NEEDS ASSESSMENT AND WEATHER DATA IMPACT STUDY

WEATHER STATION EVALUATIONS AND RECOMMENDATIONS

Tasks 3-4 Report

Prepared for TRANSCOM

By

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October 13, 2020

Table of Contents

Figures

Page

Tables

Executive Summary

This study reviewed the existing weather data in the TRANSCOM region and assessed how this data could be incorporated into the TRANSCOM transportation systems. The ultimate intent is to become proactive rather than reactive with regard to weather conditions that may impact traffic events and travel times. This assessment was completed in four tasks. The first task included a review of the existing weather systems in the region. There are multiple professional-grade weather networks within the region where observations are gathered in real time. Also, individual stations within each network have been identified and metadata for each assembled.

Task 2 focused on interviewing staff of twelve TRANSCOM Member Agencies for the purpose of obtaining their input on identifying and establishing a set of needs that will drive the development of providing essential existing weather information to these agencies through TRANSCOM. A report was issued that summarized input received from these agencies.

This current report provides results from Tasks 3 and 4. Task 3 provides: 1) a full listing of all stations and variables recorded at each network station in the TRANSCOM region and nearby states, 2) an assessment of data quality from some of the regional networks by examining several case studies, and 3) an evaluation of travel time under various notable weather conditions in relation to comparative situations where weather conditions were "quiet", also for several case studies. Data quality is satisfactory for most RWIS and non-RWIS stations, although additional quality control is recommended for RWIS observations. Travel time delays were found to correspond quite well with disruptive aspects of weather events, including heavy rain, snow, and/or strong winds.

There are three components to task 4. The first provides recommendations of enhancements that could be made to the current weather observing infrastructure within the TRANSCOM region. Aside from atmospheric and roadway weather conditions, it would be beneficial to add water level observations from tidal and river gauges to gain important information on rising waters, be they from ocean, bay or harbor surges or freshwater stream and river responses to heavy precipitation events. Another enhancement that might be considered is an advisory/alert system created for those on duty or an app that would allow selected individuals to be sent an advisory (early alert) or alert (imminent or ongoing situation) whenever and wherever the individual might be at a particular time. The conditions under which one is generated and transmitted must be based on considerable discussion amongst developers and those who will be on the receiving end of the alerts.

The second component of task 4 involves the development of an operational system that would synthesize observations from all regional weather networks. Critical aspects of this system include: 1) it being in real time,2) coordination amongst TRANSCOM and all agencies, 3) consolidation of data from multiple weather networks into a seamless and compatible format acceptable by the TRANSCOM system, 4) incorporation of ancillary information such as radar and satellite observations, 5) a high level of quality control/assurance, 6) the generation of products generated from the directly observed climate elements, such as rainfall accumulation rates, 7) adaptability such that the system is designed to have the capability of adding new

variables and stations as they become available, and 7) the development of aforementioned advisories/alerts.

The development of an integrated operational network is likely to proceed in an incremental manner, perhaps working its way from a unified structure for several networks, later incorporating more networks, adding products, and then following with water level data and an alert system too. It is important that at every step of the way insights and feedback for the TRANSCOM individuals using the data and information be part of the process.

The third and final component of Task 4 is the presentation of potential research endeavors to "test" the ability of the current and potentially enhanced network to meet the needs of TRANSCOM and its partners. Activities that would contribute to a better understanding of weather-related transportation issues and improved means of addressing them include: 1) training made available to the TRANSCOM community regarding the evaluation of weather information and its employment in evaluation and decision making processes, 2) on-going evaluation of the implementation and operation of a new weather-centric component, 3) fine-tuning an advisory/alert system to provide pertinent but not overly excessive information, 4) studies of how a weather forecast verifies versus what actually transpires during the course of impactful weather events, and 5) baseline research to gain a better understanding of spatial and scalar issues associated with various impactful weather events, the utility of non-RWIS stations in supplementing RWIS observations, and roadway products generated from RWIS station observations (e.g. various surface conditions).

To reiterate, to best accomplish the key linkages of transportation and weather information it is important to bring the combined experience of experts in both fields to the table to solidify approaches that will better understand linkages. This will best ensure highly credible means of anticipating and reacting to situations from regional to local levels and at any time of day.

Overview:

The TRANSCOM systems deliver tremendous amounts of data, which provides users with information on transportation conditions, both real-time and historical. However, at the present time, this data does not include all of the weather data that is available in the region and understanding as to how that data may play a role in creating these transportation conditions. This study reviewed the existing weather data in the TRANSCOM region and assessed how this data could be incorporated into the TRANSCOM transportation systems. The ultimate intent is to become proactive rather than reactive with regard to weather conditions that may impact traffic events and travel times.

This assessment was completed in four tasks. The first task included a review of the existing weather systems in the region. There are multiple professional-grade weather networks within the region where observations are gathered in real time. The Task 1 report provides an overview of each of these networks. Also, individual stations within each network have been identified and metadata for each assembled in summary tables and maps. This includes station location, variables observed, reporting frequency, and other pertinent information.

Task 2 focused on interviewing staff of twelve TRANSCOM Member Agencies for the purpose of obtaining their input on identifying and establishing a set of needs that will drive the development of providing essential existing weather information to these agencies through TRANSCOM. The Task 2 report provides a summary of the input received from these agencies.

This report will address Tasks 3 and 4 of the project. Task 3 involves: 1) a full listing of all stations and variables recorded at each network station in the TRANSCOM region and nearby states, 2) an assessment of data quality from some of the regional networks, 3) an evaluation of travel time under various notable weather conditions in relation to comparative situations where weather conditions were “quiet”, and 4) an evaluation of station or element gaps within the immediate TRANSCOM region. Task 4 addresses: 1) enhancements that could be made to the current weather observing infrastructure within the TRANSCOM region, 2) development of an operational system that would synthesize observations from all regional weather networks, and 3) potential research endeavors to “test” the ability of the current and potentially enhanced network to meet the needs of TRANSCOM and its partners.

<u>Task 3</u>:

3.1. Full listing of all stations and variables recorded at each network station in the TRANSCOM region and nearby states

The Table in Appendix A expands upon the information provided in Task 1, here providing information on the weather variables observed at each individual station in each network situated in Connecticut, New York, New Jersey, and the nearby states of Delaware, Maryland, and Pennsylvania. Included are available atmospheric and, in RWIS networks, roadway variables. Networks certainly differ in the type of variables observed. In many ways this makes the sum of the parts more valuable than relying on any singular network.

3.2. Assessment of network data quality

Three networks situated in New Jersey were evaluated for the quality of observations gathered for certain atmospheric and roadway variables. These include the NJ DOT RWIS network, Rutgers NJ Weather Network, and National Weather Service/FAA ASOS/AWOS network. Five cases were explored for variables including a) atmospheric air temperature measured approximately six feet above the surface, b) roadway surface temperature, roadway subsurface temperature (depth unknown), c) roadway surface conditions (specific definitions unknown), and d) maximum wind gusts measured at approximately 10 or 30 feet above the surface. This is a preliminary exploration of the quality of observations within each network. More rigorous investigations of observations based on individual station evaluations and through comparisons amongst stations are needed to reveal any persistent errors or biases. Operational quality assessment methods will benefit greatly from such continued studies.

The case studies below will include brief evaluations of noted issues and some speculation regarding observed differences. Air temperatures and wind observations can be directly compared within and across networks, roadway temperatures and surface conditions can only be compared within the RWIS network, though knowledge of atmospheric conditions is useful (e.g. temperature, precipitation, cloud cover).

<u>*Case 1: 4:30 PM EDT July 19, 2020*</u>

This case is from a hot sunny July late afternoon. Air and roadway surface temperatures are evaluated. RWIS temperatures are similar or several degrees higher than those at non-RWIS stations (Figure 1). Several RWIS sites are in the range of 5° warmer than surrounding observations, for instance the 97° reading in Passaic County. It is not surprising that roadside temperatures are a few degrees above temperatures measured at locations away from adjacent hot roadways. Any values higher than that suggest a faulty sensor or a poor placement of the shelter in which the temperature sensor is located. Further study is certainly required in an attempt to establish whether issues are due to the instrument or location. Roadway surface temperatures are exceptionally high, no doubt due to absorbing heat throughout a sunny day (Figure 2).

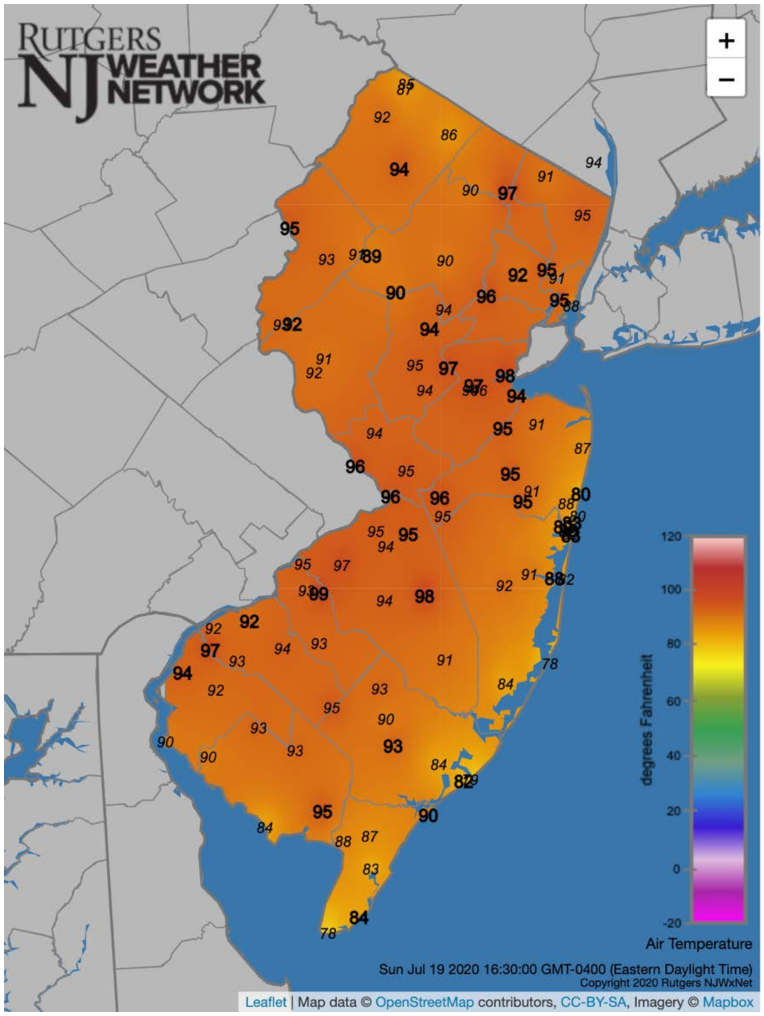


Figure 1. Atmospheric air temperatures throughout NJ at 4:30 PM EST on July 19, 2020. NJDOT RWIS station observations are in a larger font than the NJWxNet and NWS/FAA observations.

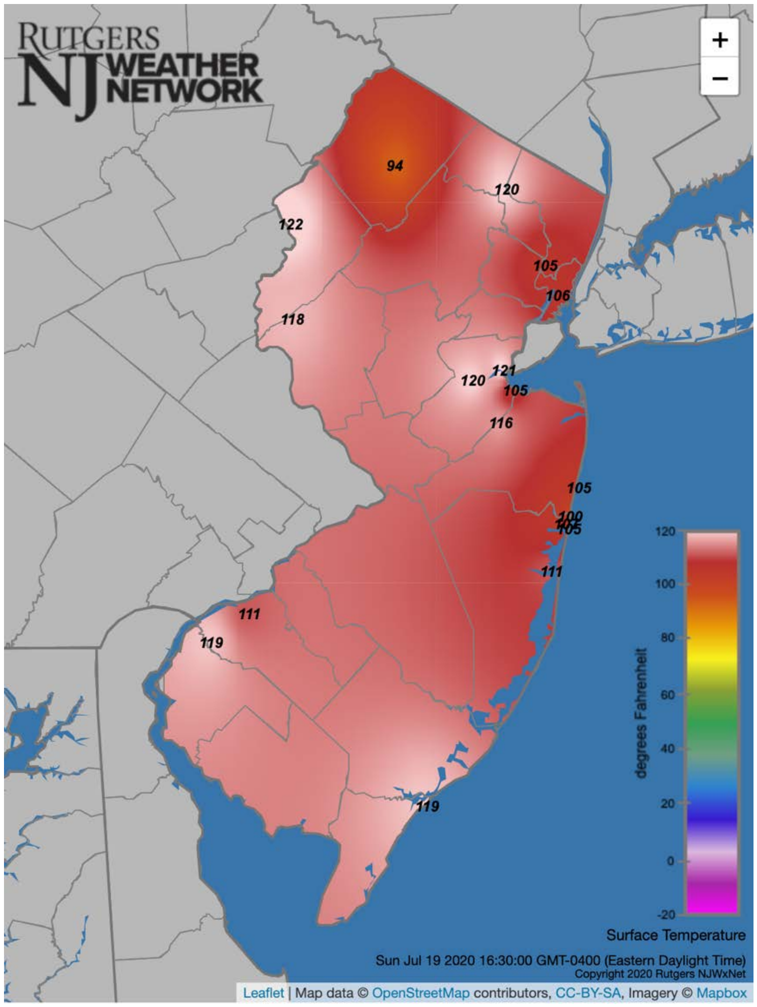


Figure 2. NJ RWIS road surface temperatures across NJ at 4:30 PM EST on July 19, 2020.

Case 2: 5:00 PM EST, January 18, 2020

This case is from a wintry event that brought some snow and rain to New Jersey and surroundings. Clouds were prevalent throughout the day. Air, roadway surface, and roadway subsurface temperatures are evaluated. Temperatures across all networks compare quite well (Figure 3). There is a somewhat high RWIS temperature at one location in Hudson County and several in lower Monmouth County that are worrisome, in particular because they are above freezing while other nearby temperatures are below freezing. Focusing on Monmouth County in Figure 4 suggests one inland 45° reading that is clearly faulty. Several higher RWIS temperatures near the coast may be associated with station placement on or adjacent to bridges sitting over milder waters, although the 42° reading still appears too high. The 36° observation may be correct and likely the 33° reading is as well, as just to the south there is a 34° NJWxNet reading at Seaside Heights. Roadway surface temperatures look reasonable on this cloudy unsettled day (Figure 5). They are generally below freezing and not too different than air temperatures, while above freezing in both cases along and near the coast in the southeast.

Subsurface road temperatures are consistently higher than road surface and air temperatures (Figure 6). This is seemingly reasonable given that daytime temperatures were well above freezing from January 10-16, thus that warmth was still being retained within the underlying pavement. A likely erroneous sensor is reading too low in Mercer County.

Descriptive remarks regarding roadway surface conditions provide an interesting assessment of conditions at 5:00 PM on the 18th (Table 1). Wet or potentially icy conditions are recognized. The snow condition is from a location in Essex County, which is perplexing, as is the only ice warning being in Jersey City. Due to these discrepancies, this table will be discussed later in this report under future research endeavors as considerable uncertainties remain regarding what the conditions mean and how they are determined.

