lasso/SVR
  - Marginal improvement for Random Forest

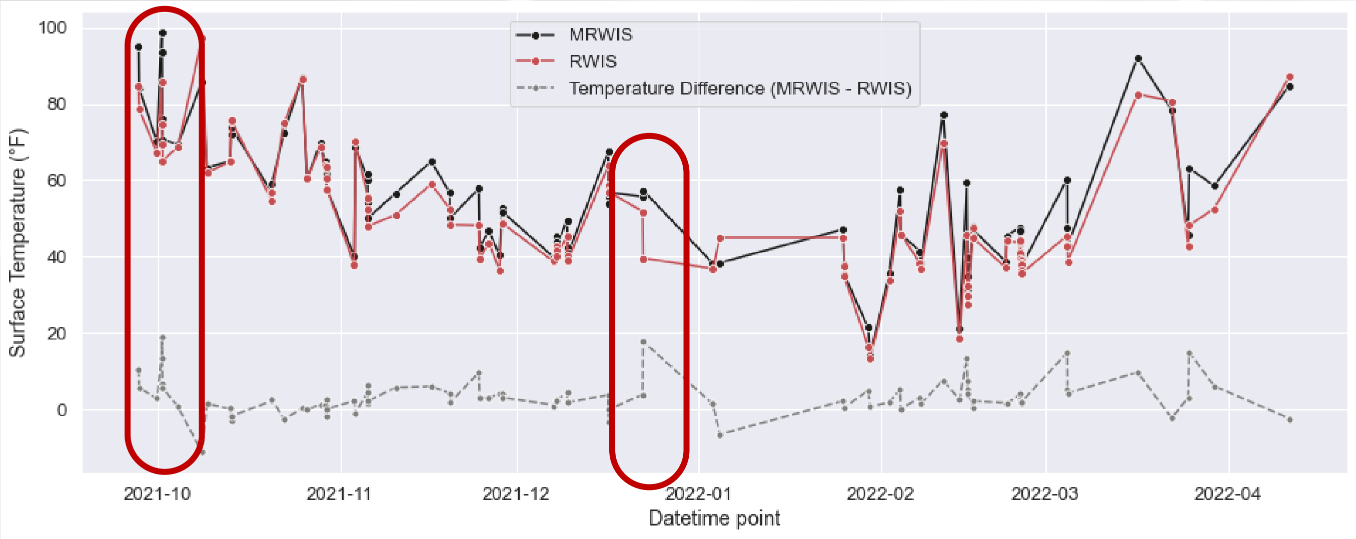
Model	MAE	RMSE
Lasso	2.18	3.02
SVR	2.12	3.35
Random Forest	1.10	2.02



Model	MAE	RMSE
Lasso + Ordinary kriging	0.96	1.78
SVR + Ordinary kriging	0.98	1.83
Random Forest + Ordinary kriging	1.00	1.89

