Regional Assessment of Weather Impacts on Freight

Weather Exposure Analysis Report

Appendix B: Highway Weather Closures Narratives

February 2016

AMERICAN ASSOCIATION OF STATE CLIMATOLOGISTS

Highway Weather Closures Narratives

Selected Localities, 2010-2014

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This report describes instances where segments of interstates were closed directly or indirectly because of major weather events in the period 2011-2014. Highway segments correspond to 13 study areas analyzed in Regional Assessments of Weather Impacts on Freight. The narratives explain weather's impact on transportation in severe conditions, where all traffic stops on the respective area's highways. The Office of the Executive Director of the American Association of State Climatologists (AASC), Asheville North Carolina, consolidated qualitative narratives on weather's impact largely written by State Climate Offices.

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The Weather Extension Study

NARRATIVES HIGHWAY CLOSURES

This study describes weather conditions that have closed highways in 13 regional study areas. For each area, the study provides qualitative accounts of weather events from 2011-2014. Each narrative has a number of photos and quotations, and complete references. The narratives explain weather's impact on transportation in severe conditions, where all traffic stops on the respective area's highways.

It is important to gauge the wider effects of severe storms on transportation. Major extreme weather events cause great impact to transport. Extreme weather events reduce the number of trucks on roadways. Highways close, traffic is diverted or stopped altogether, and trips are postponed or canceled.

INTRODUCTION

The extended weather task calls for a qualitative look at weather conditions that resulted in the closure of highways. For this analysis, we examine the Storm Events Database for the years 2010-2014, narrating remarkable events where the weather was a factor in shutting down a highway. As noted in previous reports (Cambridge 2014), searching through the Severe Weather Inventory could be time intensive. These are high-impact, low-frequency events, so it is helpful to know the dates and locations of these *a priori*. Many State Climate Offices have knowledge of significant events that disrupted commerce in their states. That knowledge is useful to paring down possible timeframes to investigate further. For this analysis, CASE worked with the Executive Director of the American Association of State Climate Offices in Asheville, North Carolina. In turn, the Executive Director coordinated with individual state offices, collected essays of 750 words or less, and consolidated the reports into a common format.

For the weather extension task, we will report on instances where the highway was closed due directly to weather (as in say, a blizzard) or indirectly (as in say, foggy weather that resulted in a multi-car pileup). Qualitative accounts of the weather's impact are included along with photos. This report includes accounts about selected highways in thirteen localities (Table 1). The locations are: Atlanta, GA, Chicago, IL, Columbus, OH, Denver, CO, Lexington, KY (to be submitted), Newark, NJ, Oklahoma City, OK, Phoenix, AZ, Pittsburgh, PA, Raleigh, NC, Rapid City, SD, Reno, NV, and Seattle, WA.

Study Area	Transportation Focus
Atlanta, GA	The I-285 Beltway.
Chicago, IL	I-57 from I-94 to the north and the Kankakee / Iroquois county line to the south.
Columbus, OH	I-70 from I-75 to the west and the Licking / Muskingum county line to the east.
Denver, CO	I-70 from SR 191 in Grand, UT to the east and the Elbert / Lincoln county line to the east.
Reno, NV	I-80 from I-5 to the west and the California / Nevada border to the east.
Lexington, KY	I-64 from I-265 to the west and the Bath / Rowan county line to the east.
Newark, NJ	I-78 from I-476 to the east and I-95 to the west.
Oklahoma City, OK	I-35 from I-44 to the north and US 70 to the south.
Pittsburgh, PA	I-79 from I-80 to the north and the Pennsylvania / West Virginia border to the south.
Raleigh, NC	I-40 from the Davie / Forsyth county line to the east and the Johnston / Sampson county line to the west.
Rapid City, SD	I-90 from the Wyoming / South Dakota state line to the west and SR 45 (Kimball) to the east.
Salt Lake City, UT	I-80 from the Nevada / Utah border to the west and the Utah / Wyoming border to the east.
Seattle, WA	I-90 from I-5 to the west and I-82 to the east.

Table 1 Areas of study

Study Area: Atlanta, GA

Weather Focus: Thunderstorm, Extreme weather

Transportation Focus: I-285 Beltway.

Lukas Buehler, CASE staff meteorologist

Interstate 285 is a 64-mile loop around Atlanta (Federal Highway Administration). Suburban sprawl has made it one of the most heavily traveled roadways in the United States. Portions slow during rush hour, sometimes to a crawl. Estimates are that more than two million people travel on Interstate 285 each day, making it by far the busiest Interstate in the Atlanta metropolitan area (Wikipedia).

September 8, 2014 Thunderstorm

A heavy thunderstorm led to flash flooding and several accidents on September 8, 2014. Cars hydroplaned and a jack-knifed tractor-trailer blocked the road (11alive). According to the Storm Events Database[1], deep tropical moisture with strong afternoon heating caused severe, slow moving thunderstorms, some producing heavy rain of 3-5 inches that then caused isolated flash flooding in several Metro Atlanta counties (Figure 1).(NOAA).

[1] See https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=543870

Figure 1. Traffic jam on the I-285 after a car crash due to heavy rain Source: (11alive).

July 14, 2014 Heavy rain

A major accident shut down part of I-285 on the afternoon of July 14, 2014[2]. The lanes were closed on the highway's southbound side due to an accident between two tractor-trailers and 16 other vehicles (Figure 2) (CBS46). According to the DeKalb County police, the event began with one accident due to the heavy rain, leading led to several chain reaction smash-ups. There were no serious injuries. Crews had hoped to have one or two lanes opened by 2:30 p.m. However, they remained closed until authorities brought in equipment to clear the scene (CBS46).

[2] See https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=543871 Storm Events Database

Figure 2. 18-vehicle accident shuts down I-285. Source (CBS46)

January 28, 2014 Winter Storm

Snow of 2.6 inches on January 28, 2014 was a one-day record, hamstringing the region, creating nightmares for commuters, truckers, students and their families (USA Today). Snow began falling around midday. Within hours, the metropolitan area was in gridlock with tens of thousands of people stranded on icy highways and interstates (Huffington Post). Thousands of drivers were hopelessly stuck for two days, many without food and water. Some people abandoned their cars altogether and walked to warmth and shelter. Aerial pictures showed parking lots (Figure 3 and Figure 4) (time.com). There was no indication of when or how the roads would be cleared(NPR).

Col. Mark McDonough, head of the Georgia State Patrol, reported there were 940 wrecks in the metro area and over 100 injuries. McDonough said that troopers assisted hundreds of motorists, and he would not advise motorists to sleep in their vehicles. "Hopefully, within the next couple of hours or by early morning, we'll see more roads clearing." (USA Today)

Meteorologists expected the storm. More than 24 hours prior to Atlanta's streets and highways turning into virtual parking lots, the National Weather Service issued a bulletin around 5 a.m. on Monday the 27th giving clear warning about an approaching winter storm (NPR). Moreover, early on Tuesday morning well before the snowfall began, the National Weather Service issued a winter storm warning with expectations of 1-2 inches of snow (see Storm Chronology, NOAA NWS). (AJC.com)

Many observers suggested that the failure to stagger release of people from schools and businesses during this light winter storm played a primary role in creating a paralyzing traffic

jam. A lack of coordination between various officials and agencies led to everyone leaving at once, prompting to a terrible traffic jam. The Mayor of Atlanta admitted that inexperience with snow 'played a role' in the gridlock (TODAY News).[3]

Figure 3. Traffic is snarled along the I-285 perimeter north of Atlanta's metro area Source: (NPR).

[3] See Storm Events Database: https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=496404

Figure 4. Abandoned cars piled on ice-covered Cobb Parkway medium at I-285 after a winter snow storm slammed Atlanta. Two inches of snow turned highways into parking lots creating massive traffic jams. Source (time.com)

Study Area: Chicago, IL

Weather Focus: Blizzard, Floods

Transportation Focus: I-57, I-80

Dr. Jim Angel, Illinois State Climatologist

Here are the dates and brief descriptions of the incidences, in chronological order, of weather-related events that closed Interstate 57 in the Chicago area. Researching news media reports of weather events in the area, one finds five events from 2011-2014. Three closures were the result of winter weather, while one was due to flooding, and another to dense fog.

January and February 2011 – Winter Weather

Two events closed Interstates near Chicago in early 2011. First, icy roads stopped traffic on I-57 on January 6, 2011. Andrei Evbuoma of the Chicago Examiner wrote that the Illinois State Police were "forced to shut down 5 miles of I-57 near Peotone this morning, as dozens of cars and trucks spun out, slid and crashed into ditches during a brief blizzard-like squall. The Interstate reportedly was shut south of Peotone Road to the Manteno exit for about 45 minutes. None of the crashes resulted in life-threatening injuries. Icy conditions are being blamed for at least 18 separate crashes close to the interchange between Interstates 57 and 80 near Homewood (Figure 5). According to the ISP Chicago district trooper, the crashes near where I-57 and I-80 intersect near Homewood started about 10:15 a.m. and at least 18 crashes had been reported as of 11:15 a.m." (Evbuoma)

On February 2, 2011 a snow storm known as the "Groundhog Day Blizzard," struck northern Illinois and especially the Chicago area hard (Figure 6, Figure 7). Fortunately, the storm was well-forecasted, resulting in much advanced preparation, such as closing schools and workplaces early and putting emergency services on full alert. Even so, most roads in the Chicago area were shut down during the blizzard due to the high winds and large snowfall totals. The snowfall total at Chicago O'Hare airport was 21.2 inches, making it the third largest snowfall in Chicago history (NBC 5 Chicago). O'Hare also reported a peak wind gust of 61 miles per hour (mph) (Allsopp and Castro).

As so many roads were closed with authorities warning people to stay put, there were no comprehensive lists of roads barred to travel. It appears that, for all practical purposes, I-57 was closed at times in the Chicago area and southward in the more open areas during the blizzard. The State Climatologist blog post on February 27, 2011, documented that approximately 1,132 miles of Interstate highway in Illinois received at least 12 inches of snow.

This was in addition to 1,762 US highway and 4,099 state highway miles, along with countless miles of city streets covered with at least 12 inches of snow from this storm (Angel, Impact of the February 1-2 Storm on Highways). Using Census data to compute an approximate number of Illinois residents, 10.9 million were in areas with 6 inches or more of snow; 9.8 million in areas with 12 inches plus and 1.5 million were surrounded by at least 18 inches. (Angel, Over 10 Million in Illinois Impacted by Storm).

April 19, 2013 Flooding

Intense rainfall on April 19th caused widespread flooding. While it was not clear if Interstate 57 was ever closed during the event, the overall effect on transportation was significant. With 4-6 inches of rain common everywhere, as much as 8 inches soaked a few areas. Doyle and McCoppin of the Chicago Tribune reported Illinois state police saying "the flooding continues to divert traffic on some highways. Along Interstate 290, ramps to North Avenue in both directions and the westbound ramp to Lake Street remain closed. Interstate 94 is also closed from the split at Interstate 57 to 147th Street in both directions. Southbound traffic on Interstate 55 is being diverted off at Interstate 80 because of flooding just north of Route 6." (Doyle and McCoppin) The State Climatologist wrote in its blog about the rains over the two-day period (Angel, Heavy Rains of April 18-19, 2013).

Figure 5 . Traffic near a standstill due to accidents and slippery roads. I-80 eastbound was shut down temporarily. Source: I-80 Webcam.

January 27, 2014 – Winter Weather

Yohnka and Garmes said in an article posted to the DailyJournal.com that “while temperatures hovered around freezing Sunday, the high winds still played havoc as numerous roads were closed for periods, including Interstate 57 between Chebanse and Manteno and Illinois Route 17 east of Grant Park. Interstate 57 reopened this morning but the toll on travelers was plain to see as numerous vehicles were stranded in the median and on the sides of the road” (Yohnka and Garmes).

February 20, 2014 – Dense Fog

Warm, moist air moved in over snow-covered ground on February 20, 2014, cooling the air down to the point that dense fog formed, which closed Interstate 57 from Wilmington-Peotone Road to Manhattan-Monee Road. Illinois State Police blame the dense fog for a crash “at about 4:40 p.m. involving 19 vehicles, including seven semi-trucks and 12 passenger vehicles on I-57 northbound in Peotone near Harlem Avenue in Will County.” Officials said “ten people were taken to area hospitals with injuries that were not considered life-threatening. One of the trucks ignited in flames but did not involve hazardous materials”. The Peotone airport reported visibility at 0.2 miles at 4:55 p.m. (Rodriguez, Nickeas and Black).

