PV 22 THE MULTI-HAZARD SEVERE EVENT OF 21 AUGUST 2019 ACROSS EASTERN NEW YORK AND WESTERN NEW ENGLAND

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1. INTRODUCTION

On 21 August 2019, a major severe weather event occurred across much of upstate New York (NY), and portions of western New England. Eastern NY and western New England had nearly three dozen severe reports of damaging winds in excess of 50 kt (25.7 m s^{-1}), hail greater than or equal to 1 in (2.54 cm) in diameter, and a couple of flash floods. Three tornadoes were also confirmed in the Albany forecast area; one EF0 in Fulton County, NY, two EF1's in Saratoga County, NY, and Windham County, Vermont (VT). The damage from the brief tornado touchdowns in eastern NY was mainly to hardwood and softwood trees. The high-end EF1 tornado (winds estimated up to 95 kt (49 m s^{-1})) in Windham County in southern VT not only produced significant tree damage, but also damaged a home in a sparsely populated town.

Observational data, as well as short-range deterministic forecasts from the High-Resolution Rapid Refresh model suggested a highly impactful severe weather outbreak would likely occur. Much of the impacted area had entered a warm sector with a warm front just north of the Mohawk Valley, Greater Capital Region, and southern VT (Fig. 1). An approaching strong upper-level short-wave and prefrontal trough would focus the strong to severe convection that afternoon. An atmospheric environment characterized by moderate-to-abundant instability and moderate to high shear was in place. Surface-based convective available potential energy values ranged from 1000 to 2500 J kg^{-1} with increasing effective bulk shear values of 30 to 40 kt (15.4 to 20.6 m s^{-1}). 0-1 km Storm-Relative Helicity values were in the 100-200 m^2 s^{-2} range. The effective bulk shear values in the 0-6 km layer suggested the possibility of mini-supercells with rotating updrafts capable of producing damaging winds, large hail, and tornadoes. Anomalous precipitable water values supported intense rainfall rates (and the potential for convection repeatedly moving over the same areas) which indicated the potential for some localized flash flooding. Ultimately, some localized flash flooding was realized over Rensselaer County in the Capital Region including the city of Troy.

This paper will focus on a detailed mesoscale and radar analysis of the event. A bow echo associated with the northern book end vortex of a line echo wave pattern will be analyzed (i.e., where a lot of the wind damage and tornadoes occurred). Traditional base and derived WSR-88D radar products will also be shown in conjunction with the Dual-Pol data. Multi-radar-multi-sensor (MRMS) Low-Level Azimuthal Shear (0-2 km AGL) and Rotational Tracks from the 3 tornadoes will also be reviewed. The storm-scale analysis will focus on helpful warning techniques, including applying results from a local rotational velocity V-R-Shear study, to examine the evolution of the tornadoes and how the tornado warning process can be improved. Also, local and Collaborative Science Technology and Applied Research Study (CSTAR) research on the role of collapsing K_{DP} columns with wet microbursts will be examined.

2. DATA

Observational data used in this case analysis include surface and upper air observations, and KENX WSR-88D data. The WSR-88D data is high-resolution 8-bit data from KENX. SPC upper air charts and soundings are also used (www.spc.noaa.gov). The Rapid Refresh mesoscale data from the SPC Mesoanalysis page will be shown in the mesoscale analysis. New York State Mesonet (NYSM) data (Brotzge et al. 2020) will also be shown briefly in the case analysis. MRMS data is analyzed for the low-level rotational tracks of the tornadoes.

Tornadoes were examined between 1980 and 2022 across NY and VT and the Weather Forecast Office (WFO) at Albany County Warning Area (CWA) with data from the National Centers for Environmental Information (NCEI)

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Storm Events Database (NCEI 2022). NOAA *Storm Data* ceased being a publication in November 2018 (U.S. Department of Commerce Storm Data 1980-Nov 2018). The date, location, strength, and time of occurrence were all recorded into spreadsheets.

3. TORNADO CLIMATOLOGY

A climatology of tornadoes was done from 1980-June 2022 for NY, VT and the WFO at Albany CWA. NY has had a total of 399 tornado events over the time period with an average of about 9 per year (Fig. 2). The most tornadoes occurred in 1992 with 25; followed by 1998 and 2011 which both had 23. Climatologically, NY state has had a history of tornadoes occurring anywhere between April and November. The tornado peak month is typically in July with 108 (Fig. 3), and the majority occurred in the spring to summer between May and August with 304 (~76%). The vast majority of the tornadoes in NY during the climatological period are EF0/F0/EFU (161) or EF1/F1 (179) which accounts for 85% of the total (Fig. 4). By contrast, over the same climatological period, VT has had only 23 tornadoes due to low populated areas and mountainous terrain. In VT, the most tornadoes also occurred from May to August with 21 or 91% of the total (Fig. 5). The EF1 Windham tornado on August 21st was the first tornado in VT since 2012 and the first one in southern VT in the ALY CWA since 21 July 2003. Similar to NY, the vast majority of the tornadoes in VT for the climatological period were EF0/EF1 (20) or 87% of the total (Fig. 6).

The tornado climatology from 1980 to June 2022 indicated about 3 tornadoes per year for the Albany (ALY) CWA (Fig. 7) that covers eastern NY and western New England. There were relative maximums in 1992, 2003, and 2020 (14 was the most all-time) but it should be stressed that results can be skewed, since several reports from one tornado case or event are entered in separately in the NCEI Storm Events Database. For example, all 13 tornado entries for 21 July 2003 accounted for the yearly total from the same event case date (11 in eastern NY and 2 in southern VT) in the ALY forecast area. When broken down for the Albany CWA by month, tornadoes occurred generally between May and August, as shown in Fig. 8. The apex in tornado occurrence across eastern NY and western New England occurred in the months of May and July with 31 each. August has also seen an increase over the past few years, including 3 in this case study. However, a few tornadoes have occurred as early as April and as late in the early cool season in the month of November. There were no reports of tornadoes in the heart of the cool season (December to March) due to generally cold and stable conditions.

Fig. 9 shows the strength of the reported tornadoes for the Albany CWA between 1980 and June 2022. Storms are generally on the weaker side of the scale, with the majority being F0/EF0/EFU and F1/EF1. 88% (105 out 120) of the ALY CWA tornadoes are F0/EF0/EFU and F1/EF1. F2/EF2 and greater tornadoes are somewhat rare (only 15 events since 1980). While no F5/EF5 tornadoes were recorded in the climatology, there were a few F4/EF4 tornadoes, which show that violent tornadoes have occurred in this region in the recent past. The August 21, 2019 event had two EF1's and one EF0 tornado (3 total), which having 3 tornadoes on the same day does not occur often in the ALY CWA (i.e., with the last time being 29 May 2013 (Wasula et al. 2014)).

4. SYNOPTIC OVERVIEW

A strong positively-tilted closed 500 hPa trough was centered over Ontario with a short-wave trough approaching from the eastern Great Lakes Region and southeast Ontario at 1200 UTC 21 August 2019 (Fig. 10). 500 hPa temperatures were in the -8°C to -10°C range over a large portion of NY and New England. One short-wave was moving across southern New England and Long Island in the morning associated with a warm front. The upstream short-wave trough helped focus the strong to severe convection late in the afternoon. A 250 hPa upper-level jet streak of 100-125 kts was situated upstream across Minnesota, Wisconsin, and into the northern Great Lakes (Fig. 11). Locations in upstate NY were closer to the anticyclonic entrance region (right entrance region) of the 75 kt jet streak over extreme southern Quebec in the morning (Uccellini and Kocin 1987). Later in the day, despite being near the anticyclonic exit region (right exit region) of the upstream jet streak moving across the northern Great Lakes Region and southeast Ontario, enough upper-level divergence was in place to enhance convection. Also, there was sufficient instability and moderate to marginal high-end 0-6 km shear in place for organized convection and the potential for tornadoes. The low-level jet at 850 hPa increased from the west to southwest at 25 to 30 kts (not shown).

At 1800 UTC 21 August 2019, a surface warm front moved slowly north to northeast across central and eastern NY and southern New England (Fig. 12a). The warm front stalled north of the Mohawk Valley and Capital Region and near southern VT. The boundary appeared to be hung over the Adirondacks and Upper Hudson Valley corridor. Limited heating and lack of instability north of the Mohawk Valley and the Capital Region into southern VT would likely limit the severe weather threat. By 2100 UTC (Fig. 12b), the warm front moved only slightly further north of the Hudson River Valley and was along the eastern Adirondacks and towards the Champlain Valley and southern VT. Most of upstate NY and parts of western New England were in a warm sector. Convection would fire south of the warm front with the mid-level short-wave and a pre-frontal surface trough (not shown). Around this time, the frontal boundary was positioned nearby and the surface to 850 hPa winds were indicating a south/southeast to southwest flow upstream. Thus, being in the proximity of the warm front helped prime local directional shear profiles for convective initiation for some rotating updrafts and the possibility of some discrete low-topped mini supercells.

5. MESOSCALE AND SOUNDING ANALYSIS

The Rapid Refresh data from the SPC Mesoanalysis at 1800 UTC 21 August 2019 indicated that a gradient of instability had set up over eastern NY into western New England with SBCAPES of 1000-2000+ J kg^{-1} (Fig. 13a). The highest amounts of SBCAPE of 2000-2500 J/kg were over the southeast Catskills, mid-Hudson Valley, southern Berkshires of MA and northwest CT. The SBCAPE values were in the 1000-2000 J/kg range over the Mohawk Valley, Greater Capital Region, Lake George Saratoga Region into the northern Berkshires into southern VT. The instability axis was also very pronounced when moving south of the Mohawk River Valley/Capital Region, as the locations to the south had more sunshine for surface destabilization. The best effective bulk shear at 1800 UTC 21 August 2019 of 30-35 kts was across eastern NY and western New England, though the shear would increase closer to 40 kts later in the afternoon at some locations (Fig. 13b). The deep shear interacting with the moderate to high instability allowed some mini supercells to form as well as bowing segments within convective lines. The 0-1 km Storm-Relative Helicity values were in the 100-200 m^2 s^{-2} range (not shown) with the Significant Tornado Parameter values (Thompson et. al 2003; Thompson et. al 2004) in the 0.5 to 1 range across extreme eastern NY into western New England at 1900 UTC via the Rapid Refresh data from the SPC Mesoanalysis. The strong to severe convection that formed in the warm sector migrated along the surface gradient of equivalent potential temperature (theta-e) over east-central NY extending from the Lake George Region into the Mohawk Valley and Capital Region at 1800 UTC. This observation was concluded based on the NYS Mesonet surface theta-e, wind and radar data overlayed with the theta-e values ranging from approximately 330 to 340K as denoted by Fig. 14. The low-level theta-e gradient was a focusing mechanism for the mini-supercells and multi-cells evolving into a line echo wave pattern with a northern bookend vortex that afternoon.