Observed Issues

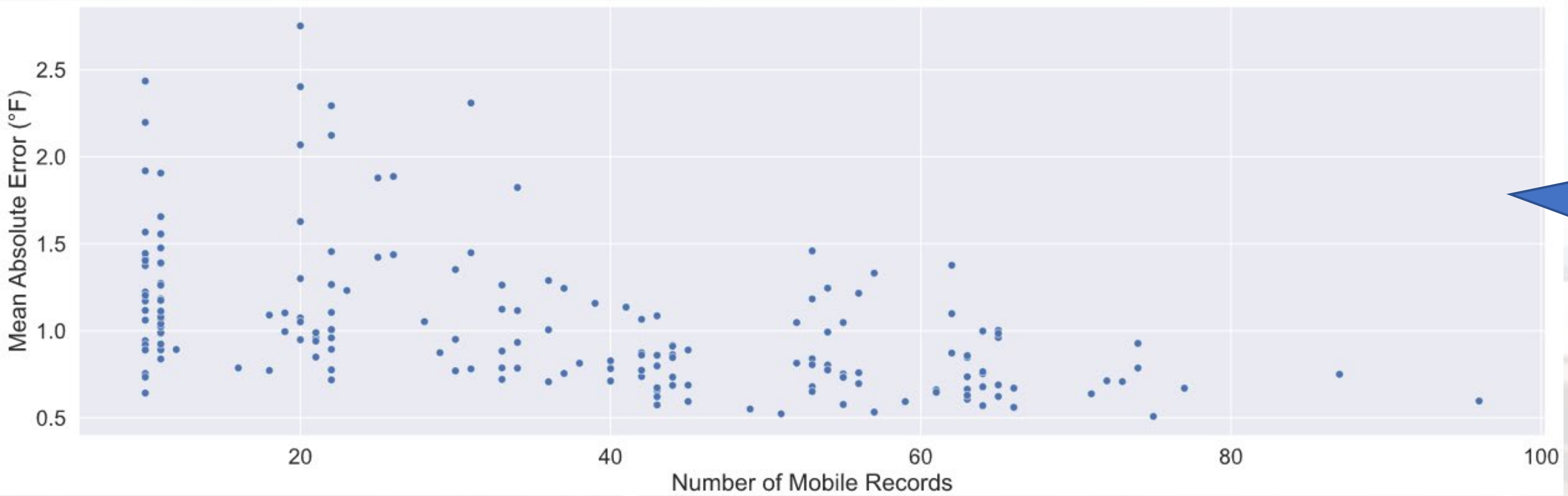
- Discrepancy between RWIS and MRWIS
  - General difference between RWIS and MRWIS readings at nearby roadway segments
  - Due to high mobility of MRWIS, the observations may vary a lot within a short time period and distance due to local fluctuations or sensor bias
  - Solutions: averaging readings, removing outliers, dealing with too few observations, fine-tuning interpolation models, can improve the quality (accuracy) of the estimate



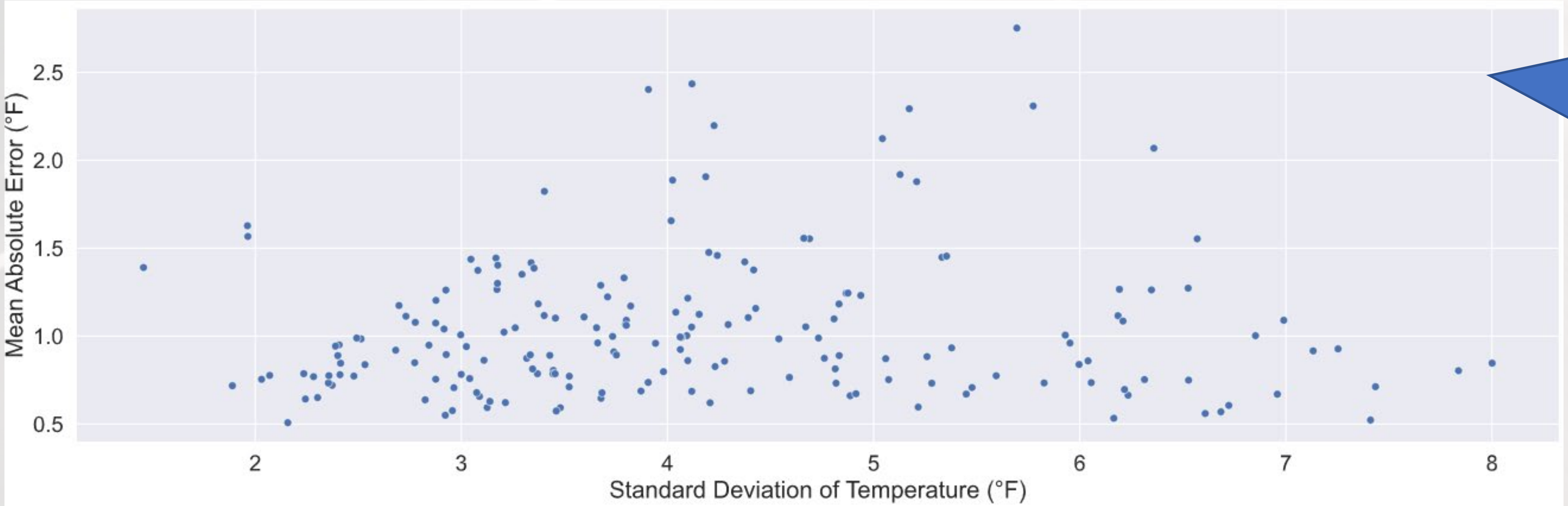
	Latitude	Longitude	MRWIS
1	40.918737	-74.586472	22.081982
2	40.918418	-74.585967	14.702026
3	40.935358	-75.102035	25.250000
4	40.489690	-74.413990	23.540000

MRWIS Surface Temperature	Z-score
24.889978	0.435249
24.134008	0.497877
25.681982	0.369635
30.397974	0.021062
25.681982	0.369635
61.681984	2.612792
24.422016	0.474017
24.260000	0.487440

Observations



Increase in MRWIS records → the error (MAE) level is lower



No clear correlation between the St. Dev of RST and the error (MAE)
→ kriging captures the spatial variation in the dataset.