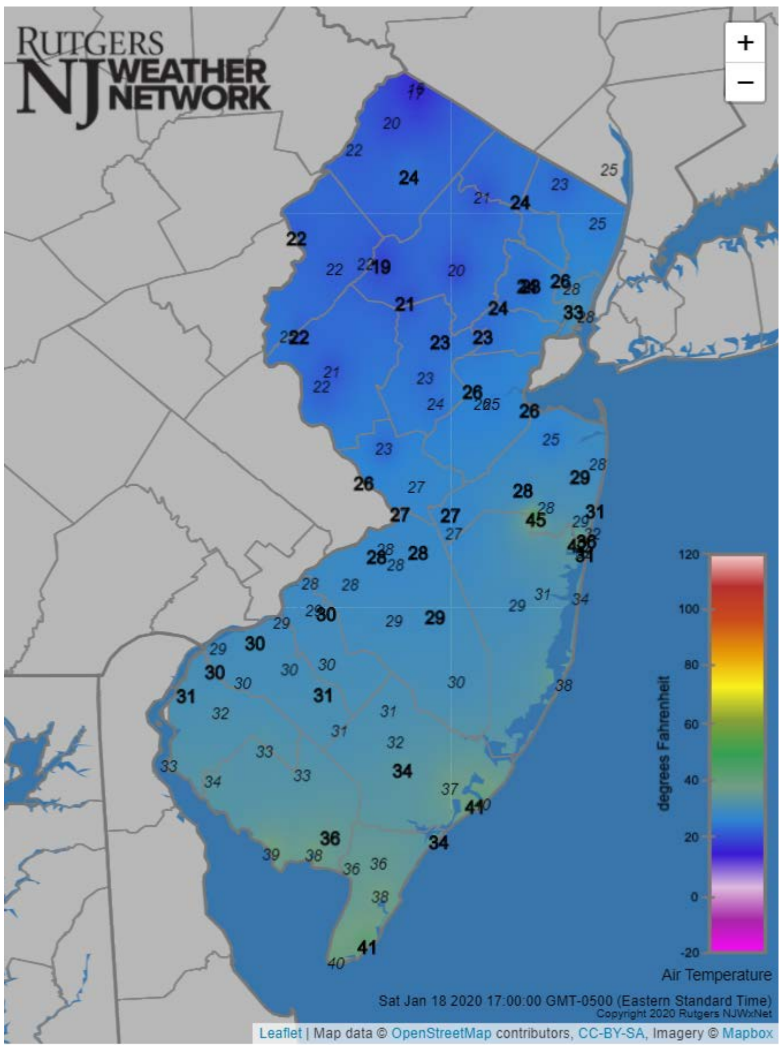


Figure 3. Atmospheric air temperatures throughout NJ at 5:00 PM EST on January 18, 2020. NJDOT RWIS station observations are in a larger font than the NJWxNet and NWS/FAA observations.

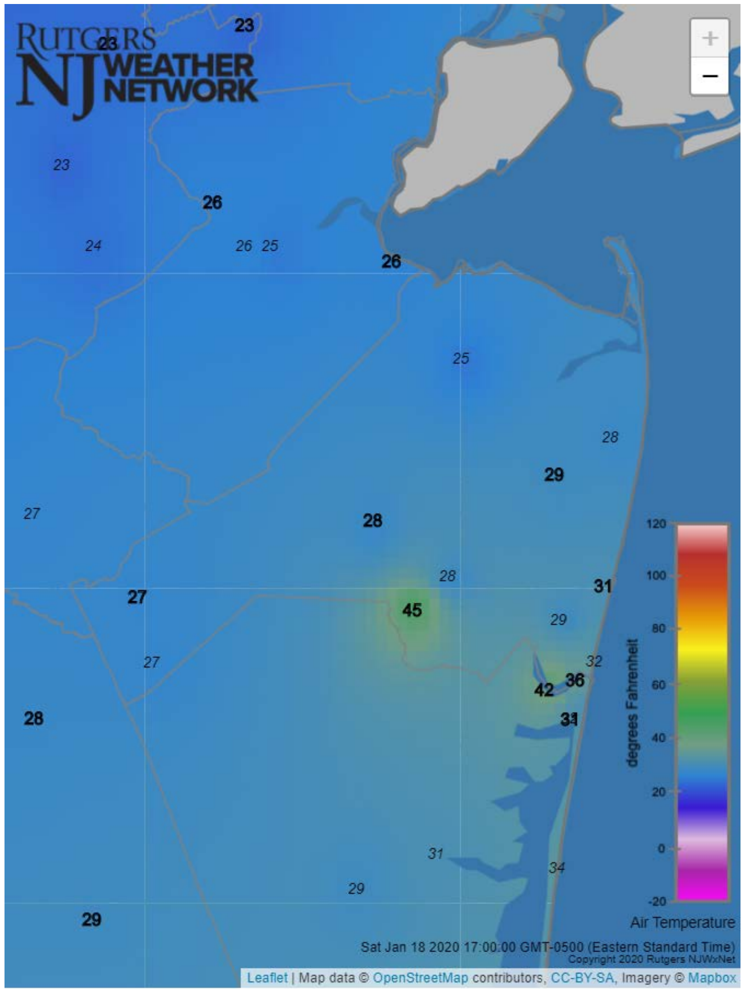


Figure 4. Atmospheric air temperatures along and near the northern NJ coast at 5 PM EST on January 18, 2020. NJDOT RWIS station observations are in a larger font than the NJWxNet and NWS/FAA observations.

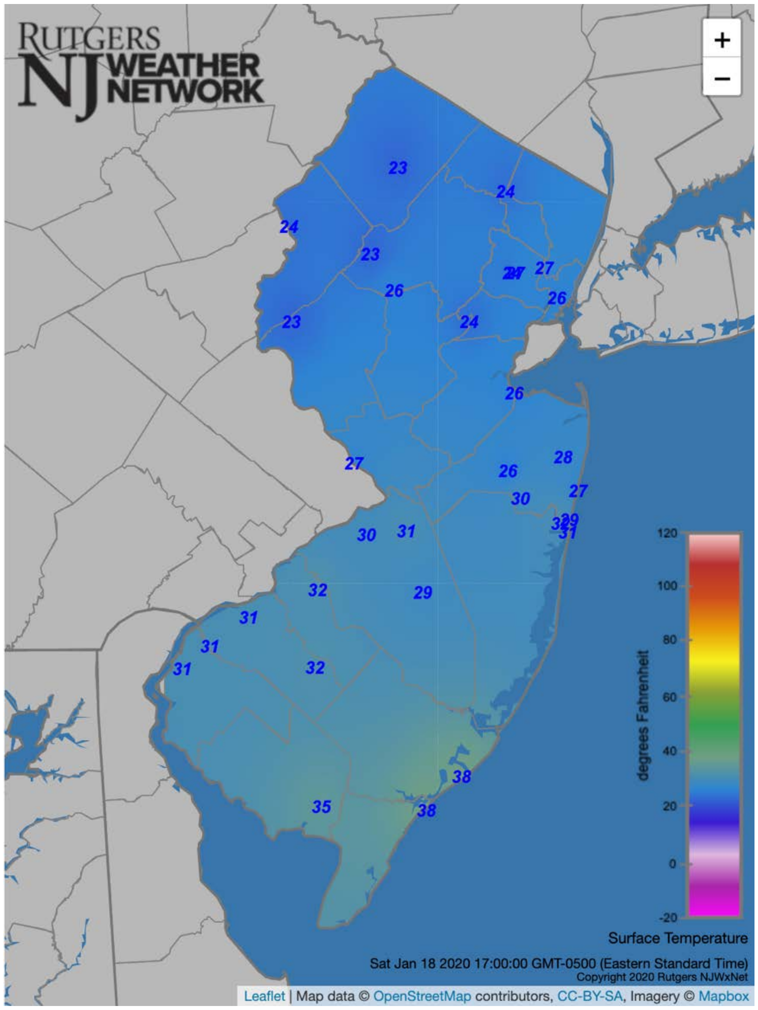


Figure 5. NJ RWIS road surface temperatures across NJ at 5:00 PM EST on January 18, 2020.

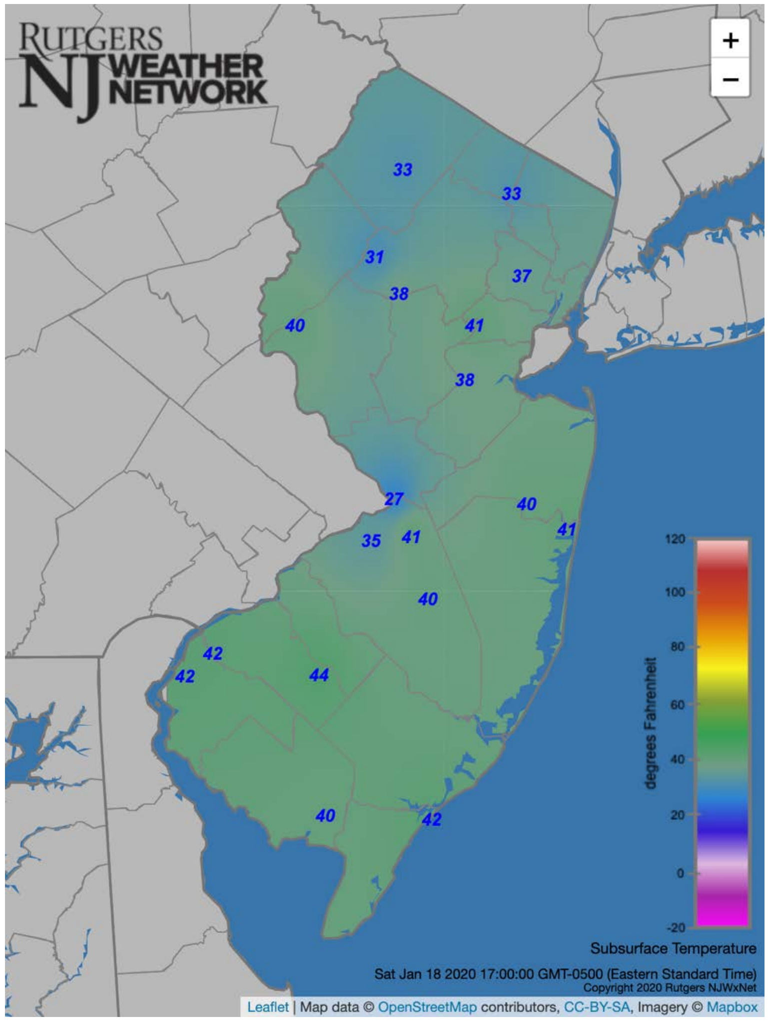


Figure 6. NJ RWIS road subsurface temperatures across NJ at 5 PM EST on January 18, 2020.

City	State	Eastern Time	Source	Surface Condition	Surface Condition 2	Surface Condition 3	Surface Condition 4
Atlantic City (NJDOT)	NJ	1/18/2020 17:00	NJDOT	Trace Moisture	Trace Moisture		
Bellville	NJ	1/18/2020 17:00	NJDOT	Ice Alarm Snowy			
Belmar	NJ	1/18/2020 17:00	NJDOT	Wet			
Berkeley Heights	NJ	1/18/2020 17:00	NJDOT		Ice Watch	Error	
Brick Twp.	NJ	1/18/2020 17:00	NJDOT			Trace Moisture	
Brielle	NJ	1/18/2020 17:00	NJDOT	Wet			
Carneys Point	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Damp	Ice Watch	
Cherry Hill (NJDOT)	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch		
Chester Twp.	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch		
Eatontown	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch		
Ewing	NJ	1/18/2020 17:00	NJDOT		Ice Watch	Error	Ice Watch
Freehold Twp.	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Error		
Greenwich (Warren)	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch		
Hamilton Twp. (Atlantic)	NJ	1/18/2020 17:00	NJDOT	Error	Error		
Hamilton Twp. (Mercer)	NJ	1/18/2020 17:00	NJDOT	Error	Error		
Howell Twp. (NJDOT)	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch	Ice Watch	Ice Watch
Jersey City (NJDOT)	NJ	1/18/2020 17:00	NJDOT	Ice Warning Icy			
Knowlton Twp.	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Error	Error	
Lafayette	NJ	1/18/2020 17:00	NJDOT		Ice Watch	Damp	
Logan Twp. (NJDOT)	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Trace Moisture		
Lower Twp. (NJDOT)	NJ	1/18/2020 17:00	NJDOT	Error	Error		
Mansfield Twp. (NJDOT)	NJ	1/18/2020 17:00	NJDOT		Ice Watch	Ice Watch	Ice Watch
Maurice Twp. 1	NJ	1/18/2020 17:00	NJDOT	Damp	Damp	Damp	Damp
Monroe Twp.	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch	Ice Watch	
Mount Olive Township	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch	Ice Watch	Ice Watch
Ocean City	NJ	1/18/2020 17:00	NJDOT	Damp	Damp	Damp	Trace Moisture
Old Bridge Twp. 2	NJ	1/18/2020 17:00	NJDOT	Wet			
Paulsboro	NJ	1/18/2020 17:00	NJDOT	Not Reported			
Pemberton	NJ	1/18/2020 17:00	NJDOT	Ice Watch			
Piscataway 1	NJ	1/18/2020 17:00	NJDOT	Error	Ice Watch		
Point Pleasant 2 (NJDOT)	NJ	1/18/2020 17:00	NJDOT				
Springfield Twp.	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch	Error	
Stafford Twp.	NJ	1/18/2020 17:00	NJDOT	Error	Error	Error	Error
Summit	NJ	1/18/2020 17:00	NJDOT	Error	Ice Watch		
Upper Freehold Twp.	NJ	1/18/2020 17:00	NJDOT				
Wanaque	NJ	1/18/2020 17:00	NJDOT		Error	Ice Watch	Ice Watch
Warren Twp.	NJ	1/18/2020 17:00	NJDOT	Error	Error	Error	
West Orange 1	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch		
West Orange 2	NJ	1/18/2020 17:00	NJDOT	Ice Watch	Ice Watch	Error	

Table 1. Descriptive road surface conditions extracted from the NJ RWIS data feed at 5:00 PM EST on January 18, 2020.

Case 3: 5:00 AM EDT, September 4, 2020

This case is from a clear early morning on September 4, 2020. Air and roadway surface temperatures are evaluated. With few exceptions, temperatures across all networks compare quite well (Figure 7). There are two likely incorrect RWIS observations in Cumberland and Ocean counties. Figure 8 focuses on the latter area. The time and day were chosen to eliminate the impact of sunlight on temperature observations, thus test whether sunlight is a dominant issue resulting in higher daytime air temperatures at RWIS on sunny days compared to non-RWIS locations. This test provides initial confirmation of this supposition.

Surface roadway temperatures at 5:00 AM are seen to be running several degrees above local air temperatures, with the exception of one faulty sensor in Atlantic County (Figure 9). Short nighttime hours at this time of year do not appear to permit the quite likely much higher road than air temperatures from the previous afternoon to cool off completely.

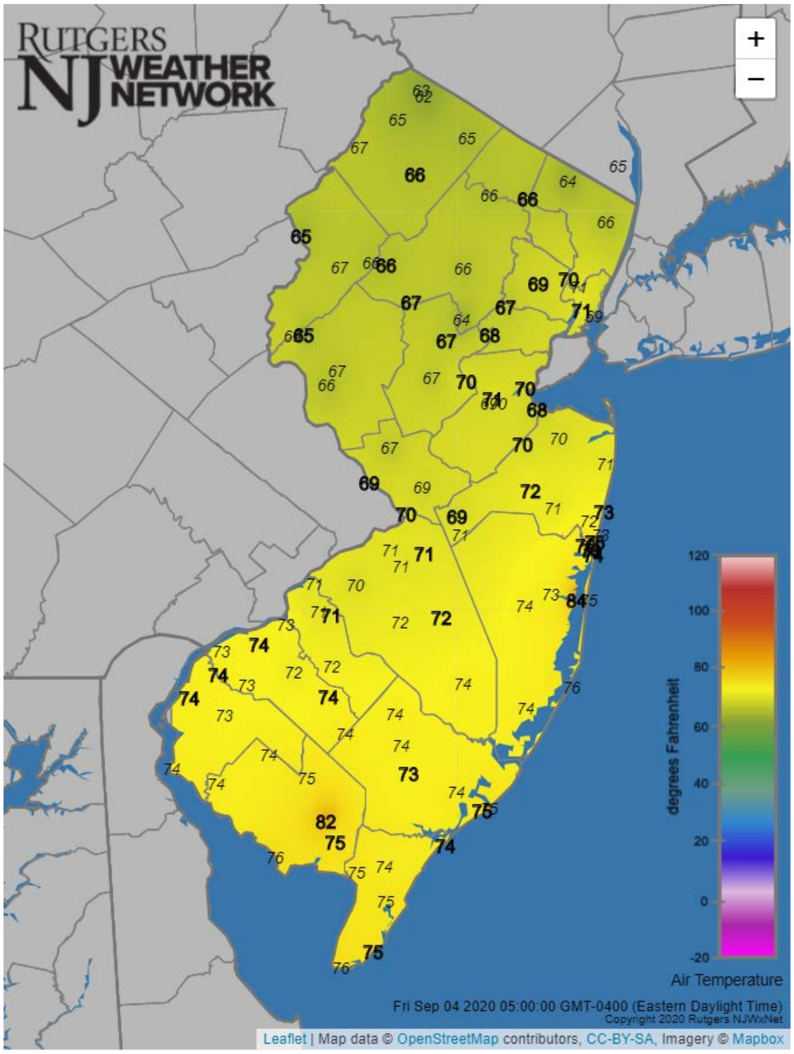


Figure 7. Atmospheric air temperatures throughout NJ at 5:00 AM EDT on September 4, 2020. NJDOT RWIS station observations are in a larger font than the NJWxNet and NWS/FAA observations.