The 1200 UTC sounding taken at KALB indicated that a fairly unstable atmosphere was in place, as some showers and thunderstorms were moving across the upper air site with the warm front in the morning. This sounding (Fig. 15) showed critical information pertaining to the mesoscale environment. The freezing level was 13.7 kft AGL, the -20°C height 25.2 kft AGL, and the wet-bulb zero height just above 12 kft AGL. In addition, the 850-500 hPa lapse rates were 6.0°C km^{-1} and the Most Unstable CAPE values were 652 J kg^{-1}, and forecasted surface CAPE was 1001 J kg^{-1}, and the best Lifted Index was -4°C using the forecast surface CAPE. There was 35 kts of shear in the 0-6 km layer, indicative of possible supercell and multi-cell formation. The 0-1 (0-3) km shear was 19 (29) kts on the sounding; indicating that the atmosphere was conducive for deep organized convection and mini discrete supercells along lifting condensation levels (LCL's) generally lowering under 1.5 km (Thompson et al. 2003) based on the sounding.

The flow was fairly unidirectional between 850 hPa to 500 hPa. The southwesterly flow in the lower to mid-troposphere indicated the potential for thunderstorms to move quickly to the east-northeast with bursts of very heavy rainfall in association with the anomalous precipitable water values (PWAT = 46.0 mm (1.81 inches)). This PWAT value was below the all-time max of 2.13" based on the SPC PWAT climatology, but above the 90th percentile moving average for the date for KALB (https://www.spc.noaa.gov/exper/soundingclimo). The 1200 UTC 21 August 2019 NAEFS indicated PWAT anomalies at 1200 UTC were 1 to 2 standard deviations above normal over NY into western New England (Fig. 16). Thus, any convection that trained or would back-build could bring a threat for isolated flash flooding across portions of eastern NY and western New England with the anomalous PWAT values that were in place and with the antecedent rainfall that occurred in the morning. A Severe Thunderstorm Watch was issued for almost the entire ALY forecast area excluding the southern Adirondacks and western edge of the Mohawk Valley. The Watch went from 1750 UTC 21 AUG to 0100 UTC 22 AUG 2019 (Fig. 1) from roughly the central Mohawk Valley, Greater Capital Region, northern Catskills and Saratoga Region south and east including western New England for widespread damaging winds, some large hail and the possibility of a few tornadoes.

6. STORM-SCALE RADAR ANALYSIS

Convection began to rapidly develop ahead of the surface trough shortly after 1700 UTC**.** One cell that developed in the Mohawk Valley around 1800 UTC began to show supercell characteristics with strong low and mid-level rotation. Initially, severe thunderstorm warnings were issued for damaging winds and large hail. The GR2Analyst (Gibson Ridge Software 2013) 0.5° normalized rotation (NROT) data had a rapid increase to 1.05 at 1808 UTC (Fig. 17a). This value was well above the locally-determined mean and medium values for tornadoes (0.90 and 0.81, Frugis and Wasula 2013). The GR2Analyst guide indicates NROT values greater than 1.0 to be significant and greater 2.5 to be extreme for tornadoes. The 0.5 KENX SRM data showed a well-defined low-level rotational couplet in south-central Fulton County (Fig. 17b). The initial severe thunderstorm warning was issued at 1803 UTC with a tornado possible tag. A severe weather statement with winds increased to 70 mph and the tornado possible tag was continued on the severe thunderstorm.

At 1821 UTC, the 0.5° KENX SRM with the V-R Shear tool overlayed showed a strong low-level rotational value (V_r) of 36.5 kts over a distance (D) of 0.5 nm with a shear (S) value of 0.0422 s^{-1} (Fig. 18). A tornado warning was quickly issued by the warning decision forecaster based on a nomogram from a recent V-R Shear local study (Frugis and Wasula 2013). The maximum mid-level mesocyclone velocity (V_m) was calculated from a cross-section (over a distance of 3.5 km across the storm) in the Four-Dimensional Storm Cell Investigator (FSI) to be 65 kts (not shown). The Gate-to-Gate Shear vs. Mesocyclone Rotational Velocity nomogram (Fig. 19) based on 41 cases from 2003-2013 in or near the ALY CWA (Frugis and Wasula 2013) indicated with a V_m =65 kts and S=0.0422 s^{-1} that there was a 63% chance of tornadic or mainly weak tornadoes (EF0s). At 1822 UTC, the MRMS 0-2 km low level rotational tracks increased to 0.015 s^{-1} (not shown). Warning Decision Training Division (WDTD) has shown values of 0.015 s^{-1} can indicate a potential tornado touch down (US Department of Commerce 2018). At 1824 UTC, an EF0 tornado touched down in Johnstown, Fulton County with peak winds of 61 – 70 knots (70 to 80 mph) downing some trees with some barn damage.

The severe thunderstorm moved into Saratoga County producing widespread wind damage and a quick spin-up tornado. A cross-section through the storm 25-minutes before the EF1 touch down near Saratoga Springs in Saratoga County showed a rising specific differential phase (K_{DP}) column at 1910 UTC that descended prior to 1931 UTC causing microburst wind damage with over a half dozen wind damage reports across the county. The descending K_{DP} column collapsed with values of 3-5 degrees/km that rose above the freezing level of around 13.5 kft AGL (Fig. 20 a-d). The collapsing K_{DP} column primarily produced the wind damage and spin-up tornado at the end of its life cycle at about 1935 UTC. The use of descending/collapsing K_{DP} columns was used for the severe thunderstorm warnings on the cell (Frugis 2020). It was not clear from the MRMS 0-2 km low-level rotational tracks that a tornado occurred. However, a damage survey determined an EF1 tornado occurred just east of Saratoga Springs, NY with maximum estimated winds of 91 kts (105 mph) with damage to a home and numerous trees snapped or uprooted. By 1945 UTC, the 0.5°KENX base reflectivity data showed a bow echo or booked vortex associated with a mini-line moving east of Saratoga County and Interstate 87 across southern Washington County. In all, 10 wind damage reports occurred across southern and central Saratoga County.

The convection would move into southern VT with little wind damage noted. However, a thunderstorm along the line would begin to show some rotation aloft as it moved east of the southern Greens Mountains into the town of Windham in Windham County, VT. At 2100 UTC, the KENX SRM data had an outbound velocity of about 50 knots with an inbound velocity of about 10 knots (Fig. 22 a). The 2102 UTC 0-2 km MRMS Low-Level Rotational Tracks were not that impressive, with values less 0.010 s^{-1} right before the EF1 tornado touchdown at 2105 UTC (Fig. 22b). A low-level mesocyclone was present at 2103 UTC along with some enhancement in spectrum width data occurring 10-15 minutes before tornadogenesis. However, with the radar beam height being around 7.0 kft AGL and the obstruction of the mountains, this made detecting this rare Vermont tornado very challenging. The tornado was the only damage report in southern Vermont.

Outside of the 3 tornadoes, several wind damage reports, and some large hail, the eventual line of thunderstorms had some training and back-building occurring with some of the cells as it moved across the Capital Region into western Rensselaer County. The Line Echo Wave Pattern (LEWP) produced some significant flash flooding in Troy (west/northwest Rensselaer County) with several roads flooded in the downtown area, as the sewers backed up and the drainage system had major issues with manhole or sewer caps popping. NYS Mesonet data indicated rainfall rates in excess of 1 inch/hour in northern Rensselaer County (Fig. 23) by 2100 UTC 21 Aug 2019. The area was hit by 1-2+ inches of rainfall earlier in the day. Soils were saturated. Portions of north/northwestern Rensselaer, southeast Saratoga and southern Washington Counties had 2 to nearly 4 inches of rainfall based on the dual polarization Storm Total Accumulation product (Fig. 24 a). The MRMS 24-hr rainfall product also showed 2-3+ inches of rainfall in this area (not shown). However, the rainfall estimates were underestimated for the Troy area with only 1-2 inches estimated in that area. The rainfall analysis the next day composed of spotter, CoCoRaHs and coop reports showed a broad area of 2-3.5" of rainfall across southern Saratoga, southern Washington and northern and western Rensselaer Counties (Fig 24 b). The intense rainfall rates, training, and back-building convection coupled with the anomalous PWAT values and the wet antecedent conditions from the earlier morning rainfall were the likely contributors for this localized flash flooding event.

7. SUMMARY

A major severe weather event occurred on 21 August 2019 across much of upstate NY and portions of western New England. Eastern NY and western New England had nearly three dozen severe reports of damaging winds, large hail, and a couple of flash floods (Fig. 25). Three tornadoes were also confirmed (all of which were brief touchdowns) in the Albany forecast area. One EF0 in Fulton County, NY and two EF1's in Saratoga County, NY and Windham County, Vermont (VT) respectively occurred. The damage from the brief tornado touchdowns in eastern NY was mainly to hardwood and softwood trees. The high-end EF1 tornado (winds estimated up to 95 kt (49 m s^{-1})) in Windham County in southern VT not only produced significant tree damage but also damaged a home in a sparsely populated town (Fig. 26 a-c).

It is rare to have 3 tornadoes occurring in the ALY CWA with the last time being on 29 May 2013 (Wasula et al. 2014) and it is uncommon to have tornadoes in VT. The EF1 Windham tornado on August 21st was the first tornado in VT since 2012 and the first one in southern VT in the ALY CWA since 21 July 2003 (Fig. 6).

Much of the ALY forecast area had entered a warm sector with a warm front just north of the Mohawk Valley, Greater Capital Region, and portions of southern VT that afternoon. An approaching strong upper-level short-wave and prefrontal trough would be the primary forcing mechanisms for the strong to severe convection that afternoon. A pre-convective environment characterized by moderate-to-abundant instability and moderate to marginally high-shear was in place which set the stage for the development of a few supercells and multi-cells. Ultimately, this convection formed into a line that went on to produce damaging winds, large hail, and tornadoes. A low-level theta-e and CAPE gradient were in place for the severe convection to migrate along in the Mohawk River Valley, Greater Capital Region, Saratoga Region and southern VT which was indicated in some of the NYS Mesonet data. Anomalous precipitable water values enabled intense rainfall rates, and the potential for convection repeatedly moving over the same areas; highlighting the potential for localized flash flooding, which did end up occurring over Rensselaer County in the Capital Region including the city of Troy.

Results from previous CSTAR work from a completed V-R shear tornado study (Frugis and Wasula 2013) were applied by the warning decision makers for the severe thunderstorm and tornado warnings. The Shear vs. Maximum Rotational Velocity nomogram (Fig. 19) and 0-2 km MRMS low-level rotational tracks were very helpful for the initial tornado warning and subsequent severe weather statements for the EF0 tornado in Gloversville, Fulton County. Also, additional CSTAR research on the role of collapsing K_{DP} columns with wet microbursts was applied successfully to warnings across Saratoga County with a bow echo/bookend vortex (Frugis 2020).