Figure 6 The Eisenhower Expressway as seen at Austin Avenue is quiet on the second day of the storm (Alex Garcia, Chicago Tribune). This accurately reflects the conditions on all the interstates in the Chicago area during the actual Groundhog’s Day Blizzard.

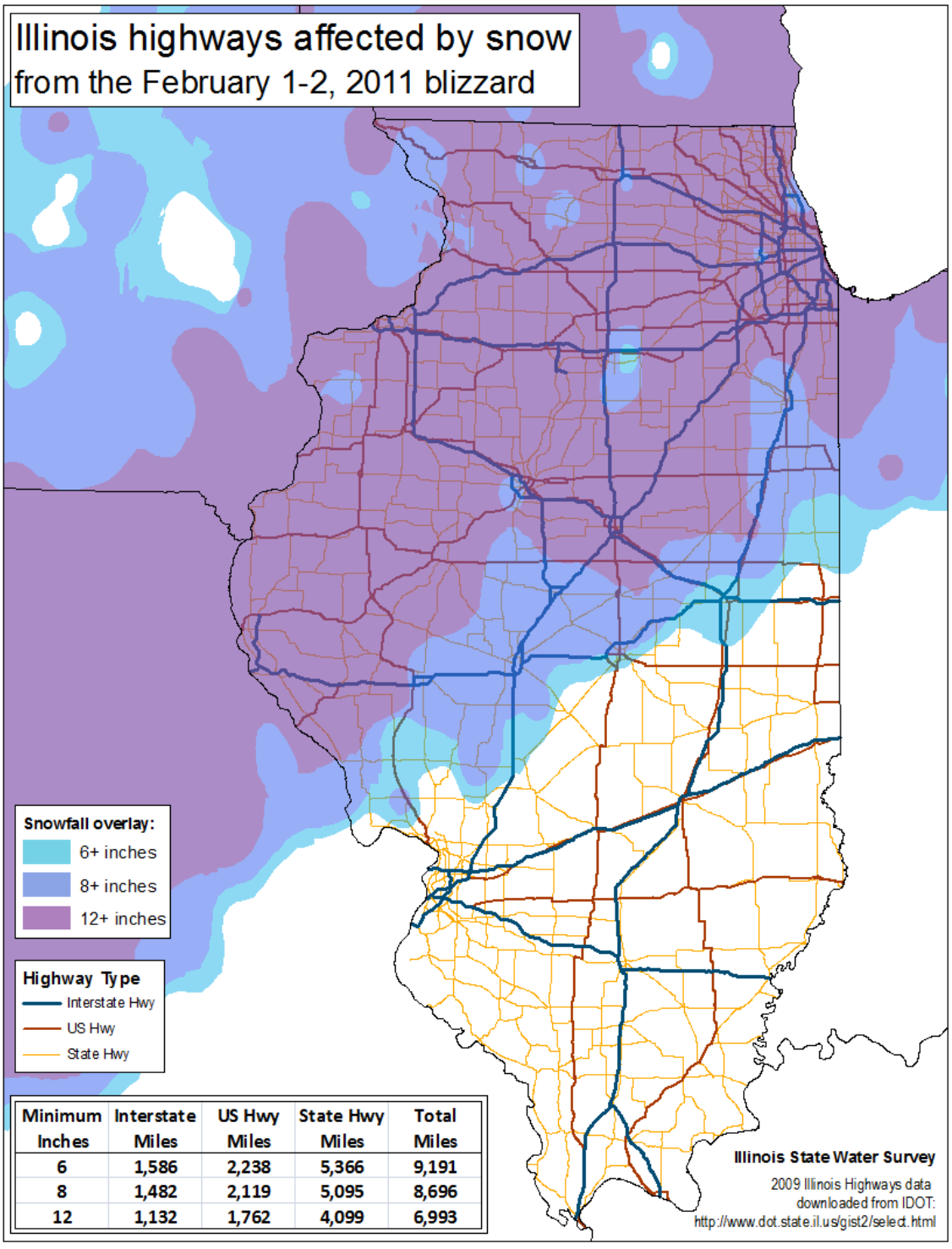

Figure 7 . Illinois highways affected by snow from the February 1-2, 2011 blizzard. This illustrates the monumental task of keeping the roads clear during heavy snowfall and high winds.

Study Area: Columbus, OH

Weather Focus: Winter closures

Transportation Focus: I-70

Dr. James DeGrand, Assistant Ohio State Climatologist

Weather can largely disrupt transportation in Ohio. Be it decreased visibility from fog or rain, or slippery conditions from a winter storm, weather can make transportation difficult and sometimes dangerous. There are multiple occurrences like this in Columbus, Ohio. A capitol located in the middle of the state, everyday Columbus has a high volume of people travelling in, out, and through the city. Therefore, when weather conditions disrupt traffic patterns, it can cause a mess. This study considers two winter weather events that were linked to closures of Interstate 70 near Columbus during 2010-2014. Events will be analyzed as a part of a study designed to determine just how large of an impact weather plays in the trucking and commerce industry.

February 16, 2013 Winter Storm

The first occurrence happened on February 16, 2013. A low-pressure system moved into the Columbus area bringing snow and wind with it, factors that combined to create near whiteout conditions. While snow accumulation was not unusually high, wind blowing the snow decreased visibility dramatically (Figure 8) (WBNS- 10TV). Along Interstate 70 towards Cleveland, storm spotters reported low visibility[4] The Port Columbus Airport (near the junction of Interstates 670 and 270) reported winds at 15 gusting to 25 mph. They observed low visibilities during the evening commute hours. Unofficial reports from Weather Underground also had reports of fog on February 16th, exacerbating the already poor circumstances. During these whiteout conditions, a tractor-trailer driver crashed into a car on Interstate 70, while switching lanes in low visibility. This initial collision caused a multi-car crash involving at least 18 vehicles. Eastbound lanes of Interstate 70 near State Route 37 were closed for three hours during an investigation and clean up. Fortunately there were no fatalities and all injuries were not life threatening(WBNS- 10TV). This event shows that one small mistake in dangerous conditions can lead to large-scale traffic delays.

November 22, 2014 Freezing Rain

[4] See Storm Events Database https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=435598

The second incident occurred on November 22, 2014. A warm front moved through Columbus, bringing precipitation to the area. The rain quickly froze as it hit the ground due to cold surface temperatures. Especially on roadways, a slushy layer of ice accumulated, as rain continued to fall. Ice on roads is particularly dangerous because it is often difficult to see on the black surface ("black ice"). Motorists do not always prepare themselves for this possible hazard (Figure 9 shows motorists cautiously travelling on icy roads). This freezing layer led to multiple accidents, some of which prompted parts of Interstates 71 and 70 to shut down. During this storm, the Columbus Fire Department employed all of its trucks responding to traffic accidents, according to Columbus's 10 TV(WBNS-10TV). There were so many crashes that the authorities could only respond to injury accident reports. Interstate 71 northbound was closed at Polaris and going into Delaware County, Interstate 71 southbound was closed as State Route 665, Interstate 70 westbound was closed at U.S. 33, and State Route 315 at Bethel Road had a car stopped facing the wrong direction (WBNS-10TV). The Columbus Dispatch kept the public updated on the closures, with some sections of interstate remaining closed for several hours (Zachariah). Multiple road crews from the state and city were actively treating the roads before and during the freezing rain, but with limited effect. Figure 10 shows a salt truck out that crashed into a parked car while treating the roads[5].

The two events discussed above focus on weather impacting Interstate 70. There are numerous other occasions where weather events have caused highway closures in the Columbus area. Two major events occurred on February 15th, one in 2014 and exactly one year later in 2015. Both involved highway closures due to winter weather in the Columbus area, impacting commerce and the trucking industry. The 2014 closures were mainly due to heavy snowfall causing multi car crashes on Interstate 71. During the 2015 closures, Interstate 70 was one of the worst interstates involved, but this event fell outside of the timeline being examined. Looking at these two events and others in the Columbus area may provide even more insight on weather impacts on freight transport.

[5] Reference also https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=548472 reports from numerous counties in Storm Events Database

Figure 8. Freezing rain causes dangerous road conditions near I-70 on 22 November 2014. Photo excerpted from video; credit: (WBNS-10TV)

Figure 9. Semi triggers multi-car crash during whiteout conditions, closing I-70 near Hebron Ohio 16 February 2013. Photo excerpted from video coverage; credit: (WBNS- 10TV)

Figure 10. A salt truck struck a parked car in Westerville, Ohio during a black ice event that closed I-71 on 22 November 2014. Photo credit: Karl Kuntz, The Columbus Dispatch)

Study Area: Denver, CO

Weather Focus: Whiteout, Floods

Transportation Focus: I-70

Dr. Nolan J. Doeskan, Colorado State Climatologist

December 2014 whiteouts

A major winter storm system that rolled though Colorado the week of December 21, 2014, dumped upwards of two feet of snow in the Rocky Mountains and brought whiteout conditions eastward to Kansas. From the 20th to the 23rd, accidents and avalanche danger caused multiple on I-70 to the west of Denver near both Vail and Loveland Pass. These closures were somewhat sporadic and generally lasted only two to three hours, but nevertheless caused terrific traffic jams (J. &. Paul). When the Interstate was open, traffic slowed to a crawl in both directions from Grand Junction all the way to Denver because of the accumulated snow and poor visibility (Figure 11). Conditions were not as bad in Denver itself, but wet and icy spots led to accidents and multiple lane closures throughout the storm (J. &. Paul). On December 22nd, snowfall and high winds contributed to whiteout conditions on I-70 east of Denver from Limon to the Kansas border. Wind gusts to 65 mph made driving difficult (Figure 12), forcing the Colorado State Patrol to close this section of I-70 for 8 hours (J. Paul). The blocked passage severely affected holiday travel plans for much of the Front Range corridor and left thousands of people stranded in Limon, as the interstate became impassable. Tuesday the 22nd was the busiest travel day at Denver International Airport for the holiday season, and I-70 closures both east and west of the airport over the previous few days only added to the chaos of airline travel that day (J. Paul). By the 24th, some ski areas in the region had accumulated close to 40 inches of new snow over the previous three to four days.