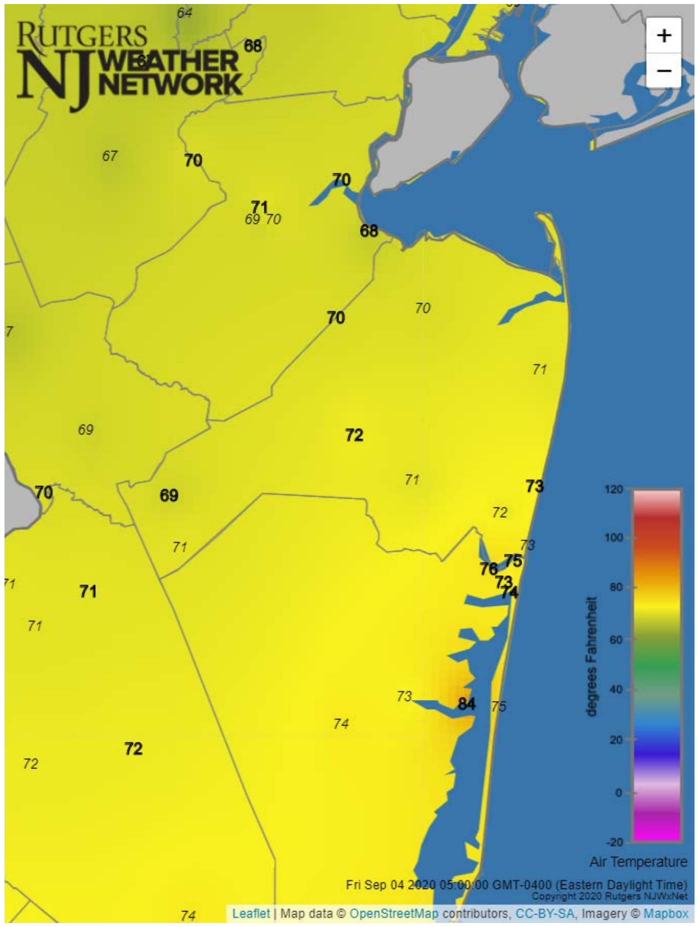


Figure 8. Atmospheric air temperatures in central and northern portions of southern NJ at 5:00 AM EDT on September 4, 2020. NJDOT RWIS station observations are in a larger font than the NJWxNet and NWS/FAA observations.

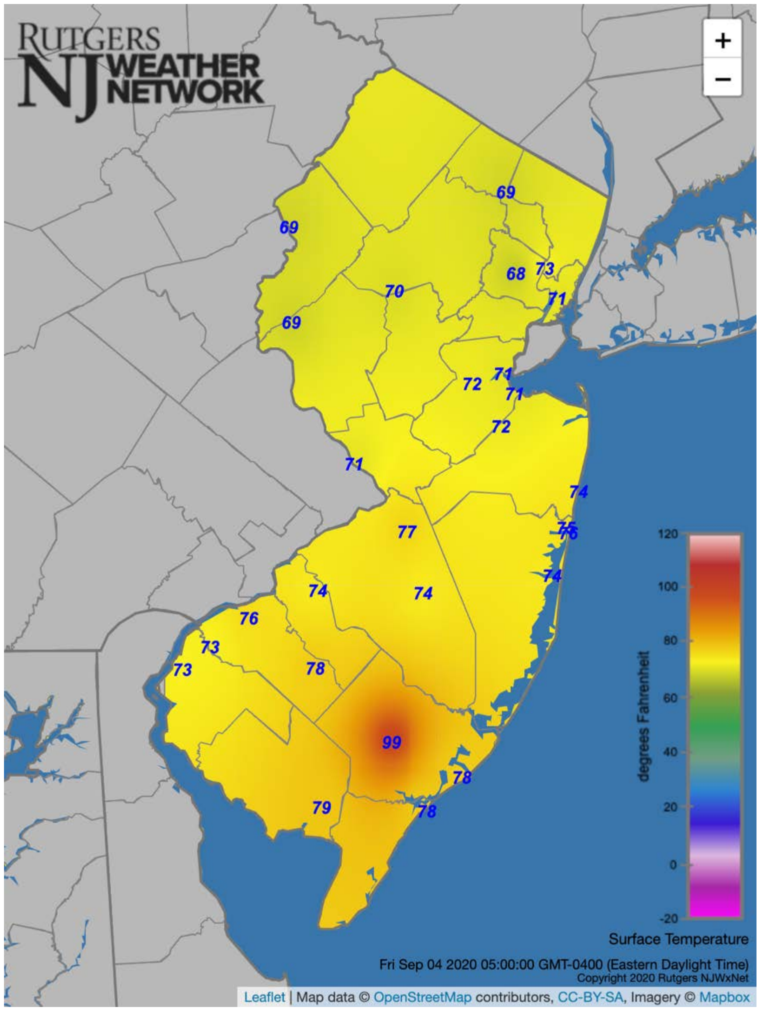


Figure 9. NJ RWIS road surface temperatures across NJ at 5:00 AM EDT on September 4, 2020.

Case 4: 1:30 PM EDT June 3, 2020

This case involves a rapid change in air temperatures following the passage of a derecho (exceptionally windy squall line) from west to east across NJ on what had been a warm early June midday. The rapid speed in which the line moved is shown in the two radar images in Figure 10. Temperatures were in the mid 80°s to about 90° prior to the storm entering NJ, and, according to the accurate readings from NJWxNet stations, fell to the upper 60°s immediately upon passage (Figure 11 and Table 2). All NJWxNet stations reported the temperature change, however only a limited number of RWIS stations in the north did so. Instead, for some inexplicable reason, most RWIS station reports had not responded to this change well past an hour of its occurrence. Note, "reports" not "observations" was stated as these errors are likely a function of something other than the instrument reading incorrectly, rather they are associated with the reporting process. This has been noted in other cases of rapid temperature changes.

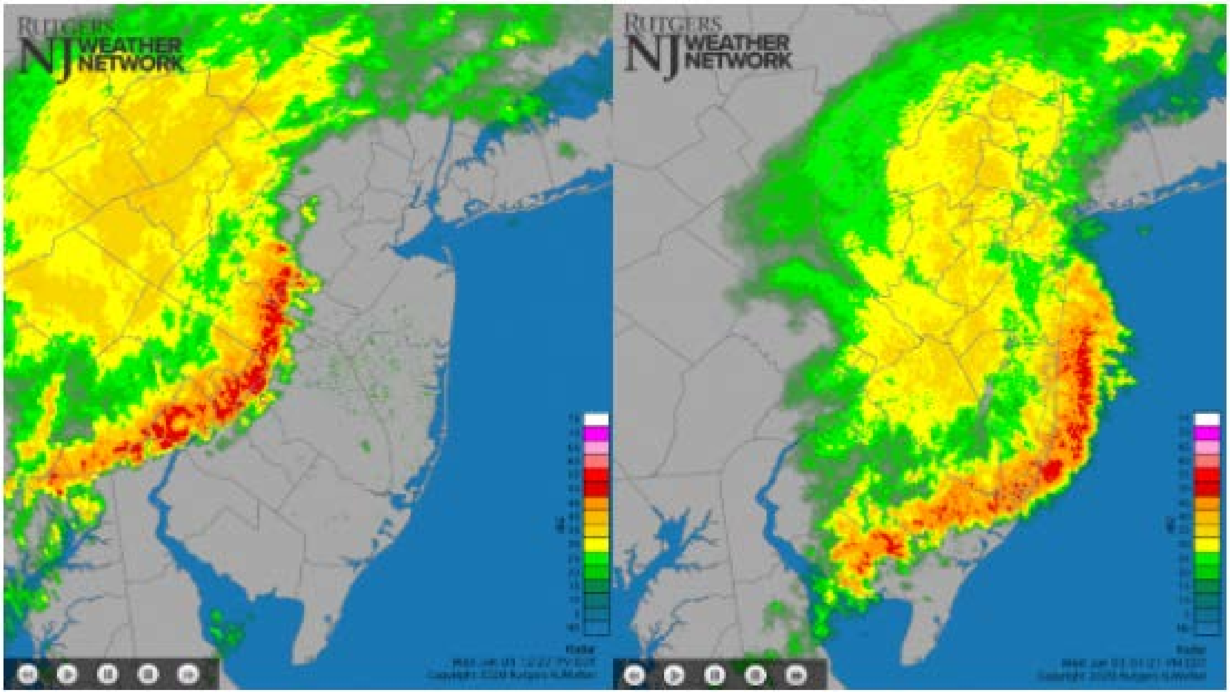


Figure 10. NJWxNet radar maps at 12:27 PM EDT (left) and 1:21 PM (right) on June 3, 2020 (radar courtesy of the NWS)

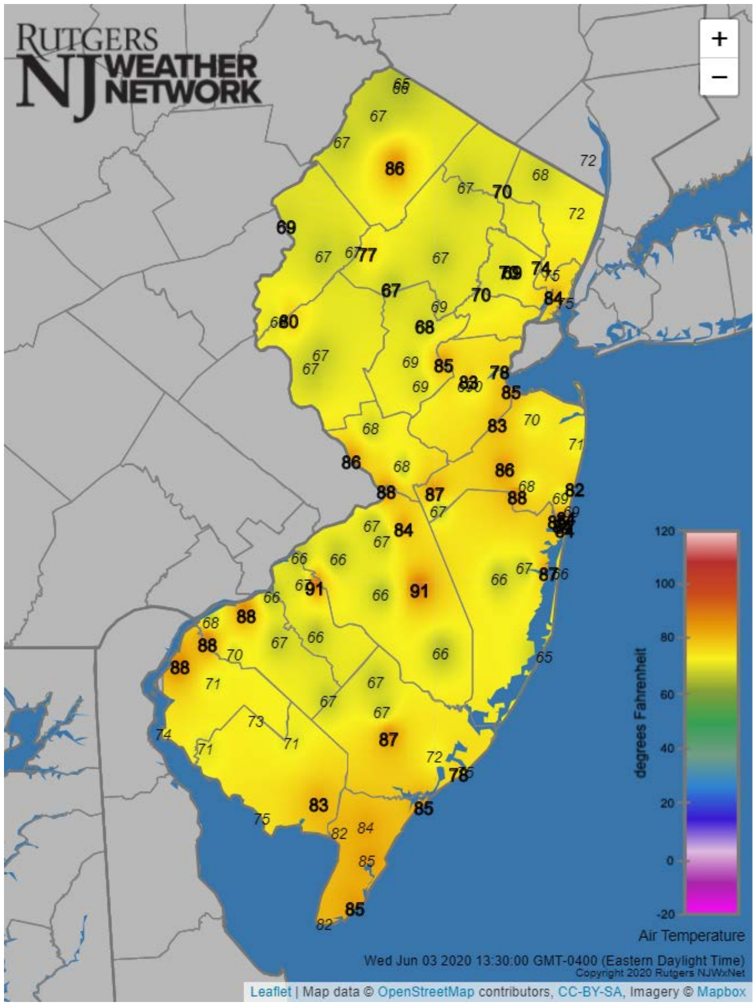


Figure 11. Atmospheric air temperatures throughout NJ at 1:30 PM EDT on June 3, 2020. NJDOT RWIS station observations are in a larger font than the NJWxNet and NWS/FAA observations.

Date/Time	Pemberton NJDOT Temp	Silas Little NJWxNet Temp
6/3/2020 12:30	85	83
6/3/2020 12:35	85	83
6/3/2020 12:40	84	83
6/3/2020 12:45	84	82
6/3/2020 12:50		73
6/3/2020 12:55	91	67
6/3/2020 13:00	91	66
6/3/2020 13:05	91	66
6/3/2020 13:10	91	66
6/3/2020 13:15	91	66
6/3/2020 13:20	91	66
6/3/2020 13:25	91	66
6/3/2020 13:30	91	66
6/3/2020 13:35	91	66
6/3/2020 13:40	91	66
6/3/2020 13:45	91	66
6/3/2020 13:50		66
6/3/2020 13:55	91	66
6/3/2020 14:00	91	66
6/3/2020 14:05	91	67
6/3/2020 14:10	91	68
6/3/2020 14:15		69
6/3/2020 14:20	91	70
6/3/2020 14:25	91	70
6/3/2020 14:30	91	71
6/3/2020 14:35	91	72
6/3/2020 14:40	91	72
6/3/2020 14:45	91	72
6/3/2020 14:50		73
6/3/2020 14:55	91	73
6/3/2020 15:00	91	73
6/3/2020 15:05	91	73

Date/Time	Howell NJDOT Temp	Howell NJWxNet Temp
6/3/2020 12:40	88	85
6/3/2020 12:45	87	84
6/3/2020 12:50		83
6/3/2020 12:55	86	82
6/3/2020 13:00	85	81
6/3/2020 13:05	88	77
6/3/2020 13:10	88	71
6/3/2020 13:15		69
6/3/2020 13:20	88	69
6/3/2020 13:25	88	68
6/3/2020 13:30	88	68
6/3/2020 13:35	88	68
6/3/2020 13:40	88	68
6/3/2020 13:45	87	68
6/3/2020 13:50		68
6/3/2020 13:55	87	68
6/3/2020 14:00	87	68
6/3/2020 14:05	87	69
6/3/2020 14:10	87	69
6/3/2020 14:15		69
6/3/2020 14:20	87	69
6/3/2020 14:25	87	70
6/3/2020 14:30	87	70
6/3/2020 14:35	87	70
6/3/2020 14:40	87	70
6/3/2020 14:45	86	70
6/3/2020 14:50		70
6/3/2020 14:55	86	70
6/3/2020 15:00	86	71
6/3/2020 15:05	86	71

Table 2. Air temperatures reported at NJ DOT RWIS stations and NJWxNet stations early in the afternoon on June 3, 2020. The left box shows 5-minute data from the Pemberton (Burlington County) RWIS and Silas Little (Burlington) NJWxNet stations from 12:30 PM EDT until 3:05 PM. The right box shows temperatures at the Howell (Monmouth) RWIS and NJWxNet stations from 12:40 PM until 3:05 PM.

Case 5: 1:00 PM EDT, August 4, 2020

This case is from midday on August 4, 2020 as Tropical Storm Isaias was tracking just to the west of southern NJ on a track north up the Delaware Valley. Winds were gusting strongly throughout NJ at this time as shown in Figure 12, which reports the highest gusts at NJ DOT RWIS, NJWxNet and NWS stations during the five minutes ending at 1:00 PM EDT. A wide range of gusts are noted within all networks due to both the squally nature of winds generated by the storm and varying station exposures. The point of this case is not to determine the cause of the differences or whether anemometers are malfunctioning, rather to see if all the networks display such variations. They certainly do, with higher values in coastal areas noted for most stations and also higher readings in known inland areas with open exposures. Results suggest the difficulty in assessing the quality of wind observations. Clearly, extended periods of evaluation are necessary, along with adequate metadata (including an array of site photos), and some knowledge of the characteristics of an ongoing weather system. This also speaks to the value of having a rich array of stations deployed across the TRANSCOM region to monitor wind.