Determining the threat for multiple tornadoes was challenging for forecasters in advance due to the lack of widespread abundant instability north of the Mohawk River Valley downstream over portions of eastern NY into western New England (southern VT) and the lack of an elevated mixed layer. Tornado detection was challenging for the Saratoga County, NY and Windham County, VT tornadoes. In the future, it is hoped that forecasters will be able to better diagnose the pre-convective storm environment in NY and New England (Tornado vs. Severe Thunderstorm Watch threat), and continue the application of the V-R Shear local study results, MRMS low-level rotational tracks, and new Dual Polarization concepts.

8. ACKNOWLEDGEMENTS

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DISCLAIMER

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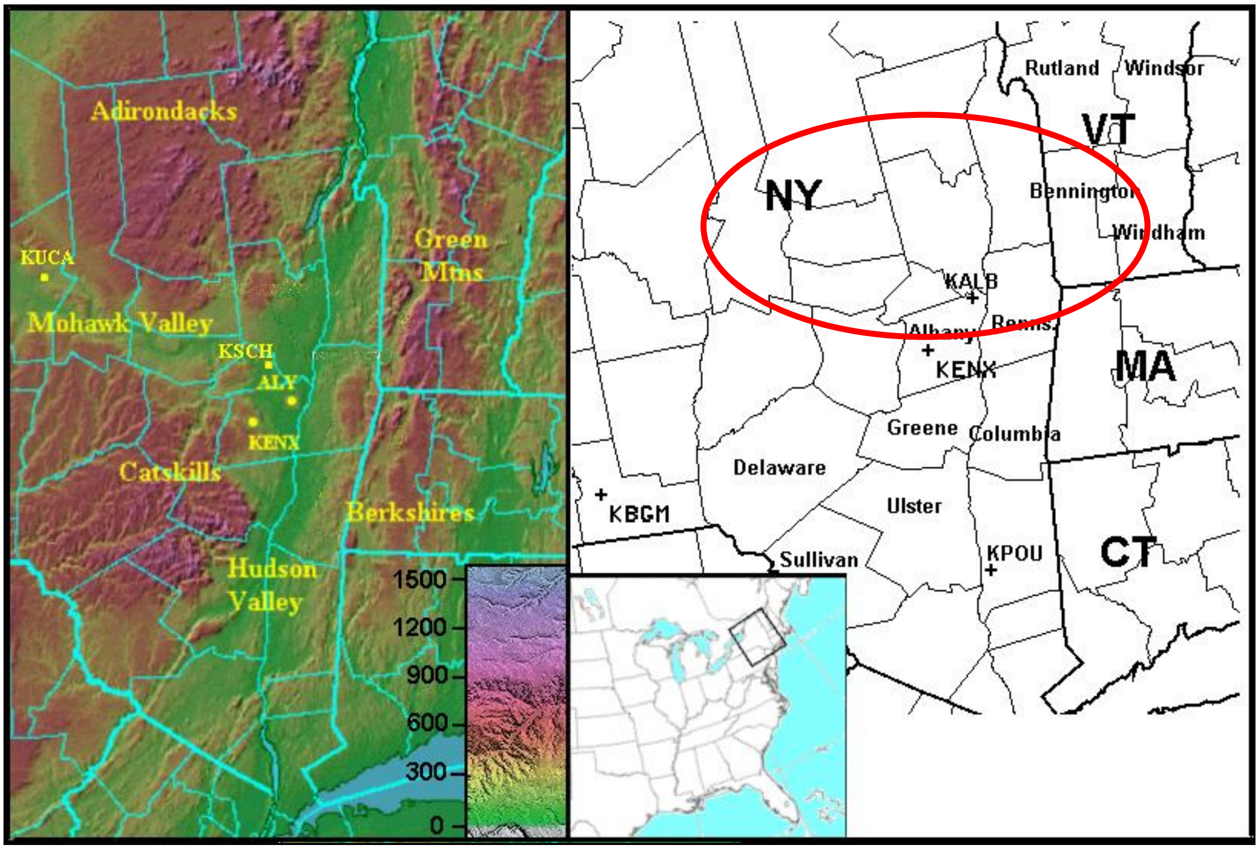

Figure 1: Map of eastern NY and western New England. The red circle denotes where tornadoes occurred and bow echo to line echo wave pattern would impact the ALY forecast area.

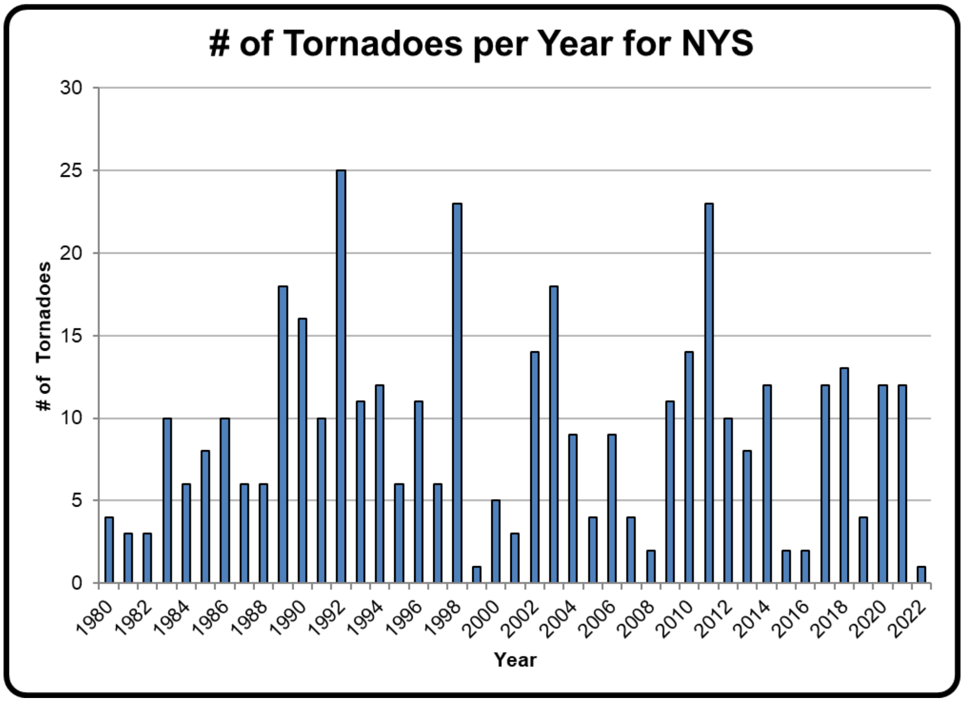

Figure 2: The number of tornadoes per year in NYS. The total of tornadoes is 399 from 1980 to June 2022.

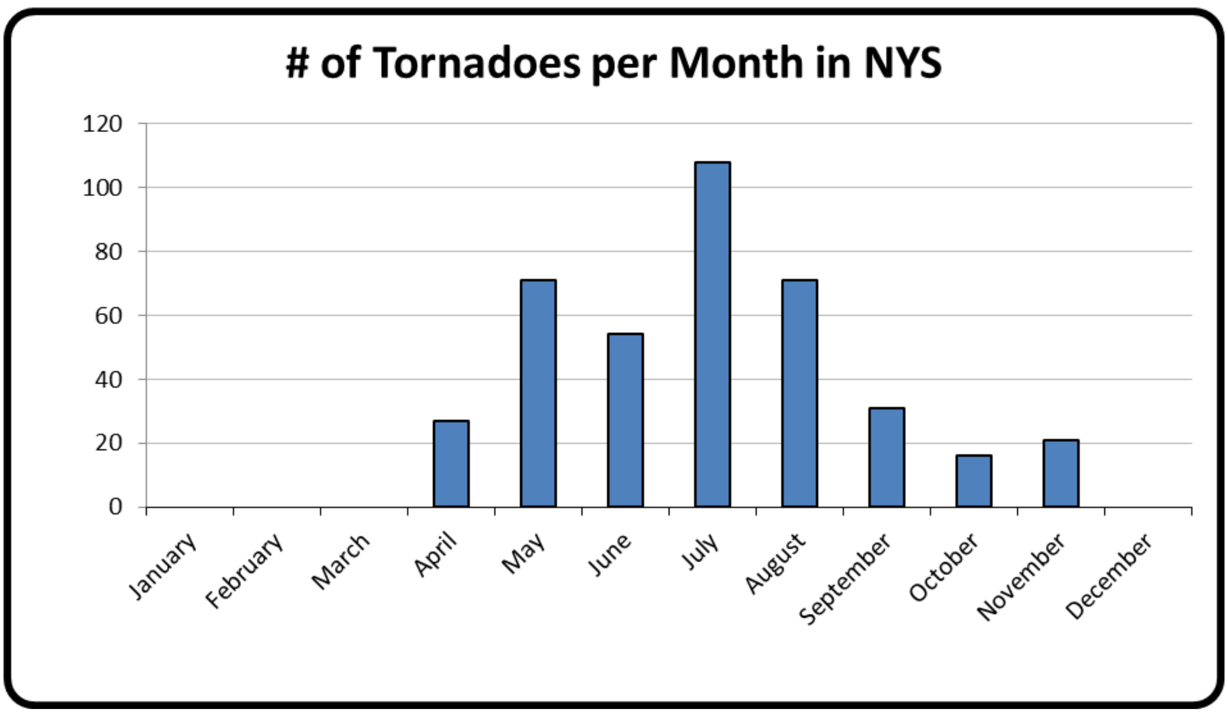

Figure 3: Number of tornadoes by month in NYS from 1980 to June 2022.

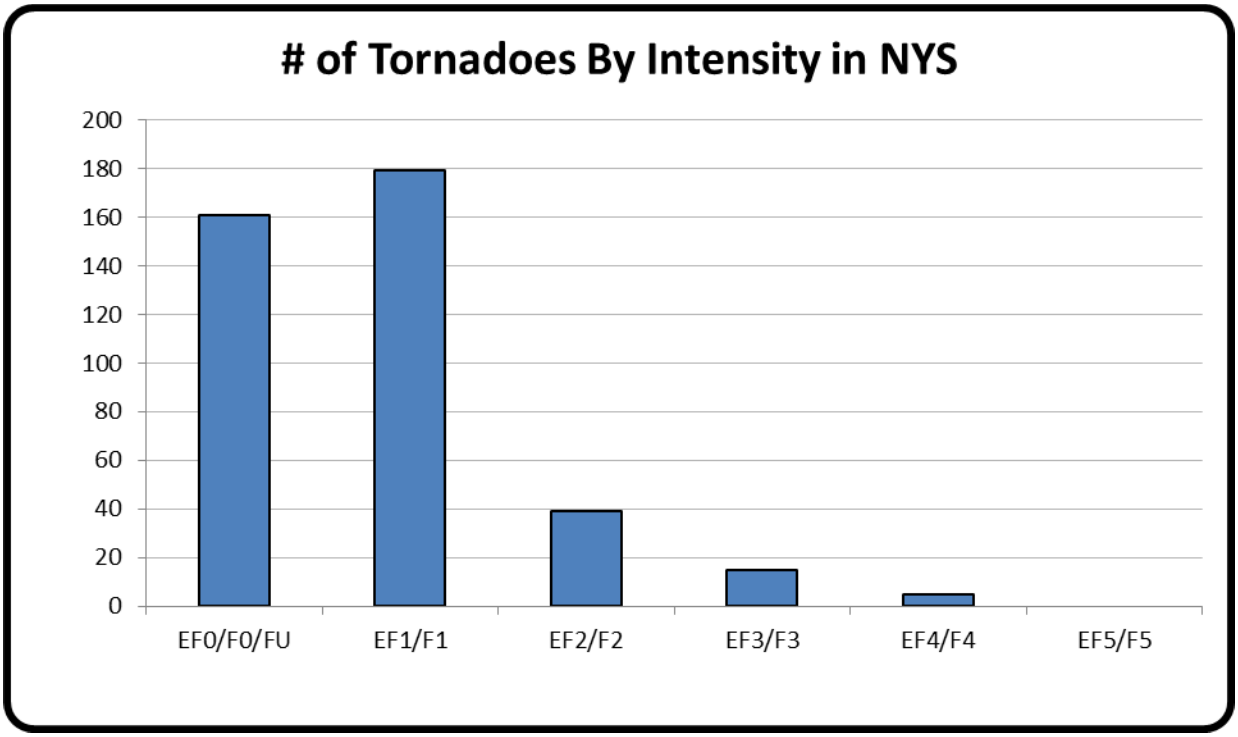

Figure 4: Number of Tornadoes by intensity or strength in NYS from 1980 to June 2022.