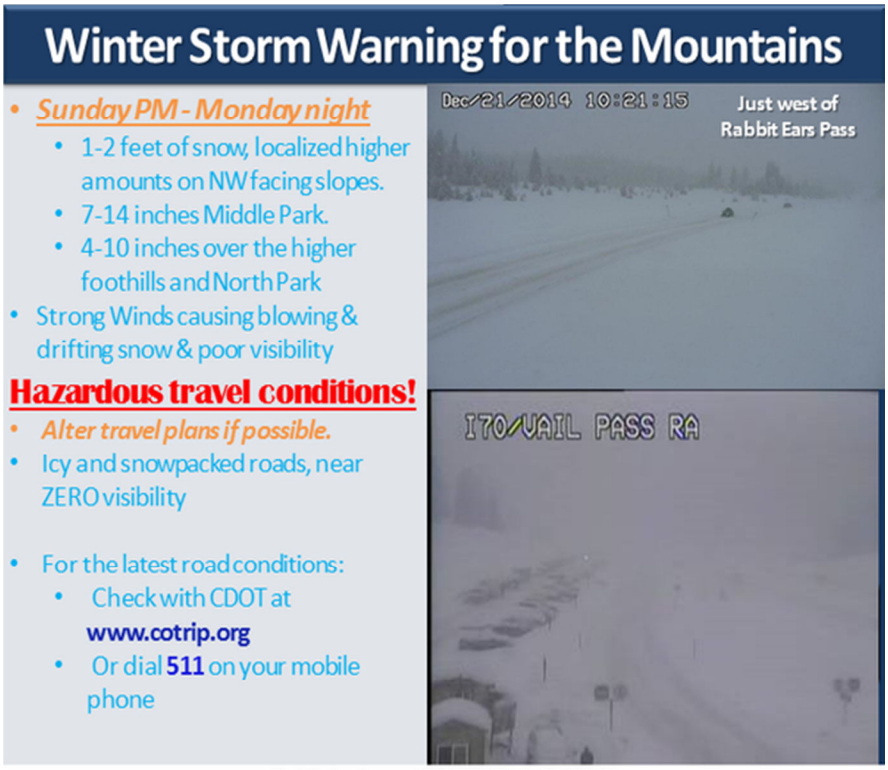

Figure 11 Source: NWS Goodland

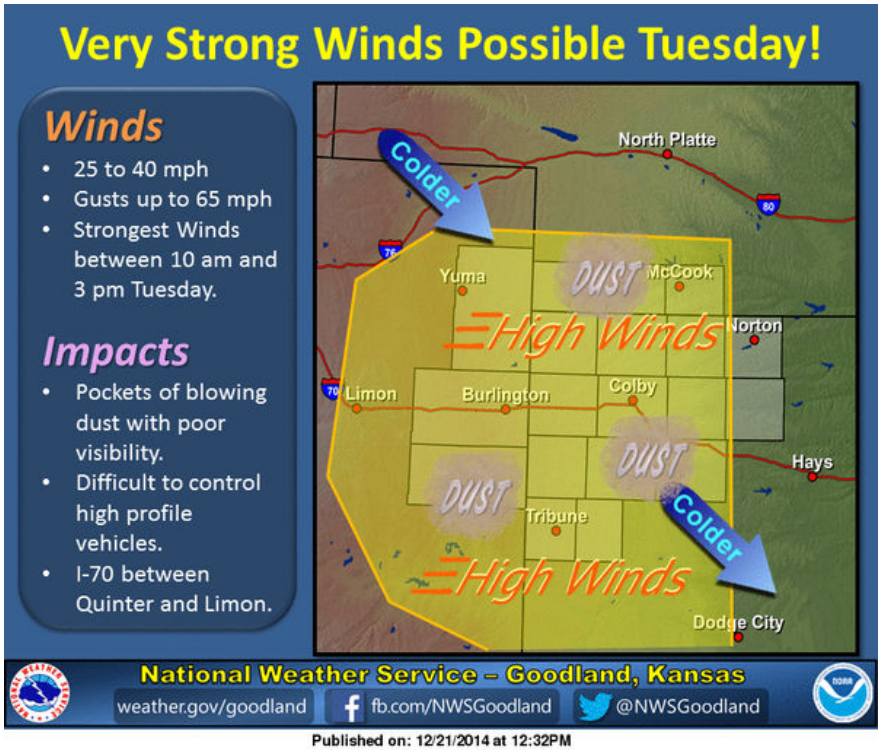

Figure 12 Source: NWS Goodland

September 2013

Historic flooding occurred during mid-September 2013 in parts of Colorado. The onslaught began on September 9th with scattered heavy thunderstorms that then transitioned to widespread multiday downpours along the Front Range of the Rocky Mountains in northern Colorado. This culminated in a declared federal state of emergency on September 14th. The storm cost the state of Colorado close to $2 billion in damage and resulted in at least 8 deaths (Federal Emergency Management Agency (FEMA)). There were multiple closures of several state and federal highways, including Interstate 25 between Denver and the Wyoming border (BreakingNews.com). Floodwaters washed out parts of several major highways were washed out including US 34 in Big Thompson Canyon west of Loveland and east of Greeley, and U.S 36 near Lyons, Colorado, NW of Boulder, closing the roads for several weeks (Mitchell).

The heaviest rains fell from late afternoon on September 11th into the morning of September 13th. Rainfall exceeded 12 inches in parts of northern Colorado's Front Range foothills and also in the eastern parts of the Denver metropolitan area. The deluge flooded Boulder Creek, through and downstream of the City of Boulder, and the St. Vrain River, from the mountains eastward through Longmont (Mitchell). The Poudre and Big Thompson Rivers located north of Denver also experienced prolonged extreme flooding (Mitchell). Canyon flooding and highway washouts began on September 12th and peaked early on the 13th. Flood waters converged downstream east of the mountains, and overtopped many highways including I-25 in at least three locations (Figure 13). I-25 did not wash out, but was closed in both directions between Denver and the Wyoming border for several hours. Flooding spread eastward, eventually shutting down many highways that cross the South Platte River near and downstream of Greeley (Mitchell).

Due to the Interstate and scores of smaller roads being under water, the University of Colorado-Boulder and Colorado State University in Fort Collins closed at the end of the week, as did offices of the municipal governments in each respective town (Nicholson). Because these floods rendered most portions of the interstate impassible, not only did closures prevent residents from traveling, they also severely hampered rescue and recovery efforts by the Colorado National Guard and other agencies. By the evening of Friday the 13th, portions of the interstate near Fort Collins opened again. However, parts of I-25 north and south (near Longmont) of the city remained closed for at least another day.

Figure 13 Source: nowcowx.com

Study Area: Lexington, KY

Weather Focus: Tropical Storm Conditions,

Transportation Focus: I-64

Although fierce storms closed other sections of highway in the years 2010-2014, and although snow, ice, and flooding closed I-64 near Lexington, KY in years just before and after the study period, weather was not a factor in any significant closure of I-64 during the years 2010-2014.

Study Area: Newark, NJ

Weather Focus: Floods and Snow

Transportation Focus: I-280, I-287

Dr. David A. Robinson New Jersey State Climatologist & Professor, Rutgers, The State University of New Jersey

December 26-27, 2012 Blizzard

A major blizzard impacted New Jersey from the morning of December 26, 2010 into the early morning hours of the 27th. A combination of heavy snowfall and strong winds crippled the eastern half of the state. Several areas received 24.0-31.0 inches, among the heaviest snowfalls on record in the state, even while western portions received only single digits of wind-driven flakes. (See sharp precipitation gradient in Figure 14) Many roadways became impassable during the height of the storm, leaving travelers stranded, some for several hours. No highway was impacted more severely than Interstate 280 in Essex County. This road has a steep grade in the Oranges area, just west of Newark, making it a prime candidate for difficulties during snow and ice events. Storm snowfall reports from Essex ranged from 21-25 inches (ONJSC), with winds gusting at Newark Airport up to 52 mph and the temperature close to 25°F.

As it progressed, the storm stranded 300 vehicles on this [Essex County] section of I-280 (Figure 15, Figure 16) Over the course of several hours, the State Department of Transportation and the State Police evacuated 200 individuals, towed at least 200 vehicles and assisted 200 other vehicles off the interstate (Simpson). One stranded motorist videoed portions of their 18-hour ordeal (Uncle Sun, 2010). Assistance arrived after sunrise on the 27th. Authorities did not clear the road of vehicles, enabling them to open it, until midday of the 28th.

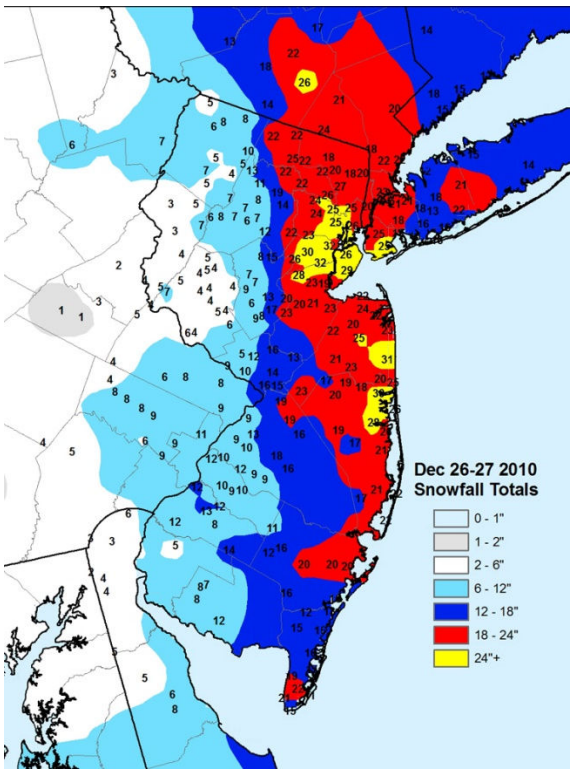

Figure 14 Snowfall totals across NJ and nearby areas for the December 26-27, 2010 blizzard. I-280 is at the northern end of the yellow zone in the northeast (ONJSC, 2010).

Figure 15 Vehicles marooned on I-280 in Essex County, NJ during the height of the December 26-27, 2010 blizzard (screen capture of video from (Sun)Uncle Sun, 2010).

Figure 16 Vehicles marooned on I-280 in Essex County, NJ on the morning of December 27, 2010 (screen capture of video from Uncle Sun (Sun).

August 28, 2011 Tropical Storm Irene

Hurricane Irene arrived in northern New Jersey with its rain sheild on the evening of August 27, 2011. At times, rainfall rates exceeded over an inch per hour, Flash flooding quickly became a dangerous hazard. By dawn on the 28th, shortly after being downgraded from hurricane status, Irene made landfall near Little Egg Harbor. By mid-morning, heavy rain exited northern New Jersey, leaving storm totals in the 5-10 inches range. The statewide average of 7.20 inches placed Irene as the 3rd greatest storm since record-keeping began in 1895. By the 28th, major flooding of streams and rivers occurred, with the Passaic River in north Jersey not cresting until the 30th. The Rockaway River, a tributary of the Passaic, achieved a record crest at Boonton, Morris County. By the 29th, the Rockaway's powerful flow had eroded its bank along a river bend immediately adjacent to the northbound lanes of Interstate 287 in Boonton. Subsequently, the right shoulder of the roadway collapsed into the river (Figure 17, Figure 18.), video from scene(Boonton).

The collapse closed the northbound lanes, which normally join other major roads across the state, specifically portions of state routes 1, 18, 23, 29, 46, 202, and 206, respectively (Sherman). Most roads reopened within a day or two of the storm. Repairing the damage on I-287 required an around the clock effort. One northbound lane accommodated traffic on the 30th and all three opened at 5 a.m. on August 31st.

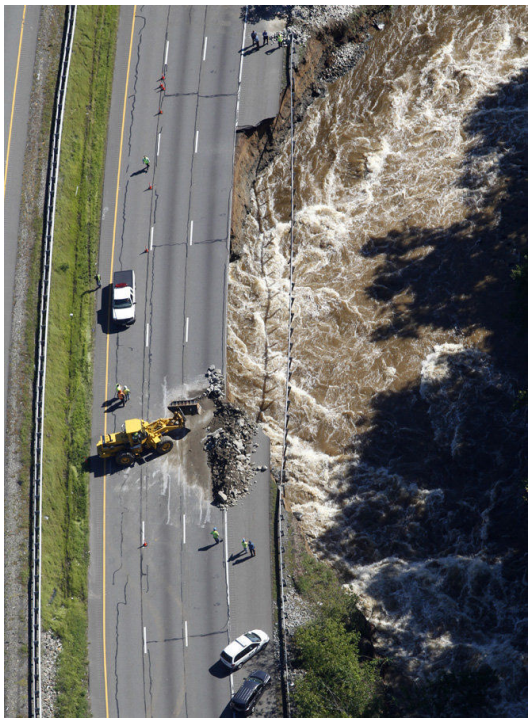

Figure 17 Aerial view of the collapse of I-287 in Boonton, NJ, August 29, 2011. A. Mills, Star Ledger.

Figure 18 Collapsed shoulder of I-287 in Boonton, NJ on August 29, 2011. Steve Hockstein for the Star Ledger.

October 29, 2012 Post Tropical Storm Sandy

Water levels along the mid-Atlantic coast began rising on the morning of the October 29, 2012, as Hurricane Sandy was still well to the south. Some coastal roadways were overrun at high tide. But this flooding paled in comparison to the storm surge atop the high tide that evening as Sandy, by then having transitioned to a post tropical cyclone, made landfall just north of Atlantic City. A record surge inundated beaches, bays, harbors, and lower reaches of tidal rivers and streams from central coastal New Jersey into southeastern New York and Connecticut.

Because the surge happened at high tide, Sandy Hook, at the northern tip of the coast and adjacent to Raritan Bay, experienced an estimated rise in sea level of 14.4 feet above mean lower low water (the gauge was destroyed at about 13 feet). The water was approximately 9 feet above what the normal high tide should be on this date, and 4.3 feet above the previous century-long record at this location. A long fetch of wind toward the coast, a full moon and landfall coming at high tide contributed to the record surge.

The storm surge inundated roads along the coast, destroying them in some locations, such as state route 35 in Mantoloking, where the ocean meets Barnegat Bay (Figure 19). The storm surge pushed water into Raritan Bay and up the Raritan River, flooding state route 18 in New Brunswick. It moved through New York Harbor and up the lower Hudson River, flooding much of the city of Hoboken (Figure 20). The powerful water inundated the New Jersey Meadowlands, putting many roads and the main New Jersey Transit train yard underwater. Approximately 190 state highways experienced full or partial closures at some point during the storm (Drewniak).