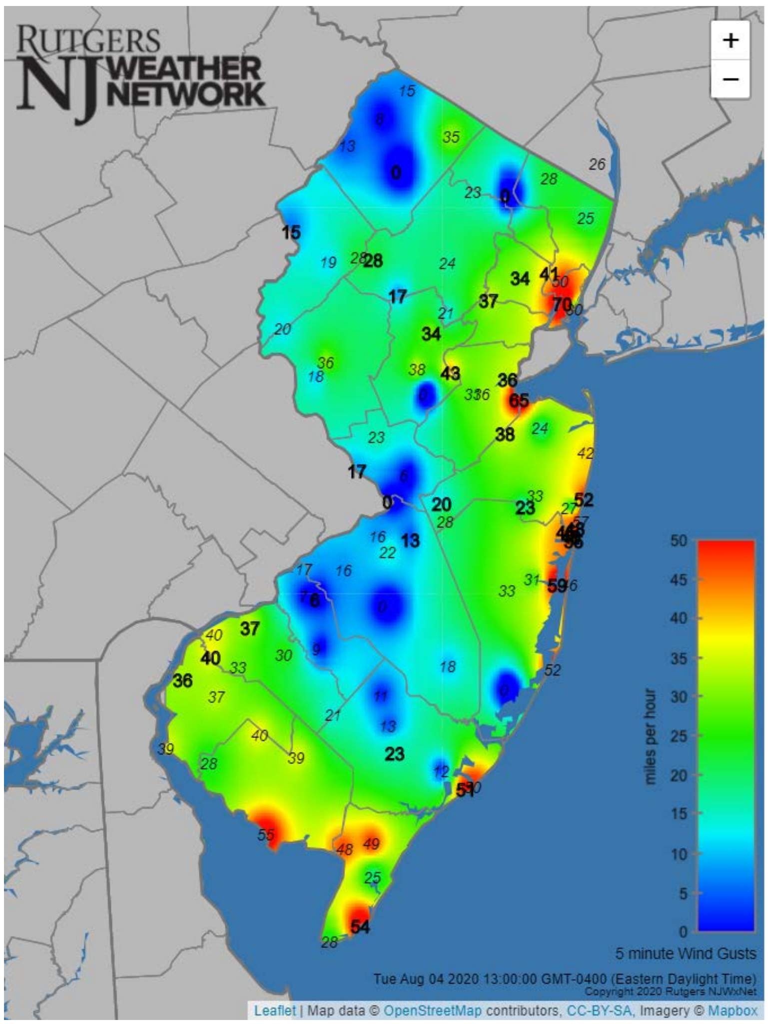


Figure 12. Highest wind gusts in the five-minute interval ending at 1:00 PM EDT on August 4, 2020. NJDOT RWIS station observations are blue and in a larger font than the NJWxNet and NWS/FAA observations which are in black.

Case study summary

A general evaluation of the assessments conducted in the case studies finds that most observations appear quite reasonable. This is not unexpected, as the hallmarks of professional weather networks are good instrumentation, adequate maintenance, reasonable siting, and useful quality control procedures. While NJWxNet and NWS/FAA quality control measures are known, it has yet to be determined what level of QC is applied to RWIS observations.

Some issues with NJ RWIS observations are recognized. They may be associated with faulty instruments, instrument placement, and observation transmission. Again, further studies will be able to identify the underlying causes of differences among observations.

3.3. Evaluation of travel time under various weather conditions

Five case studies were generated for select intervals and roadway segments where weather conditions were likely the explanation for considerable travel time delays. For each case, the weather scenario is explained and illustrated with maps and tables. Accompanying each is also a travel time graph for the roadway segment under study, including times during the event, the same time of day and day of week shortly before or after the case when weather was not a travel issue and for free flow conditions.

Case results clearly demonstrate the impacts of extreme weather conditions on travel times, even resulting in road closures. They also suggest that real-time knowledge of atmospheric and roadway conditions can prove helpful in preparing and responding to anticipated and ongoing weather conditions. With such knowledge delays can be minimized and accidents avoided.

<u>*Case Study #1*</u>

March 6-7, 2018 (noon to 11:30 PM EST)

Coastal storm with heavy snow, ice, and rain across the Northeast.

Roadway study region: I-80 Express Lanes EB mile maker 40.8 to I-95 [27.62 miles] (Figure 13).

Weather scenario

Occurring only a few days after another nor'easter affected the region on March 1-3, this storm resulted in several fatalities in NJ, caused power outages to one million NJ customers, and resulted in hundreds of canceled flights across the region. The storm was born near Cape Hatteras, North Carolina and rapidly intensified as it moved north along the coast, reaching a minimum pressure of 986 mb (29.11 inches). In New Jersey, wind speeds reached 48 mph along the coast at Harvey Cedars (NJWxNet). New Jersey snowfall exceeded two feet at some Highlands locations (Figure 14), as reported by the Office of the NJ State Climatologist.

Whiteout conditions (exceedingly low visibility) occurred along portions of many roadways. In the travel time study region, storm snowfall was between 8.0 and 9.0 inches.

East Bound traffic on I-80 Express Lanes to I-95 was delayed from 1:00 PM to 11:30 PM on March 7. The nearby National Weather Service station in Caldwell reported the heaviest snowfall between 4:00 PM to 5:00 PM, 5:20 PM to 6:00 PM, 6:30 PM to 7 PM, and 7:30 PM to 8:00 PM (Table 3). Air temperature in the area was between 31°F and 34°F during the study period.

These periods of heavy snowfall coincide with the longest delays at 5 PM, 6PM and 8:30 PM along the roadway, where speeds decreased from normal conditions by 25 MPH and travel times increase by over 30 minutes on a 27 mile trip.

Figure 13: Traffic delays on March 7, 2018 from I-80 Exp East Bound to I-95.

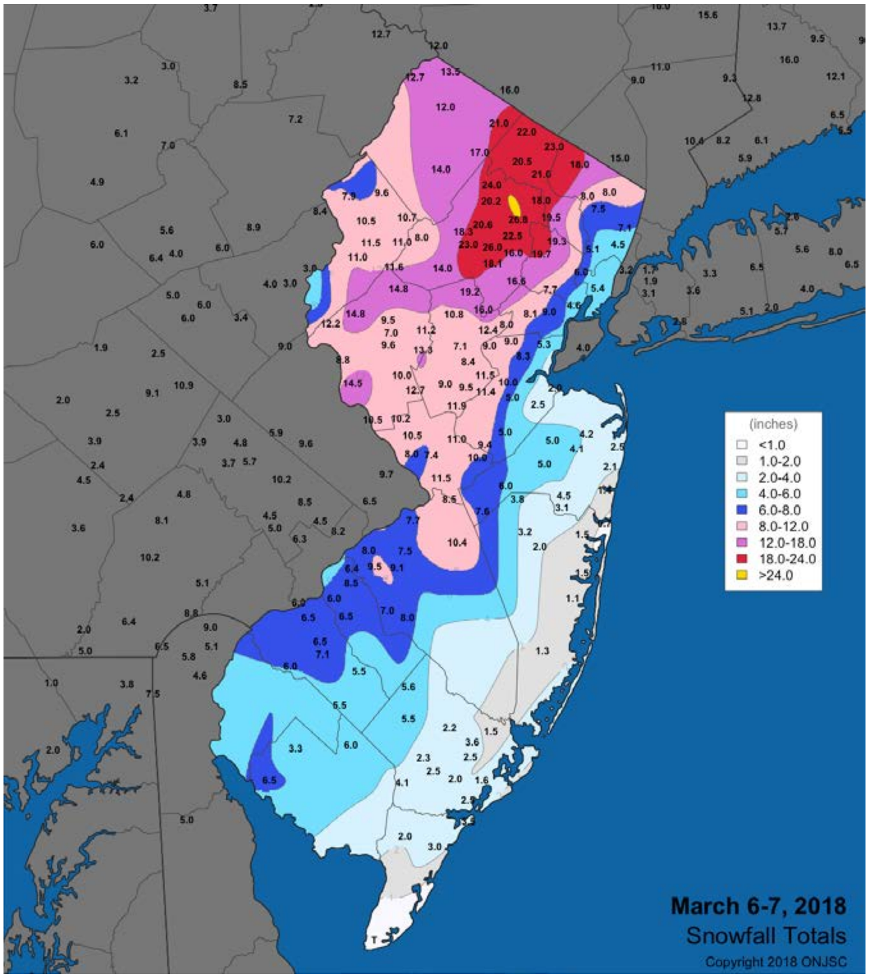


Figure 14: Snowfall for the March 6-7, 2018 storm (Office of NJ State Climatologist).

07	1100	7	OVC:08 7	1.75	-SN:03 BR:1 |SN |	33	0.6	33	0.6	33	0.6	100	11	060	21	29.52				FM-16	T	29.71
07	1134	7	OVC:08 7	0.75	-SN:03 BR:1 |SN |	33	0.6	33	0.6	33	0.6	100	9	060	20	29.50				FM-16	0.01	29.69
07	1142	7	BKN:07 7 OVC:08 11	1.00	-SN:03 BR:1 |SN |	33	0.6	33	0.6	33	0.6	100	10	060	20	29.49				FM-16	0.01	29.68
07	1151	6	BKN:07 7 OVC:08 11	0.75	-SN:03 BR:1 |SN |	34	1.1	34	1.1	34	1.1	100	9	050		29.48				FM-16		29.67
07	1153	7	BKN:07 6 OVC:08 10	0.75	-SN:03 BR:1 |SN |	33	0.6	33	0.6	33	0.6	100	8	050		29.48			29.69	FM-15	0.01	29.67
07	1253	7	OVC:08 8	0.50	SN:03 FG:2 |FG SN |	33	0.6	33	0.6	33	0.6	100	9	050	18	29.43	7	+0.09	29.65	FM-15	0.01	29.62
07	1303	7	BKN:07 6 OVC:08 9	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	9	050		29.43				FM-16	0.01	29.62
07	1315	7	VV:09 4	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	9	050	20	29.42				FM-16	0.03	29.61
07	1353	7	VV:09 4	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	9	050		29.42			29.63	FM-15	0.13	29.61
07	1453	7	VV:09 4	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	8	030		29.40			29.61	FM-15	0.21	29.59
07	1507	7	VV:09 5	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	9	VRB		29.40				FM-16	0.03	29.59
07	1532	7	VV:09 6	0.50	SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	9	VRB		29.40				FM-16	0.09	29.59
07	1546	7	OVC:08 5	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	3	VRB		29.42				FM-16	0.12	29.61
07	1551	6	OVC:08 3	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	3	VRB		29.42				FM-16		29.61
07	1553	7	OVC:08 3	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	3	VRB		29.42	5	+0.01	29.63	FM-15	0.17	29.61
07	1653	7	VV:09 4	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	10	VRB	20	29.43			29.64	FM-15	0.28	29.62
07	1753	7	VV:09 3	0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	6	VRB		29.47			29.67	FM-15	0.27	29.65
07	1821	7		0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	11	020	20	29.47				FM-16	0.14	29.66
07	1853	7		0.25	+SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	7	VRB		29.47	1	-0.04	29.67	FM-15	0.28	29.65
07	1905	7		0.50	SN:03 FG:2 |FG SN |	32	0.0	32	0.0	32	0.0	100	7	VRB		29.47				FM-16	0.05	29.66
07	1948	7		1.50	-SN:03 BR:1 |SN |	32	0.0	32	0.0	32	0.0	100	6	VRB		29.47				FM-16	0.17	29.66
07	1953	7		1.50	-SN:03 BR:1 |SN |	32	0.0	32	0.0	32	0.0	100	5	VRB		29.47			29.67	FM-15	0.14	29.65
07	2007	7		2.50	-SN:03 BR:1 |SN |	32	0.0	32	0.0	32	0.0	100	6	VRB		29.45				FM-16	T	29.64
07	2016	7	BKN:07 7 BKN:07 30 OVC:08 85	2.50	-SN:03 BR:1 |SN |	32	0.0	32	0.0	32	0.0	100	9	VRB		29.47				FM-16	T	29.65
07	2023	7	SCT:04 7 BKN:07 34 OVC:08 85	9.00		32	0.0	32	0.0	32	0.0	100	6	VRB		29.47				FM-16	T	29.66
07	2050	7	BKN:07 21 OVC:08 80	10.00		32	0.0	32	0.0	32	0.0	100	7	VRB		29.48				FM-16	T	29.67
07	2053	7	BKN:07 21 OVC:08 80	10.00		32	0.0	32	0.0	31	-0.6	96	7	320		29.49			29.70	FM-15	T	29.68
07	2132	7	SCT:04 23 OVC:08 50	10.00		33	0.6	32	0.0	30	-1.1	89	8	320	17	29.50				FM-16		29.69
07	2153	7	FEW:02 18 OVC:08 49	10.00		33	0.6	32	0.0	31	-0.6	92	7	340		29.50	1	-0.04	29.71	FM-15	0.00	29.69
07	2253	7	OVC:08 60	10.00		33	0.6	32	0.0	31	-0.6	92	5	320		29.50			29.71	FM-15	0.00	29.69
07	2353	7	BKN:07 60 OVC:08 100	10.00		33	0.6	32	0.0	31	-0.6	92	6	300		29.51			29.72	FM-15	0.00	29.70

Table 3: Hourly weather reports from Caldwell Essex County Airport (KCDW) (NCEI COOP). Highlighted are time, visibility, wind gust (mph) and Precipitation (in).

Case Study #2

June 20, 2019 (12:15 AM-noon EDT)

Flooding and downed trees from heavy rain New Jersey.

Roadway study region: I-295 NB mile marker 22.9 to Ben Franklin Bridge [10.43 miles] (Figure 15).

Weather scenario
Beginning on the afternoon of June 19, heavy rain and flash flooding continued into the night, as noted in radar images (Figure 16). With rainfall concentrated in Camden, Gloucester, and Burlington counties, flooding was substantial in this region. NJ CoCoRaHS observers reported as much as 4.9 inches (Figure 17). Due to flooding, many roads such as the NJ Turnpike, I-295, and routes 30, 74 and 130 were closed. Other forms of transportation were also suspended, including the PATCO commuter train service between Philadelphia and Camden County.

The rain fell overnight and into the early morning hours, ending around 3am (Table 4), but had impacts on commuting hours the following morning with many roads remaining closed. Delays on I-295 were reported from 1:00 AM to 10:30 AM from heavy rainfall in the early morning. Nearby, a Rutgers NJWxNet Station at West Deptford recorded 5.06 inches between midnight and 6:00 AM with 4.87 inches falling between 1:00 AM and 3:00 AM. Although the rain finished at 6 AM the flooding did not subside until later than morning, delaying traffic well beyond the conclusion of rainfall.

The traffic conditions coincide with this weather data in that I-295 was completely closed in the early morning and then had speed decreases from normal conditions of 20 MPH and travel time increases of nearly 25 minutes on a 10 mile trip.