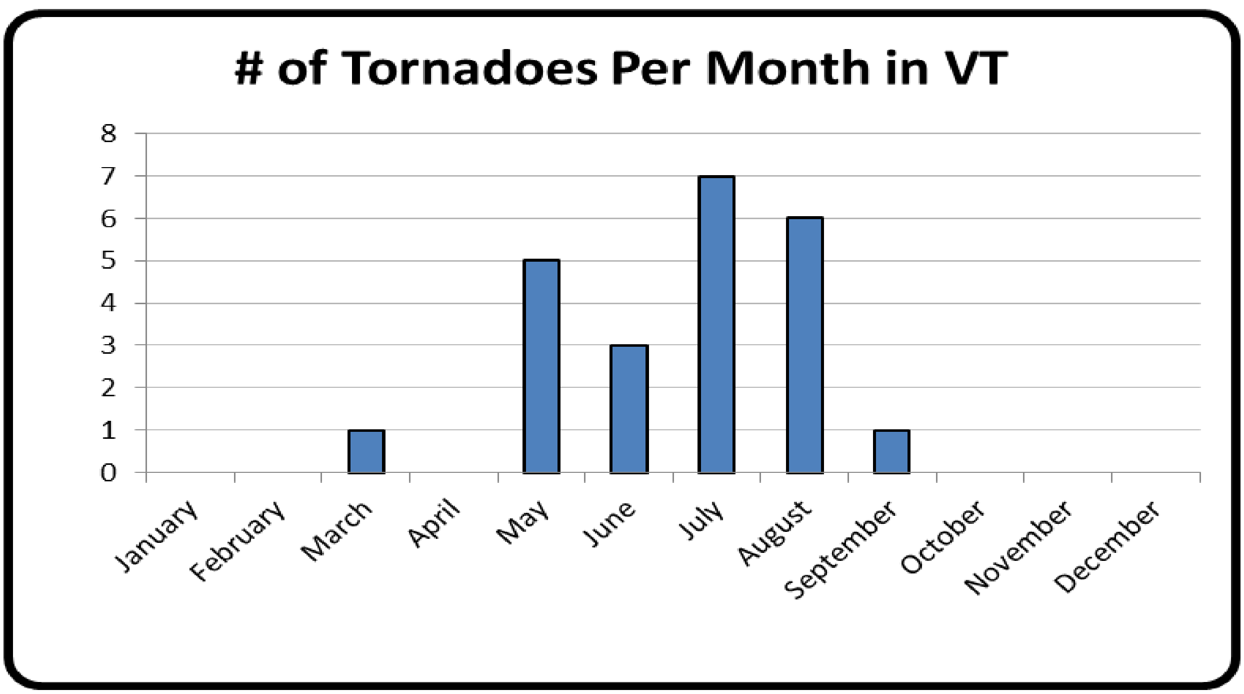

Figure 5: Number of Tornadoes by month in VT from 1980 to June 2022.

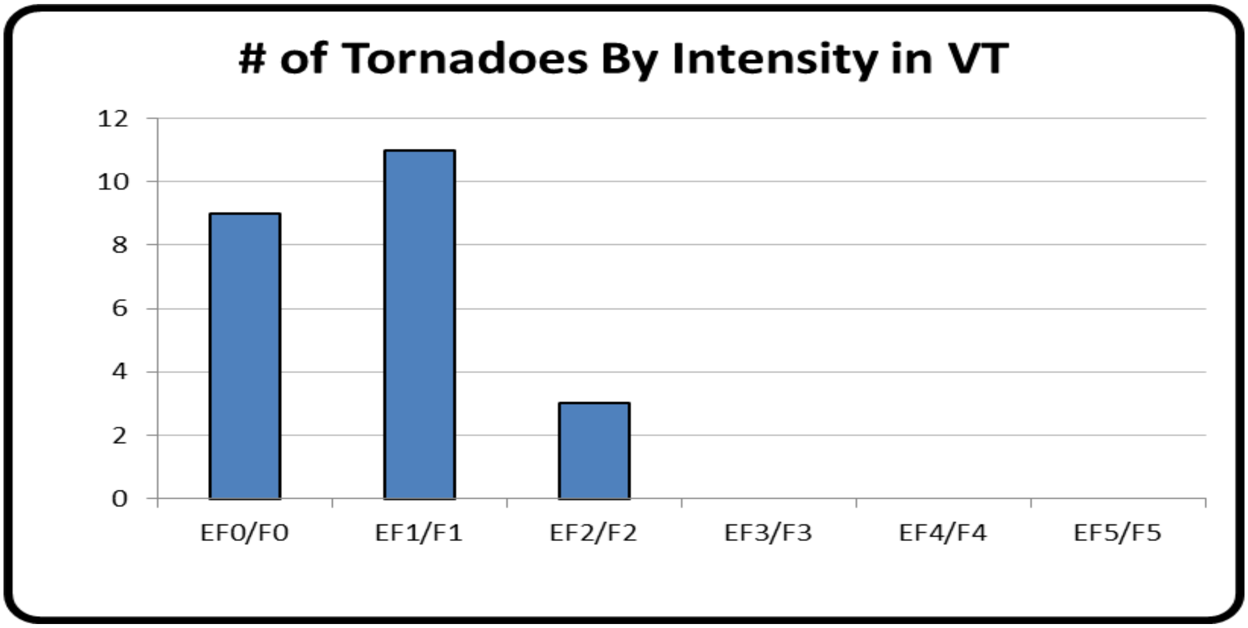

Figure 6: Number of Tornadoes by intensity or strength in VT from 1980 to June 2022.

