Review of the 9 January 2024 Claremont, NC Tornado

1. Event Overview

A powerful storm system impacted the southeast United States on January 9, 2024 bringing multiple hazards to the western Carolinas and northeast Georgia including winter weather, flooding and severe thunderstorms. A line of thunderstorms, some of which were severe, moved across the Upstate of South Carolina during the morning hours and into the North Carolina foothills and Piedmont by early afternoon. Numerous reports of wind damage were received (Fig. 1) and one tornado was confirmed in the Claremont community in Catawba County, North Carolina (Fig. 2). A subsequent damage survey determined that the tornado touched down at 1227 pm and tracked for 9 miles from south of the city of Claremont to Interstate 40 in Iredell County just on the east side of the Catawba River. The tornado was 250 yards wide and had estimated peak winds of 110 mph. Damage was rated at EF-1 intensity. Tragically, the tornado struck a mobile home community where one fatality occurred along with 4 injuries.

Unfortunately, no tornado warning was issued for this storm with the tornado also forming north of the Tornado Watch that was in effect (Fig. 3). The Storm Prediction Center (SPC) did have a marginal risk for severe thunderstorms across Catawba and Iredell counties (Fig. 4) with a 2% chance for a tornado (Fig. 5). Forecaster analysis based on available data during the event determined that the atmospheric environment over northern Catawba County was not favorable for the formation of tornadoes. The following event review will serve to assess the environment along with radar data to determine how a deadly tornado was able to form in an otherwise unfavorable environment. Several hypotheses for how the tornado was able to form will be discussed along with recommendations for future severe weather events.

2. Analysis of the Environment

a. Large-Scale Features

An intense low pressure system moving rapidly from the Southern Plains to the Midwest on January 8-9 set the stage for potential severe thunderstorms across the area. The intensity of the storm system resulted in extremely strong winds across parts of the Southeast into the Carolinas. Unusually strong winds of 86 mph in the lower portions of the atmosphere were located across the western half of the Carolinas. These very strong low-level winds greatly enhanced the low-level wind shear, which was the main factor in the severe thunderstorm risk.

At the surface, a cold and dry area of high pressure was located across the western Carolinas at 7 am on January 8th (Fig. 6). Observations of dewpoint were in the mid to upper 20s °F with northeast wind maintaining a supply of dry air into the region. A strong surface low pressure center of 988 mb was located over Missouri and the mid-Mississippi River Valley region at 7 am on January 9th, with another area of low pressure (997 mb) located over east central Alabama, while a retreating 1031 mb surface high pressure was located off the southern New England Coast (Fig. 7). A warm front was analyzed from the Alabama low, across central Georgia, to the Coastal Plain of the Carolinas. By 10 am, the latter surface low had moved over north Georgia in the vicinity of the Atlanta metro area and the warm front had lifted north from Athens, Georgia, to Charlotte, North Carolina (Fig. 8). The intense low-level winds were able to rapidly move low- to mid-60s °F dewpoints into central/southern Georgia and much of South Carolina.

b. Regional and Local Features

The environment was much more complex farther north across the Upstate of South Carolina and foothills of North Carolina. Initial precipitation falling into the dry air north of the warm front evaporated and cooled the air. This allowed a common feature known as Cold Air Damming (CAD) to develop where the mountains act as a dam with low-level cold air pooled up against them. The presence of CAD resulted in a very sharp temperature and moisture difference along the warm front that separated the cool and stable CAD air from the warmer air on the south side of the warm front (Fig. 8). The warm front was able to slowly lift north through the morning hours as the CAD gradually dissipated.

At 1207 pm, 20 minutes before the tornado impacted the area, the warm front was located between Hickory, North Carolina and Statesville, North Carolina. Two personal weather stations located near the tornado were used to further refine the location of the warm frontal boundary. Observations from a weather station in Claremont depicted this location to be on the cool and stable side of the warm front, with northeast winds and temperature and dewpoint in the upper 40s °F (Table 1). Another weather station near Catawba was on the warm side of the front with the warm frontal passage noted between 1130-1135 am, with winds shifting to out of the southeast and temperature and dewpoint rising into the mid 50s °F (Table 2). Based on these observations, the warm front was more precisely located between Claremont and Catawba. The tornado track, when overlaid on a map showing the location of the personal weather stations, suggested the tornado occurred either right along or just barely south of the warm frontal boundary (Fig. 9).

Intense wind fields allowed for extreme values of wind shear, which is a necessary ingredient for the development of organized severe weather. At the time of the tornado, low-level wind shear was assessed to be around 60 kts (Fig. 10). Low level wind shear of 30 kts or more is typically considered to be favorable for tornadoes.

In addition to wind shear, forecasters must also consider how much instability is present in the atmosphere. Instability, or “thunderstorm fuel”, is a measure of the tendency for air to rise vertically in the atmosphere and is expressed in units of energy (J/kg). Values of 500 J/kg and greater are generally considered favorable for severe weather. Instability was much more limited, however, and struggled to make northward progress with 100 J/kg analyzed near Columbia, South Carolina (Fig. 11). Also available during the event was temperature, dewpoint and wind data collected by commercial aircraft ascending and descending at Charlotte Douglas International Airport (KCLT). Data was transmitted through the Aircraft Communication Addressing and Reporting System (ACARS) and plotted in a traditional SkewT, log-P sounding, which shows the vertical profile of the atmosphere. The 1220 pm KCLT ACARS sounding (Fig. 12) was heavily referenced by forecasters during the event. The sounding supported the wind shear analysis with 58 kts of low-level shear. The temperature profile (red line in Fig. 12) also depicted a deep constant temperature layer extending from the surface to just above 850 mb where a notable temperature inversion was in place. The temperature inversion, where temperatures briefly increase with height, acts as a lid on the atmosphere that prevents the development of thunderstorms from the surface. Of note, though, is that 70 J/kg of instability was sampled within the constant temperature layer beneath the temperature inversion. The KCLT observation at 1218 pm had a temperature of 60° F and a dewpoint of 57° F, which was a 5° F warmer temperature and 2° F higher dewpoint compared to the Catawba personal weather station. Thus, it can be assumed that any instability extending farther north into Catawba County was likely less than the 70 J/kg noted on the KCLT ACARS sounding.

Such environments are commonly characterized as high-shear, low-instability, which are commonly found during the winter in the southeastern United States. These environments are a challenge for forecasters as conventional techniques for forecasting significant severe weather typically perform poorly and severe weather can occur with little to no lightning. These environments are also traditionally characterized by instability less than 500 J/kg and wind shear greater than 35 kts. This event far exceeded these thresholds and practically falls into a category of its own with extreme wind shear and minuscule instability.

3. Radar Analysis

The FAA Terminal Doppler Weather Radar on the northwest side of Charlotte (the TCLT radar) had the best viewing angle of the line of storms and was the primary radar used to investigate the thunderstorms (Fig. 13). A narrow and shallow line of thunderstorms was approaching the southwest corner of Catawba County at 1201 pm (Fig. 14). Surface observations at 1200 pm (not shown) indicated that the line of storms was elevated above the CAD inversion layer with cool stable air located beneath the storms. In these situations, damaging winds and tornadoes are typically unable to develop due to the stable air beneath the storms.

At 1222 pm, five minutes prior to the tornado touching down, TCLT continued to depict poor storm structure with a narrow and shallow line of storms (Fig. 15). Of note, however, was the velocity data with broad rotation noted over south central Catawba County (Fig. 16). Three minutes later, at 1225 pm (two minutes before the tornado), the area of rotation began to tighten northeast of Maiden with a more defined rotation signature present (Fig. 17). By 1227 pm, at the time the tornado touched down, rotation persisted south of Claremont, but a stronger rotation signature indicative of a possible tornado was not yet present (Fig. 18). While hard to decipher, a more notable strong rotation signature was apparent at 1229 pm as the tornado was ongoing (Fig. 19). This signature persisted for two minutes at 1230 pm and 1231 pm (Figs. 20 and 21) before the tornado dissipated.

4. Discussion

A line of storms moved within a high-shear and low-instability environment across the foothills and western Piedmont of North Carolina. However, the northern extent of instability was in question. Real-time analysis determined that the environment over northern Catawba County was not favorable for tornadoes owing to a lack of instability and poor temperature profiles noted on the KCLT ACARS sounding. Furthermore, poor radar structure of the line and a lack of wind damage reports contributed to the warning decision process, and eventually the decision to not issue a tornado warning. How tornadoes form within a line of storms, radar signatures commonly associated with line-embedded tornadoes, and how these factors played into the warning decision process will be discussed in the following section. Several hypotheses are also presented for how the tornado was able to occur in an otherwise unfavorable environment.

a. Tornado Formation Mechanisms, Radar Signatures Associated with Line-Embedded Tornadoes, and the Warning Decision Process

It is important for forecasters to understand the tornado formation process and what role the environment plays, especially in terms of instability. Small-scale areas of rotation embedded within lines of storms are responsible for the production of line-embedded tornadoes. These tornadoes often occur rapidly with an average lead time of approximately five minutes. Small-scale areas of rotation are formed as horizontal rotation from wind shear is tilted vertically and then stretched by instability along the leading edge of lines of storms.

The environment during the Claremont Tornado was assessed to have more than sufficient wind shear for storm organization. The main uncertainty was whether there was sufficient instability to tilt and stretch areas of horizontal rotation that would lead to the development of tornadoes within the line. Analysis of the environment did not indicate the presence of instability across Catawba County. The KCLT ACARS sounding provided the best depiction of the environment with reliable real time data. As previously noted, 70 J/kg of instability was sampled on the 1220 pm ACARS sounding. While some degree of instability may have extended into Catawba County, it was likely less than the 70 J/kg observed on the ACARS sounding. Furthermore, forecaster analysis during the event determined that the constant temperature profile and temperature inversion would be detrimental to instability needed to effectively tilt and stretch horizontal rotation within the line and produce tornadoes.

Radar signatures also play a prominent role in the warning decision process. National Weather Service forecasters frequently utilize a robust multi-step ingredients based approach in order to anticipate the development of line-embedded tornadoes. This approach involves the assessment of common radar signatures such as surges/bows in the line, breaks in the line, and appendages on the leading edge of the line along with the strength and orientation of the wind shear. The number of common radar signatures that are present in conjunction with an assessment of the environment provides forecasters with a guide as to the potential for tornadoes to develop within a line of storms. For this event, multiple radar signatures that typically serve as a precursor to line-embedded tornadoes were not present.

Forecasters incorporated both the local environment and radar signatures into their analysis and warning decision process during the event. The decision not to issue a tornado warning for the line of storms was ultimately based on the lack of instability needed to tilt and stretch horizontal rotation, poor temperature profiles sampled in the KCLT ACARS sounding, and the lack of common radar signatures frequently associated with line-embedded tornadoes. Furthermore, storms were moving exceptionally fast at 74 mph with the tornado formation process happening rapidly in a matter of five minutes or less, leaving forecasters with very little time to quickly assess an extremely challenging warning environment. The line of storms also extended through southern portions of the NWS GSP office’s area of responsibility, forcing forecasters to interrogate numerous other segments of the line in addition to the portion that produced the Claremont Tornado.

b. Hypotheses for Tornadic Development

It is imperative to investigate how a tornado is able to develop in what appears to be an unfavorable environment for tornado formation. Understanding what allowed this tornado to form will help forecasters better anticipate such low predictability events in the future. The formation of the Claremont Tornado appears to have been governed by subtle local and storm-scale features. Identifying these features and how they support tornado formation will help refine the process for anticipating line-embedded tornadoes. The authors hypothesize that a combination of relatively small local changes in the environment not captured by available model guidance or analysis, influence from the nearby warm front, and storm-scale processes all contributed to the tornadogenesis process. The following subsections will discuss each of these factors in greater detail. It is important to note that these are just hypotheses and limited observational data from near the storm prevents knowing exactly how the tornado was able to develop.

(i) Subtle Changes in the Local Environment and Storm-Scale Processes

The KCLT ACARS sounding was heavily referenced during the event and was the most accurate depiction of the atmospheric profile available. Thus, it will be used as the starting point and primary reference for how small local environmental changes and storm-scale processes may have influenced the temperature profile and available instability. Any increase in instability would have been driven by an increase in surface dewpoint and/or removal of the temperature inversion through local storm-scale processes. There were subtle differences between forecaster analysis, model guidance, and the observed environment that likely contributed to a subtle unexpected increase in instability over Catawba County. Based on the ACARS temperature profile, any instability that was present at the time of the Claremont Tornado would have been focused in the lowest levels of the atmosphere. However, elevated instability above the temperature inversion cannot be ignored. Storm-scale processes may have proven sufficient to locally erode the temperature inversion and allow the line of storms to tap into more favorable temperature profiles aloft, thus yielding more instability than anticipated.