The remaining error (≈ 1°F) is due to variability that can not be explained by the applied models.

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Potential Solutions

- Addressing the inconsistencies in local and regional RST variations
  - Increase the number of MRWIS units and study the underlying variations (could help address potential measurement bias or the location bias)
  - Explore additional interpolation models
  - Explore integration of short-term past predictions (generally the RST does not change significantly in short intervals)
  - Hierarchical (bi-level) interpolation that uses stationary RWIS data for at regional scale and the mobile RWIS to make adjustments at the local scale

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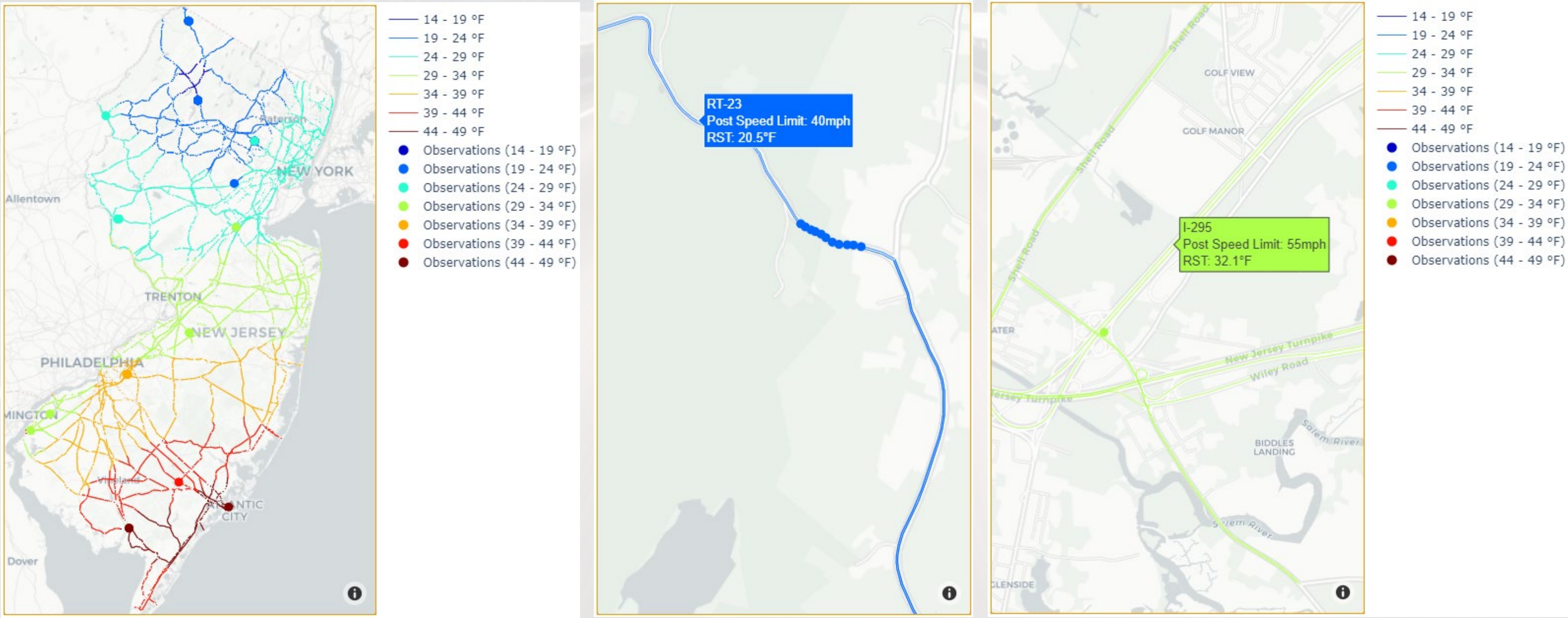
Practical Application