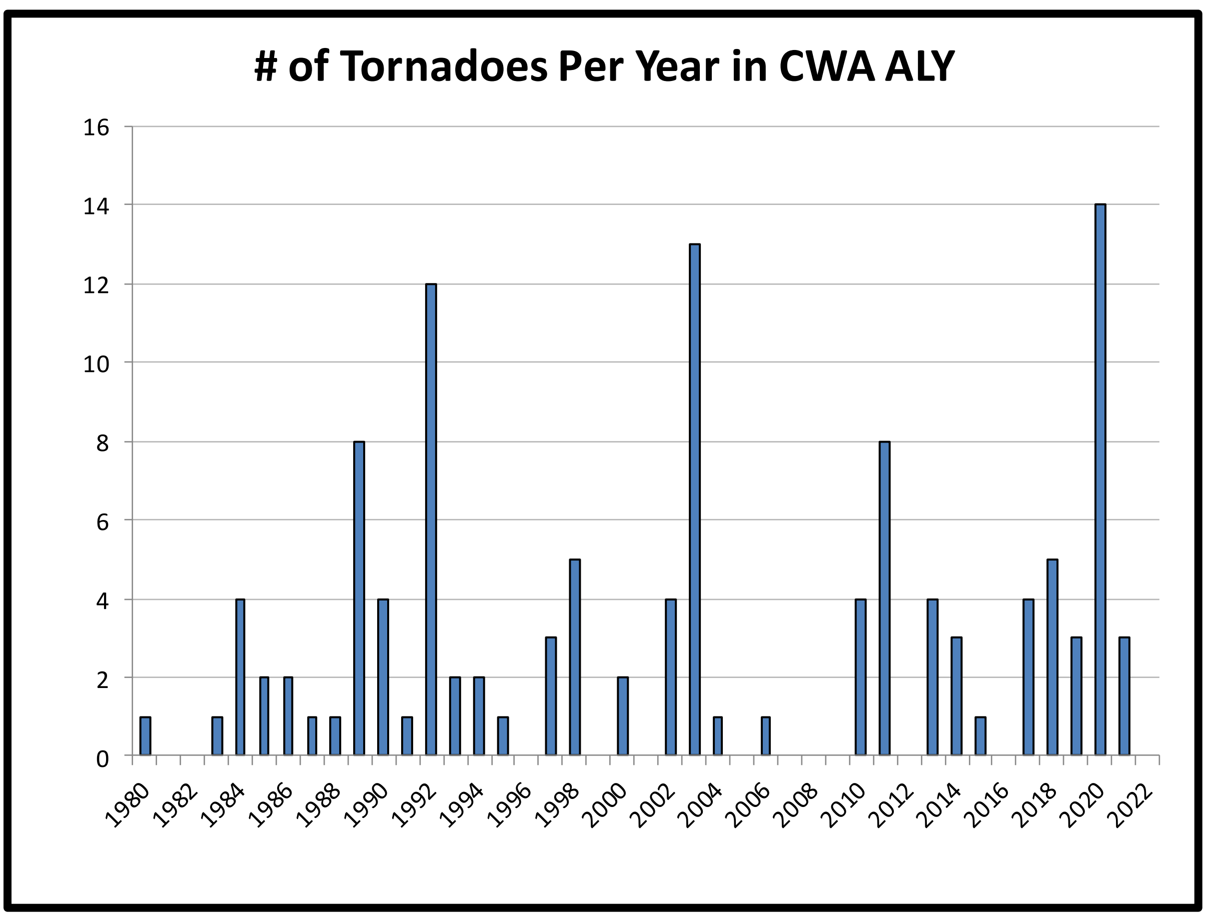

Figure 7: Number of Tornadoes in the Albany CWA from 1980 to June 2022

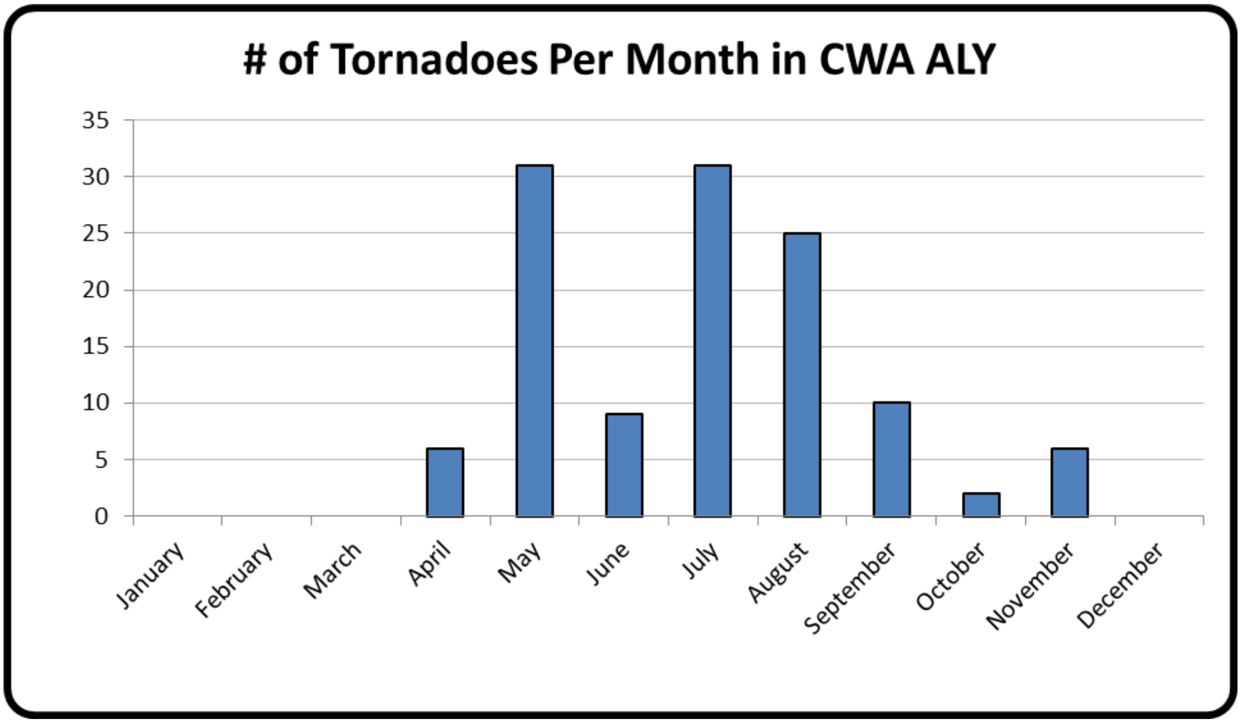

Figure 8: Number of Tornadoes by month for the Albany CWA from 1980 to June 2022

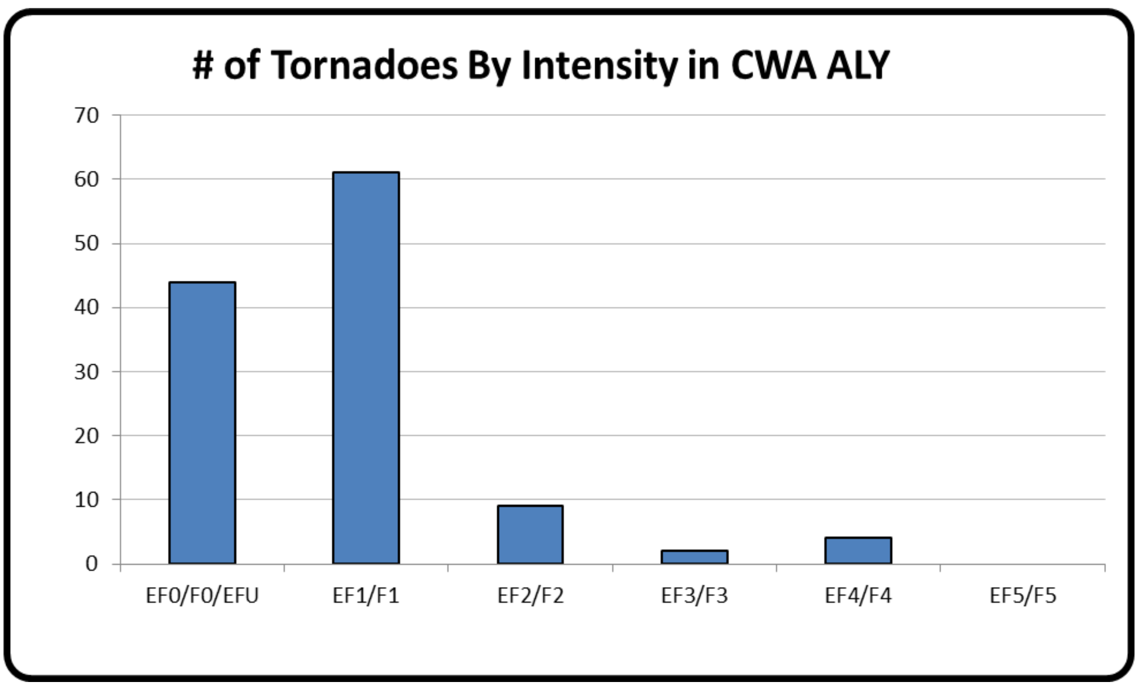

Figure 9: Number of Tornadoes by intensity or strength in the Albany CWA from 1980 to June 2022

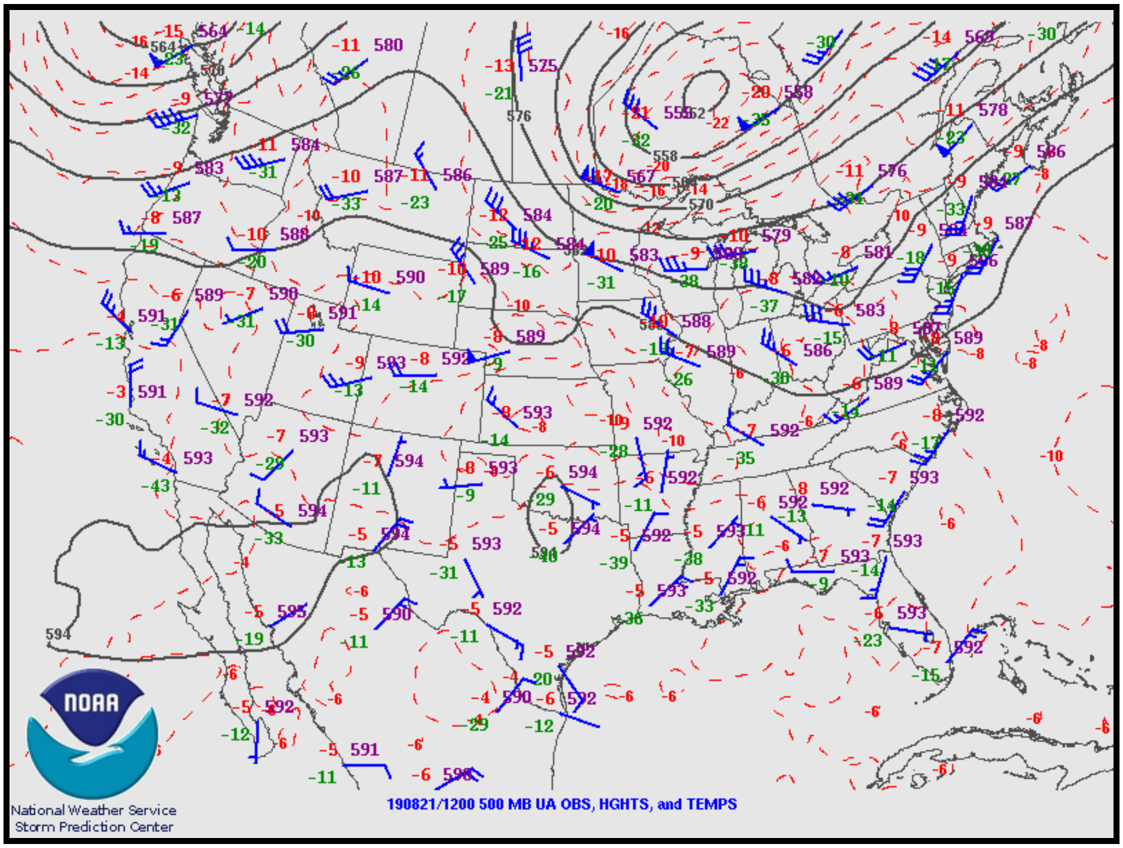

Figure 10: 500 hPa height (dam, solid), temperatures (°C, dashed red), winds (knots) and dewpoint depression from RAOB (green), valid 1200 UTC 21 August 2019 (www.spc.noaa.gov).

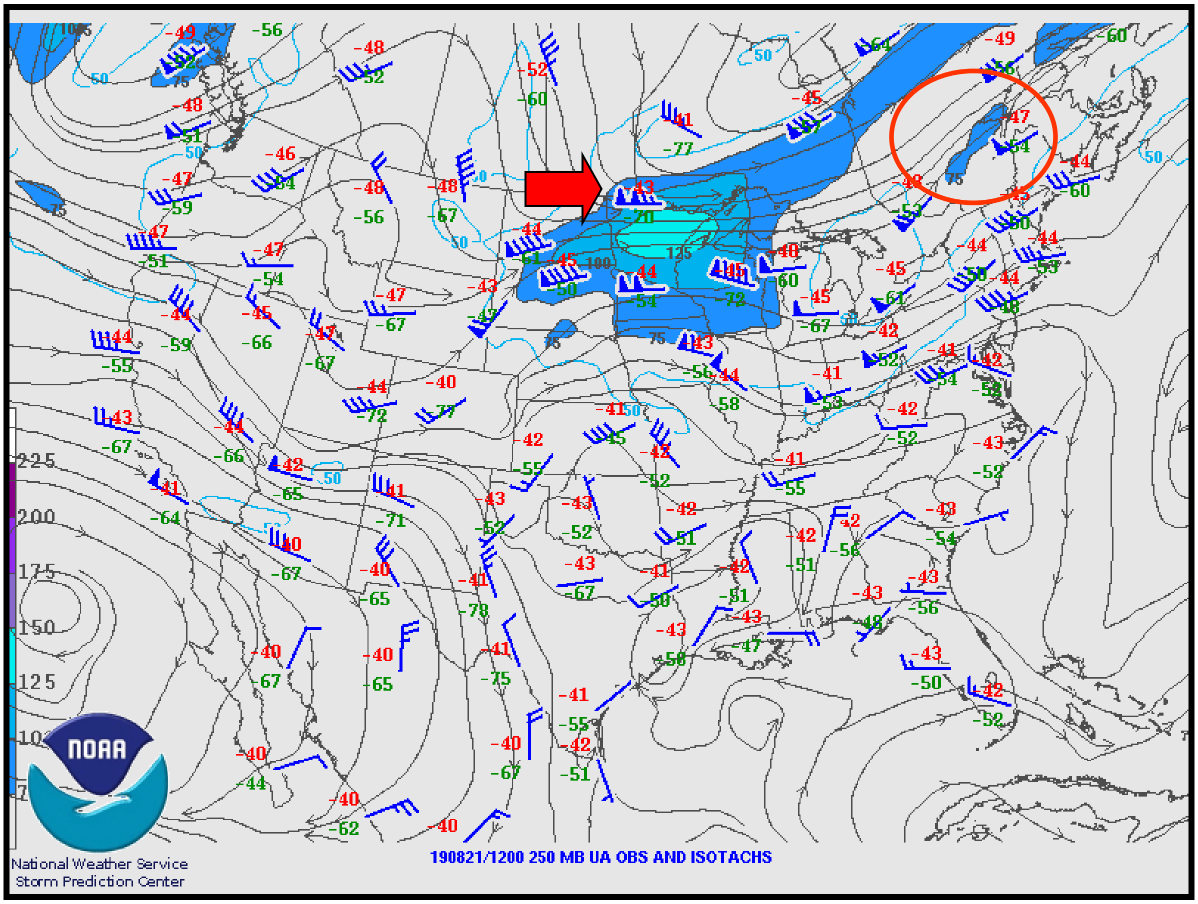

Figure 11: 250 hPa streamlines (black), temperatures and dewpoint depressions from RAOB network (°C, red and green digits), isotachs (shaded, knots), and winds (blue barbs, knots) valid 1200 UTC 21 August 2019 (www.spc.noaa.gov).