(ii) Warm Frontal Influence and Large-Scale Contributions

In addition, the very close proximity of the warm front to the tornado track likely played a key role in enhancing the near-storm environment to be more favorable for tornado formation. Surface observations at 1200pm (Fig. 22) indicated a very sharp change in temperature and dewpoint across the warm front separating the cold stable CAD air from the warm sector. This supported a deeper layer of moist air with a local maximum in surface dewpoints along the warm front.

Based on the subtle changes in the environment discussed in the subsections above, the overarching hypothesis for the formation of the Claremont Tornado is as follows.

A line of thunderstorms moved from the Upstate of South Carolina northeast into the foothills of western North Carolina. Initially, these storms were elevated above cold and stable CAD air, but approached the warm front and warm sector which was in place over the eastern third of Catawba County. Forecaster analysis and model guidance both underestimated the temperature and dewpoint in the warm sector by several degrees. Increased moisture along the warm front contributed to a narrow swath of locally higher moisture that extended into northeast Catawba County. The increase in moisture had implications on the available instability, which while limited, was non-zero. While only 70 J/kg of instability was sampled on the KCLT ACARS, local storm-scale processes were likely able to overcome the temperature inversion and tap into elevated instability aloft. Exactly how much instability was realized across Catawba County remains uncertain, but apparently there was sufficient instability to support the development of a tornado. As the line of storms crossed the warm front it encountered this favorable environment. The tornado developed very rapidly as the line of storms crossed the narrow moisture swath.

5. Summary and Recommendations

A powerful storm system impacted northeast Georgia and the Carolinas on January 9th, 2024. A line of thunderstorms, some of which were severe, moved across the Upstate of South Carolina and into the foothills of western North Carolina during the morning to early afternoon hours. A deadly EF-1 tornado occurred in the Claremont, North Carolina, community north of the tornado watch that was in effect and in the absence of a tornado warning. The tornado occurred in an unusual environment characterized by extreme values of wind shear and what was assessed to be little to no instability. Traditional forecaster analysis and radar interrogation techniques determined that the environment was not supportive for the development of tornadoes. Storms were also moving very fast with the tornado formation process occurring rapidly over five minutes or less. This created an extremely challenging warning environment for even the most experienced forecasters.

Post-event review determined that model analysis underestimated a narrow, weakly unstable swath of increased moisture against a warm front separating cool and stable CAD air from the warm sector. This was supported by the KCLT ACARS sounding which sampled small amounts of instability along with elevated instability above a temperature inversion. A hypothesis for the development of the tornado is that a portion of the line of storms crossed the warm front with local storm-scale processes removing the temperature inversion and tapping into higher values of instability aloft with a subsequent tornado rapidly developing. Rapidly developing tornadoes embedded in lines of storms in such marginal environments present one of the most challenging warning scenarios a forecaster may ever be faced with. Historically, these rapidly developing line-embedded tornadoes are only warned 30% of the time, thus presenting an area needing additional research and improvement.

Several recommendations are identified that can be implemented into severe weather operations. It is highly recommended that forecasters compare observations to model analysis fields and identify any errors that may be present. This is especially key in high-shear, low-instability environments where even 40-50 J/kg of instability can make a difference between tornadic and non-tornadic thunderstorms. Identifying exact locations of fronts is also imperative with a focus on lines of storms that cross the front. From a radar/warning perspective it is also recommended to err on the side of caution in unusual environments when instability is in question. Tornado warnings should not be issued well into the stable CAD air, but if the storm is no longer elevated above the temperature inversion and is near/crossing a warm front, a tornado warning should be issued if the mechanisms are present for tornadoes to develop despite uncertainty regarding temperature profiles.

Given limited near-storm observational data, the hypothesis for tornadic development presented by the authors cannot be confirmed at this time. As such, future work will focus on collaborating with a university to pursue high-resolution modeling of the line of storms in order to verify what mechanisms allowed for tornadogenesis and the validity of the hypothesis.

6. Figures and Tables

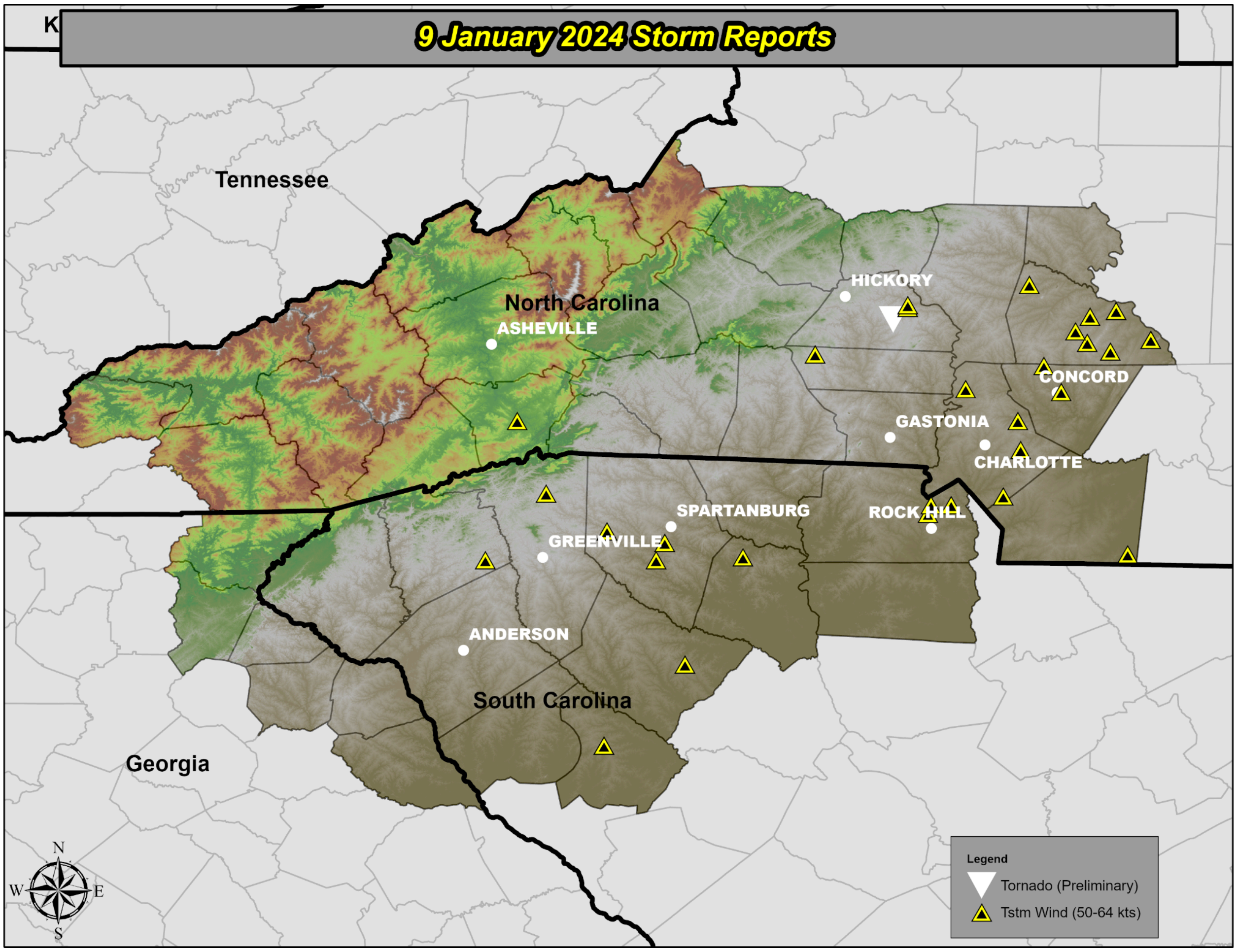
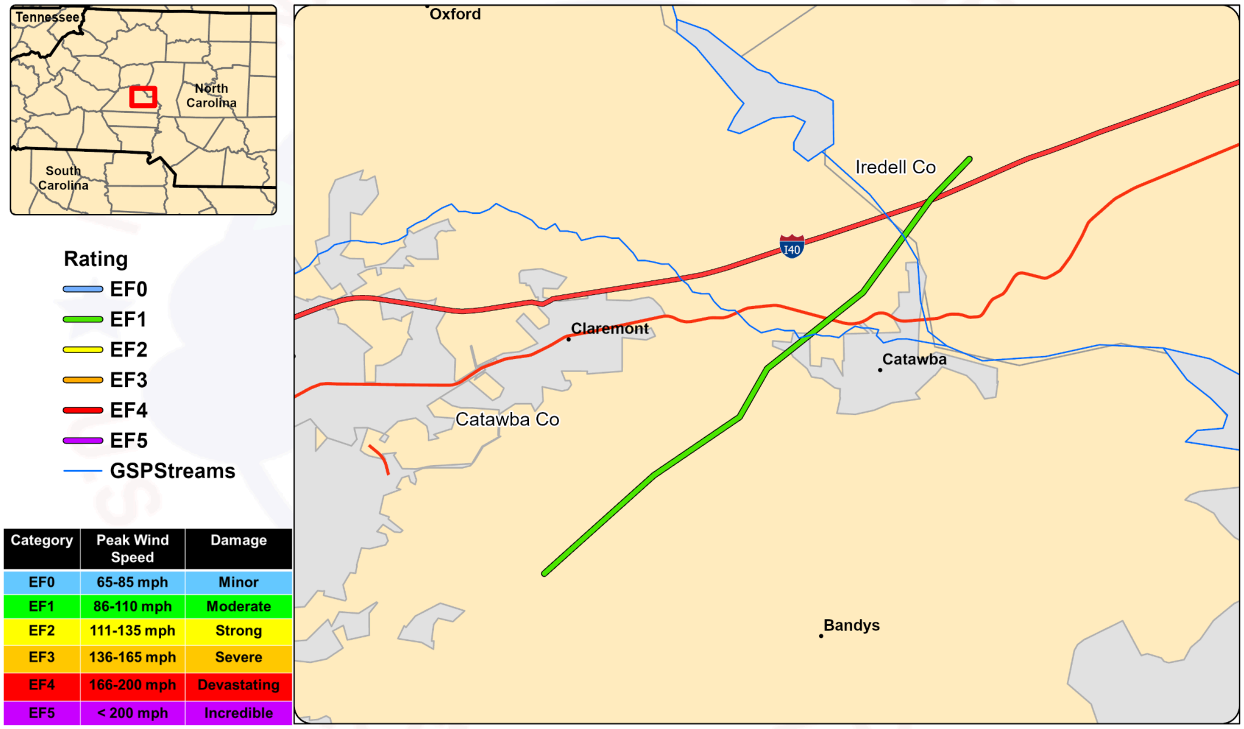


Fig. 1. Local storm reports received for the 24-hour period from 700 am on 9 January to 700 am on 10 January 2024 (NWS Storm Prediction Center). The white upside-down triangle denotes the start of the Claremont Tornado track. Black and yellow triangles show locations of wind damage reports.

9 Jan 2024 Claremont, NC Tornado Path



Category	Peak Wind Speed	Damage
EF0	65-85 mph	Minor
EF1	86-110 mph	Moderate
EF2	111-135 mph	Strong
EF3	136-165 mph	Severe
EF4	166-200 mph	Devastating
EF5	< 200 mph	Incredible

Fig. 2. Path of the Claremont Tornado (thick green line) across eastern Catawba and western Iredell counties on 9 January 2024.