06/20/2019: 1215 AM to Noon

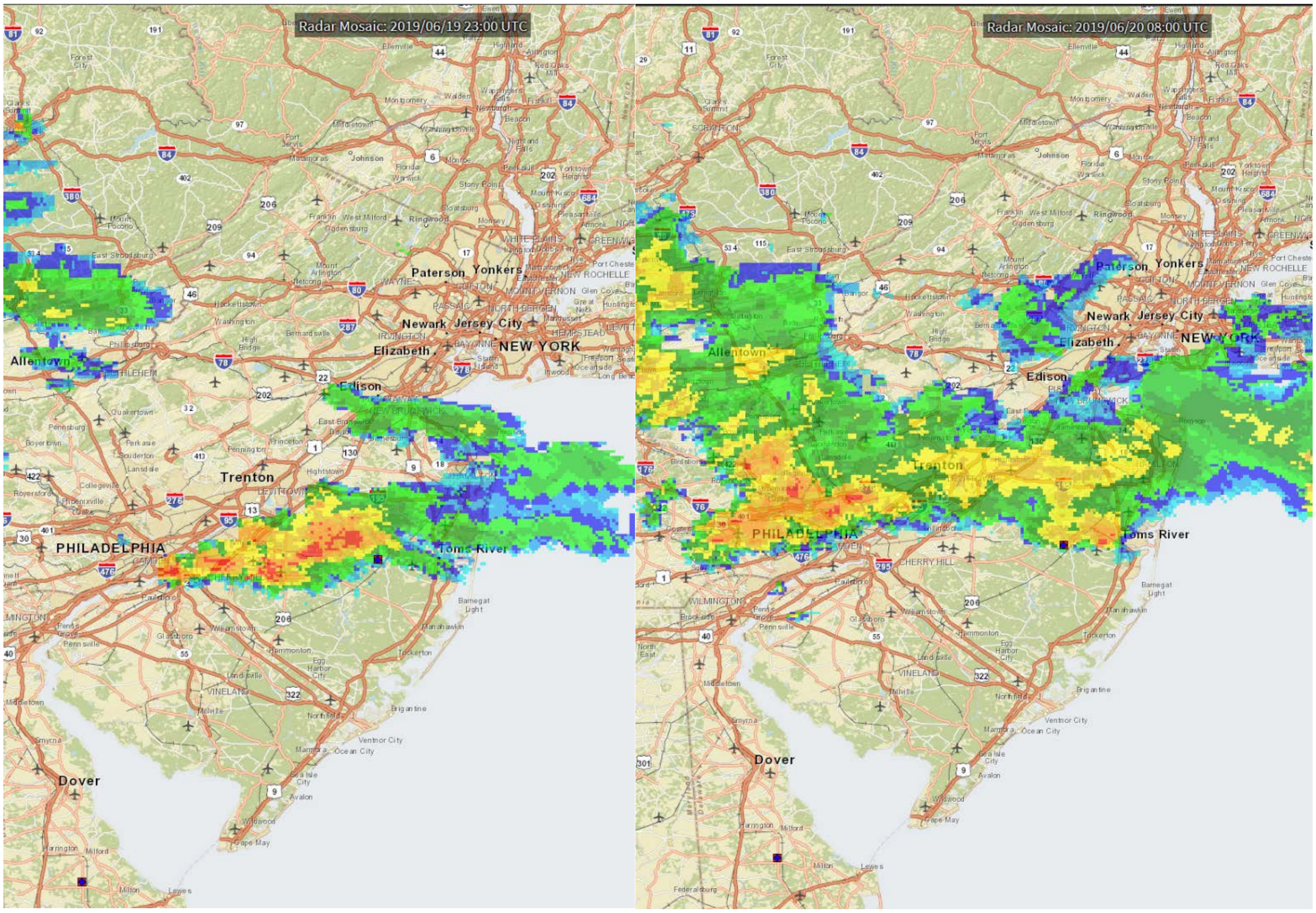
I-295 NB MP 22.9_TT TO Ben Franklin Bridge [Length 10.43 miles]

Heavy Rain - Flooding - Closure

Travel Time

Speed

Figure 15: Traffic Delays on June 20, 2019 from I-295 North Bound to Ben Franklin Bridge.



06/19/2019 - 6pm   06/20/2019 - 3am

Figure 16: Radar images from June 19-20, 2019 (NCEI Radar Archives).

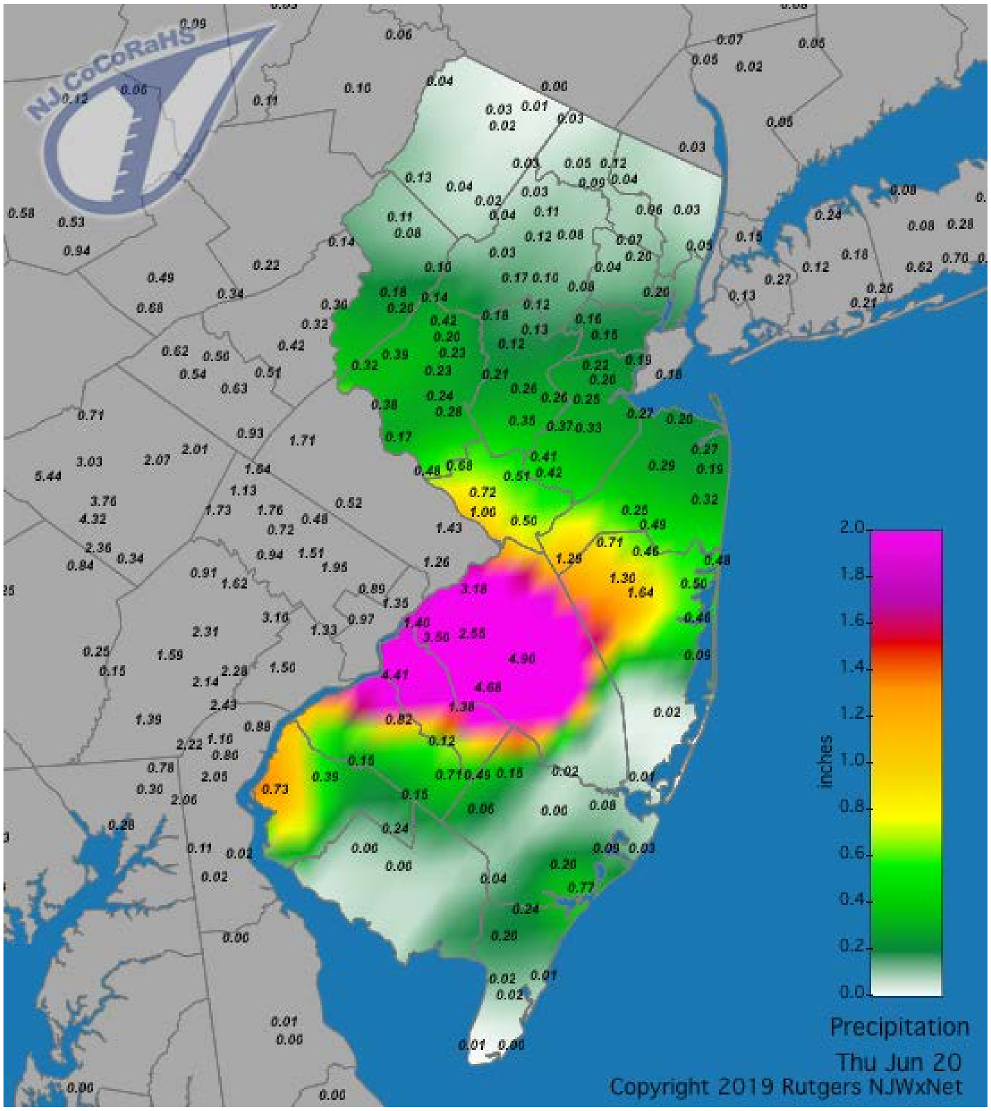


Figure 17: CoCoRaHS precipitation totals from approximately 7AM June 19 to 7AM June 20, 2019 (Office of NJ State Climatologist).

City	State	Eastern Time	Source	1 Hour Precip	1 Hour Wind Max
West Deptford	NJ	2019-06-19 15:00	Mesonet	0.00	6
West Deptford	NJ	2019-06-19 16:00	Mesonet	0.00	8
West Deptford	NJ	2019-06-19 17:00	Mesonet	0.00	7
West Deptford	NJ	2019-06-19 18:00	Mesonet	0.00	7
West Deptford	NJ	2019-06-19 19:00	Mesonet	0.00	13
West Deptford	NJ	2019-06-19 20:00	Mesonet	0.00	12
West Deptford	NJ	2019-06-19 21:00	Mesonet	0.00	8
West Deptford	NJ	2019-06-19 22:00	Mesonet	0.00	11
West Deptford	NJ	2019-06-19 23:00	Mesonet	0.00	6
West Deptford	NJ	2019-06-20 00:00	Mesonet	0.07	9
West Deptford	NJ	2019-06-20 01:00	Mesonet	1.35	10
West Deptford	NJ	2019-06-20 02:00	Mesonet	2.76	13
West Deptford	NJ	2019-06-20 03:00	Mesonet	0.76	10
West Deptford	NJ	2019-06-20 04:00	Mesonet	0.01	6
West Deptford	NJ	2019-06-20 05:00	Mesonet	0.05	5
West Deptford	NJ	2019-06-20 06:00	Mesonet	0.06	6
West Deptford	NJ	2019-06-20 07:00	Mesonet	0.00	4
West Deptford	NJ	2019-06-20 08:00	Mesonet	0.00	5
West Deptford	NJ	2019-06-20 09:00	Mesonet	0.00	4
West Deptford	NJ	2019-06-20 10:00	Mesonet	0.00	6
West Deptford	NJ	2019-06-20 11:00	Mesonet	0.00	11
West Deptford	NJ	2019-06-20 12:00	Mesonet	0.00	11

Table 4: One-hour precipitation and maximum wind speed reported on the morning of June 20, 2019 from West Deptford (Rutgers NJWxNet).

Case Study #3

August 7, 2019 (2:30 PM-9:30 PM EDT)

Flooding and downed Trees from heavy afternoon rainfall across New Jersey.

Roadway Study Region: US 1 SB Woodbridge Avenue to NJ 130 (3.82 miles) (Figure 18).

Weather scenario:
In the early afternoon of August 7, a cold front associated with a shortwave trough met a warm, moist air mass that had built up during the day in the mid-Atlantic region. The interaction between these air masses resulted in strong instability and convection producing storms across the state, many of which became severe. Strong winds, heavy rain, hail, and a few brief tornadoes were reported. In some parts of central New Jersey, precipitation totaled up to nearly 4 inches (Figure 19). One tornado in Millville, New Jersey briefly touched down in a field of solar panels. Another in Hightstown, New Jersey did damage to a greenhouse in which the roof was shattered.

Delays were experienced southbound on US 1 to NJ 130 between 4:00 PM and 8:00 PM. Peak delays occurred from 5:30 PM to 7:15 PM. Nearby, a NJWxNet station at New Brunswick recorded temperature, wind speed and rainfall during the peak of delays (Table 5). Another NJWxNet Station at East Brunswick captured similar conditions (Table 6). At both stations, temperatures dropped dramatically from 86°F to 69°F within a short period. This temperature change coincided with maximum wind gusts reported up to 30 mph and the occurrence of heaviest precipitation. At 5 PM, maximum wind speeds were recorded at 18 mph with 1.45 inches of rain falling during the hour in New Brunswick. Figure 20 shows the heavy precipitation over the area on radar. The tables show the high winds and heavy rainfall subsiding during the evening hours. A total of 3.32 inches of rain precipitation fell during this 5-hour period resulting in early evening flash flooding.

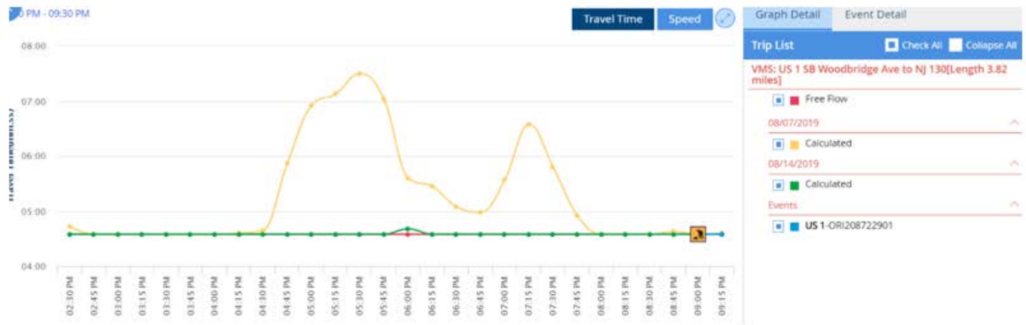
During its peak, speed decreases from normal conditions by 20 MPH and travel time nearly double on a 4 mile trip.

08/07/2019: 2:30 PM to 9:30 PM

US 1 SB Woodbridge Avenue to NJ 130 (length 3.82 miles)

Flooding, Down Trees

Travel Time



Speed

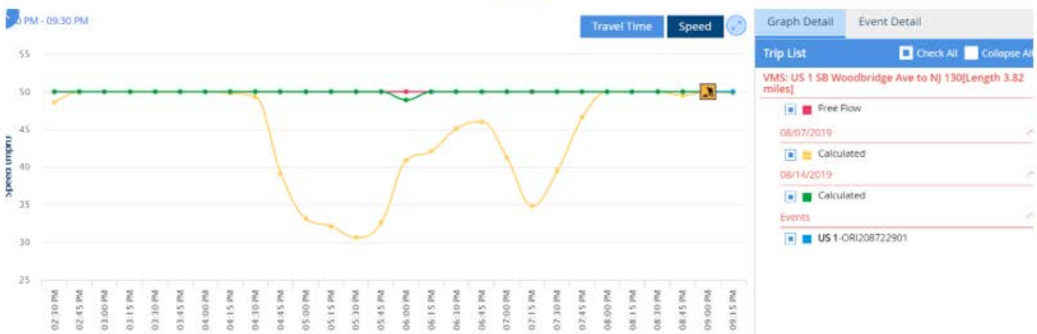


Figure 18: Traffic delays on August 7, 2019 from US 1 Southbound Woodbridge Avenue to NJ 130.

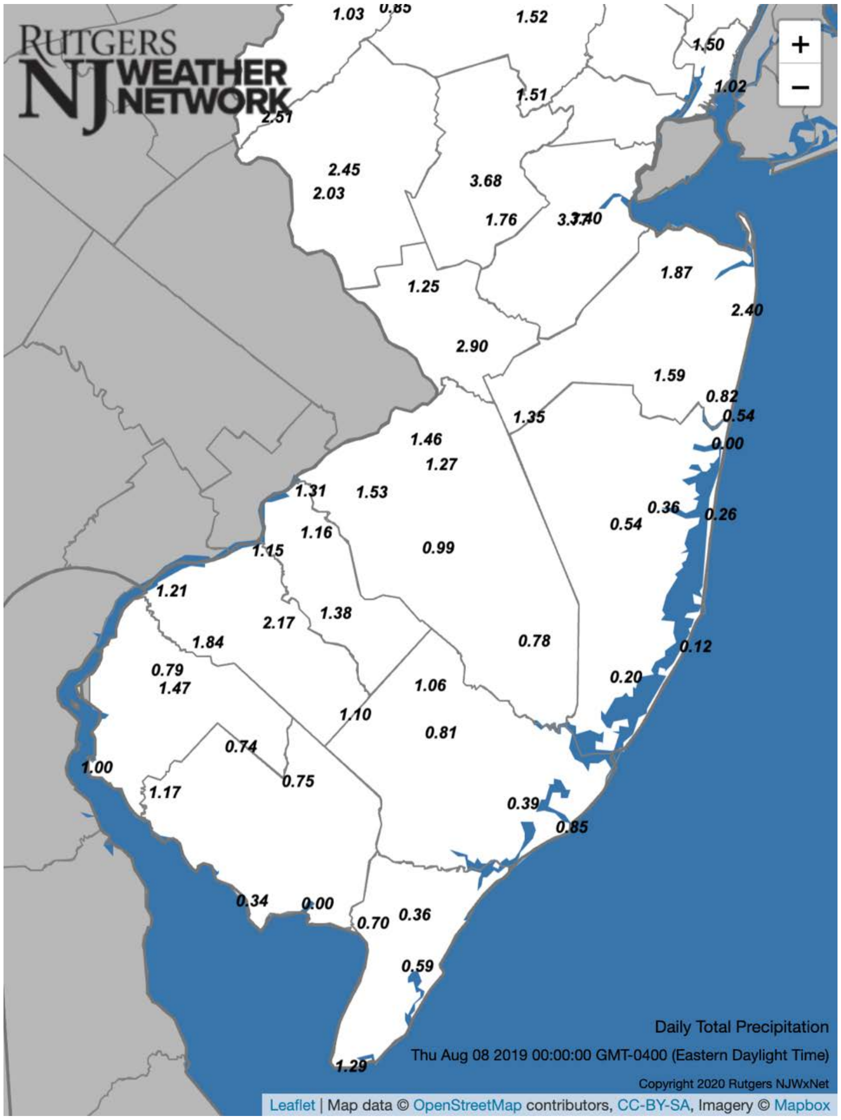


Figure 19: Precipitation totals for August 7, 2019 (Rutgers NJWxNet). Note the overlapping totals in the area of the Brunswicks (Middlesex County), with more data for these stations in the accompanying tables.