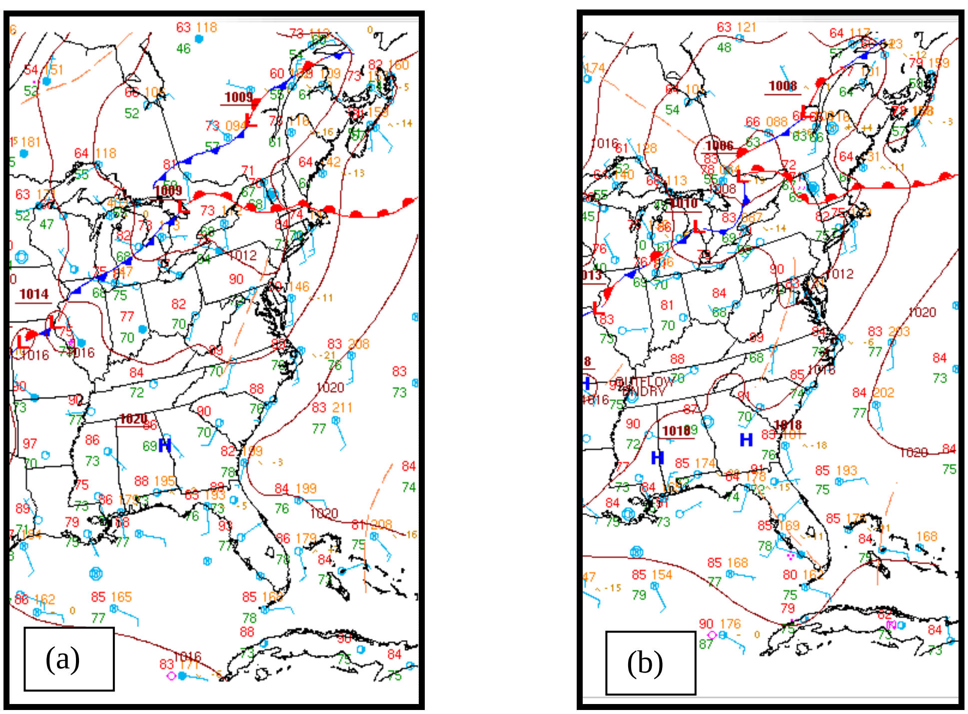

Figure 12: (a) 1800 UTC 21 Aug 2019 and (b) 2100 UTC 21 Aug 2019 WPC Surface Maps.

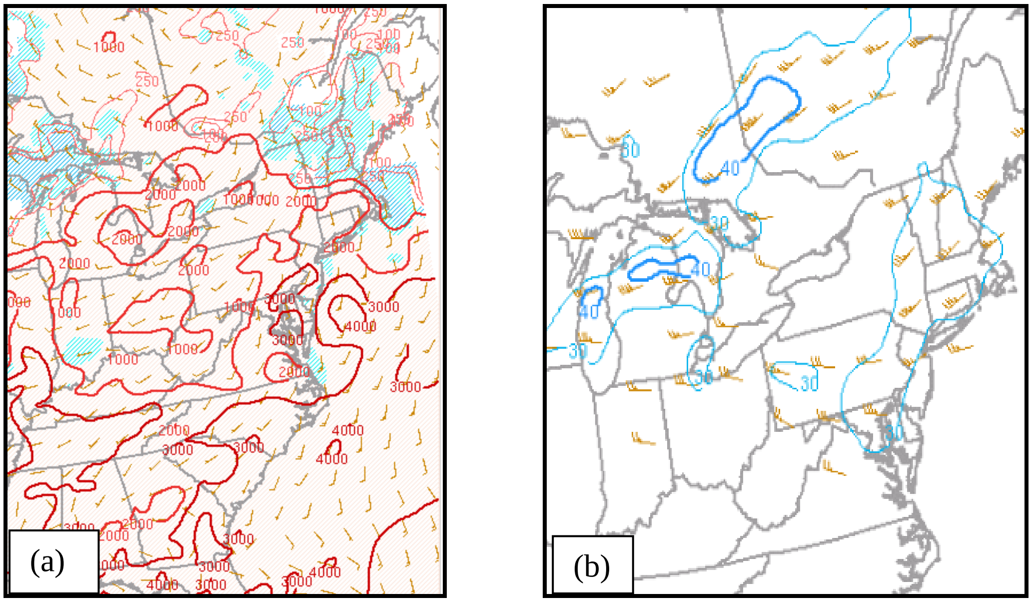

Figure 13: (a) 1800 UTC 21 August 2019 SPC Mesoanalysis Page (Rapid Refresh) SBCAPE (J kg^{-1}) red contoured every 1000 J kg^{-1} and SBCIN (J kg^{-1}) and (b) Effective Bulk Shear (kts) from (www.spc.noaa.gov).

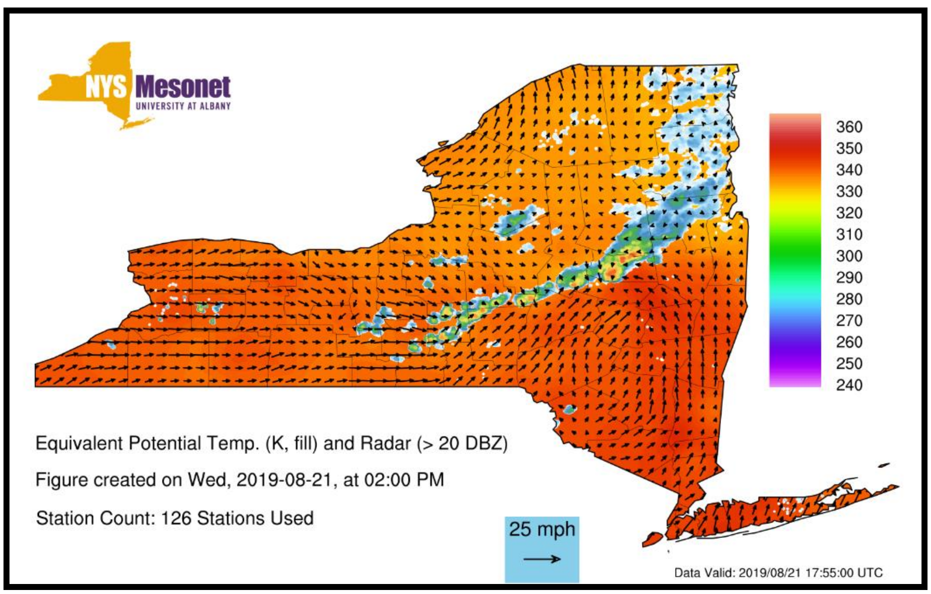

Figure 14: 1800 UTC 21 August 2019 NYS Mesonet Surface theta-e (K), wind and radar data (> 20 dBZ).

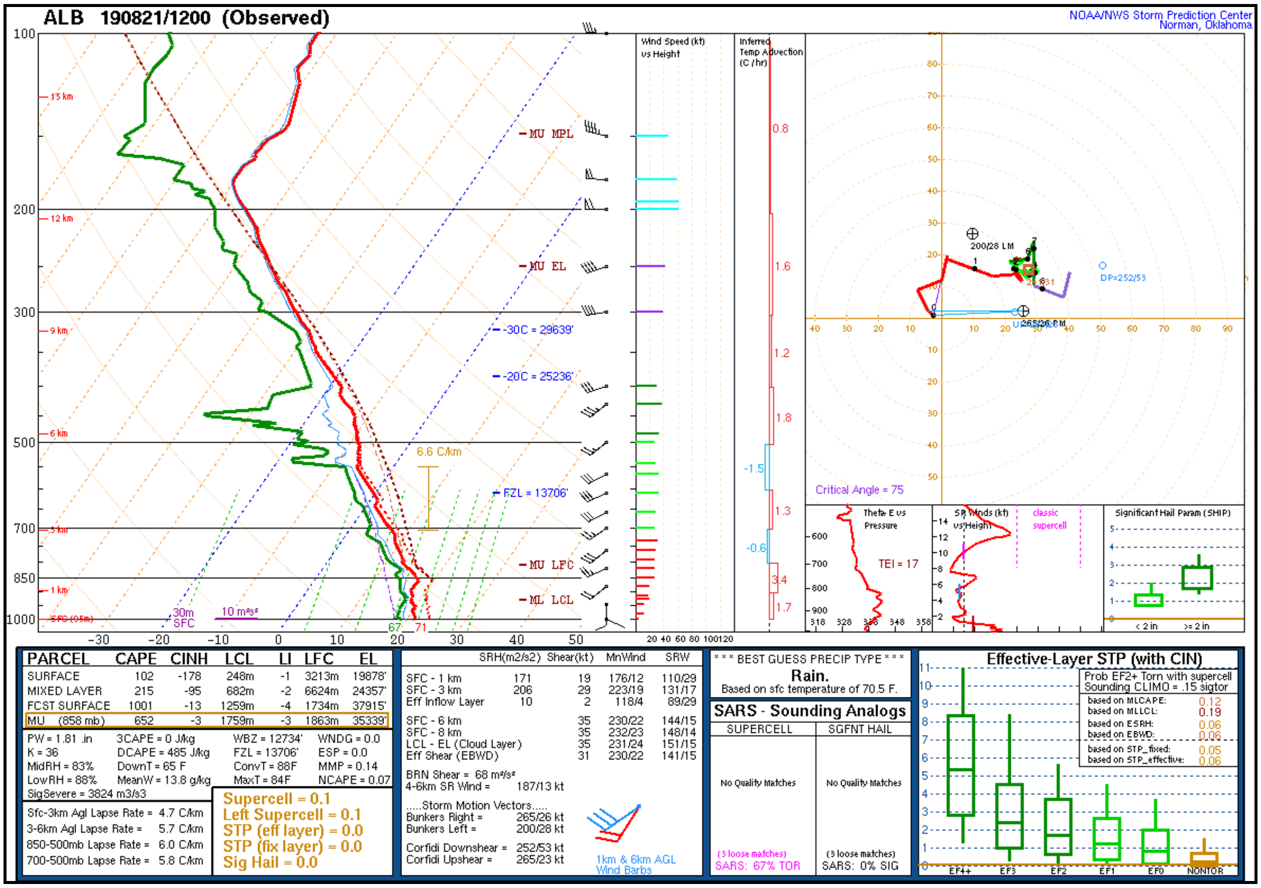

Figure 15: 1200 UTC 21 August 2019 Albany, NY (ALB) Sounding (www.spc.noaa.gov).