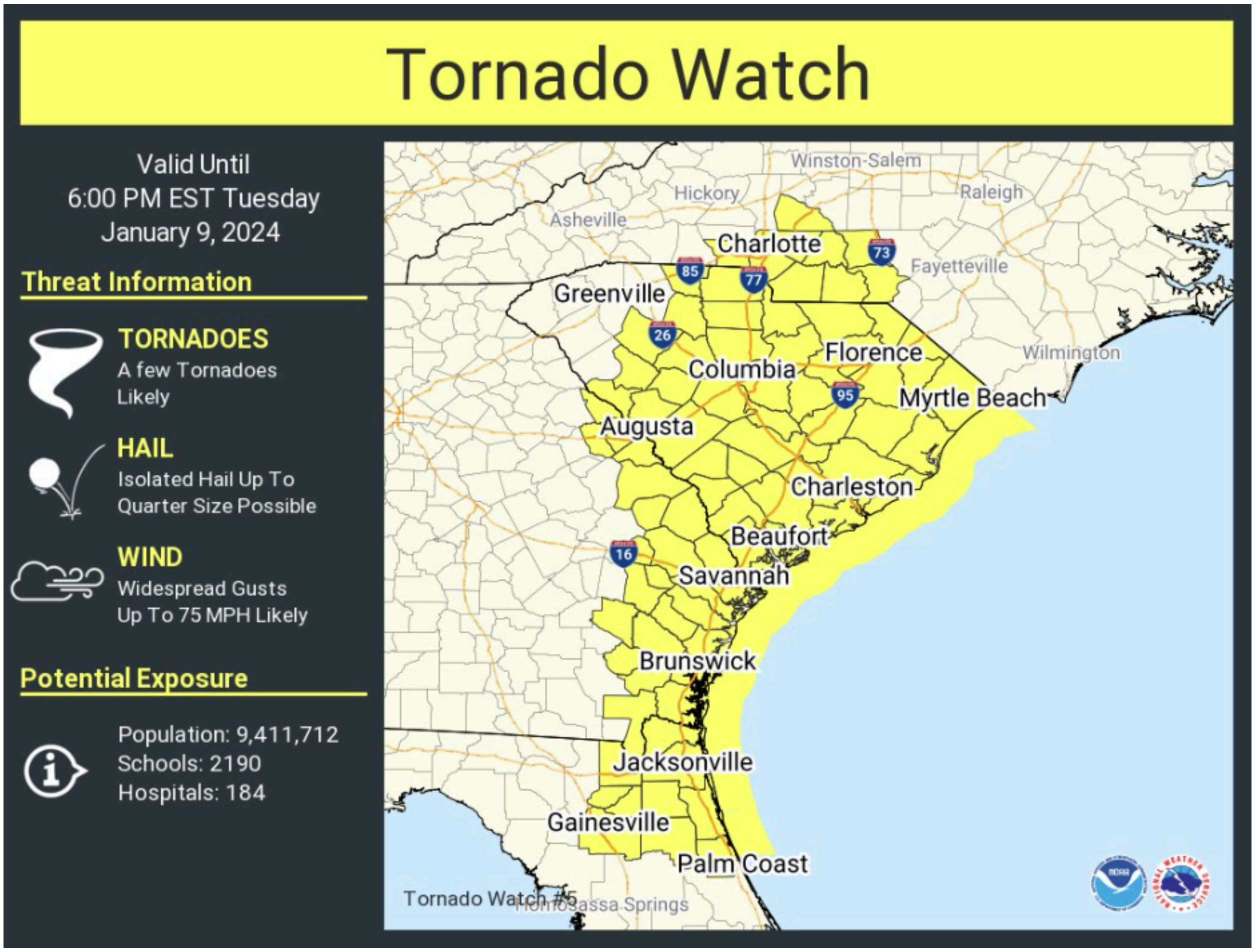


Fig. 3. Tornado Watch (#5) issued by the Storm Prediction Center at 1140 am valid until 600 pm on 9 January 2024. Counties included in the Tornado Watch are highlighted in yellow.

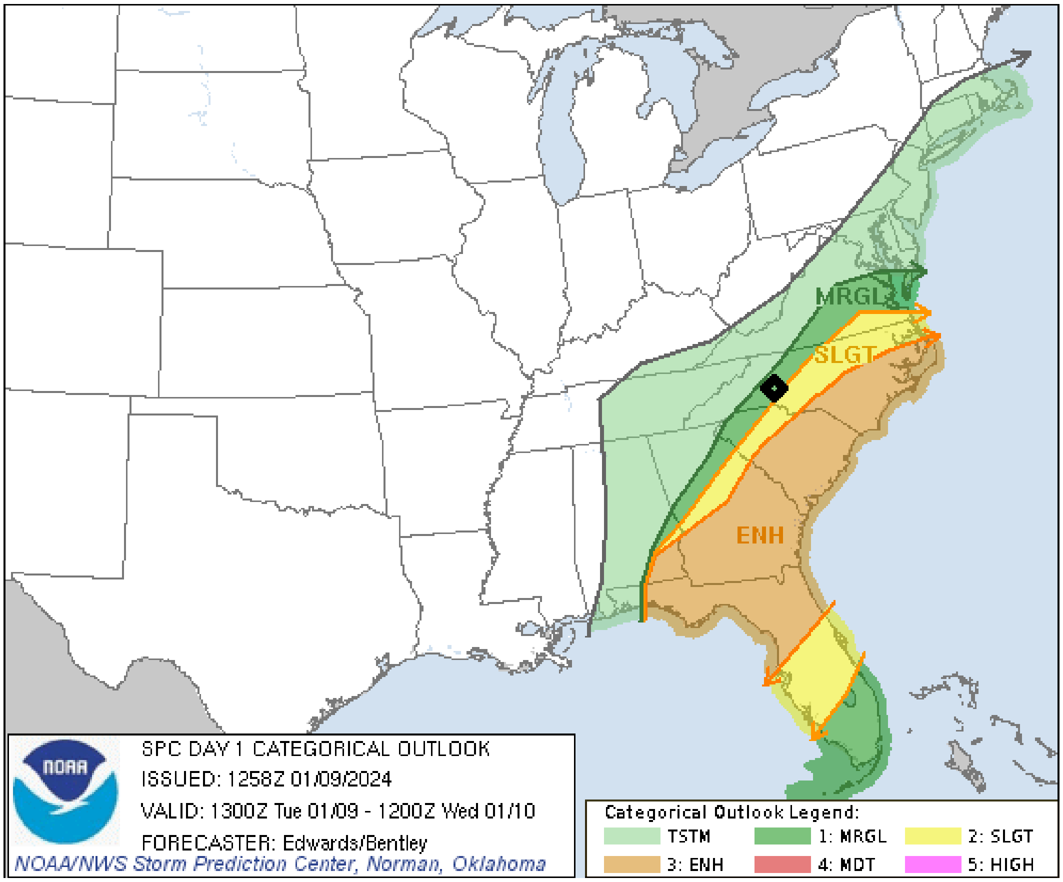


Fig. 4. Day 1 Convective Outlook issued by the Storm Prediction Center at 758 am on 9 January 2024 for the period 1300 UTC on 9 January to 700 am on 10 January. The black diamond indicates the approximate location of the Claremont Tornado. Risk categories given according to the legend at the lower right of the figure.

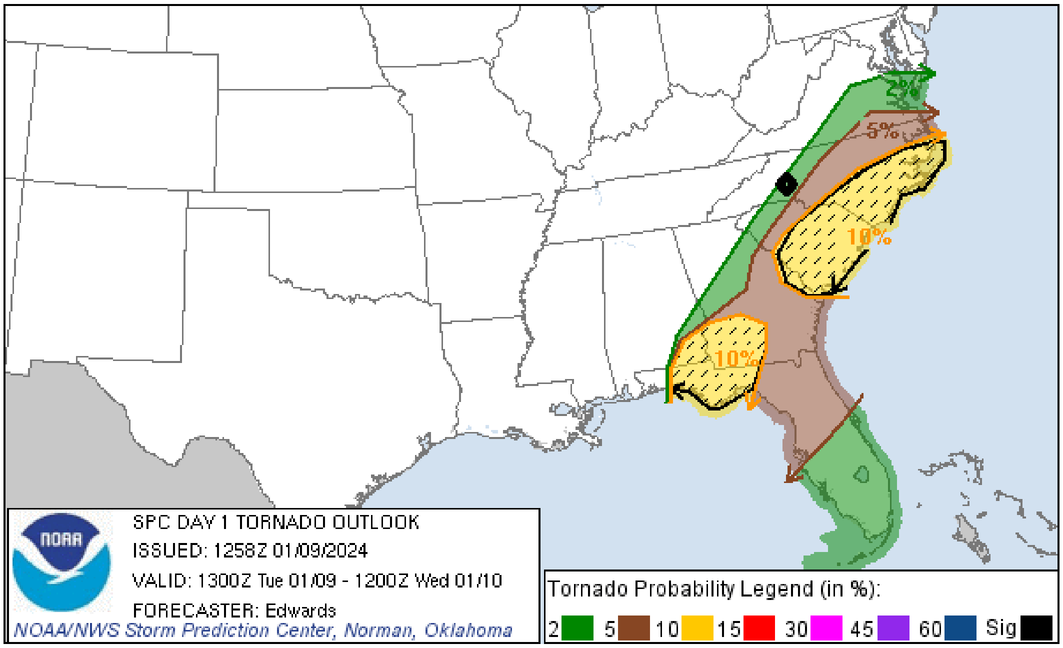


Fig. 5. Tornado probabilities on the Day 1 Convective Outlook issued by the Storm Prediction Center at 758 am on 9 January 2024, for the period 800 am on 9 January to 700 amC on 10 January. Hatched areas denote the possibility of a significant tornado (damage EF-2 or greater).

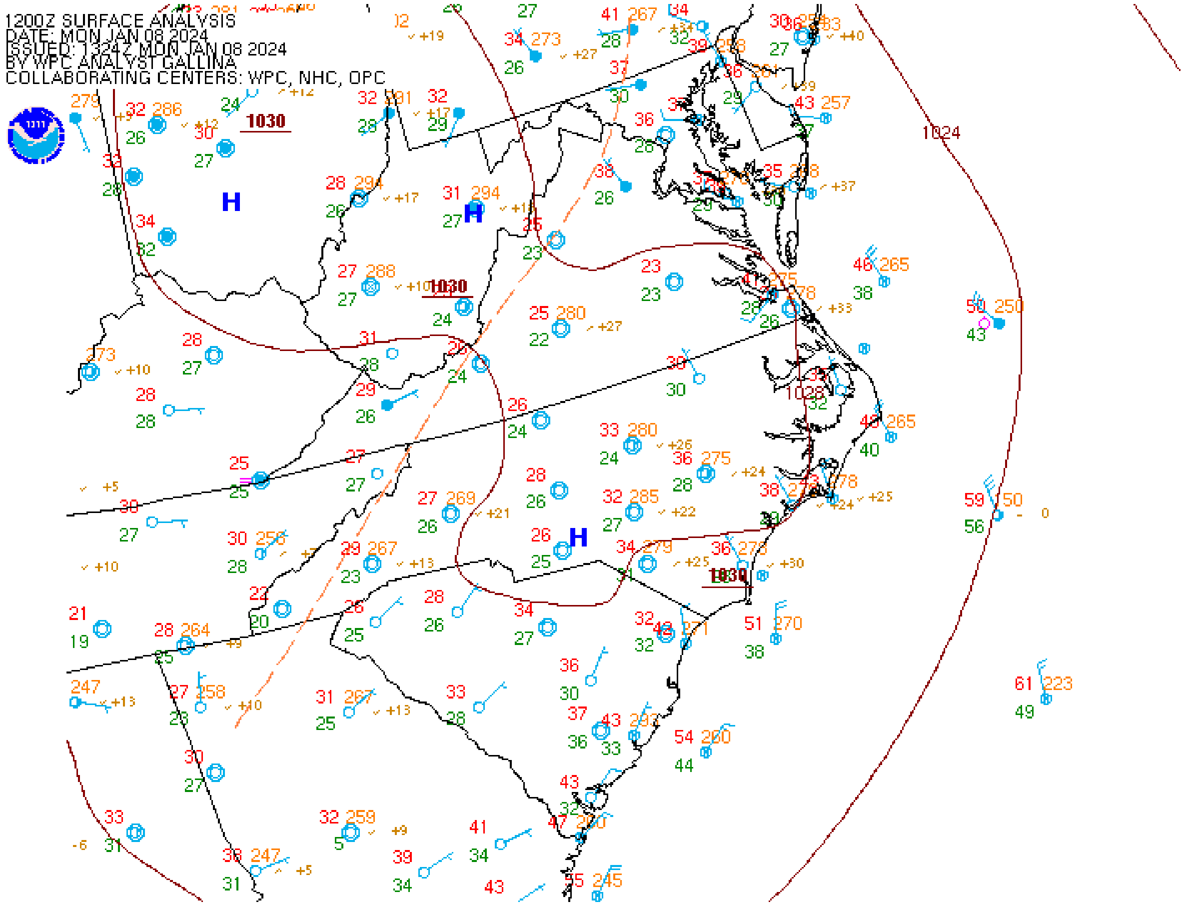


Fig. 6. Weather Prediction Center surface analysis of sea level pressure (mb, brown contours), pressure centers, and fronts at 700 am on 8 January 2024. Select surface observations are indicated according to the traditional station model.