City	State	Eastern Time	Source	1 Hour Temp Avg	1 Hour Precip	1 Hour Wind Speed Avg	1 Hour Wind Max
New Brunswick	NJ	2019-08-07 13:00	Mesonet	86	0.00	4	12
New Brunswick	NJ	2019-08-07 14:00	Mesonet	86	0.00	4	14
New Brunswick	NJ	2019-08-07 15:00	Mesonet	76	0.18	4	29
New Brunswick	NJ	2019-08-07 16:00	Mesonet	74	0.11	4	11
New Brunswick	NJ	2019-08-07 17:00	Mesonet	72	1.45	4	16
New Brunswick	NJ	2019-08-07 18:00	Mesonet	69	1.24	3	14
New Brunswick	NJ	2019-08-07 19:00	Mesonet	69	0.44	2	8
New Brunswick	NJ	2019-08-07 20:00	Mesonet	69	0.08	2	6
New Brunswick	NJ	2019-08-07 21:00	Mesonet	69	0.17	1	4
New Brunswick	NJ	2019-08-07 22:00	Mesonet	69	0.01	2	7
New Brunswick	NJ	2019-08-07 23:00	Mesonet	68	0.00	1	4

Table 5: One-hour precipitation and maximum wind speed reported from New Brunswick on August 7, 2019 (Rutgers NJWxNet).

City	State	Eastern Time	Source	1 Hour Temp Avg	1 Hour Precip	1 Hour Wind Speed Avg	1 Hour Wind Max
East Brunswick	NJ	2019-08-07 13:00	Mesonet	87	0.00	7	14
East Brunswick	NJ	2019-08-07 14:00	Mesonet	88	0.00	7	14
East Brunswick	NJ	2019-08-07 15:00	Mesonet	76	0.60	10	30
East Brunswick	NJ	2019-08-07 16:00	Mesonet	75	0.12	9	20
East Brunswick	NJ	2019-08-07 17:00	Mesonet	73	0.74	7	18
East Brunswick	NJ	2019-08-07 18:00	Mesonet	69	1.29	7	20
East Brunswick	NJ	2019-08-07 19:00	Mesonet	69	0.33	4	10
East Brunswick	NJ	2019-08-07 20:00	Mesonet	70	0.07	4	12
East Brunswick	NJ	2019-08-07 21:00	Mesonet	69	0.17	3	7
East Brunswick	NJ	2019-08-07 22:00	Mesonet	69	0.02	4	7
East Brunswick	NJ	2019-08-07 23:00	Mesonet	69	0.00	3	6

Table 6: One-hour temperature average, precipitation total, wind speed average and wind gust from East Brunswick on August 7, 2019 (Rutgers NJWxNet).

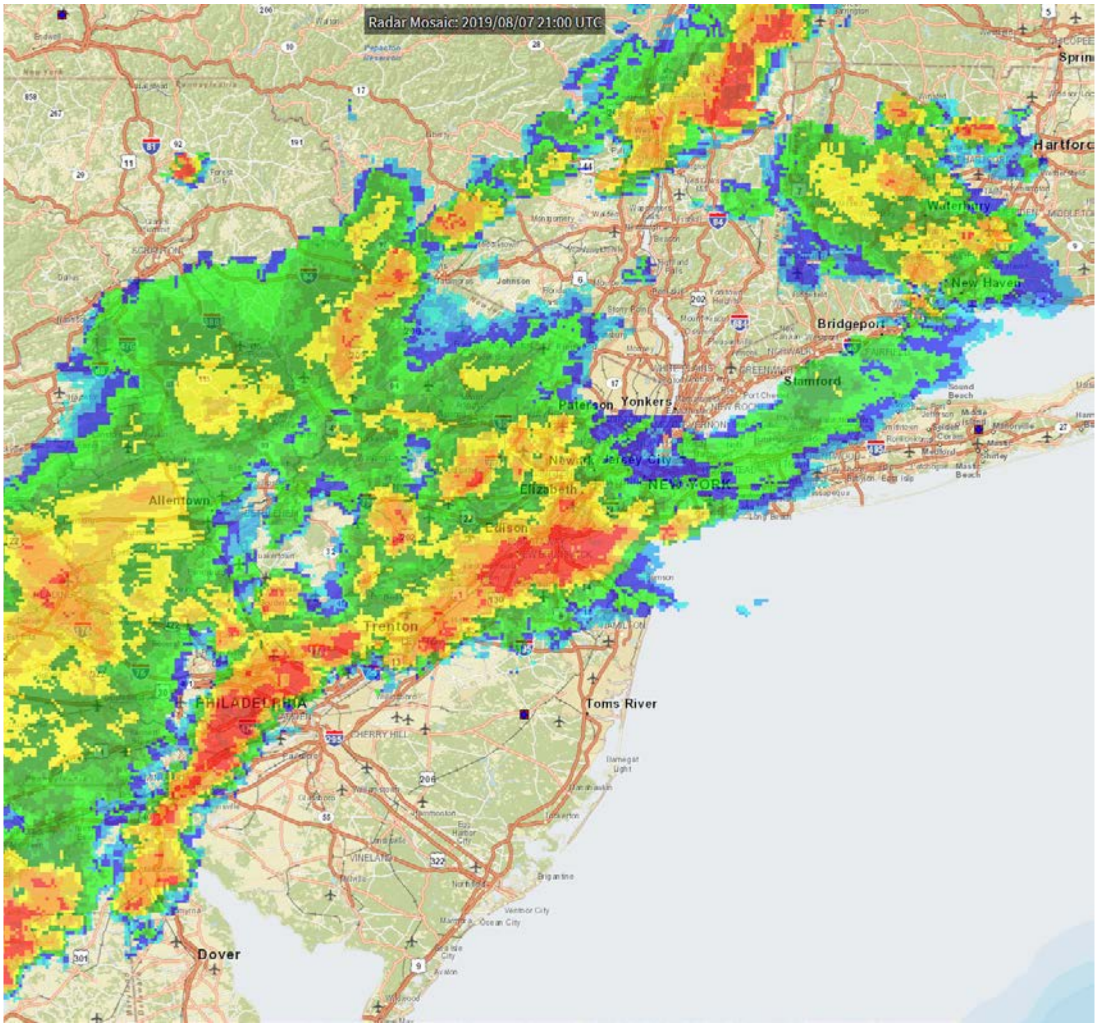


Figure 20: Radar image from 5 PM August 7, 2019 (NCEI Radar Archives).

Case Study #4

January 7, 2017 (1:30 PM-8:15 PM EST)

Coastal storm with heavy snow, ice, and rain across the Northeast.

Roadway Study Region: I-80 WB mile marker 66.3 to Garden State Parkway via local (3.57 miles) (Figure 21).

Weather Scenario:

This event comes after a storm that entrenched a cold arctic air mass over the mid-Atlantic. This previous event provided the necessary ingredients for a strong winter storm, as cold air mixed with a low-pressure system off the New Jersey coast to produce heavy snowfall. The highest totals were reported along the southern coast with approximately 4 inches falling in the case study area (Figure 22). This event caused numerous flight delays and cancellations at Philadelphia International Airport and Newark International Airport. Additionally, New Jersey State police responded to 318 motor vehicle accidents throughout the event.

Delays were experienced on local roads between I-90 and the Garden State Parkway between 1:30 PM to 8:15 PM due to plowing and salting. Teterboro Airport, a nearby station, captured weather conditions at hourly or shorter intervals during this event (Table 7). The peak delays were experienced between 3 PM and 8 PM. Throughout the day, snow was reported, with visibility decreasing to a quarter mile of visibility. Most of the 4 inches of snow along with gusts up to 25 mph occurred during the five-hour period.

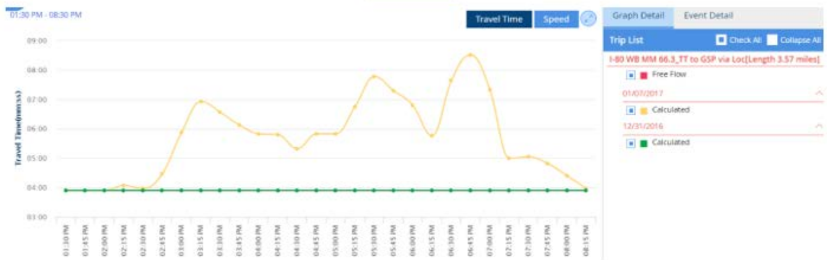
The traffic conditions coincide with this weather data in that I-80 had speed decreases from normal conditions of 30 MPH and travel time increases of nearly 5 minutes on a 3.5 mile trip.

01/07/2017: 1:30 Pm to 8:15 PM

I-80 WB MM 66.3 to Garden State Parkway via local (length 3.57 miles)

Plowing and Salting

Travel Time



Speed

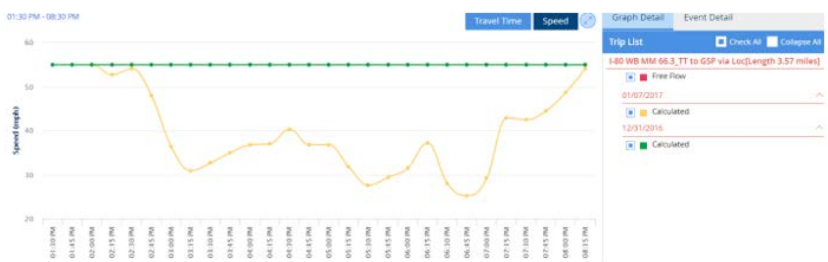


Figure 21: Traffic delays on January 7, 2017 from I-80 West Bound to Garden State Parkway.

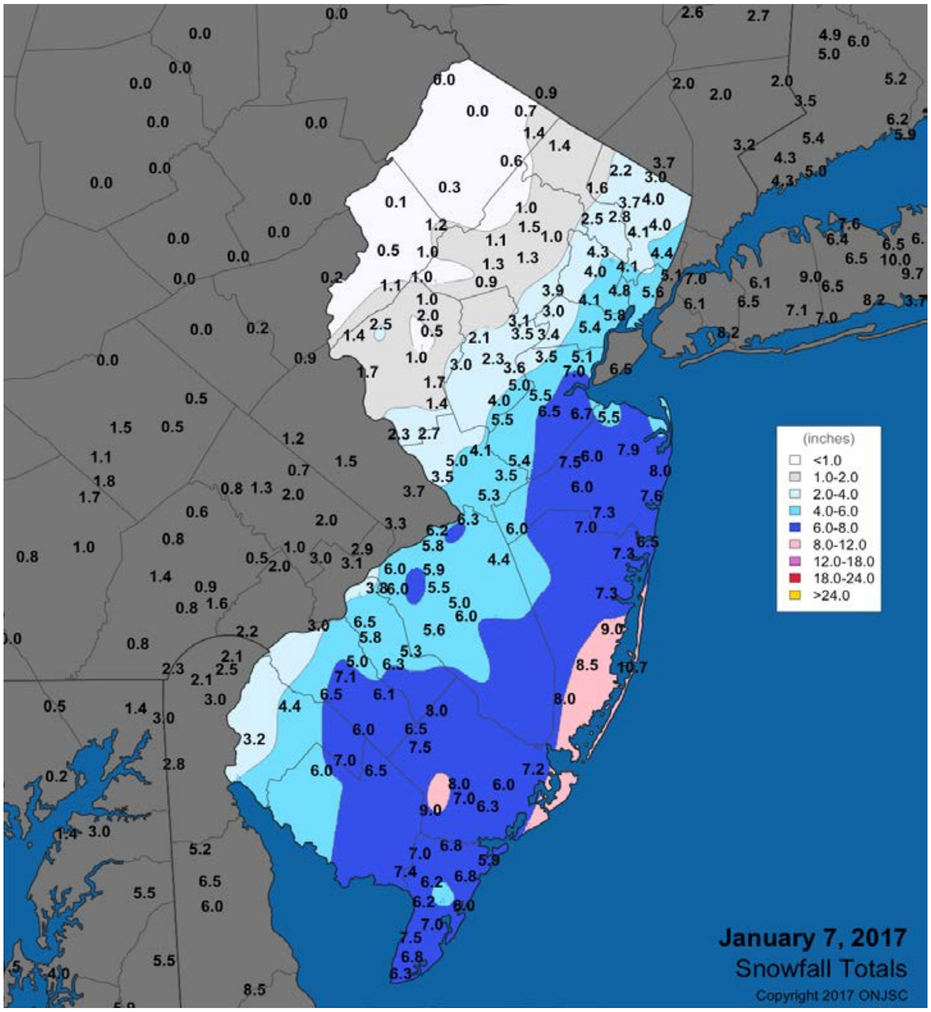


Figure 22: Snowfall for the January 7, 2017 storm (Office of NJ State Climatologist).

U.S. Department of Commerce
National Oceanic & Atmospheric Administration
National Environmental Satellite, Data, and Information Service

Local Climatological Data
Hourly Observations
January 2017
Generated on 09/03/2020

National Centers for Environmental Information
151 Patton Avenue
Asheville, North Carolina 28801

Current Location: Elev: 9 ft. Lat: 40.8500° N Lon: -74.0614° W
Station: **TETERBORO AIRPORT, NJ US WBAN: 72502594741 (KTEB)**