Statewide estimation of road surface temperature (using the regression kriging model)



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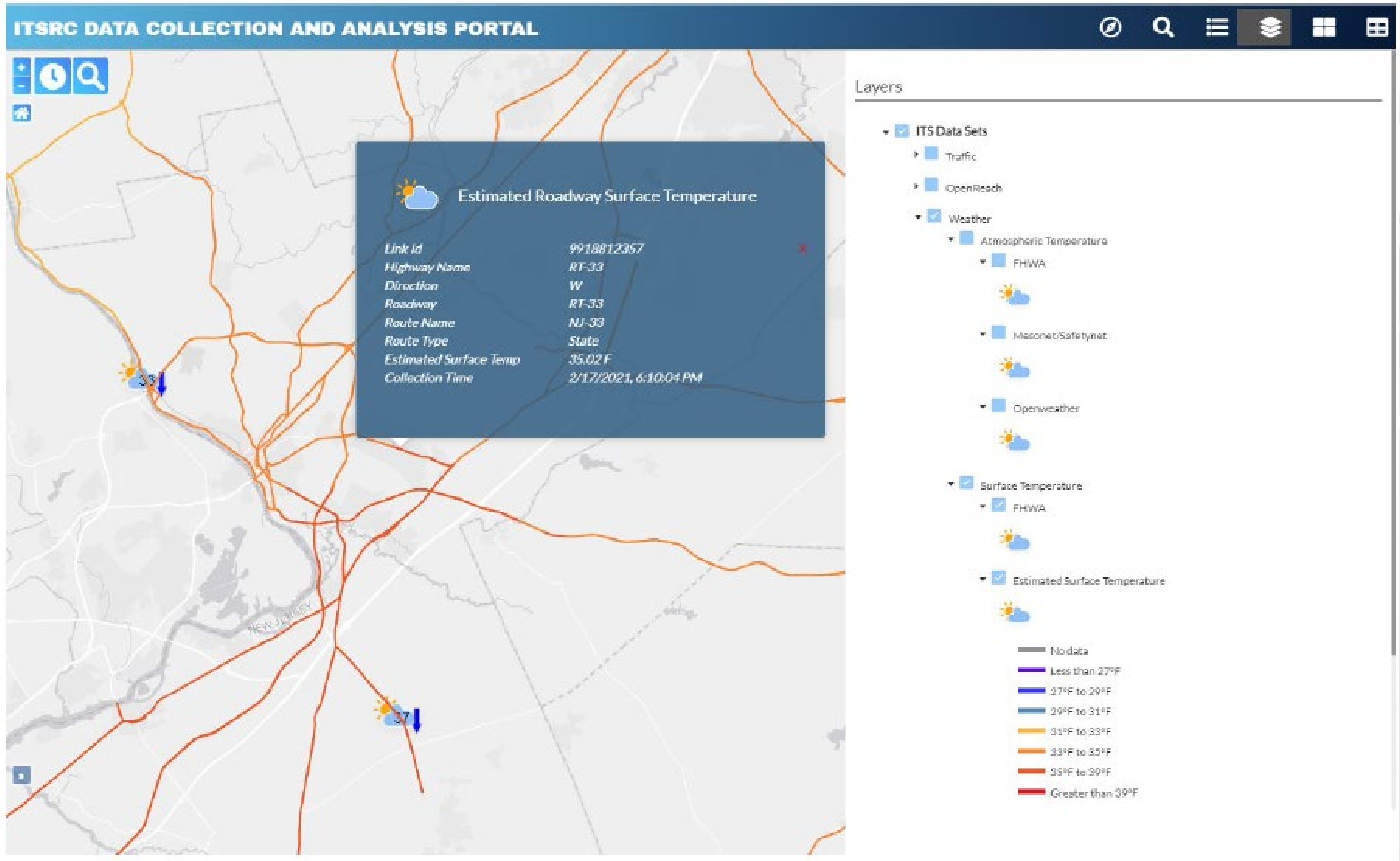
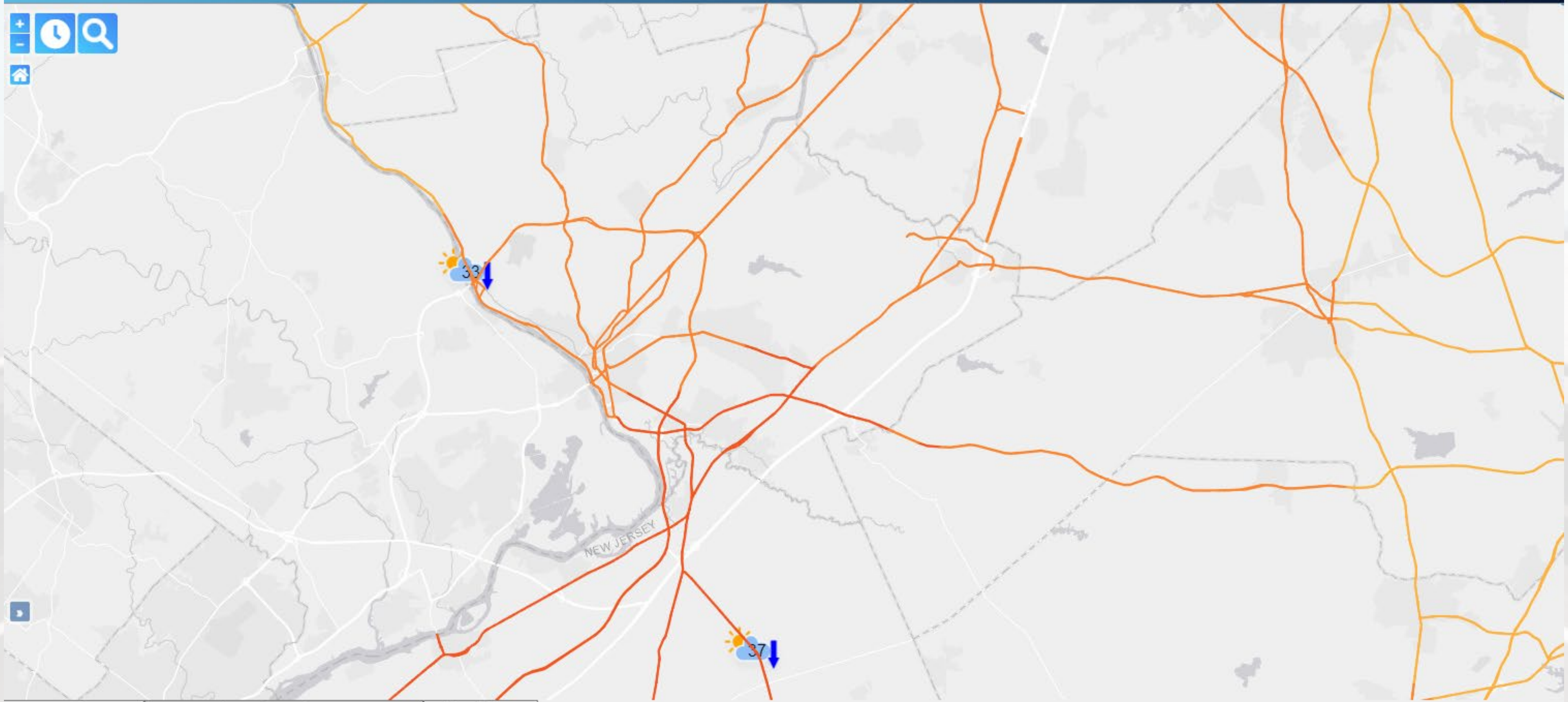
Practical Application – Web-based Map Tool



ITSRC DATA COLLECTION AND ANALYSIS PORTAL



Surface Weather - FHWA | Surface Weather - Estimated Surface Temperature | Mobile Vehicle Data

Filter by extent | Column Visibility | Search:

45,802 features

XCM_DFE_LINK_ID	XCM_DFE_HIGHWAY_NM	XCM_DFE_DIRECTION	XCM_DFE_ROADWAY	XCM_DFE_ROUTENAME	XCM_DFE_ROUTETYPE	RASTERVALU	COL_TIME
16836712	I-80	W	I-80	I-80	Interstate	32.1938195	1613603404000
16836713	I-80	E	I-80	I-80	Interstate	32.1938195	1613603404000
16836715	I-80	W	I-80	I-80	Interstate	32.1938195	1613603404000
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16836736	MEMORIAL PKY	E	US-22	US-22	US	30.59407367	1613603404000

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