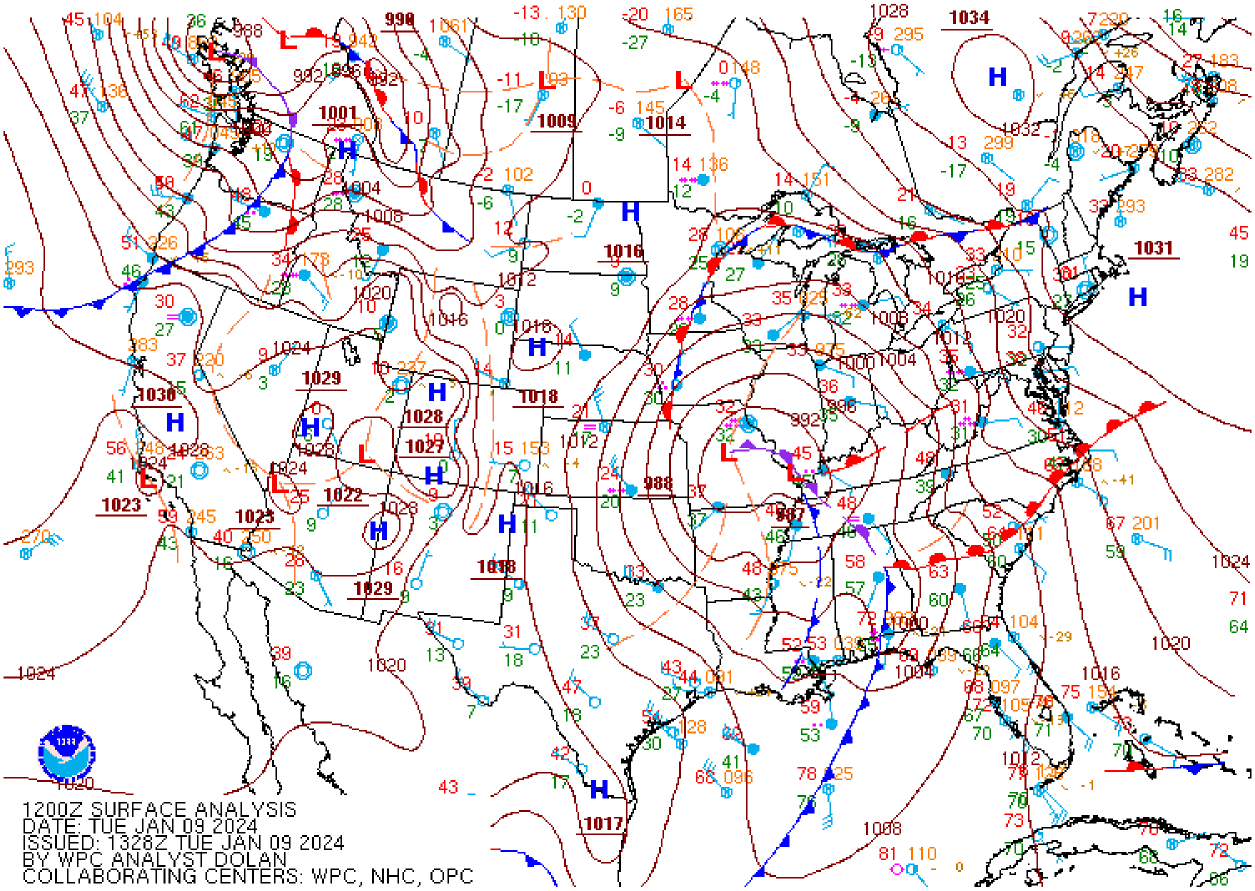


Fig. 7. As in Fig. 6, except for 0700 am on 9 January 2024.

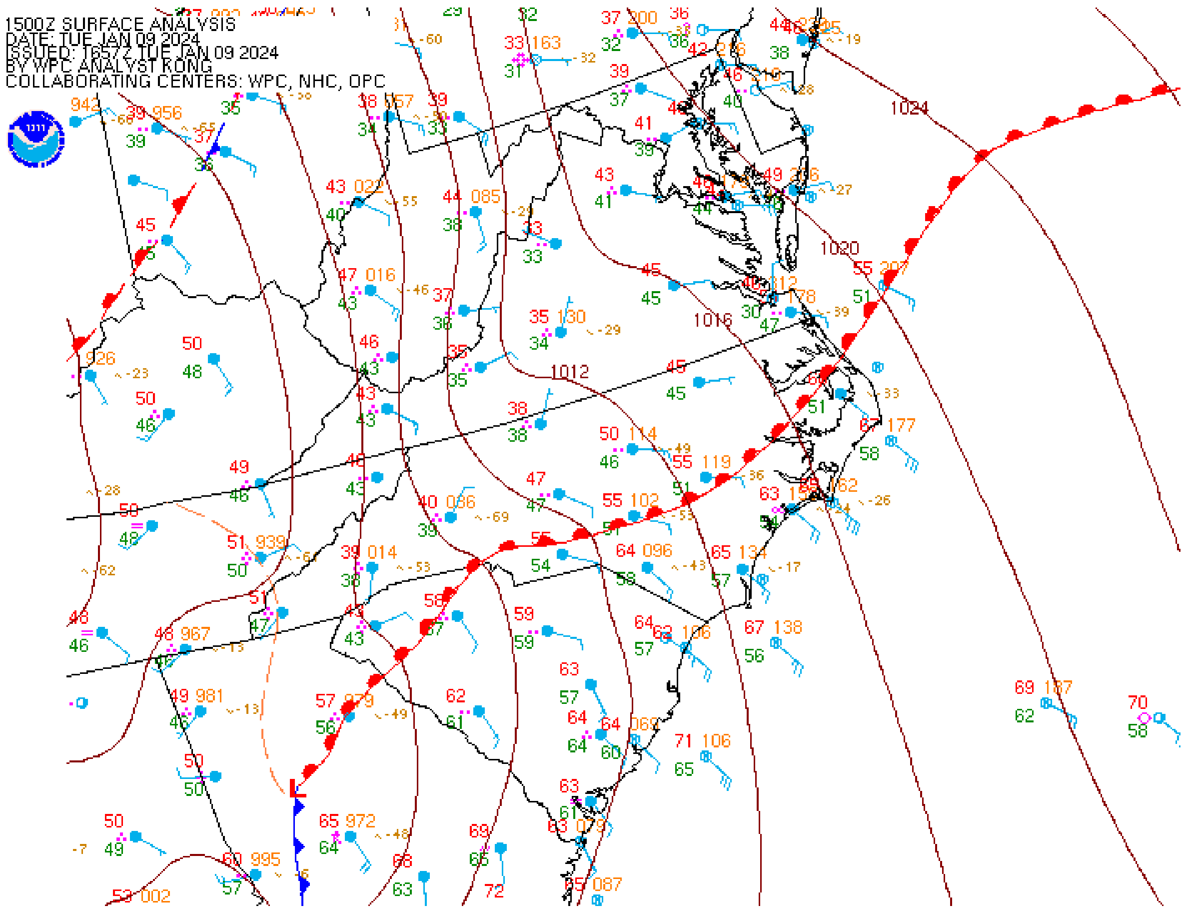
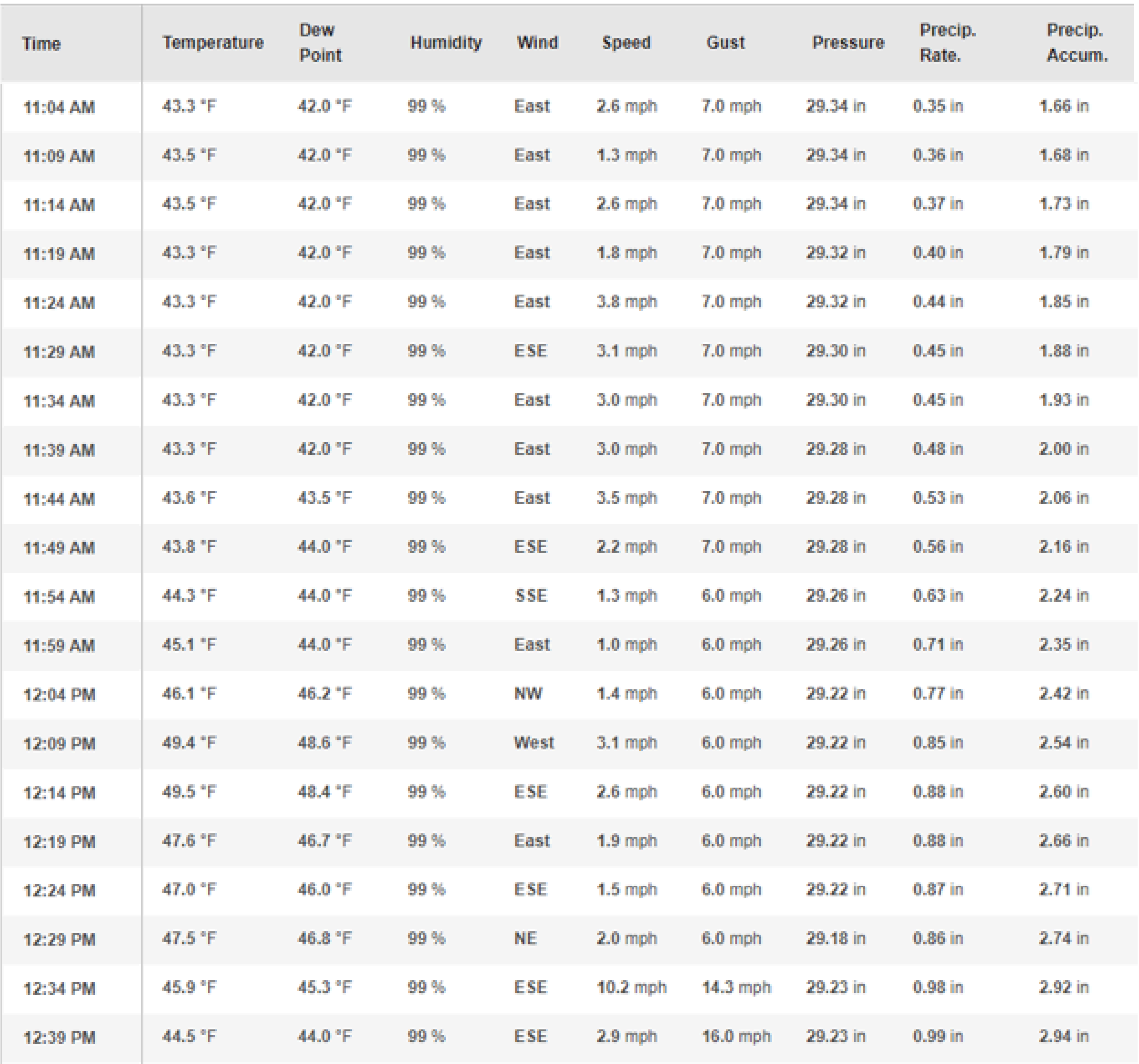