Tidal streams adjacent to Raritan Bay and the Arthur Kill surged out of their banks, covering sections of the New Jersey Turnpike (I-95), leaving in their wake 7-foot tall piles of debris between exits 10 and 14 and two dozen freight train containers strewn along the Turnpike's northbound side near exit 12. A ramp washed out at Exit 12 in Carteret. The roadway was closed above Exit 14 in Newark because of chlorine fumes in Kearny. The southernmost 129 miles of the Garden State Parkway closed south of Woodbridge prior to the arrival of Sandy and throughout the storm.

Most motorways opened within days of the storm, while some took several weeks to repair. The New Jersey Turnpike Authority estimated labor, fuel, and lost tolls cost at least $15.4 million. This exceeds that of any previous weather event for the Turnpike and Parkway, both of which are under the purview of the Authority. The previous high was close to $14 million for the December 2010 blizzard (Frassinelli).

Figure 19 Aerial photo of Mantoloking, NJ breach following Sandy. NJ State Route 35 is destroyed (left to right in middle of photo) where the ocean meets the bay at the Herbert St. (Ocean County Route 28) bridge (G. Thompson, US Fish and Wildlife Service)

Figure 20 Flooded roadway in Hoboken, NJ following Sandy (M. Bocchieri/Getty Images)

Study Area: Oklahoma City, OK

Weather Focus: Thunderstorms and Tornados

Transportation Focus: I-35 Approach from Texas to OKC

Lukas Buehler, CASE staff meteorologist

Interstate 35 is the main north-south connection between Oklahoma and Texas. Over 200,000 commuters, freight trucks, and business travelers drive, on the I-35 (Advisory Committee Plan, I-35 Corridor).

October 18, 2012 Dust Storm

A massive dust storm swirling reddish-brown clouds over northern Oklahoma triggered a multi-vehicle accident along the Interstate 35, forcing police to shut down part of the heavily traveled roadway amid near blackout conditions (Huffington Post). Visibility was less than 10 feet (NBC News). The highway patrol said the dust storm caused a multi-car accident with nearly three dozen vehicles and tractor-trailers involved (Figure 21 (AP) (Huffington Post). Authorities closed I-35 in both directions about 1 p.m., reopening it just before 7 p.m. that same evening. (NewsOK).

Figure 21. Massive dust over northern Oklahoma triggered a multi-vehicle accident (AP).

The area had suffered through an extended drought during summer. Many farmers had recently loosened the soil to prepare for the winter wheat season. "You have the perfect combination of extended drought ... and we have the extremely strong winds," reported Gary McManus, the Oklahoma Associate State Climatologist (Huffington Post). This dust storm does not appear in the Storm Events Database for Oklahoma.

May 20, 2013 Tornado

The 2013 Moore Tornado was an EF5[6] tornado that affected the region around Moore, Oklahoma on the afternoon of May 20, 2013 (NOAA). The wind peak was estimated at 210 mph. The tornado killed twenty-five people (news9.com) and injured 377 while damaging or destroying over 1,200 homes (AFP). The twister was part of a larger weather system that had produced several other tornadoes across the Great Plains over the previous two days (including five that struck Central Oklahoma on May 19th) (Wikipedia).

The Storm Prediction Center issued a moderate risk of severe thunderstorms during the early morning hours of May 20th from southeastern Missouri to north-central Texas, including the possibility of isolated, strong tornadoes across central and eastern Oklahoma, and a threat of large hail and damaging straight-line wind gusts (Storm Prediction Center, Norman, OK).

At 2:12 p.m., the National Weather Service issued a severe thunderstorm warning and at 2:40 p.m., when they spotted a vortex forming near Moore, they issued a tornado warning. Sixteen minutes later the mile-wide tornado touched down near Newcastle and started tearing through homes, schools, and businesses. That 16 minute warning gave residents enough time to run for cover, to huddle in hallways or, if they had them, storm shelters (Dzieza). Residents already were on alert after weekend storms and days of advisories (Associated Press - AP). The community of approximately 60,000 people had been hit by four tornados since 1998.[7]

[6] Enhanced Fujita scale: EF-5: Total destruction of buildings, EF-4: Extreme damage, EF-3: Severe damage, EF-2: Considerable damage. EF-1: Moderate damage.

[7] . Storm Events Database: https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=451572

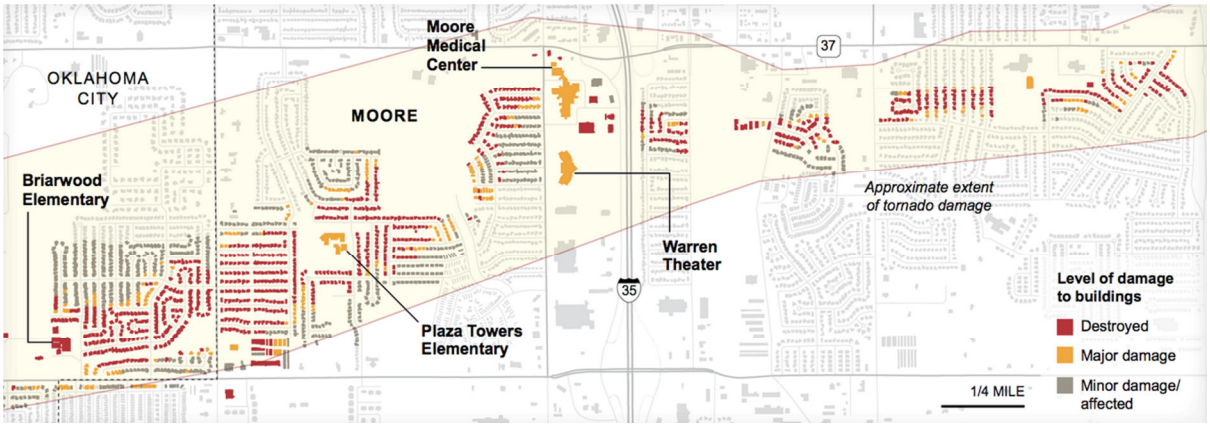

Figure 22. Tornado track in More, OK and level of damage to buildings (The New York Times)

The tornado crossed I-35 and continued in an easterly direction as shown in Figure 23 (The New York Times). Damaged vehicles, power poles and debris littered Interstate 35 (Figure 24), causing the Oklahoma Highway Patrol to close the highway for several hours in both directions between I-240 and Indian Hills. I-35 reopened later that night; but traffic was extremely slow (news9.com). The Highway Patrol asked motorists to steer clear of the road near Moore to free up lanes for disaster response services rushing into the area (CNN).

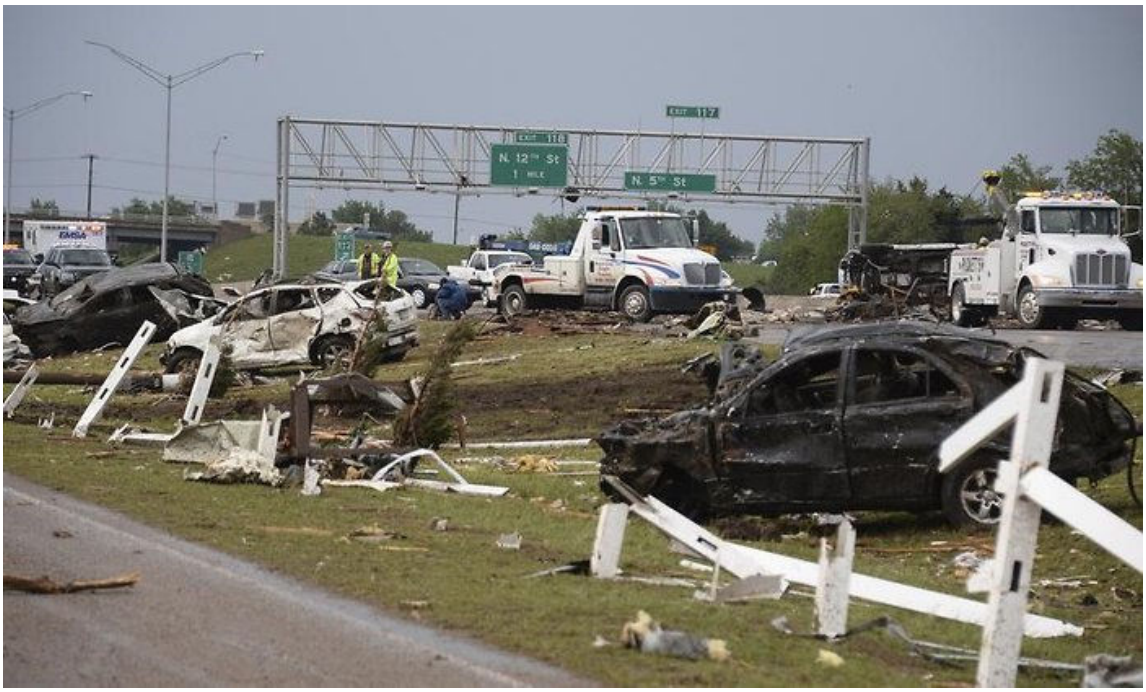

Figure 23. Destroyed cars are seen along Interstate 35 after the tornado struck Moore, Oklahoma

July 17, 2013 Flash Flood

An approaching upper level system and front, combined with seasonably high moisture content, led to a heavy rain event in the North Texas area. Rainfall on the early morning of July 17th caused significant flash flooding along Interstate 35 in the Sanger to Valley View areas (Figure 24)(CBSDFW). Over 11 inches of rain fell (CNN) along this corridor (NOAA). NewsOK reported that heavy rainfalls were expected, lasting for nearly a week (NewsOK).

Figure 24. Cars were flooded during the flash flood at a gas station in Denton County (The Dallas Morning News)

For much of the morning Interstate 35 was closed due to the flooding, causing the Denton County Sheriff's Department to request extra support (The Dallas Morning News). While I-35 was closed, numerous cars were stranded (Figure 24. Cars were flooded during the flash flood at a gas station in Denton County(The Dallas Morning News). Authorities made several high water rescues and water entered at least one business in the Valley View area. The flash floods were deep enough to strand an 18 wheeler (Figure 26. A massive 18 wheeler is stuck too. This is a river now, not a highway. Extreme danger @NBCDFW" tweeted Jeff Smith from NBC5(Smith).).

Water also reached or entered homes in the Krum area of Denton County (NOAA). Cooke County emergency coordinator Ray Fletcher reported that approximately 30 drivers called 911

asking for help to escape vehicles flooded and stranded by flash floods[8]. First responders and firefighters had to physically rescue around 10 people from their autos (NBCDFW).

Figure 25. I-35 Northbound was down with water covering one of the lanes and the southbound lanes were completely covered) (NBCDFW)

According to News12, the closed sections of Interstate 35 opened at 8 a.m. (News12). Yet, the Texas Department of Transportation said that although the highway was opened; “travel was unreliable because of floodwaters - seek alternate routes” (Star-Telegram).

[8] Storm Event Database: https://www.ncdc.noaa.gov/stormevents/eventdetails.jsp?id=534977

Figure 26. A massive 18 wheeler is stuck too. This is a river now, not a highway. Extreme danger @NBCDFW" tweeted Jeff Smith from NBC5 (Smith).

Study Area: Phoenix, AZ

Weather Focus: Summer Monsoon

Transportation Focus: I-10 and I-17

Dr. Nancy J. Selover, Arizona State Climatologist

Phoenix, Arizona regularly experiences extreme weather events, particularly during the summer monsoon season. Dry washes and surface streets frequently flood as part of the drainage system design in the older parts of the metropolitan area. The major highways and Interstates are largely above grade, though pumping systems are in place for areas where the highway drops below grade through the city. In particular, Interstates 10 and 17 and US Highway 60 all have significant stretches below grade. Most of the infrastructure, including the pumping systems, is designed for the 100-year precipitation and flood event.

In 2014, an FHWA Climate Change Resilience Pilot project looked at climate risks to highway infrastructure in three areas of Arizona, including the Phoenix stretches of Interstates 10 and 17 (Cambridge Systematics, Inc.). Their report indicated that the future risk from flooding of highways in the Phoenix area is uncertain, as some models are projecting drier conditions. However, climate models only capture winter precipitation, due to their coarse spatial resolution.