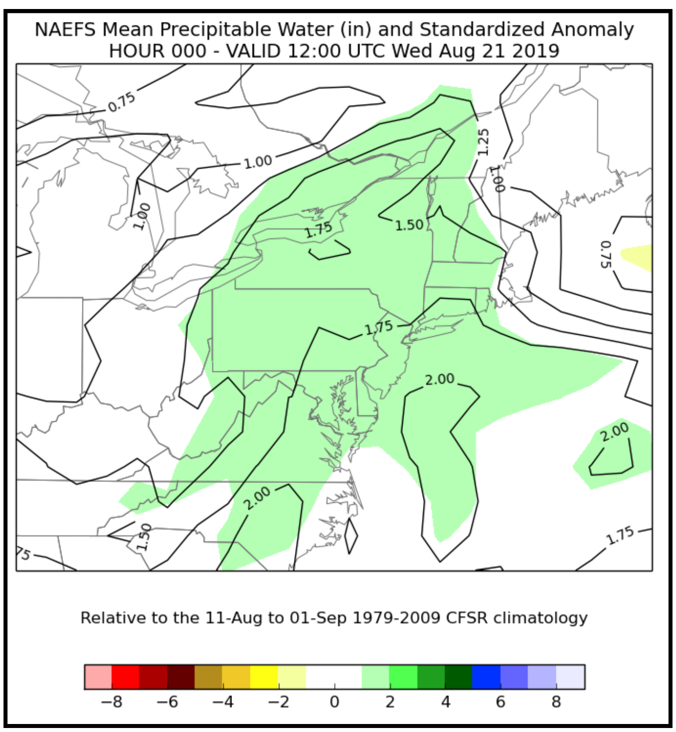

Figure 16: 1200 UTC 21 August 2019 00 Hour NAEFS mean PWATs (in) and Standardized Anomalies

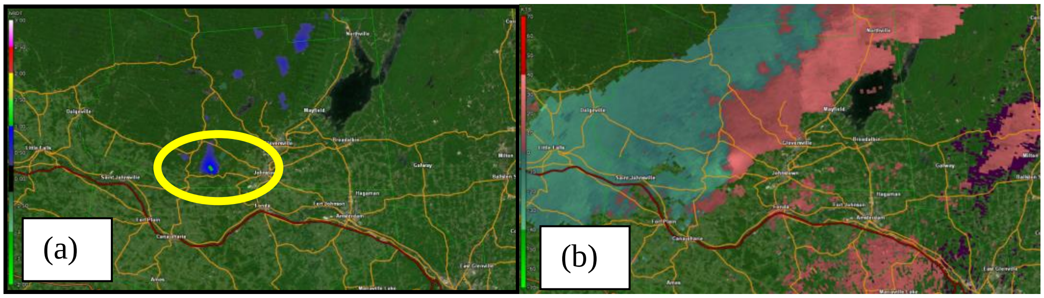

Figure 17: (a) 1808 UTC 21 August 2019 0.5° KENX N_{rot} = 1.05 (b) KENX 0.5° SRM (kts) showing a low-level rotational couplet over south-central Fulton County.

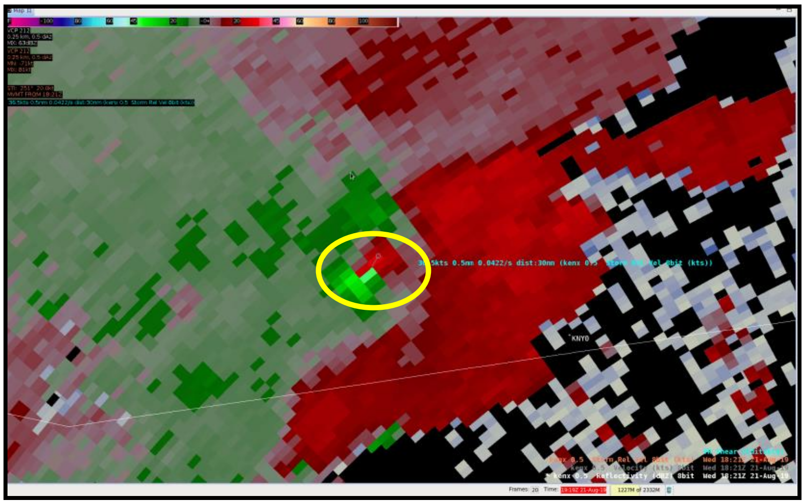

Figure 18: 1821 UTC 21 August 2019 0.5° KENX SRM (kts) data with the V-R Shear tool had a low-level rotational velocity of 36.5 knots gate to gate with a shear value of 0.0422 s^{-1} over a 0.5 nm radius at distance of 30 nm from the RDA. A tornado warning was issued within a few minutes. An initial severe thunderstorm warning issued at 1803 UTC had a tornado possible tag, and a Severe Weather Statement (SVS) was issued at 1818 UTC with winds increased to 70 mph, and the tornado possible tag continued.

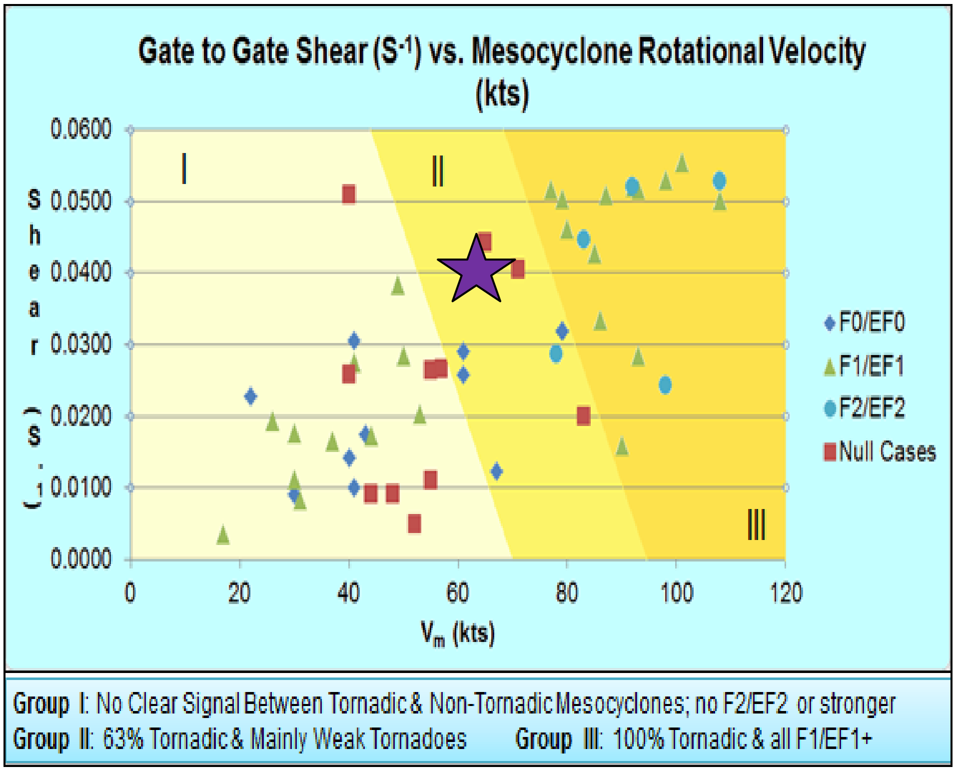

Figure 19: Gate to gate shear vs. Mesocyclone Rotational Velocity nomogram based off 41 tornadoes in or near the Albany CWA from 2003 to 2013. D (gate to gate shear calculation) was set to 0.5 for all storms from 2008 to 2013. The previous study methodology was used for D for events between 2003 and 2008. The large purple star is the placement for the EF0 Johnstown, Fulton County tornado where V_m=65 kts and S=0.0422s^{-1} (Frugis and Wasula 2013).

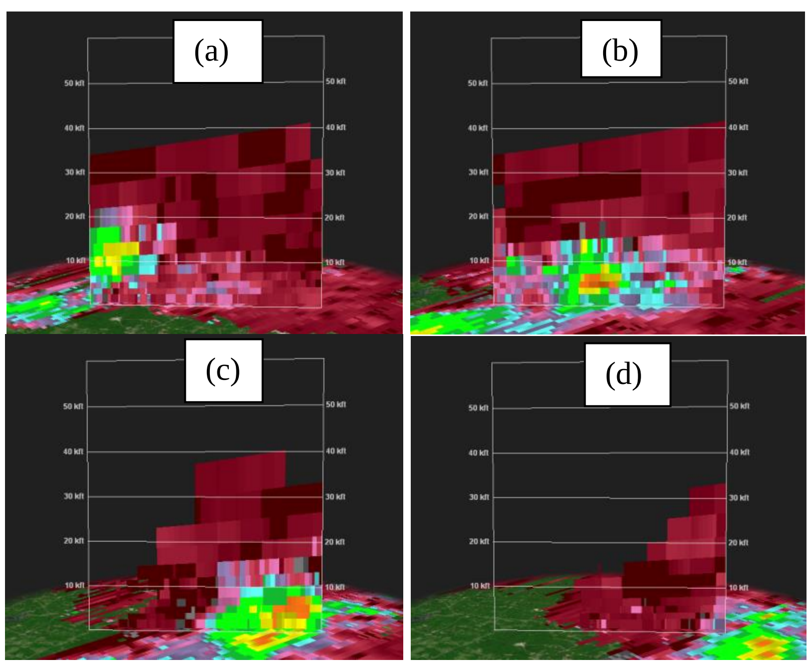

Figure 20: 21 August 2019 KENX Specific Differential Phase (K_{DP}) Cross-section for a severe thunderstorm over Saratoga County near Saratoga Springs at (a) 1910 UTC, (b) 1917 UTC, (c) 1924 UTC and (d) at 1931 UTC. A microburst occurred near Saratoga Springs with a descending K_{DP} column that collapsed with values of 3-5 deg/km that rose above the freezing level (~13.5 kft AGL) and descended with widespread wind damage at 1925-1935 UTC. A tornado occurred at the end of the life cycle.