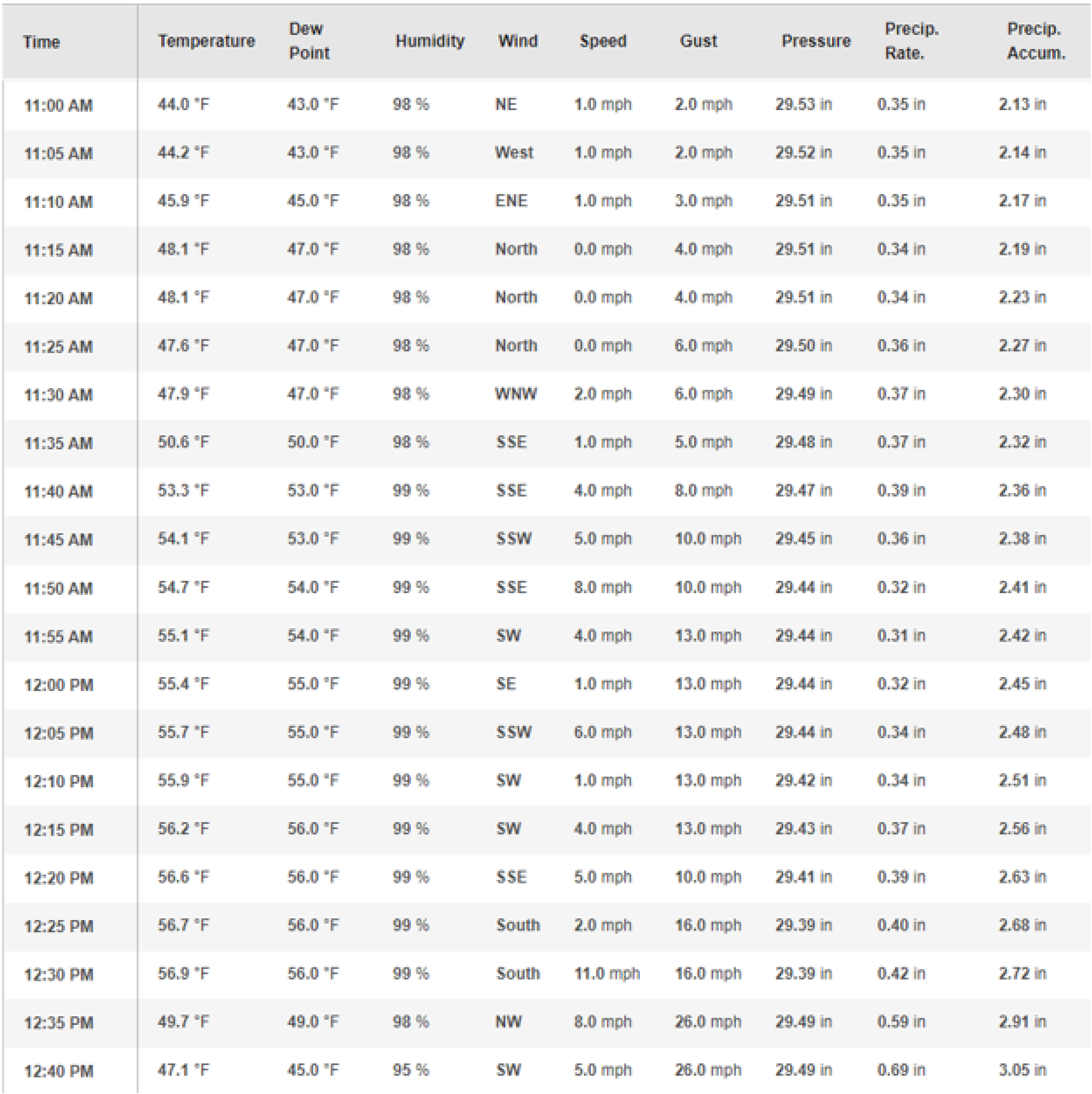
Fig. 8. As in Fig. 6, except for 1000 am on 9 January 2024.

Table 1. Five minute observations from Claremont, NC.



Time	Temperature	Dew Point	Humidity	Wind	Speed	Gust	Pressure	Precip. Rate.	Precip. Accum.
11:04 AM	43.3 °F	42.0 °F	99 %	East	2.6 mph	7.0 mph	29.34 in	0.35 in	1.66 in
11:09 AM	43.5 °F	42.0 °F	99 %	East	1.3 mph	7.0 mph	29.34 in	0.36 in	1.68 in
11:14 AM	43.5 °F	42.0 °F	99 %	East	2.6 mph	7.0 mph	29.34 in	0.37 in	1.73 in
11:19 AM	43.3 °F	42.0 °F	99 %	East	1.8 mph	7.0 mph	29.32 in	0.40 in	1.79 in
11:24 AM	43.3 °F	42.0 °F	99 %	East	3.8 mph	7.0 mph	29.32 in	0.44 in	1.85 in
11:29 AM	43.3 °F	42.0 °F	99 %	ESE	3.1 mph	7.0 mph	29.30 in	0.45 in	1.88 in
11:34 AM	43.3 °F	42.0 °F	99 %	East	3.0 mph	7.0 mph	29.30 in	0.45 in	1.93 in
11:39 AM	43.3 °F	42.0 °F	99 %	East	3.0 mph	7.0 mph	29.28 in	0.48 in	2.00 in
11:44 AM	43.6 °F	43.5 °F	99 %	East	3.5 mph	7.0 mph	29.28 in	0.53 in	2.06 in
11:49 AM	43.8 °F	44.0 °F	99 %	ESE	2.2 mph	7.0 mph	29.28 in	0.56 in	2.16 in
11:54 AM	44.3 °F	44.0 °F	99 %	SSE	1.3 mph	6.0 mph	29.26 in	0.63 in	2.24 in
11:59 AM	45.1 °F	44.0 °F	99 %	East	1.0 mph	6.0 mph	29.26 in	0.71 in	2.35 in
12:04 PM	46.1 °F	46.2 °F	99 %	NW	1.4 mph	6.0 mph	29.22 in	0.77 in	2.42 in
12:09 PM	49.4 °F	48.6 °F	99 %	West	3.1 mph	6.0 mph	29.22 in	0.85 in	2.54 in
12:14 PM	49.5 °F	48.4 °F	99 %	ESE	2.6 mph	6.0 mph	29.22 in	0.88 in	2.60 in
12:19 PM	47.6 °F	46.7 °F	99 %	East	1.9 mph	6.0 mph	29.22 in	0.88 in	2.66 in
12:24 PM	47.0 °F	46.0 °F	99 %	ESE	1.5 mph	6.0 mph	29.22 in	0.87 in	2.71 in
12:29 PM	47.5 °F	46.8 °F	99 %	NE	2.0 mph	6.0 mph	29.18 in	0.86 in	2.74 in
12:34 PM	45.9 °F	45.3 °F	99 %	ESE	10.2 mph	14.3 mph	29.23 in	0.98 in	2.92 in
12:39 PM	44.5 °F	44.0 °F	99 %	ESE	2.9 mph	16.0 mph	29.23 in	0.99 in	2.94 in

Table 2. Five minute observations from just south of Catawba, NC. The warm front lifted through this location between 1630-1635 UTC (1130-1135 AM EST).



Time	Temperature	Dew Point	Humidity	Wind	Speed	Gust	Pressure	Precip. Rate.	Precip. Accum.
11:00 AM	44.0 °F	43.0 °F	98 %	NE	1.0 mph	2.0 mph	29.53 in	0.35 in	2.13 in
11:05 AM	44.2 °F	43.0 °F	98 %	West	1.0 mph	2.0 mph	29.52 in	0.35 in	2.14 in
11:10 AM	45.9 °F	45.0 °F	98 %	ENE	1.0 mph	3.0 mph	29.51 in	0.35 in	2.17 in
11:15 AM	48.1 °F	47.0 °F	98 %	North	0.0 mph	4.0 mph	29.51 in	0.34 in	2.19 in
11:20 AM	48.1 °F	47.0 °F	98 %	North	0.0 mph	4.0 mph	29.51 in	0.34 in	2.23 in
11:25 AM	47.6 °F	47.0 °F	98 %	North	0.0 mph	6.0 mph	29.50 in	0.36 in	2.27 in
11:30 AM	47.9 °F	47.0 °F	98 %	WNW	2.0 mph	6.0 mph	29.49 in	0.37 in	2.30 in
11:35 AM	50.6 °F	50.0 °F	98 %	SSE	1.0 mph	5.0 mph	29.48 in	0.37 in	2.32 in
11:40 AM	53.3 °F	53.0 °F	99 %	SSE	4.0 mph	8.0 mph	29.47 in	0.39 in	2.36 in
11:45 AM	54.1 °F	53.0 °F	99 %	SSW	5.0 mph	10.0 mph	29.45 in	0.36 in	2.38 in
11:50 AM	54.7 °F	54.0 °F	99 %	SSE	8.0 mph	10.0 mph	29.44 in	0.32 in	2.41 in
11:55 AM	55.1 °F	54.0 °F	99 %	SW	4.0 mph	13.0 mph	29.44 in	0.31 in	2.42 in
12:00 PM	55.4 °F	55.0 °F	99 %	SE	1.0 mph	13.0 mph	29.44 in	0.32 in	2.45 in
12:05 PM	55.7 °F	55.0 °F	99 %	SSW	6.0 mph	13.0 mph	29.44 in	0.34 in	2.48 in
12:10 PM	55.9 °F	55.0 °F	99 %	SW	1.0 mph	13.0 mph	29.42 in	0.34 in	2.51 in
12:15 PM	56.2 °F	56.0 °F	99 %	SW	4.0 mph	13.0 mph	29.43 in	0.37 in	2.56 in
12:20 PM	56.6 °F	56.0 °F	99 %	SSE	5.0 mph	10.0 mph	29.41 in	0.39 in	2.63 in
12:25 PM	56.7 °F	56.0 °F	99 %	South	2.0 mph	16.0 mph	29.39 in	0.40 in	2.68 in
12:30 PM	56.9 °F	56.0 °F	99 %	South	11.0 mph	16.0 mph	29.39 in	0.42 in	2.72 in
12:35 PM	49.7 °F	49.0 °F	98 %	NW	8.0 mph	26.0 mph	29.49 in	0.59 in	2.91 in
12:40 PM	47.1 °F	45.0 °F	95 %	SW	5.0 mph	26.0 mph	29.49 in	0.69 in	3.05 in

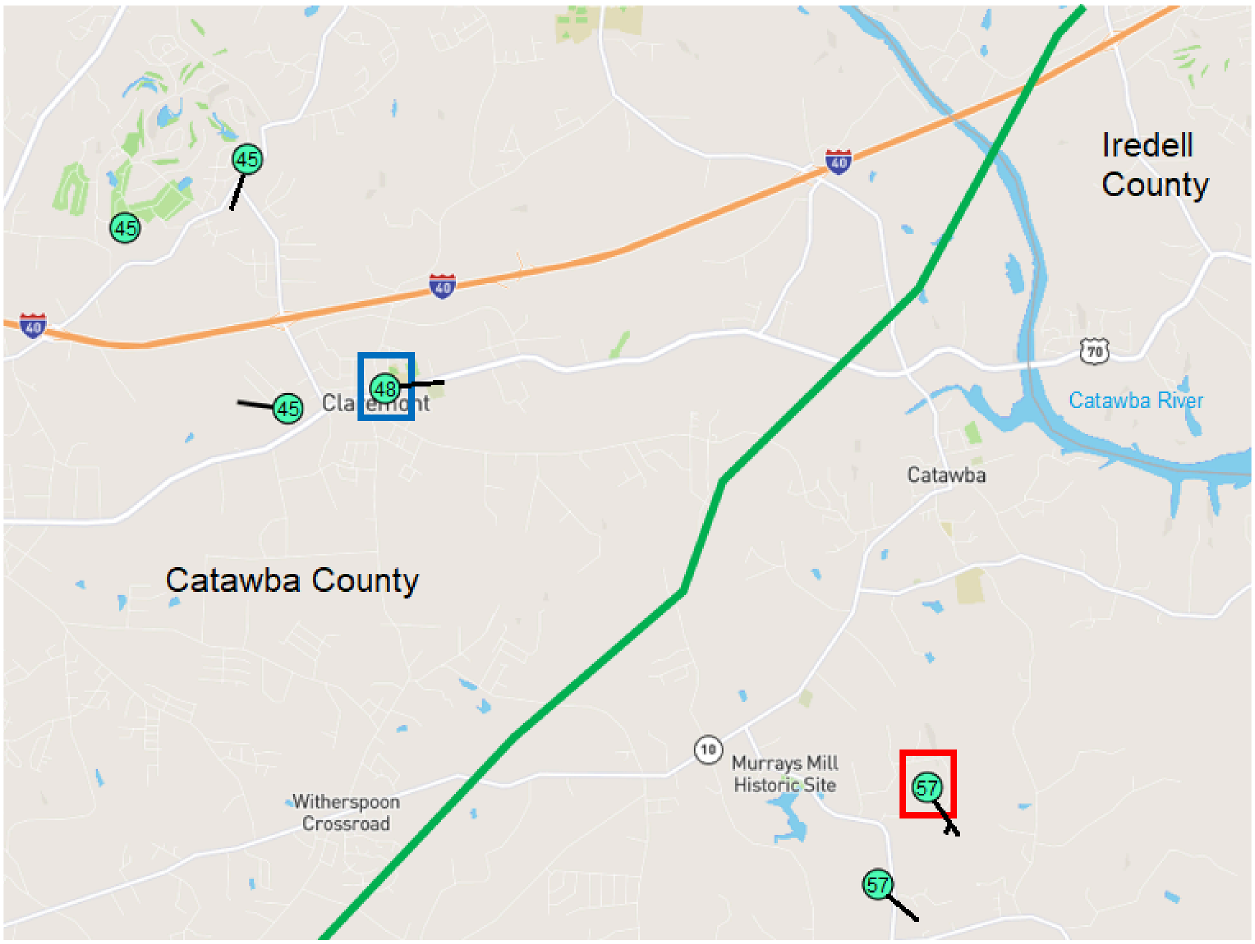


Fig. 9. Temperature (ºF) and wind (mph) from Weather Underground stations from 1215 pm to 1220 pm 9 January (observation time closest to the beginning time of the Claremont Tornado). The location of the Claremont weather station on the cool side of the warm front is shown by the blue box and the Catawba weather station on the warm side of the front is shown in the red box. The tornado track (green line) is also overlaid.