During the monsoon season, convective precipitation dominates and thunderstorms are too small for global climate models to recognize. To the extent that warmer temperatures arise from warmer ocean waters off the Baja California and Mexican coasts, there is likely to be an increase in available moisture for thunderstorm activity in the southwest. This happened during the summer of 2014, when the Phoenix metropolitan area experienced three extreme rainfall events that exceeded the 850-year return interval, due to increased moisture from eastern Pacific hurricanes moving up the western coast of Mexico. The strongest of these was Norbert, which was downgraded to a Tropical Storm on September 5th.

September 8, 2014, Extreme Precipitation Closes I-10 through Phoenix

The moisture from Norbert strengthened the monsoon moisture that moves into Arizona from northern Mexico. On September 8th, an upper level low pressure system triggered two strong thunderstorm systems, known as mesoscale convective systems, that collided over central Arizona, dumping over 5 inches of rain on the Phoenix metropolitan area within a six-hour period. Phoenix Sky Harbor Airport received 3.30 inches, a new record for that date, the greatest amount for a calendar day, and the second highest 24-hour rainfall on record, though the entire amount fell within an eight-hour period. A section of Interstate 10 at 43rd Avenue,

just west of downtown Phoenix, flooded when the pumping system could not keep up with rising water during morning rush hour, stranding and floating dozens of cars. The flooded section resembled a lake with water above the hoods of abandoned vehicles, and the Interstate was shut down (Figure 27).. Governor Jan Brewer declared a statewide emergency, as dozens of roadways were flooded and emergency crews performed 14 water rescues during the morning hours (Davenport). The flooded parts of Interstate 10 were re-opened by the evening rush hour. Depressed sections of Interstate 17 in north Phoenix and US Highway 60 in Mesa were also closed when their pumps failed.

Figure 27. Major flooding along Interstate 10 at 43rd Avenue (ADOT Traffic Operations Center).

Interstate 17 at Indian School Rd. was blocked off at 5 a.m. It re-opened by noon. US 60 was closed during the morning commute in Mesa at Val Vista, in Tempe at Priest Dr. and in Glendale at 51st Street and 59th avenues, but re-opened by mid-afternoon. The storm system not only affected Phoenix, but also the lower Colorado River valley all the way north to Las Vegas. The cost of cleanup and repair to roadways and other transportation infrastructure in Arizona was over $12.5 million.

While the storm exceeded single day rainfall records in many parts of the valley, local flooding was not unexpected. The National Weather Service had begun issuing severe weather statements indicating the potential for significant rainfall and flooding in the Phoenix

area three days before the storm, as they monitored the progress of Hurricane/Tropical Storm Norbert. Heavy rain was originally expected to reach central Arizona on Sunday afternoon, but the system slowed as it crossed southern California. The Arizona Department of Transportation was on alert with their Emergency Operations Center in anticipation of road flooding. The Maricopa County Flood Control District (FCDMC) had 20 gauges that reported six-hour rain totals exceeding the 1000-year return interval (Figure 28). For the six-hour duration, the 100-year rain event is 2.42 inches, and the 1000-year event is 3.36 inches. Of the 354 FCDMC ALERT gauges, over 79 gauges reported 3 inches or more, 17 reported 4 inches plus, and two reported 5 inches or more. Single gauge reports of a 250-year return interval for a one-hour rainfall occur from time to time, but such widespread heavy rain is unprecedented in the metropolitan area (Figure 29) (Flood Control District, Maricopa County AZ). Throughout the early morning of the following day, the wind pattern contributed to re-development of thunderstorms over the same area.

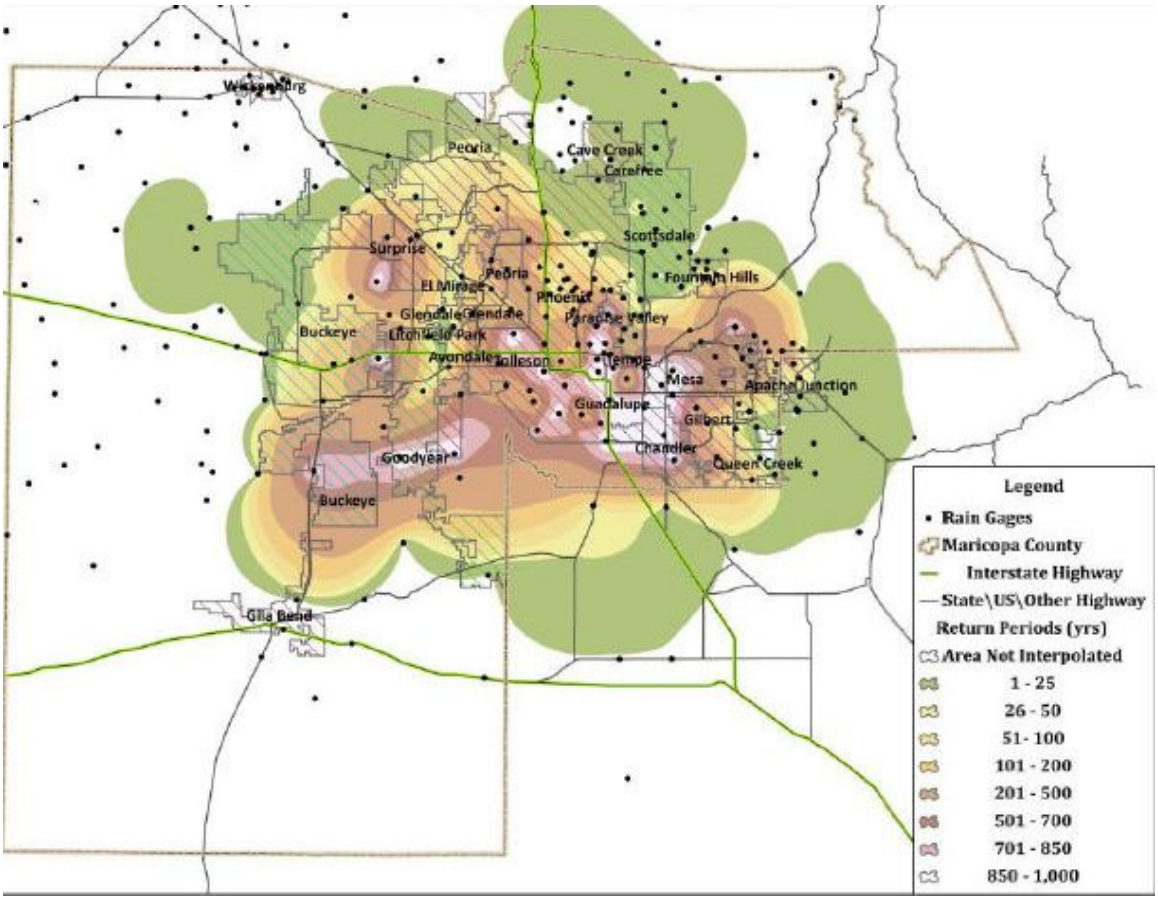

Figure 28. 6-Hour Rainfall Return Periods, Storm of September 8, 2014 (Flood Control District, Maricopa County AZ).

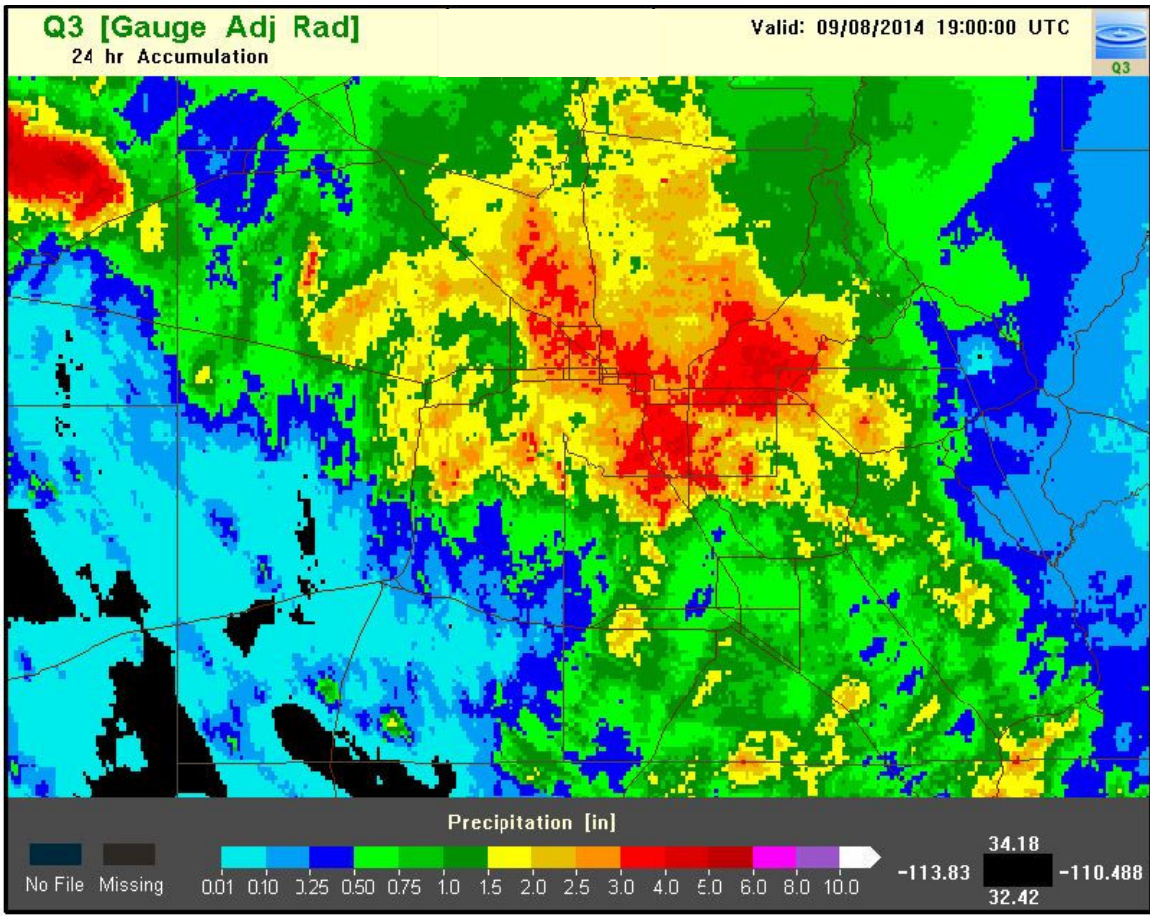

Figure 29. 24-hour accumulated precipitation (Flood Control District, Maricopa County AZ).

Study Area: Pittsburgh, PA

Weather Focus: Winter storms, lake effect snow

Transportation Focus: I-79 between Pittsburgh and Erie

Dr. Kyle Imhoff, Pennsylvania State Climatologist

Interstate 79 is the primary north-south route across western Pennsylvania. It provides the most direct line between Pittsburgh and Erie. I-79 is located to the west of the Appalachian Mountains with little elevation change along the interstate. I-79 too far west or protected by the mountains from hazardous weather associated directly with coastal winter storms, much of the time. The highway's location is in an area susceptible to frequent lake-effect snow throughout the cold season. These events occur when a persistent northwesterly wind carries cold air over the relatively warm Great Lakes, generating enough instability for snow to form downwind of the lakes. This often happens following a frontal passage or from a departing coastal storm prior to ice formation over the lakes. Lake-effect snow events result in hazardous travel conditions because they are highly localized, produce heavy snowfall rates, and are difficult to accurately forecast. These heavy snows form in bands as seen in Figure 30. They are typically associated with strong winds that result in reduced visibilities from blowing and drifting snow along roadways.

February 25, 2012 Pile-Ups on I-79 and I-80

On February 24, 2012, a center of low pressure progressed northeast through the Ohio Valley. Later in the afternoon, a secondary low began to form just to the west of the Delmarva area.

The initial low tracking over the Great Lakes began to weaken, while the secondary low strengthened as it traversed northeastward over the coast, a typical evolution of east coast storms during the cold season (National Centers for Environmental Prediction, Weather Prediction Center). By sunrise on the 25th, the system centered itself over northeastern Maine and a persistent and strong northwest flow was present over the Great Lakes and Mid-Atlantic regions. As a result of the storm-induced wind pattern, lake-effect snow bands began to form downwind of Lake Erie, across much of western Pennsylvania as seen in Figure 30.