Date	Time (LST)	Station Type	Sky Conditions	Visibility	Weather Type (see documentation) AU | AW | MW	Dry Bulb Temp (F)	Dry Bulb Temp (C)	Wet Bulb Temp (F)	Wet Bulb Temp (C)	Dew Point Temp (F)	Dew Point Temp (C)	Rel Hum %	Wind Speed (MPH)	Wind Dir (Deg)	Wind Gusts (MPH)	Station Press (inHg)	Press. Tend	Net 3-Hr Change (inHg)	Sea Level Press. (inHg)	Report Type	Precip Total (in)	Altimeter Setting (inHg)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
07	0051	7	CLR:00	10.00		25	-3.9	20	-6.7	7	-13.9	46	8	350		30.27	3	-0.04	30.28	FM-15	0.00	30.28
07	0151	7	CLR:00	10.00		25	-3.9	20	-6.7	7	-13.9	46	7	020		30.29			30.30	FM-15	0.00	30.30
07	0251	7	FEW:02 120	10.00		24	-4.4	20	-6.7	7	-13.9	48	7	040		30.31			30.32	FM-15	0.00	30.32
07	0351	7	FEW:02 120	10.00		24	-4.4	19	-7.2	6	-14.4	46	7	040		30.31	1	-0.04	30.32	FM-15	0.00	30.32
07	0451	7	SCT:04 120	10.00		24	-4.4	19	-7.2	5	-15.0	44	9	030		30.32			30.33	FM-15	0.00	30.33
07	0551	7	OVC:08 110	10.00		24	-4.4	19	-7.2	5	-15.0	44	7	020		30.30			30.31	FM-15	0.00	30.31
07	0651	7	OVC:08 95	10.00		24	-4.4	19	-7.2	6	-14.4	46	10	010		30.28	8	+0.03	30.29	FM-15	0.00	30.29
07	0751	7	OVC:08 60	10.00		24	-4.4	19	-7.2	5	-15.0	44	7	010	18	30.29			30.30	FM-15	0.00	30.30
07	0851	7	OVC:08 43	5.00	-SN:03 BR:1 |SN |	24	-4.4	19	-7.2	6	-14.4	46	9	010		30.30			30.31	FM-15	T	30.31
07	0930	7	OVC:08 8	2.00	-SN:03 BR:1 |SN |	23	-5.0	19	-7.2	10	-12.2	57	9	020		30.29				FM-16	T	30.30
07	0951	7	OVC:08 8	2.00	-SN:03 BR:1 |SN |	22	-5.6	19	-7.2	13	-10.6	68	9	010		30.30	0	-0.01	30.31	FM-15	T	30.31
07	1026	7	OVC:08 5	1.00	-SN:03 BR:1 |SN |	22	-5.6	20	-6.7	14	-10.0	71	9	020		30.29				FM-16	T	30.30
07	1051	7	OVC:08 5	0.50s	-SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	16	-8.9	81	8	020		30.27			30.28	FM-15	0.02	30.28
07	1151	7	OVC:08 5	0.75	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	11	010		30.22			30.23	FM-15	0.03	30.23
07	1234	7	OVC:08 5	1.25	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	11	350		30.21				FM-16	0.01	30.22
07	1242	7	OVC:08 5	0.75	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	11	360		30.19				FM-16	0.01	30.20
07	1249	7	OVC:08 5	1.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	80	13	010	20	30.17				FM-16	0.01	30.18
07	1251	7	OVC:08 5	1.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	8	360	20	30.18	5	+0.10	30.19	FM-15	0.01	30.19
07	1258	7	OVC:08 5	1.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	11	350	17	30.18				FM-16	T	30.19
07	1335	7	OVC:08 5	0.75	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	13	350		30.17				FM-16	0.01	30.18
07	1351	7	OVC:08 5	0.75	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	11	350	22	30.16			30.17	FM-15	0.02	30.17
07	1408	7	OVC:08 6	1.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	10	350		30.14				FM-16	T	30.15
07	1441	7	OVC:08 6	0.25s	SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	17	-8.3	85	13	350		30.16				FM-16	0.01	30.17
07	1451	7	OVC:08 3	0.50s	SN:03 s BR:1 s |s SN s |	20	-6.7	19	-7.2	17	-8.3	89	10	350	21	30.16			30.17	FM-15	0.02	30.17
07	1508	7	OVC:08 3	0.25s	SN:03 s BR:1 s |s SN s |	20	-6.7	19	-7.2	17	-8.3	89	11	350	22	30.15				FM-16	0.01	30.16
07	1531	7	OVC:08 3	0.50s	SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	17	-8.3	85	10	350		30.14				FM-16	0.03	30.15
07	1551	7	OVC:08 3	0.50s	SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	17	-8.3	85	13	350	21	30.12	8	+0.06	30.13	FM-15	0.05	30.13
07	1644	7	OVC:08 6	0.50s	SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	17	-8.3	85	11	360		30.12				FM-16	0.01	30.13
07	1651	7	OVC:08 6	0.50s	SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	17	-8.3	85	9	350		30.12			30.13	FM-15	0.03	30.13
07	1751	7	OVC:08 6	0.50s	SN:03 s BR:1 s |s SN s |	21	-6.1	20	-6.7	17	-8.3	85	13	360	25	30.13			30.14	FM-15	0.04	30.14
07	1844	7	OVC:08 15	1.50	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	10	350		30.13				FM-16	0.02	30.14
07	1851	7	OVC:08 15	1.50	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	10	350	21	30.13	0	-0.01	30.14	FM-15	0.01	30.14
07	1919	7	OVC:08 15	5.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	9	350	21	30.12				FM-16	T	30.13
07	1943	7	OVC:08 15	2.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	10	340	21	30.12				FM-16	T	30.13
07	1951	7	OVC:08 15	2.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	16	-8.9	81	13	340	23	30.12			30.12	FM-15	T	30.13
07	2051	7	OVC:08 15	2.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	10	340	18	30.12			30.13	FM-15	T	30.13
07	2058	7	OVC:08 47	3.00	-SN:03 BR:1 |SN |	21	-6.1	20	-6.7	17	-8.3	85	9	340	17	30.12				FM-16	T	30.13
07	2151	7	OVC:08 55	10.00		21	-6.1	20	-6.7	16	-8.9	81	7	340		30.13	3	-0.01	30.14	FM-15	T	30.14
07	2251	7	OVC:08 60	10.00		21	-6.1	19	-7.2	14	-10.0	74	10	330	21	30.15			30.15	FM-15	0.00	30.16
07	2351	7	BKN:07 70	10.00		21	-6.1	18	-7.8	8	-13.3	57	17	320	22	30.15			30.16	FM-15	0.00	30.16

Table 7: Reported weather conditions from Teterboro Airport (KTEB) on January 7, 2017 (NCEI COOP).

Case Study #5

January 23, 2017 (2:30 PM-8:00 PM EST)

Coastal storm with wind, heavy rain and flooding across New Jersey

Roadway Study Region: NJ 42 SB from Walt Whitman Bridge (PA side) to NJ 55 via I-76 (6.05 miles) (Figure 23).

Weather Scenario:
Developing over North Carolina, a low-pressure system strengthened as it moved northeast along the coast. A steep pressure gradient just off the New Jersey coastline produced damaging winds with speeds exceeding 50 mph (Figure 24). Along with strong winds, the storm also produced some tidal flooding which resulted in the closure of some roadways along the shore. Temperatures in the northwest portion of the state were low enough to result in some snowfall; up to 3 inches at Highland Lakes. Cold temperatures also caused slick road conditions. High winds and falling trees resulted in numerous power outages. The heavy rain and flooding continued into the morning of the 24^{th}.

Traffic delays on the Walt Whitman Bridge began at 3:30 PM and continued through rush hour. Travel time increased by 50% between 5:30 PM and 6:00 PM compared to normal traffic while speeds decreased by 15 MPH on a 6 mile trip. On the New Jersey side of the bridge, wind gusts reached a maximum of 51 mph (Figure 24). Close by, a Rutgers NJWxNet station in West Deptford recorded maximum gusts up to 36 mph and average wind speeds up to 14 mph from 1 PM to 5 PM. During this period, temperatures reached a maximum 39° and precipitation totaled 0.66 inches (Table 8).

01/23/2017: 2:30 PM to 8 PM

NJ 42 SB from Walt Whitman Bridge (PA side) to NJ 55 via I-76 (length 6.05 miles)

High Winds

Travel Time

Speed

Figure 23: Traffic Delays on January 23, 2017 on NJ 42 SB from Walt Whitman Bridge to NJ 55 via I-76.

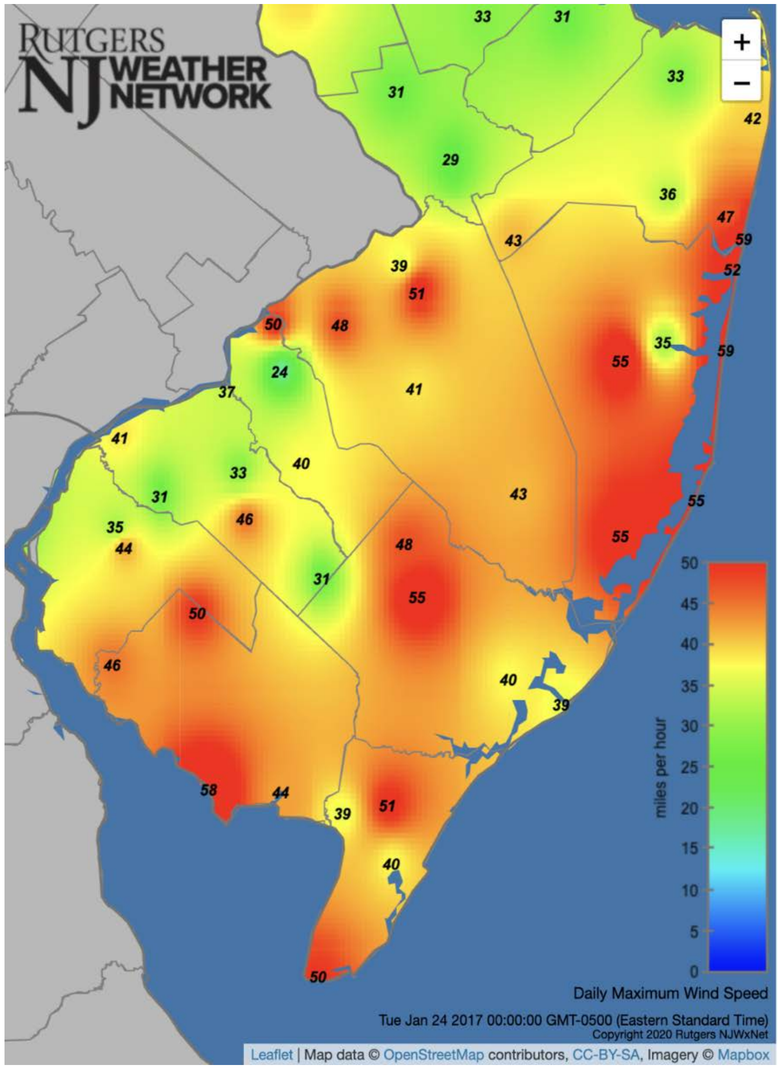


Figure 24: Maximum Wind Gusts on January 23, 2017 (Rutgers NJWxNet).

City	State	Eastern Time	Source	1 Hour Temp Avg	1 Hour Precip	1 Hour Wind Speed Avg	1 Hour Wind Max
▾ West Deptford	NJ	2017-01-23 22:00	Mesonet	39	0.00	14	34
▾ West Deptford	NJ	2017-01-23 21:00	Mesonet	39	0.00	12	29
▾ West Deptford	NJ	2017-01-23 20:00	Mesonet	38	0.00	12	27
▾ West Deptford	NJ	2017-01-23 19:00	Mesonet	38	0.00	11	24
▾ West Deptford	NJ	2017-01-23 18:00	Mesonet	37	0.07	11	28
▾ West Deptford	NJ	2017-01-23 17:00	Mesonet	38	0.25	11	28
▾ West Deptford	NJ	2017-01-23 16:00	Mesonet	38	0.07	13	35
▾ West Deptford	NJ	2017-01-23 15:00	Mesonet	39	0.16	14	31
▾ West Deptford	NJ	2017-01-23 14:00	Mesonet	39	0.09	14	33
▾ West Deptford	NJ	2017-01-23 13:00	Mesonet	39	0.02	14	36

Table 8: Reported average temperature, precipitation, wind speed and wind speed maximum during the January 23, 2017 storm (Rutgers NJWxNet).

3.4. Evaluation of station or element gaps

Upon examination of the current location of RWIS and off-roadway weather stations within the immediate TRANSCOM region (approximate 50 mile radius from Times Square), recommendations are made of where more stations might be added. This initial evaluation identifies 37 locations along roadways where RWIS stations might be installed (Figures 25 and 26, Table 9). It is possible that in some cases instead of roadside installations, particularly in locations away from major highways, it might be prudent to better site these stations as mesonets. These would be cases where traffic volume would not dictate the need for roadway information; rather mesonet stations would provide sufficient information and better regional monitoring of weather conditions. This evaluation does not delve into additional equipment to be added to existing stations to record pertinent weather observations. These might include sensors for visibility (likely best at RWIS sites) snow depth (best at mesonet stations some distance from roadways), and freezing rain (likely best some distance away from where chemical applications are made to roadways).

Decisions on where to make recommendations are based on feedback gathered during Task 2 questionnaires and interviews, discussions with other transportation experts, knowledge of local and regional weather/climate, and recognizing where gaps in coverage are found along major transportation corridors and intersections. Agency feedback focused on flood-prone areas, roadways with inclines/declines, significant curvature, elevated sections and bridge decks, quiet pavement, and those located at higher elevations. Information not immediately available for the recommendations provided in this report but of likely pertinence to station siting is knowledge of known accident prone areas that might be associated with poor weather conditions, areas with quiet pavement, and areas with common double chemical applications.

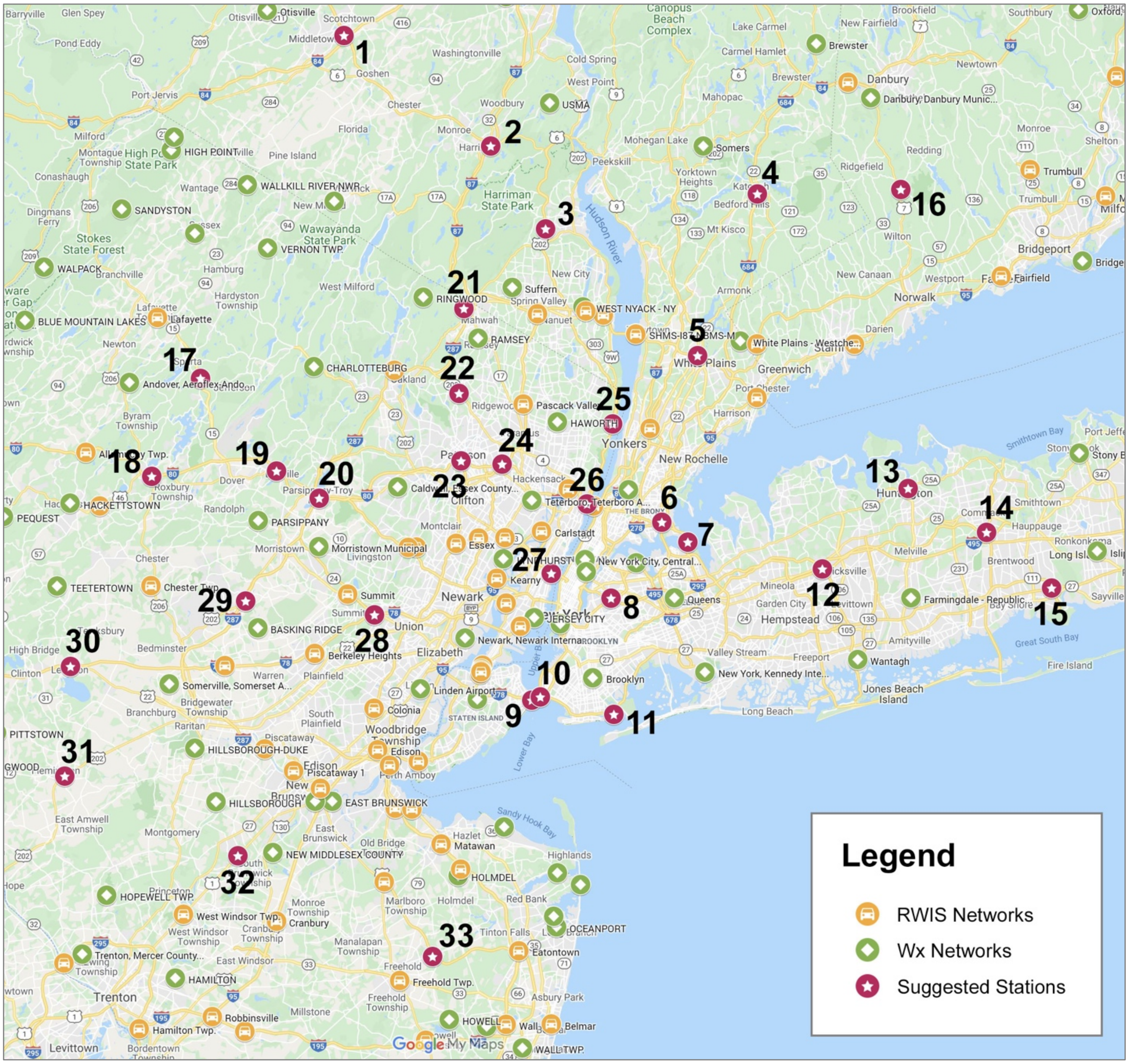


Figure 25. Locations of existing RWIS stations (orange circles with auto symbol) and mesonet stations (green circles with diamond symbol) within an approximate 50 mile radius of Time Square. Red circles with star symbol identify those roadside locations where addition RWIS stations are recommended. Numbers correspond to locations denoted in Table 9. This map can be viewed online at: https://www.google.com/maps/d/edit?mid=1-ci7GyY4Uin7JG8gJtBP5H9bBMSehXK6&usp=sharing