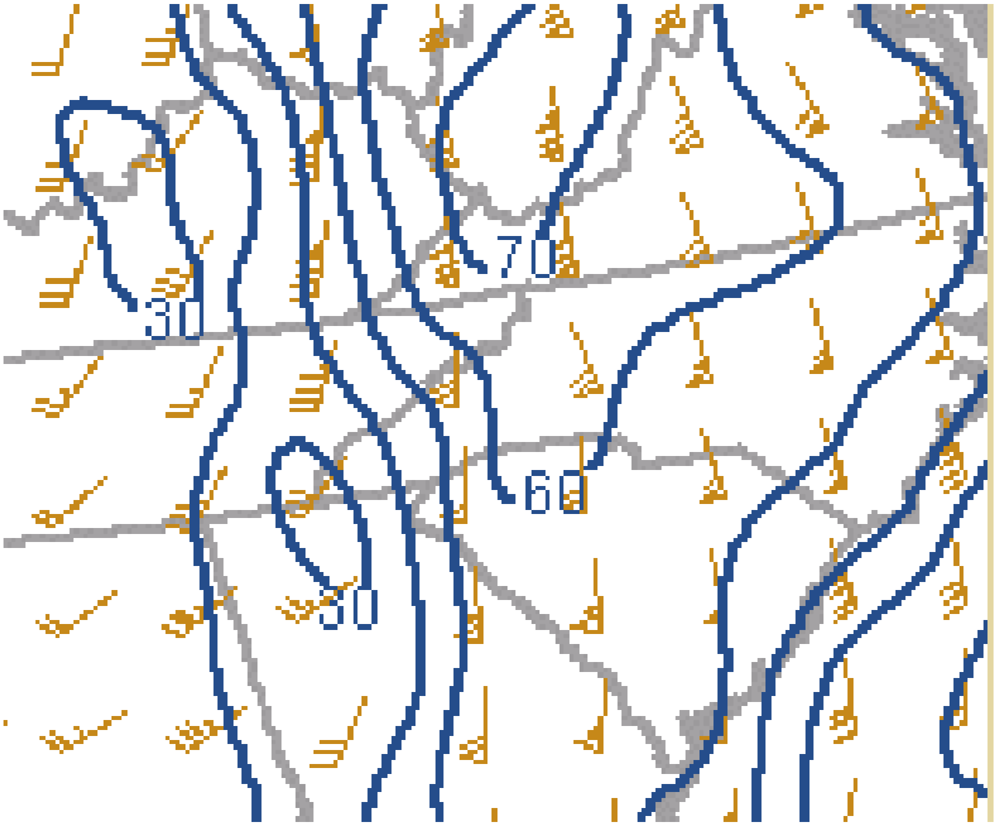


Fig. 10. SPC objective analysis of surface-to-1 km bulk shear (kt; dark blue contours) and shear vector (barbs) at 1200 pm 9 January.

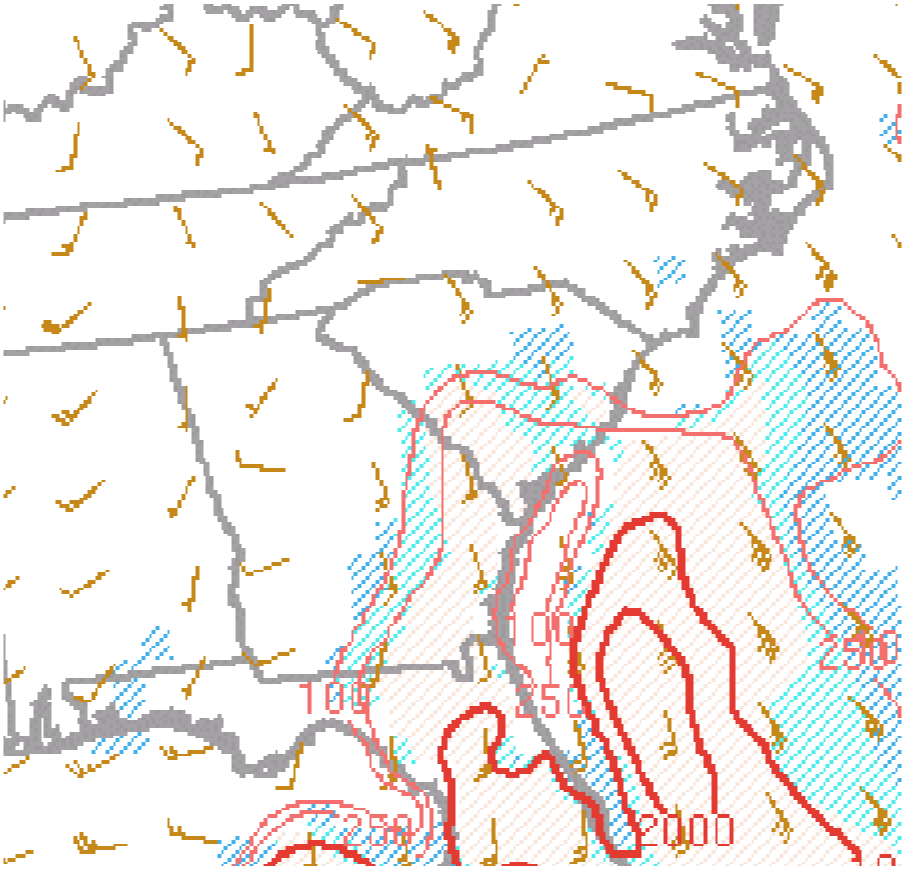


Fig. 11. SPC objective analysis of SBCAPE (J kg^{-1}; red contours) and surface-based convective inhibition (SBCIN, J kg^{-1}; cross hatching) at 1200 pm 9 January.

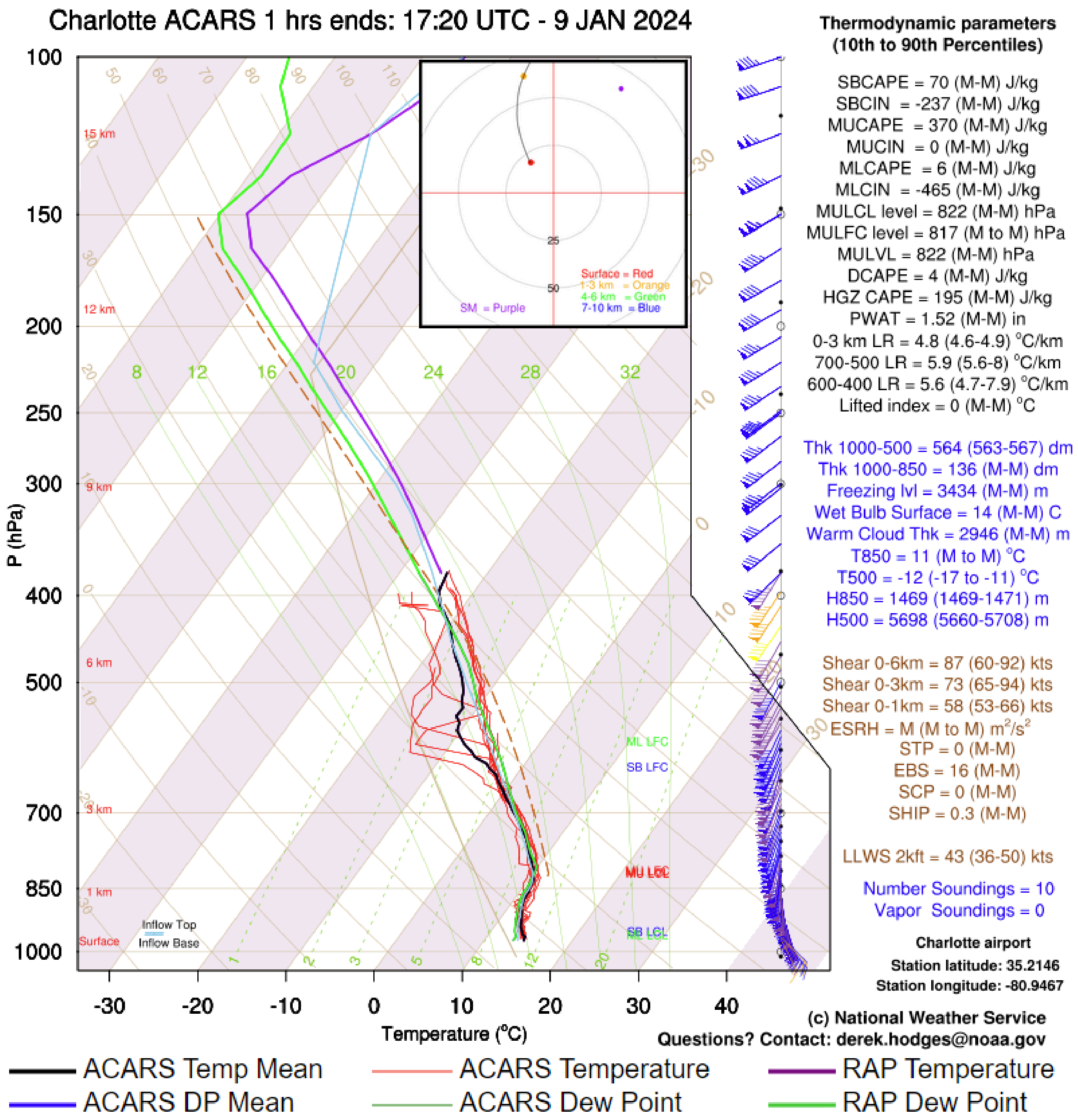


Fig. 12. ACARS sounding at KCLT at 1220 pm on 9 January.

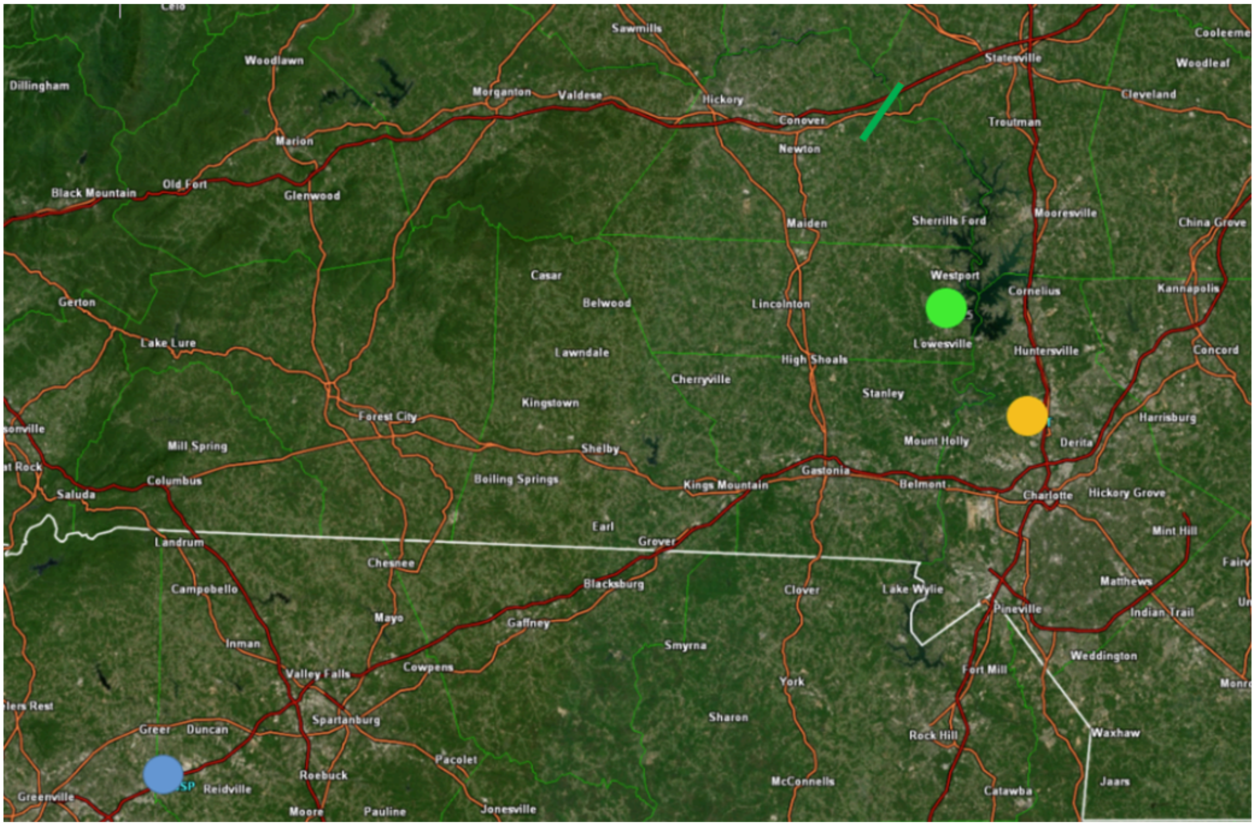


Fig. 13. Location of KGSP (blue circle), TCLT (orange circle), and V025 (green circle) in relation to the tornado track (green line).