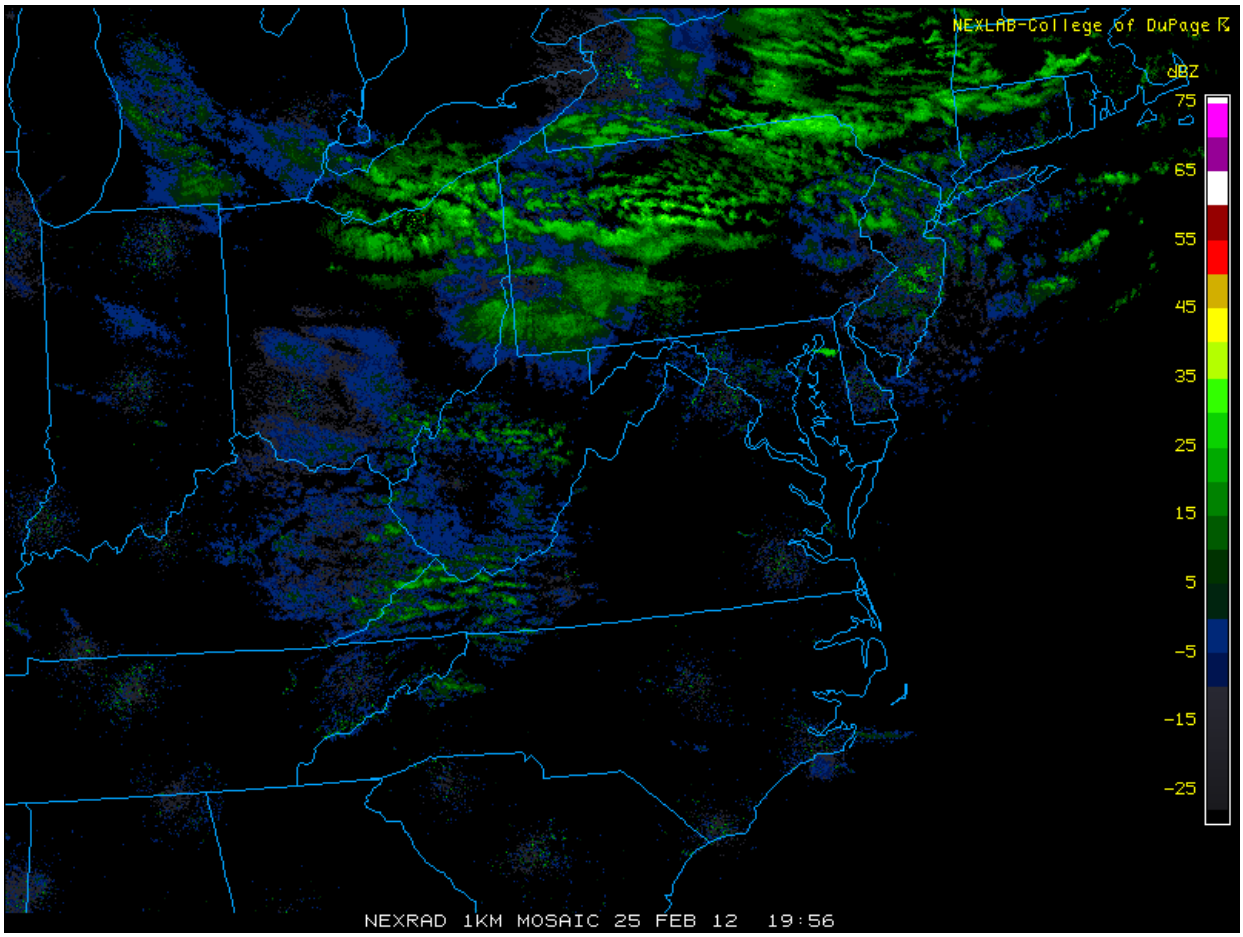

Figure 30. Radar imagery taken from February 25, 2012 shows the banded nature of precipitation that forms downwind of the Great Lakes. Image courtesy of NEXLAB/College of DuPage (National Center for Atmospheric Research).

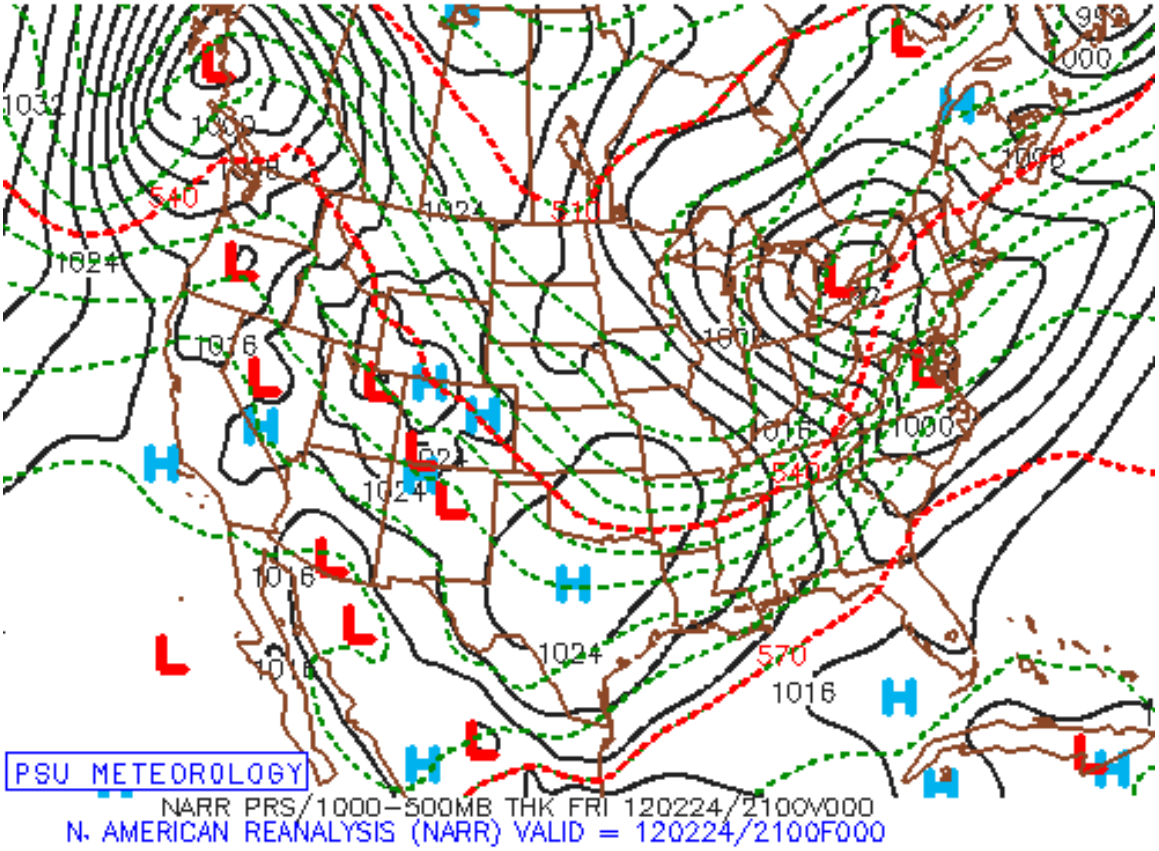

Figure 31. Surface analysis valid 21z on 24 February from the North American Reanalysis (NARR) dataset. Solid black contours correspond to Mean Sea Level Pressure values and dashed green/red lines indicate 1000-500mb thickness values. Secondary low formation can be seen (indicated by red 'L' over eastern Virginia) near the Delmarva at this time. (Penn State Department of Meteorology)

These reduced visibilities resulted in a massive pile-up along Interstate 79 on the morning of the 25th. The accident occurred in Mercer County approx. 50 miles south of Erie (Figue 32). The accident was reported at 11 a.m. on the 25th, closing the highway shortly thereafter. Several injuries, but no fatalities, were reported. Authorities estimated of the crash involved 30 to 40 vehicles. They believed that reduced visibilities, high winds, and blowing snow caused the crash. As can be seen (Figure 30, Figure 31), the accident location was co-located with some of the intense, persistent bands of snow appearing on radar that day. The interstate remained closed for approximately 5 hours, re-opening around 4 p.m. that afternoon (AccuWeather).

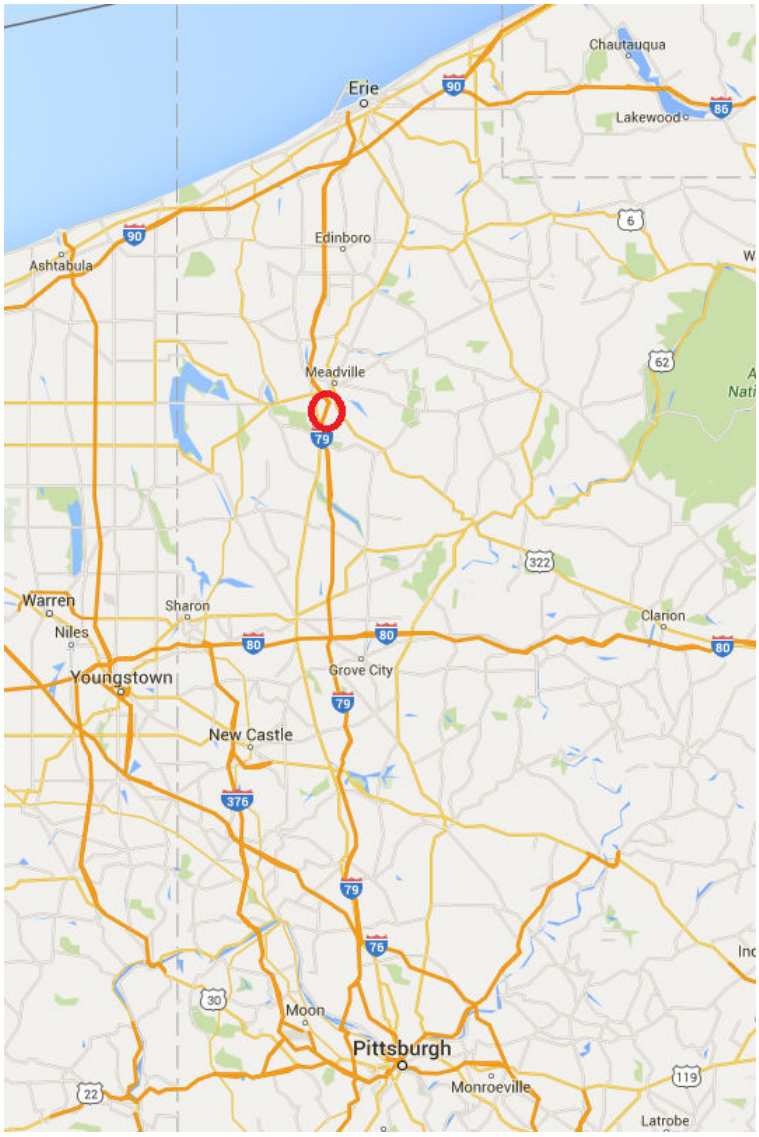

Figure 1 Map of I-79 between Pittsburgh and Erie. The red circle indicates the approximate location of the accident. Image courtesy of Google Maps.

Additionally, a portion of Interstate 80 (one of the primary east-west routes across the state and heavily used by trucks) was closed about 20 miles east of where I-79 and I-80 intersect and 55 miles north of Pittsburgh (see Figure 33 below). Involving 50-70 vehicles, including numerous tractor-trailers, this crash resulted in three deaths and many injuries (Mendak). At the time of the incident, drivers reported dangerously low visibilities and blowing snow.

Eastbound lanes of the interstate were closed for the remainder of the evening and westbound lanes until the following day, creating major headaches for travelers throughout the area (CBS Pittsburgh).

Western Pennsylvania roadways (particularly I-79 given its north-south orientation across the region) are highly susceptible to lake-effect snows and abrupt whiteout conditions during the cold season. These events can lead to multi-vehicle pile-ups, injuries, and fatalities as highlighted in this case-study.

Figure 33. Tractor-trailers that were involved in the pile-up along I-80 on the afternoon of Feb. 25th The accident resulted in at least portions of the interstate to be closed for nearly 24 hours. Image courtesy of Kara Spagnola.

Study Area: Raleigh, NC

Weather Focus: Tropical Storm Conditions, Transportation

Transportation Focus: I-40 between Raleigh and Greensboro

Lukas Buehler, CASE staff meteorologist

Interstate 40 is an east-west route that connects major cities in North Carolina. This study area focuses on the section between Greensboro and Raleigh including the "Research Triangle" around Durham and Chapel Hill. The population of this metropolitan area is approximately 2 million (U.S. Census Bureau).