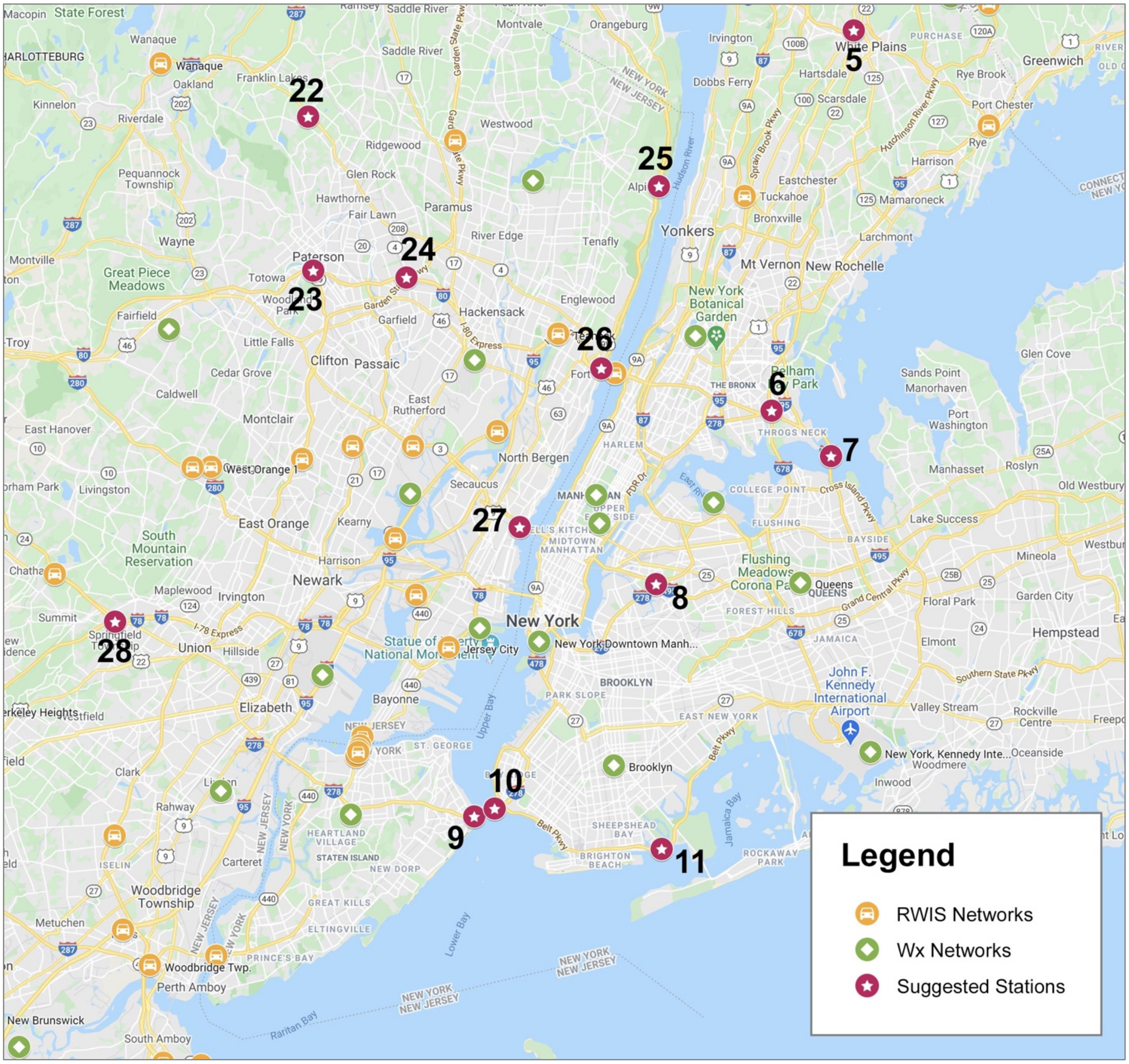


Figure 26. A view of the portion of the map in figure 25 close to Times Square. Circles/symbols are the same as in figure 25 (minus the black circles which are outside of this small domain).

Site	Roadway(s)	Community	Justification
NY			
1	84/17	Middletown	intersection
2	87/6/17	Central Valley	intersection
3	Palisades Inter. Pkwy (PIP)	Thiells	hill, elevation
4	684/Saw Mill Pkwy	Bedford Hills	intersection, elevation
5	287/ Bronx River Pkwy	White Plains	intersection
6	95/278/678	Bronx	intersection
7	Throgs Neck Bridge/295	Bronx	bridge, congestion
8	495/278	Queens	intersection
9	Verrazzano Bridge/278	Staten Island	bridge
10	Verrazzano (mid span)	Brooklyn/Staten I	bridge
11	Belt Pkwy	Brooklyn	congested
12	Northern /Wantaugh pkwys	Westbury	intersection
13	25A/110	Huntington	underrepresented
14	Northern/Sunken Meadow pkwys	Commack	underrepresented
15	Sunrise Hwy/S State Pkwy	East Islip	underrepresented
CT			
16	7/57	Wilton	underrepresented
NJ			
17	15	Sparta	hill, elevation
18	80/46/206	Netcong	intersection, elevation
19	80/46	Denville	intersection, hill
20	80/287	Parsippany	intersection
21	287/17/87	Mahwah	Intersection
22	208	Wyckoff	congested, hill
23	80/19	Paterson	intersection
24	80/Garden State Pkwy	Saddle Brook	intersection
25	PIP	Alpine	elevation
26	95/PIP/G Washington Bridge	Fort Lee	intersection
27	495/Lincoln Tunnel	Weehawken	congested, hill
28	78/24	Springfield	congested, hill
29	287/202	Basking Ridge	congested, hill
30	78/22	Lebanon	intersection, hill
31	202/12	Flemington	underrepresented
32	1	South Brunswick	congestion, hill
33	18/537	Colts Neck	underrepresented

Table 9. Locations of recommended additions to RWIS networks within the TRANSCOM region and a brief justification for choices. Where an intersection or bridge is listed it assumes that these locations are often congested. Underrepresented is listed for locations where current RWIS and mesonet stations are not close by and it is considered useful to have weather observations at these locations.

<u>Task 4</u>:

4.1. Enhancements that could be made to the current weather observing infrastructure within the TRANSCOM region.

In addition to the additional stations and observational elements recommended under task 3 part 4, there are additional enhancements that are worthy of consideration as TRANSCOM endeavors to enhance their reporting capabilities by incorporating useful physical observations. Aside from atmospheric and roadway weather conditions, it would be beneficial to add water level observations. This includes reports from tidal and river gauges to gain important information on rising waters, be they from ocean, bay or harbor surges or freshwater stream and river responses to heavy precipitation events. The NOAA HADS network is the primary network to consider incorporating into the physical data feed, providing water levels and also some accompanying atmospheric information at some locations. There are also USGS gauges that could be added to the mix and perhaps gauges from other entities, including the gauges within the Stevens Institute NY Harbor and Monmouth University Shrewsbury networks. While federal agency observations are freely available, it remains to be determined if charges would apply to secure real-time data from other networks.

Another enhancement that might be considered is an advisory/alert system. This could be created for those on duty or even be an app that would allow selected individuals to be sent an advisory (early alert) or alert (imminent or ongoing situation) whenever and wherever the individual might be at a particular time. However an advisory or alert might be disseminated, the conditions under which one is generated and transmitted would be based on considerable discussion amongst developers and those who will be on the receiving end of the alerts. It is absolutely vital that the user community makes the final decisions on conditions/thresholds reached under which an advisory/alert is released for a given variable (or suite of variables). It would likely be determined based on a combination of element magnitude, the rate of change of the element, the timing of the event (e.g. rush hour, nighttime, weekday/weekend), and perhaps antecedent conditions.

4.2. Development of an operational system that would synthesize observations from all regional weather networks

There are multiple critical aspects to any operational system delivering weather observations to the TRANSCOM community. They are discussed as follows:

a. *Real time*: Timeliness is of the essence when monitoring potentially impactful weather conditions. It is imperative that observations from each network are processed within minutes of being received by the entity in charge of the operational system. Most potential networks observe and rapidly report in 5 minute up to 15-minute intervals. Any slower response and the data are likely not worthy of consideration unless there is no other means of securing information regarding a particular element.

b. *Coordination*: Rapport must be established and maintained between those responsible for gathering and processing observations from each network and those maintaining the joint operational network. This will ensure that any changes to an individual network's operations are known quickly (e.g. new or retired stations, new variables, adjustments in data dissemination).

c. *Consolidation*: The charge to the joint operational network must achieve just this, amalgamation of data from multiple network sources into a unified seamless and compatible format that is acceptable by the TRANSCOM system. This applies to station observations gathered throughout the region. It appears that the greatest challenge may be in translating roadway variables into a unified nomenclature.

d. *Incorporation of ancillary information into observational feed*: This includes radar and satellite observations.

e. *Quality control/assurance*: Any observation available for inclusion in the unified database and potentially transmitted to TRANSCOM users must be evaluated for accuracy. In most cases, the data received by the consolidating entity will have to undergo some level of quality evaluation by each contributing network. It may be that some suspect data are not forwarded but more than likely all data will be transmitted with a flag denoting whether or not they have passed an assurance procedure. Whatever the case, it will be up to the consolidating source to determine what observations are suitable for amalgamation into the unified data base/feed. This can be achieved by first looking at the quality assessment of the source network and then conducting single station and spatial evaluations of data quality. Having data from multiple networks available will be exceedingly useful in making final decisions regarding what data to transmit to TRANSCOM or to be incorporated in product generation.

f. *Product generation*: It will be valuable to the TRANSCOM user to not only be provided with individual observed weather elements but also with products derived from one or more elements. In an individual sense this might include a report on rate of change, for instance rapidly falling temperatures or rainfall accumulating at an excessive rate. Integrated products might include heat index, wind chill, differences in air and roadway temperatures. They could also be a combination of precipitation totals gathered from ground stations versus radar estimates.

g. *Adaptability*: The operational system must be designed to have the capability of adding new variables and new stations to the existing mix. Also to inform TRANSCOM users when stations are closed or even when they are temporarily not providing data for a particular variable or any data at all.

h. *Advisories/alerts*: This was discussed in Task 4 section 1. It will take a critical cooperative effort amongst the development staff and the TRANSCOM users to come up with a system that leads to critical advisories alerts being disseminated to the correct individuals without overwhelming them with messages that in actuality are not deemed critical. This does not mean that there won't be occasions where an advisory or alert situation may not "live up to its promise", rather it will take a careful balance and some trial and error to fine tune a system that will perform in the best possible manner.

The development of an integrated operational network is likely to proceed in an incremental manner. Perhaps it could start with formatting several networks into a unified structure and relying on the quality control metrics from the contributing networks. Next would be incorporating more networks while proceeding with a unified quality control. Products might then follow, first for station weather observations, then for those integrating other sources of information. Later on, water level data could be added and an alert system too. It is important that at every step of the way insights and feedback for the TRANSCOM individuals using the data and information be part of the process. Feedback has already been provided through the initial interview process but this is only a start. Those with their "boots on the ground" will prove invaluable in creating a system that provides the best weather information to the transportation community.

4.3. Potential research endeavors to "test" the ability of the current and potentially enhanced network to meet the needs of TRANSCOM and its partners.

Based on the results of Task 2 surveys and interviews, it is apparent that the TRANSCOM community recognizes the importance of pursuing a proactive approach to addressing critical weather events and the serious impacts they are likely to exert on transportation within the Tri-State region. The inclusion of a major weather data component to the TRANSCOM system represents an important step in this direction. Next, it is important to bring the combined experience of transportation and weather experts to the table to solidify approaches that will better understand linkages, in the process better anticipate and react to situations from regional to local levels and at any time of day. Below, are suggestions of activities that would contribute to a better understanding of weather-related transportation issues and improved means of addressing them.

a. *Training*: It was made clear within the agency interview sessions that it is imperative that ample training be made available to the TRANSCOM community regarding the evaluation of weather information and its employment in evaluation and decision making processes. Training activities could include how transportation issues manifest themselves under various weather conditions (e.g. snow, heavy rain, poor visibility, excessive wind), recognizing actual weather conditions as they unfold versus what was forecast, post mortem reporting capabilities, proactive use of weather data versus reactive, and how tidal and river flooding differ in area and circumstance.

   Over the course of the training process it might be better determined what combinations of weather and products generated from them would make the data more meaningful. Training could also reveal when and which advisories and alarms make sense to operators.

b. *On-going evaluation*: Certainly, much will be learned over the course of the implementation and operation of a new weather-centric component. This can be achieved through post-mortem evaluations, including extensive interviews with individuals involved with operational transportation decision processes. Assessments of forecast versus actual conditions in regard to timing, amounts, locations, extent of coverage, etc. should be part of the process.

c. *Advisories/Alerts*: It is imperative that early efforts to develop an advisory/alert system be evaluated in order to provide the best information possible to the operational TRANSCOM community. Periodically, perhaps quarterly, all issued advisories and alerts should be evaluated to determine whether they proved useful or might not have been necessary. So too, should situations where weather impacted transportation yet an advisory or alert was not issued. Such evaluations should lead to improved utility of the advisory/alert system as a critical contribution to the transportation sector.

d. *Forecast versus actuality*: Beyond what is mentioned under post-mortems in section b, further study of how a forecast compares with what actually transpires during the course of impactful weather events is warranted. This goes beyond just looking at the overall event and its association with transportation issues to see how forecasts hold or may be adjusted over the course of selected events. It recognizes that forecasts may differ across the region, for instance outlooks for 2" of snow in New York City, 6" at inland suburbs, and more than 10" at higher elevation. All part of a challenging undertaking that requires keen knowledge of sub-regional characteristics. Part of this study should involve an assessment of whether a meteorologist might be employed specifically for the TRANSCOM region.

e. *Baseline research*: In addition to the more focused applied research efforts mentioned above, it would be beneficial to pursue additional studies in order to gain better baseline knowledge of weather behavior within the TRANSCOM region. This can be achieved through a variety of case studies, the results of which will be utilized in aspects of forecasting, advisory/alert dissemination, and real-time decision making. Examples of such studies include:
    1. Examine spatial patterns of weather observations under various situations. For instance identifying nuances in the location of freezing air temperatures and freezing road temperatures in marginal freezing situations. Or patterns in the onset of snow, or transition from snow to rain or the opposite across the region.
    2. Study scalar issues that determine when a local transportation agency should best pay attention to only local conditions within their operating realm (e.g. fog, isolated summer storms) or whether they should look over more regional conditions (e.g. approaching snow, approaching squall line). Making the most efficient use of time rather than having to continually look at all scales (or for

that which matter at any given time) will draw attention to weather "happenings" when such scrutiny is needed and only when needed.

3. Evaluate the utility of weather stations away from roadways to aid in weather-related transportation decisions. How much might RWIS and Mesonet observations differ given the siting of each type of station. For instance, how do roadway observations of air temperature differ from those away from roadways and how might this be a function of weather conditions, time of day, and amount of roadway traffic?
4. Gain a better understanding of roadway products generated from RWIS station observations (e.g. various surface conditions).

Report Summary:

It is apparent from the results of Task 2 surveys and interviews, that the TRANSCOM community recognizes the importance of pursuing a proactive approach to addressing critical weather events and the serious impacts they are likely to exert on transportation within the Tri-State region. The inclusion of a major weather data component to the TRANSCOM system represents an important step in this direction. Task 1 introduced available weather networks in the TRANSCOM region and adjacent areas that can contribute a wide-range of data. This was expanded in Task 3 to identify all available weather stations, be they from roadside networks or other locations in the region. Task 3 also provided a preliminary assessment of observation quality, which appeared acceptable in most cases, while leaving some need for quality control/assurance at RWIS locations. Task 3 also verified the critical impacts of weather on traffic travel times, pointing to the utility of having information on multiple weather and roadway variables. Finally, Task 3 provided recommendations for new RWIS stations in areas susceptible to weather-induced travel delays associated with heavy rain/flooding, snow/ice, fog, and wind. Task 4 provided recommendations for enhancement of the current observing infrastructure, including an advisory/alert notification system when impactful weather is expected to occur or is underway. Thoughts regarding a phased standardization of all available weather data and products were discussed, along with potential research endeavors to improve overall understanding of relationships between weather and traffic. This includes the need to better appreciate weather forecasting challenges in the region and understand potential pronounced weather differences and their importance when making transportation decisions across the TRANSCOM domain. To best accomplish beneficial endeavors that lie ahead, it is important to bring the combined experience of transportation and weather experts to the table to solidify approaches that will better understand linkages. This will best ensure highly credible means of anticipating and reacting to situations from regional to local levels and at any time of day.