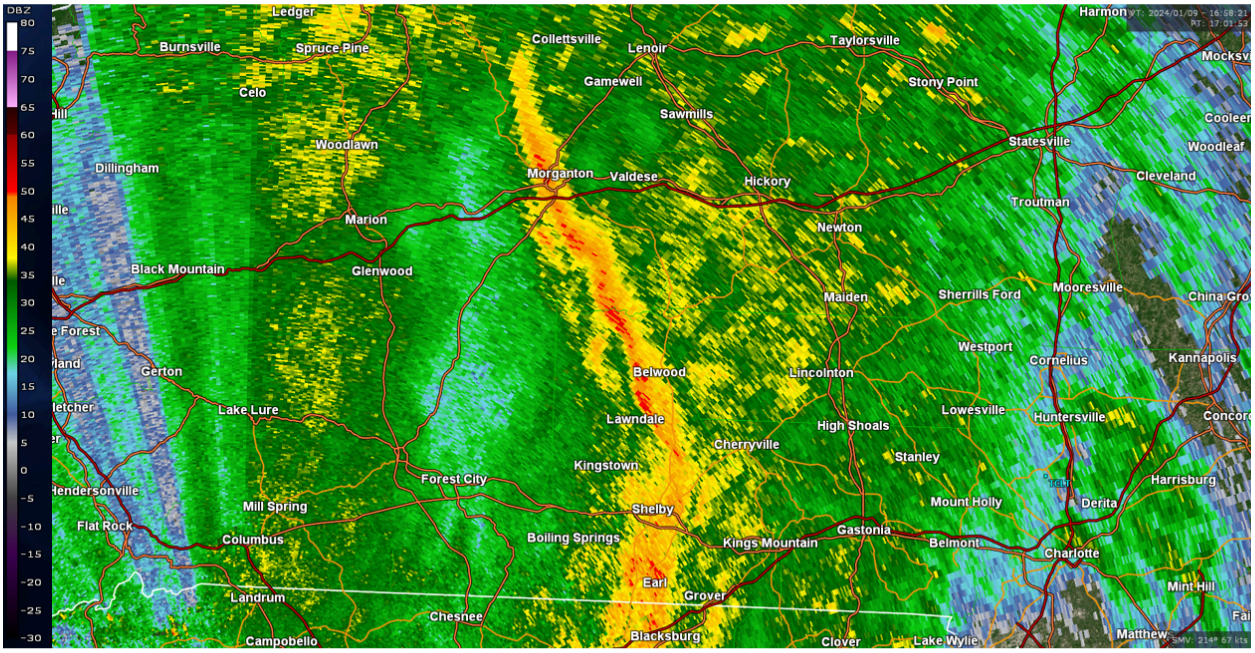


Fig. 14. Base reflectivity (dBZ; 0.2° scan) from KGSP at 1201 pm.

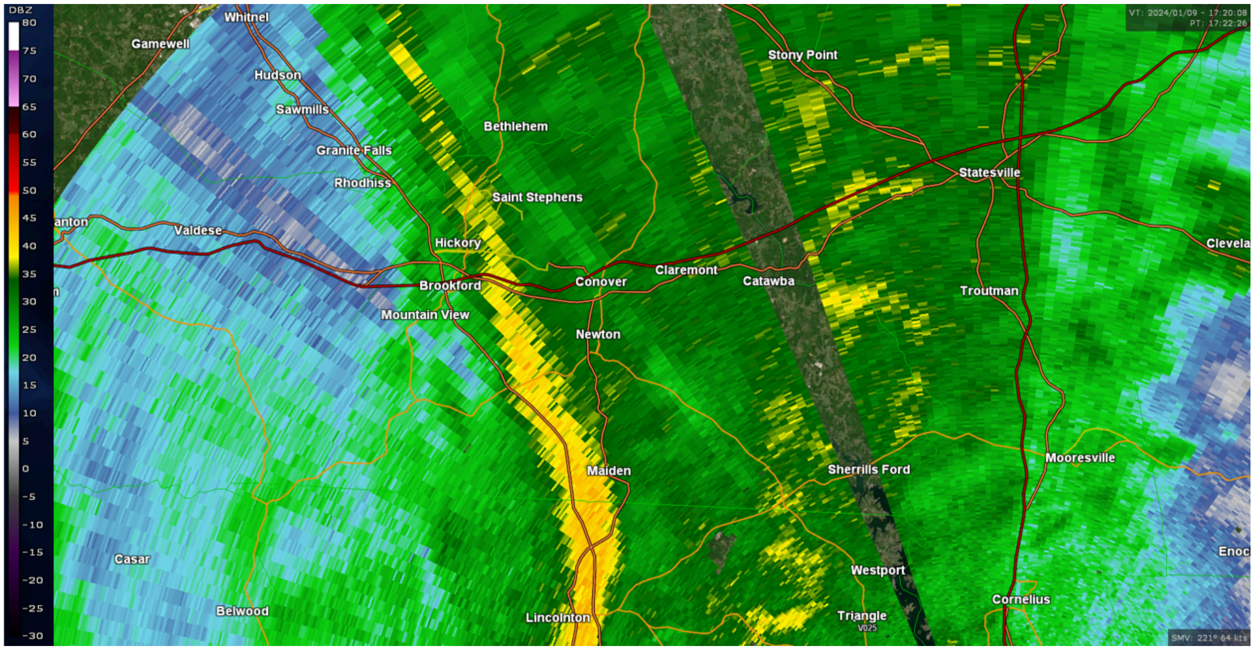


Fig. 15. Base reflectivity (dBZ; 0.2° scan) from TCLT at 1222 pm.

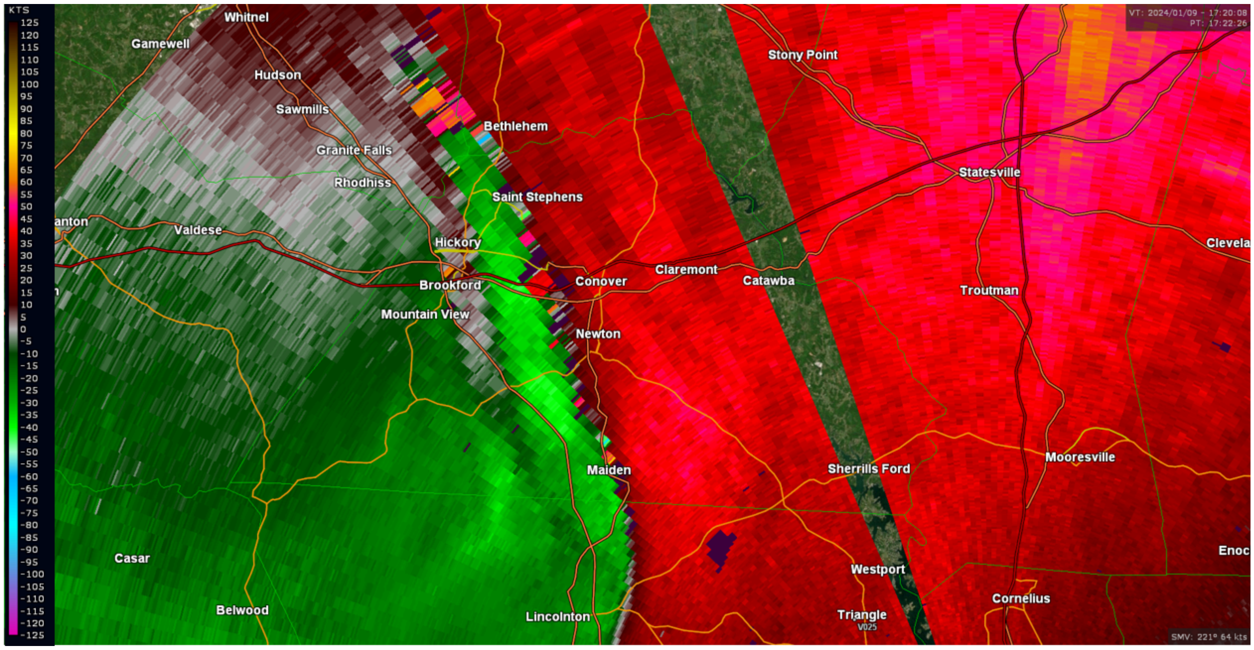


Fig. 16. As in Fig. 15, but for base velocity (kts).

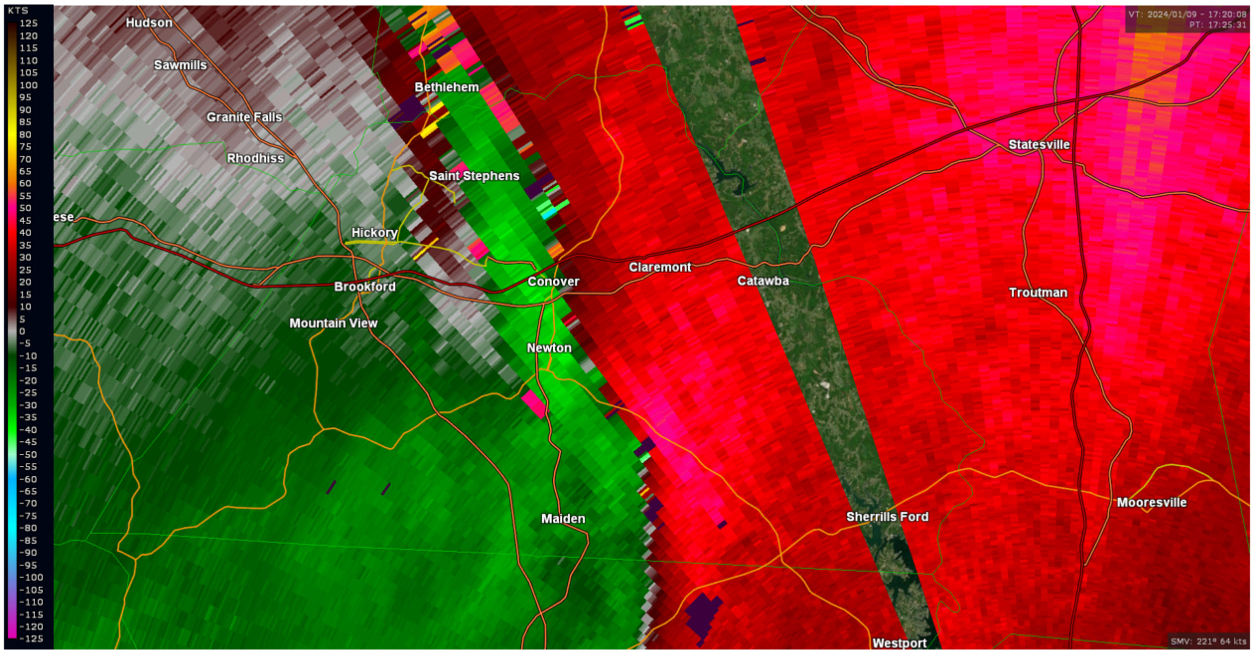


Fig. 17. Base velocity (kts; 0.2° scan) from TCLT at 1225 pm.