February 12, 2014 Winter storm

In February 2014, a large snow storm covered the Southeastern US with around 6-12 inches of snow, causing traffic chaos in the study area. The Governor of North Carolina signed a state-of-emergency declaration (Jackson). Major highways including the Interstates 40 and 540, as well as the Durham Freeway closed due to the weather (WARL).

Traffic jams started soon after the snow began falling at midday, with some drivers forced to abandon vehicles along highways and trouble spots by late afternoon (Siceloff and Gallagher) (Figure 34).

Figure 34. Abandoned vehicles sit along a roadside in Chapel Hill (Broome).

Columns of cars were halted on snow-whitened streets and highways, trapping many on the road during the worst storm of the storm (Figure 34). By 5 p.m. most public transport systems in the Triangle had taken their buses off the roads. Southpoint Mall in Raleigh, which

closed at 4 p.m., opened its doors again later that day, to shelter drivers who had been stranded on I-40.

Figure 35. Very slow moving traffic on I-40 near Raleigh (WARL)

Chapel Hill police warned via Twitter, “Road conditions are terrible throughout town” (Chapel Hill Police). In Raleigh, traffic was blocked at South Saunders Street on the way out of downtown, while major highways had slowed to a crawl for miles. Police units and emergency responders scrambled throughout the afternoon to reach stranded drivers and dozens of vehicle crashes, while nightfall and the expected change of snow to ice threatened to make the situation worse (Siceloff und Gallagher). Street conditions improved the next day; but more than 40,000 customers were still without power two days after the snowfall, utility officials reported (Duke Energy).

Figure 36 Vehicles travel west on Interstate 40 following a North Carolina Department of Transportation's snowplow in Orange County, North Carolina (Thomas).

According to NOAA, the heavy snowfall arose from a low pressure system that moved from the Gulf of Mexico into the Southeast. Once the storm reached a cold air mass, it caused widespread wintry precipitation as it moved from the southeast along the East Coast into the northeast. Many southeastern cities received the most snow and ice in over a decade (NCEI).

April 16, 2011 Tornado

During the afternoon of April 16, 2011, a moderately large and intense tornado developed in Sanford, North Carolina. After destroying three warehouses and 30 homes, the storm tracked northeast in the direction of downtown Raleigh. Live WRAL camera footage showed a rain-wrapped tornado approach the city from the southwest (Figure 37). The funnel crossed Intestate-40 at South Saunders Street, accompanied by power flashes and flying debris (National Weather Service), badly damaging many homes and businesses.

Figure 37. The rain-wrapped tornado near downtown Raleigh, NC (WARL)

Several NCDOT crews were called to remove storm debris from state roads. Official issued caution warnings to drivers on Interstate-40(NCDOT). Downed power lines (as shown in Figure 38), caused several major roads to close for more than two days(LeClaire).

Figure 38. Debris fills the street after the tornado in Raleigh (Vos Iz Neias)

The Sanford-Raleigh Tornado, an EF-3[9], caused $172,075,000 in damage alone. A total of 24 individuals lost their lives in North Carolina. Thirty confirmed tornadoes occurred in the state on April, 16, 2011, the greatest one-day total on record. Nine tornadoes occurred in the Raleigh CWA, among which were two EF-3, four EF-2, and three EF-1 tornadoes. Four supercell thunderstorms produced the nine tornados in the Raleigh county warning area

[9] EF-3: Severe damage, EF-2: Considerable damage. EF-1: Moderate damage.

(CWA), with each supercell generating at least two tornadoes. The Sanford-Raleigh and the Fayetteville-Smithfield tornados were on the ground for more than 55 miles. The nine tornadoes in central North Carolina remained on the ground for a total of 196.4 miles, touching down between 2-5 p.m. The Weather Forecast Office in Raleigh issued 31 Tornado Warnings during the event with a probability of detection of 97%, false alarm rate of 48%, and an event average lead time of 19.5 minutes (National Weather Service).

Study Area: Rapid City, SD

Weather Focus: Winds, whiteout

Transportation Focus: I-90

Collin McKellar and Dennis Todey, South Dakota State Climate Office

Winter Storms in the northern plains provide different combinations of reasons for road closures. Heavy snow, often coupled with strong winds, is common during the winter season. The strong winds, even unaccompanied by heavy, snow can frequently lead to road closure. A few inches of snow with 40-50 mph winds or more can lead to road closures, due to limited visibility. Frequently fierce winds on the plains make western South Dakota a prime candidate for these events. Often authorities suspend winter road maintenance, as trucks cannot keep up with drifting snow.

October 3-5, 2013 Blizzard

The first example of a road closure due to weather comes from a strong storm system that produced not only blizzard conditions, but also significant amounts of snow. From the evening of October 3rd through the afternoon of October 5th, a record setting heavy, wet snowfall occurred in western South Dakota. Snowfall reports in the Rapid City area were generally between one and three feet, with locally higher totals of five feet in the northern Black Hills. This early season storm also generated a maximum wind gust of 71 mph at the Automated Surface Observing System (ASOS) station at Ellsworth Air Force Base in western South Dakota, resulting in zero visibilities, along with significant blowing and drifting snow (Figure 39Figure 40and Figure 41). Before losing power, the ASOS station in Rapid City recorded sustained winds of 44 mph and gust upwards of 55 mph.

By the morning of October 4th, Interstate 90 from Murdo, South Dakota to the Wyoming border closed due numerous accidents, less than half-mile visibilities, and vehicles hydroplaning in wet slushy snow. According to a report by National Public Radio, local officials on the morning of October 4th asked volunteers who owned snowmobiles to help rescue roughly 80 motorists stranded overnight in their cars. The Red Cross set up aid stations in western South Dakota to help those in difficulties, along with local communities cut off from local supplies by closed highways. Interstate 90 remained shut down until midday on Saturday, October 5th. Airlines cancelled numerous flights in and out of Rapid City. Conditions stranded attendees at meeting of Western States Water Council Missouri River Association of States and Tribes for two days.

Figure 39 Rapid City, SD. Photo credit: Jeanne Apelseth

Figure 40 October 2013 blizzard outside Ellsworth Air Force Base. Photo Credit: Rob Griffith.

March 31, 2014

Storm systems that produced blizzard conditions (but significantly less snowfall than the October 2013 event) illustrate the next two examples of I-90 closing in the Rapid City area. The first incident occurred on March 31, 2014 when a system produced strong winds and blizzard conditions across western South Dakota. Compared to the October 2013 blizzard, snowfall totals in the Rapid City area were upwards of 3 inches. However, the combination of wind gusts up to 50 mph and snow created quickly deteriorating conditions in the Rapid City area. Low visibility and numerous accidents necessitated closing I-90, just east of Rapid City, briefly at midday on the 31st.

December 30-31, 2010

The second example is a winter storm between December 30th and the 31st. This tempest first produced upwards of 6 inches of snow in the Rapid City area with locally higher amounts of as much as a foot in the northern Black Hills. The main part of the storm system then pushed through on the 31st of December with 30 to 40 mph sustained winds and gusts above 50 mph as recorded at the Rapid City ASOS station. The combination of strong winds and snow on the ground resulted on blizzard conditions on the 31st, shutting down I-90 for nearly 24 hours from Rapid City eastward to Sioux Falls (almost completely across South Dakota). Zero visibilities, drifting snow and dangerous wind chill temperatures of -25 to -35F caused the road closure.

Figure 41 Downtown Rapid City's 6th street between Main and Saint Joe on Saturday, October 5th. . Image retrieved December, 4th from http://listen.sdpb.org/post/black-hills-still-digging-out-after-blizzard#stream/0

Study Area: Reno, NV

Weather Focus: Winter Weather closures

Transportation Focus: I-80 over Donner Pass to California

Dr. Stephanie McAfee, Nevada Assistant State Climatologist

Interstate 80, the Alan S. Hart Freeway, is a primary east-west route across the Sierra Nevada Mountains in northern California (Figure 42). I-80 is the most direct route between Reno, NV and Sacramento and San Francisco. It crosses the Donner Summit at just under 7,250 feet in elevation. The Summit averages over 400 inches of snowfall a year(Central Sierra Snow Laboratory). Even the name, Sierra Nevada, Spanish for Snowy Mountains, refers to the characteristic winter snows.

Traffic over the Summit is subject to weather-related restrictions, such as snow tire or chain requirements, traffic holds, and closures between October and April. The National Geographic channel created a documentary titled “Hell on the Highway”(National Geographic Channel), about tow truck drivers and Caltrans District 3 maintenance personnel who work Donner Summit, known collectively as the “Sierra Snow Fighters”(California Department of Transportation). Since the winter of 2009-2010, authorities closed I-80’s east and west-bound lanes 27 and 28 times, respectively. During those years, the area experienced about 60 hours of white-out conditions. The vast majority of the closures and zero-visibility situations occurred during the winters of 2009-2010 and 2010-2011(CalTrans District 3), when snowfall amounts were above normal(Central Sierra Snow Laboratory). Significant drought in the last four years meant particularly low snowfall amounts, much to the dismay of skiers; but one benefit has been a reduction in the number of road closures from about 10 in previous winters to just a few each season.

(b) April 2014

June 2014

(a) Classic sierra landscape

Figure 42 Aerial imagery - I-80 over Donner Summit. Apr 2015 (a). Area is classic Sierra landscape of open areas of granite with sporadic coniferous forest. Scenes from April 2014 (b) and June 2011 show that snow can linger into the spring and even early summer. Imagery courtesy Google Earth.

Figure 2. (a) Map of Donner Summit with Donner Pass Road highlighted in orange. Arrow indicates where rockslide occurred. Image courtesy Google Earth. (b). The rockslide covered the road with granite boulders, blocking traffic and damaging guard rail. Photo courtesy George Lamson.

February 6. 2015 Rock Slide on old Highway 40

Although I-80 carries much of the traffic over Donner Pass, old Highway 40, also known as Donner Pass Road, is an important local route giving access to residential and recreational areas (Figure 43a above). On February 6, 2015, a rockslide near Donner Pass caused officials to close about 3 miles of the highway (Figure 44b above)(Staab). U.S. 50 near Lake Tahoe experienced a similar incident at about the same time(KTVN Channel 2 News). (Although this event is outside the 2011-2014 study period, it was included for its unique aspects).

These slides occurred during the early days of an atmospheric river event that affected the area (Figure 44). Atmospheric rivers develop when circulation patterns align to direct a narrow band of wet tropical air toward the West Coast. These storms typically bring heavy precipitation; but their tropical source means that most of the precipitation falls as rain, rather than snow. Two weather stations near Donner Pass received over 2 inches of rain on February 6st. Local stations higher than about 5600 feet, received from 4 to 8.5 inches of rain between February 6th and 9th(National Centers for Environmental Information).

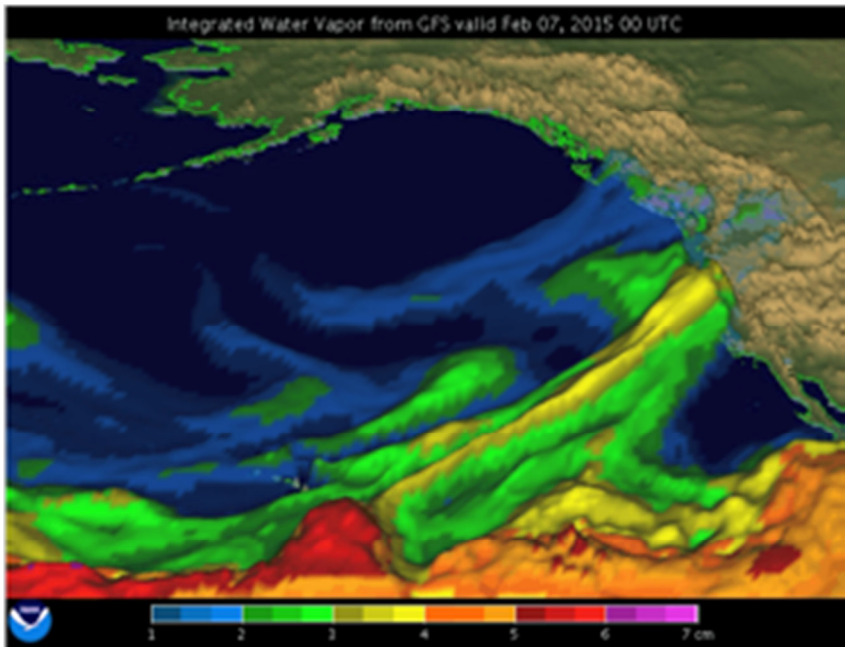

Figure 44. Atmospheric moisture content during the late morning of February 6st. Wet air is just beginning to impact the northern Sierra Nevada Mountain. Image courtesy NOAA Earth System Research Laboratory.