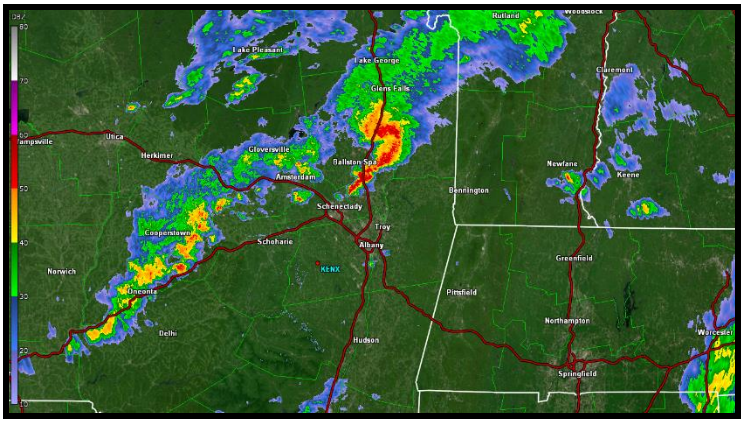

Figure 21: 1945 UTC 21 August 2019 KENX 0.5° Base Reflectivity (dBZ) depicts a bookend vortex or bow echo moving east of Saratoga County across I-87 into Washington County.

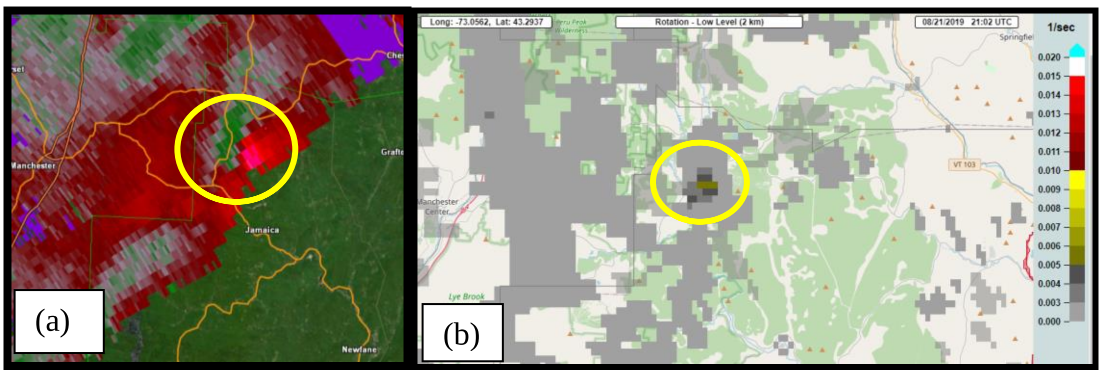

Figure 22: (a) 0.5° KENX SRM data showing a strong outbound velocity around 50 knots and (b) 2102 UTC 0-2 km MRMS Low-Level Rotational Tracks with values less than 0.010 s^{-1}.

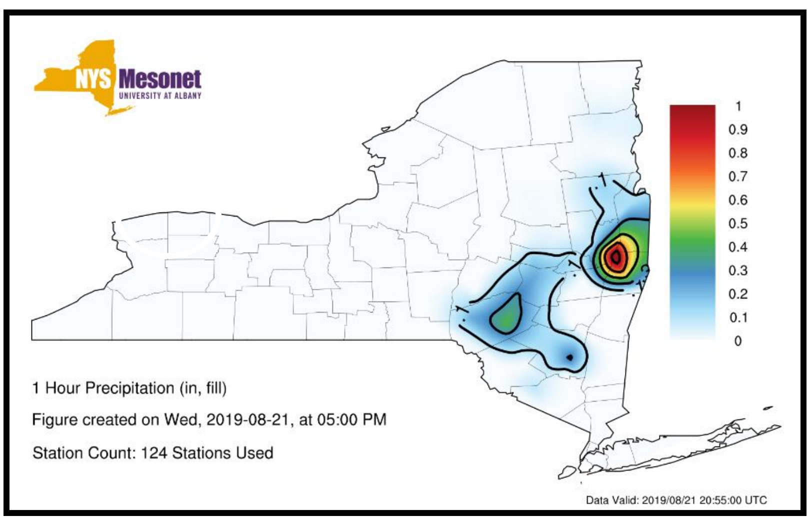

Figure 23: 2100 UTC 21 August 2019 KENX NYS Mesonet rainfall rate map (inches/hour)

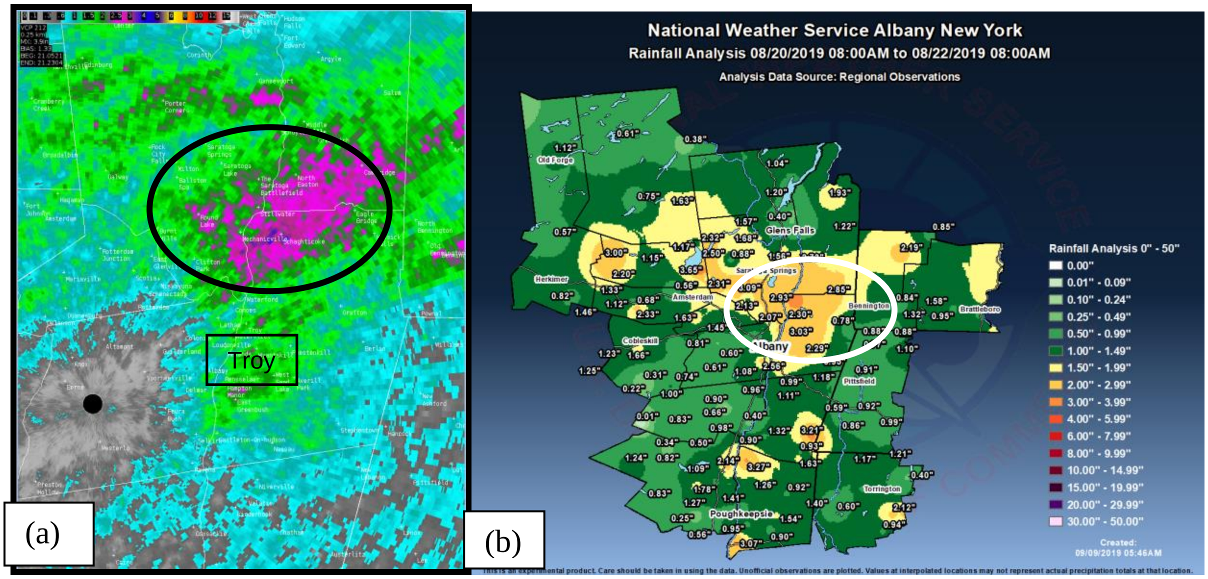

Figure 24: (a) 2304 UTC 21 August 2019 Storm Total Accumulation product (0521 UTC to 2304 UTC), (b) 1200 UTC 20 August 2019 to 1200 UTC 22 August 2019 local GAZPACHO rainfall analysis map across eastern NY and western New England.

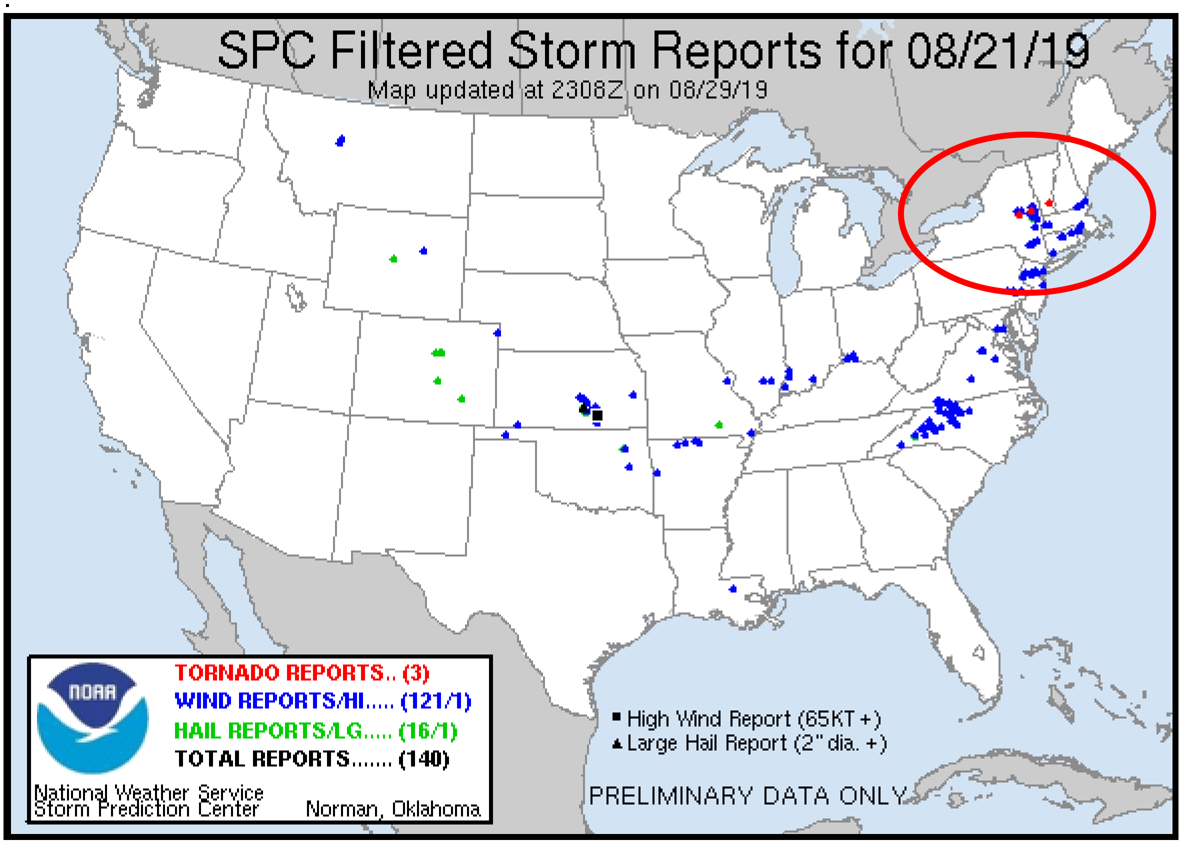

Figure 25: SPC Storm Reports for 21 August 2019 (www.spc.noaa.gov). The red circle indicates the numerous wind and large hail reports. There were 3 tornadoes in the ALY forecast area.

Figure 26: (a) EF0 tornado that touched down in Johnstown, Fulton County at 1824 UTC near the intersection of Route 67E between Johnstown and Tribes Hill (picture by Shelley Brienza (b) EF1 tornado damage at 1935 UTC at a home just east of Saratoga Springs, NY (picture by Mike Evans – NWS at Albany), (c) EF1 tornado damage at a home in Windham, Windham County, VT at 2105 UTC (picture by Raymond O'Keefe – NWS at Albany).