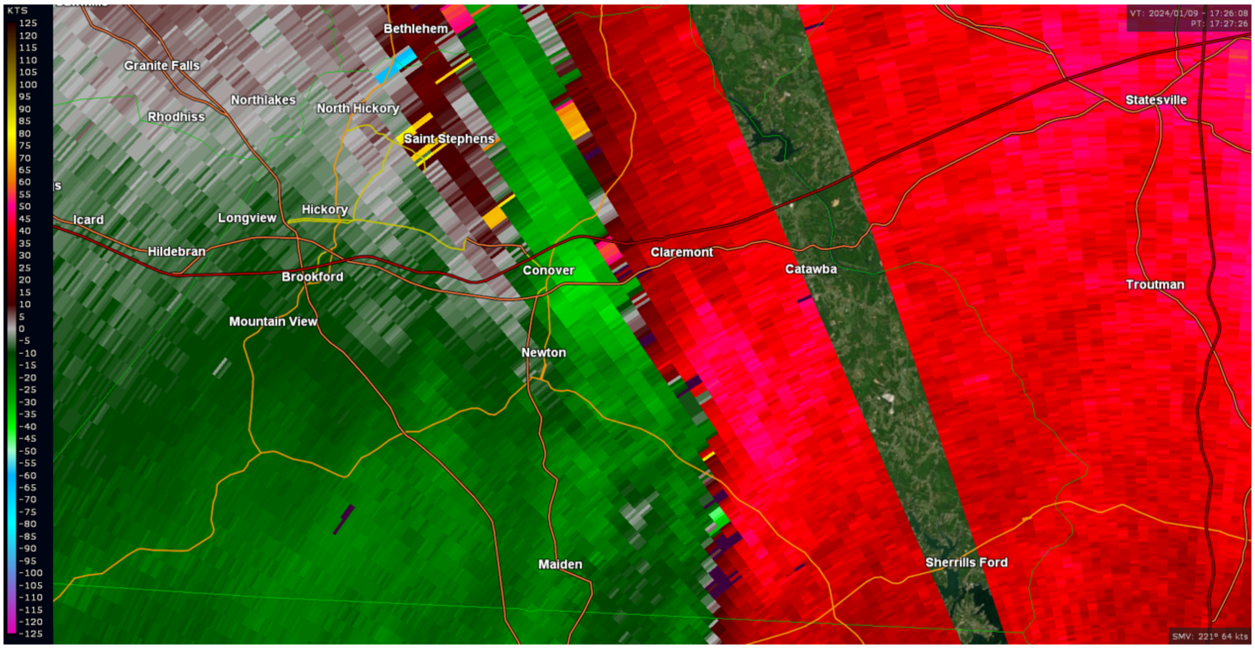


Fig. 18. As in Fig. 17, but at 1227 pm.

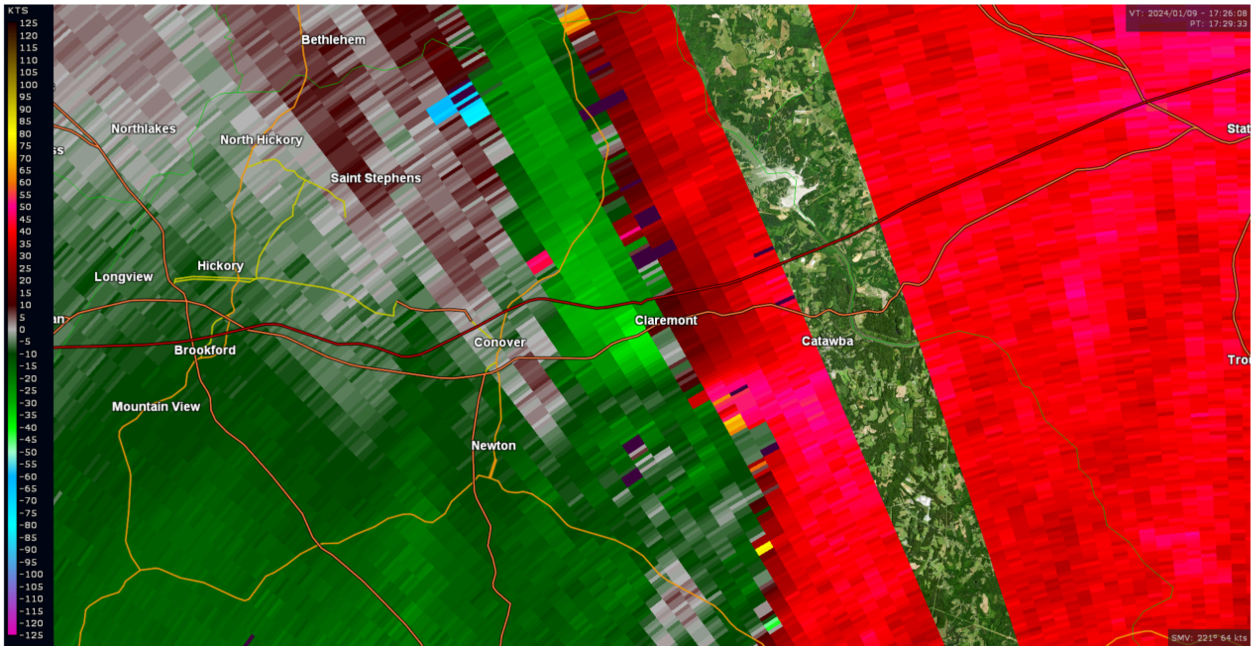


Fig. 19. As in Fig. 17, but at 1229 pm.

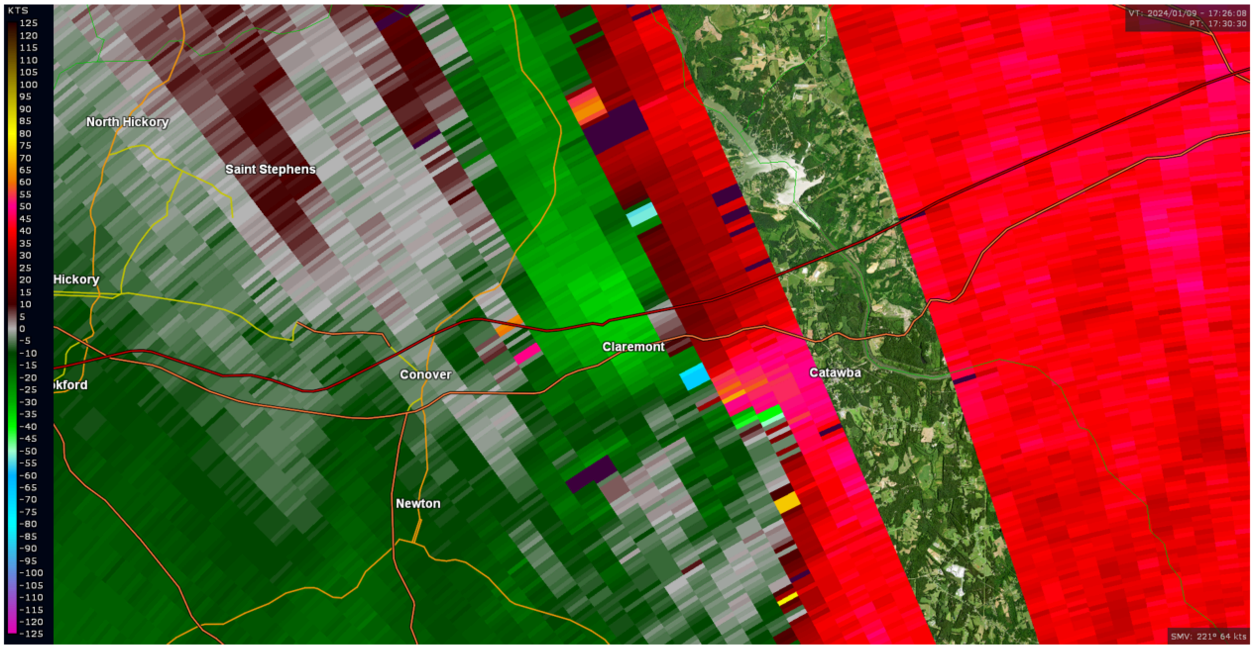


Fig. 20. As in Fig. 17, but at 1230 pm.

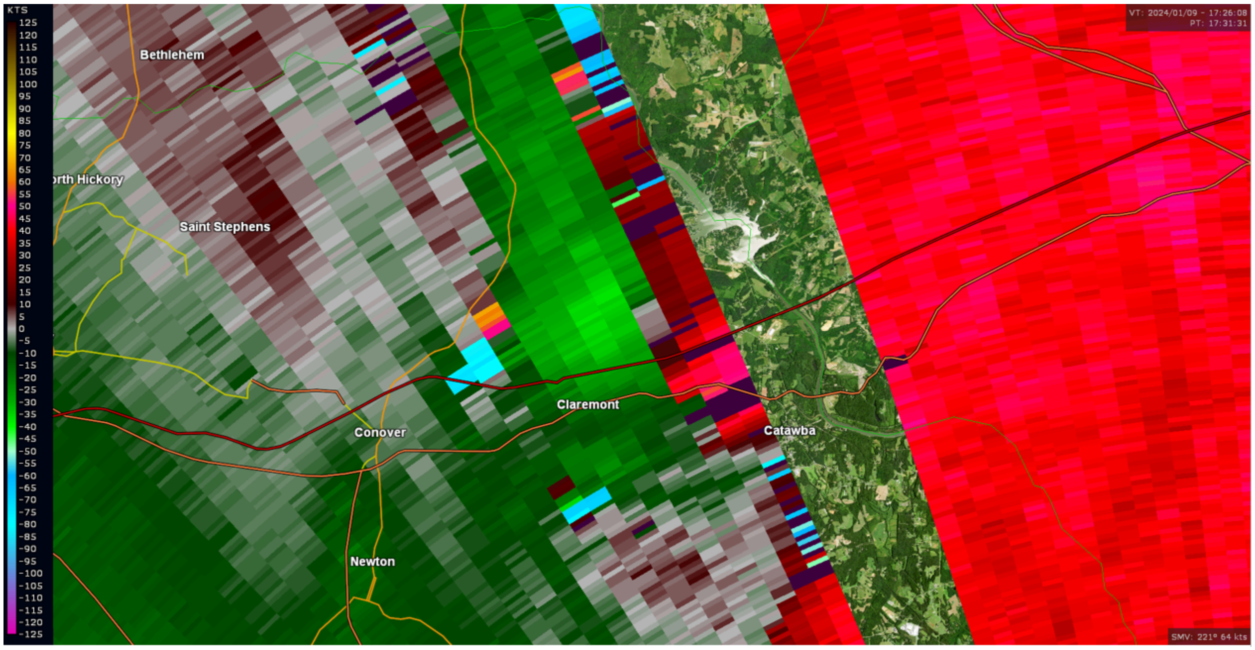


Fig. 21. As in Fig. 17, but at 1231 pm.

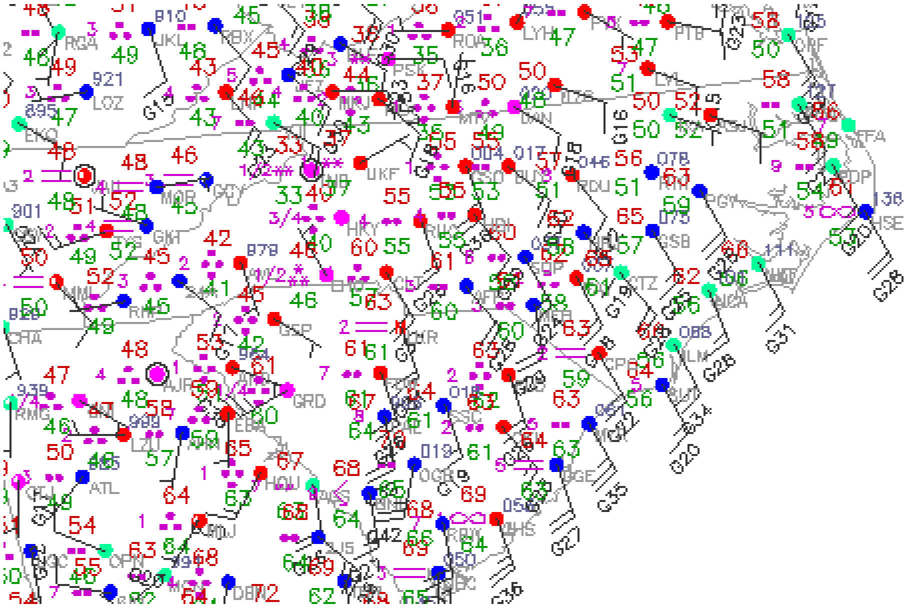


Fig. 22. Surface observations at 1200 pm on 9 January 2024.