March 2011 Whiteout Conditions

The winter of 2010-2011 was a snowy one in the Sierra. By season's end, snowfall amounted to 1.58 times average, for a total of almost 54 feet. Forty feet of that snow remained on the ground near Lassen National Park, a few hours to the northeast of Donner, (Figure 45) at the end of July 2011. A series of storms moved through the area between March 13th and 31st delivering nearly five feet of snow to Truckee-Tahoe Airport and nearly eight feet at Donner Memorial State Park(National Centers for Environmental Information). The Central Sierra Snow Laboratory received over 16 inches of liquid precipitation, piling up around 10 feet of new snow in less than three weeks. During this March 2011 period, near whiteout conditions closed westbound lanes of I-80 for about three days, following a 45-car pileup with one fatality (James), as documented in the show, "American Trucker" (Speed-Channel). The California Department of Transportation District Director notified superiors that, "We had 12 rotary plows working in tandem all night—going back and forth and they couldn't keep it [I-80] cleared. Westbound lanes are above [higher than] the eastbound lanes and we are having to move the snow twice because there is nowhere to put it. We are clearing the westbound lanes by pushing/blowing the snow onto the eastbound lanes and then pushing/blowing it again over the side. The snow was falling so heavily that as soon as they finished, it was snowed over again." (California Department of Transportation)

The northern Sierra Nevada Mountains are subject to significant winter weather impacts, even in low-snow years, like 2015, when an atmospheric river delivered significant rain to the region. Repeated snowstorms, such as those that occurred in late March 2011 can deliver

massive amounts of snow, causing major traffic delays, significant economic costs, and even loss of life.

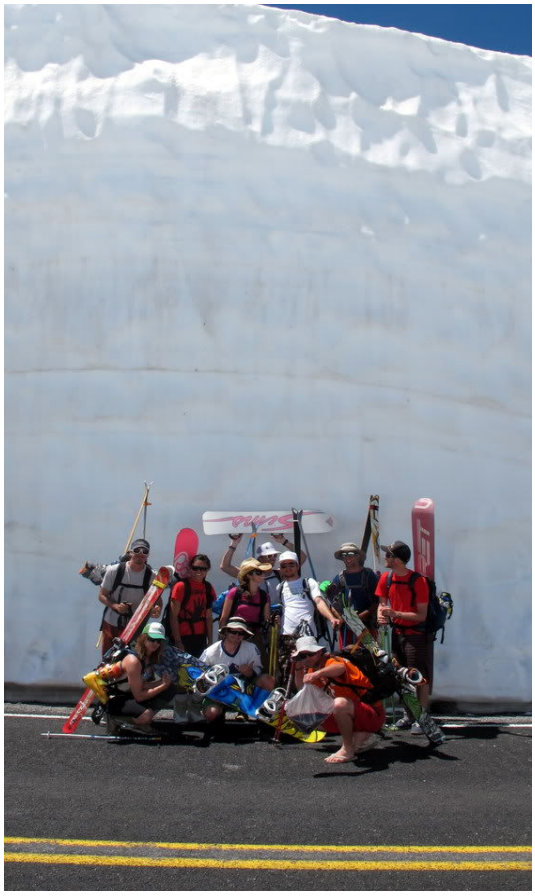

Figure 45. As late as July 4, 2011, snow banks up to 40 feet tall still lined mountain roads in California. Photo courtesy Ben Hatchett.

Acknowledgements

Many thanks to Liza Whitmore and Laurie James of Caltrans, who provided invaluable information and to George Lamson and Ben Hatchett who provided photographs.

Study Area: Seattle, WA

Weather Focus: Freezing Fog and Dust Storms

Transportation Focus: I-90

Karin Bumbaco and Nicholas Bond Office of the Washington State Climatologist, University of Washington

A number of weather hazards impact travel throughout Washington State. The climate varies greatly across the Cascade Mountains, with downed trees from high wind, landslides, and flooding more common on the western side; and thunderstorms, freezing fog, snow, and ice more common at higher elevations and on the eastern side. In such a varied climate, there are a number of hazards that close roads and numerous examples to choose from. Here we focus on two instances in the last few years – one winter and one summer – that resulted in full closure of a portion of Interstate-90 in Washington State.

November 27, 2013 visibility

A freezing fog event occurred on November 27, 2013 in eastern Washington, A fatal accident in the early morning that involved multiple vehicles closed eastbound lanes of Interstate-90 (I-90) for at least four hours near Medical Lake (southwest of Spokane). Figure 46 shows that a tractor-trailer rig involved in the crash, careened off of I-90 (KHQ-TV News). Icy conditions and low visibility likely contributed to the accident. Below freezing temperatures persisted for over a week prior to the event. Spokane Airport reported heavy fog with a low temperature of 22°F on the 27th. Minimum temperatures at another weather station in the Spokane area dipped to 19°F that morning.

December and January are the foggiest months east of the Cascade Mountains. These months bring Spokane an average of 7.3 and 9.6 days of heavy fog, respectively (average of 1996-2008). Visibility of less than or equal to 0.25 miles comes with heavy fog. The eastern part of the state is among the “winners” with the highest heavy fog frequency in December (Figure 47). Cold temperatures at the surface often accompany fog during this time of year, leading to a phenomenon known as freezing fog, that is, fog on surfaces that are below freezing temperatures leads to relatively rapid development of ice on roadways. In this specific event [November 27 th], an area of persistent high pressure was in place, resulting in dry and cold conditions at the surface. The high pressure typically blocks any weather systems bringing precipitation, and instead leads to surface-based temperature inversions and stagnant air conditions, often accompanied by heavy fog and poor air quality.

August 12, 2014 Dust storm - Haboob

Another example of I-90 closing in eastern Washington occurred on August 12, 2014 as the result of altogether different conditions. A dust storm, or haboob, associated with strong thunderstorms throughout eastern Washington caused a six-vehicle accident, 22 miles east of Ritzville on I-90. Low or zero visibility contributed to the serious crash that fortunately was without fatality. Still, reports say that the eastbound lanes of I-90 were closed temporarily (Komo News), before one lane re-opened for traffic.

Observations from the Ritzville Weather Station recorded at 8 a.m. on August. 13th show a high temperature of 93°F and 0.07 inches of precipitation during the previous 24 hours. The dry and warm July and early August helped prime conditions for the dust storm. An east-west oriented line of thunderstorms out of eastern Oregon moved north through eastern Washington in the late afternoon and early evening of the 12th, causing a dust storm over a large portion of the area. Figure 48 shows an archived radar image at 4:25 p.m, with some thunderstorm convection appearing across southern Washington. During these types of events, thunderstorms with strong outflows pick up and transport dust and small debris. According to the Spokane National Weather Service, the edge of the dust storm was 4-5 miles ahead of parent thunderstorms at times. Figure 49 shows a photo of the dust storm on August 12th (USA Today). Dust storms of this magnitude are relatively rare in the state, but they happen periodically east of the Cascade Mountains. Between 1996 and 2005, the Spokane National Weather Service reported five instances. (Erdman).

These two examples – freezing fog in winter and a large summertime dust storm – are but two types of weather hazards that can disrupt travel in the state of Washington. Other examples include landslides and avalanches that often affect smaller state routes, downed trees due to high winds, and flooding that has been known to close interstates in the past (e.g., I-5 near Chehalis in December 2007). Closures due to floods are relatively predictable, since they tend to occur in known problem locations and have considerable lead-time. The two examples presented here can represent real forecast challenges, and climatology of their occurrence would be informative.

Figure 46. A semi-truck that swerved off of I-90 on November 27, 2013 due to a collision (KHQ-TV News).

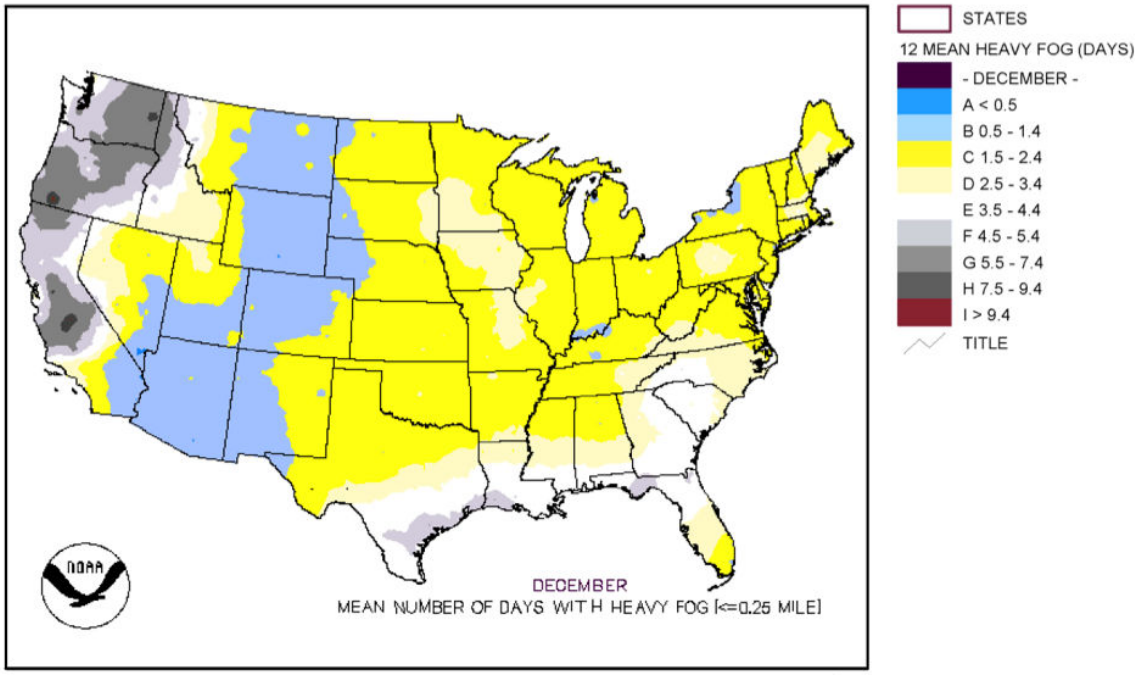

Figure 47. The average (1961-1990) frequency of heavy fog over the US for December (from the National Centers for Environmental Information).

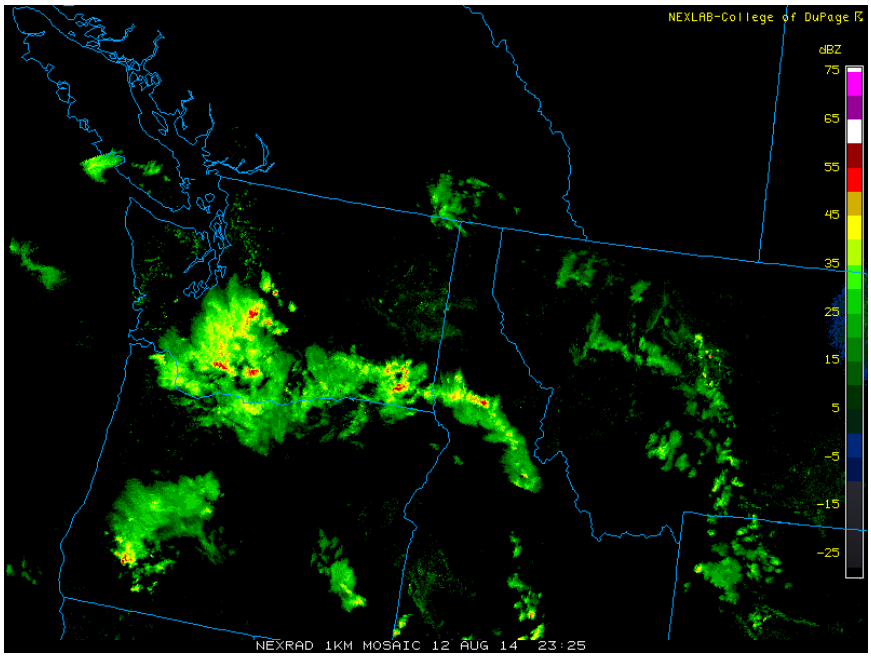

Figure 48. An archived radar image from 4:25 pm on August 12, 2014 (from UCAR).

Figure 49. A photo of the dust storm in eastern WA on August 12, 2014 (USA Today) Photo taken by Chad Devine.

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