

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



ERA23FA219

METEOROLOGY

Specialist's Factual Report

October 17, 2023

TABLE OF CONTENTS

A. ACCIDENT	3
B. METEOROLOGY SPECIALIST	3
C. DETAILS OF THE INVESTIGATION	3
D. FACTUAL INFORMATION	4
1.0 SYNOPTIC SITUATION	4
1.1 Surface Analysis Chart.....	4
1.2 Upper Air Charts	5
2.0 STORM PREDICTION CENTER CONVECTIVE OUTLOOK	9
3.0 SURFACE OBSERVATIONS	14
4.0 UPPER AIR SOUNDING	17
5.0 SATELLITE DATA.....	19
6.0 NATIONAL RADAR IMAGERY	21
7.0 WEATHER SURVEILLANCE RADAR IMAGERY.....	22
7.1 Volume Scan Strategy	23
7.2 Beam Height Calculation	24
7.3 Reflectivity.....	24
7.4 Base Reflectivity and Lightning Data	25
8.0 PILOT REPORTS	28
9.0 SIGNIFICANT METEOROLOGICAL INFORMATION	29
10.0 CENTER WEATHER SERVICE ADVISORIES	30
11.0 AIRMEN'S METEOROLOGICAL INFORMATION.....	31
12.0 GRAPHICAL FORECASTS FOR AVIATION.....	31
13.0 TERMINAL AERODROME FORECAST	32
14.0 NATIONAL WEATHER SERVICE AREA FORECAST DISCUSSION	32
15.0 WINDS AND TEMPERATURE ALOFT FORECAST.....	35
16.0 PILOT WEATHER INFORMATION	35
17.0 ASTRONOMICAL DATA	36
E. LIST OF ATTACHMENTS	36

A. ACCIDENT

Location: Reliance, Tennessee
Date: May 7, 2023
Time: 1849 eastern daylight time
2249 coordinated universal time (UTC)
Airplane: Cessna 182Q; Registration: N725AS

B. METEOROLOGY SPECIALIST

Paul Suffern
Senior Meteorologist
National Transportation Safety Board
Washington, DC

C. DETAILS OF THE INVESTIGATION

The NTSB's Senior Meteorologist did not travel for this investigation but gathered all data remotely. Data for this investigation were collected from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the Weather Prediction Center (WPC) and the National Center for Environmental Information (NCEI). This Specialist's Factual Report contains the meteorological factors pertinent to the weather surrounding the accident time. All times are eastern daylight time (EDT) and are based upon the 24-hour clock, where local time is -4 hours from UTC. Directions are referenced to true north and distances are in nautical miles. Heights are above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles. NWS station identifiers use the standard International Civil Aviation Organization 4-letter station identifiers versus the International Air Transport Association 3-letter identifiers, which deletes the initial country code designator "K" for U.S. airports.

The accident site (main wreckage site) was located at approximate latitude 35.225799° N, longitude 84.421951° W, and elevation of 1,280 feet (ft).

D. FACTUAL INFORMATION

1.0 Synoptic Situation

The synoptic or large-scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction and the WPC, located in College Park, Maryland. These are the base products used in describing synoptic weather features and in the creation of forecasts and warnings for the NWS. Reference to these charts can be found in the Federal Aviation Administration (FAA) "Aviation Weather Handbook", FAA-H-8083-28.¹

1.1 Surface Analysis Chart

The NWS Surface Analysis Chart centered over the eastern United States for 2000 EDT is provided as figure 1 with the location of the accident site within the black circle. The chart depicted an outflow boundary² south of the accident site at 2000 EDT. Over northcentral Kentucky a high-pressure system at 1017-hectopascals (hPa) was located. Outflow boundaries can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present.

The station model closest to the accident site depicted an air temperature of 62 degrees Fahrenheit (°F), dew point temperature of 57°F, cloudy skies, heavy rain, and a southeast wind at 5 knots.

¹ [FAA-H-8083-28](#)

² Outflow Boundary - A storm-scale or mesoscale boundary separating thunderstorm-cooled air (outflow) from the surrounding air; similar in effect to a cold front, with passage marked by a wind shift and usually a drop in temperature. Outflow boundaries may persist for 24 hours or more after the thunderstorms that generated them dissipate, and may travel hundreds of miles from their area of origin. New thunderstorms often develop along outflow boundaries, especially near the point of intersection with another boundary ([NOAA's National Weather Service - Glossary](#))

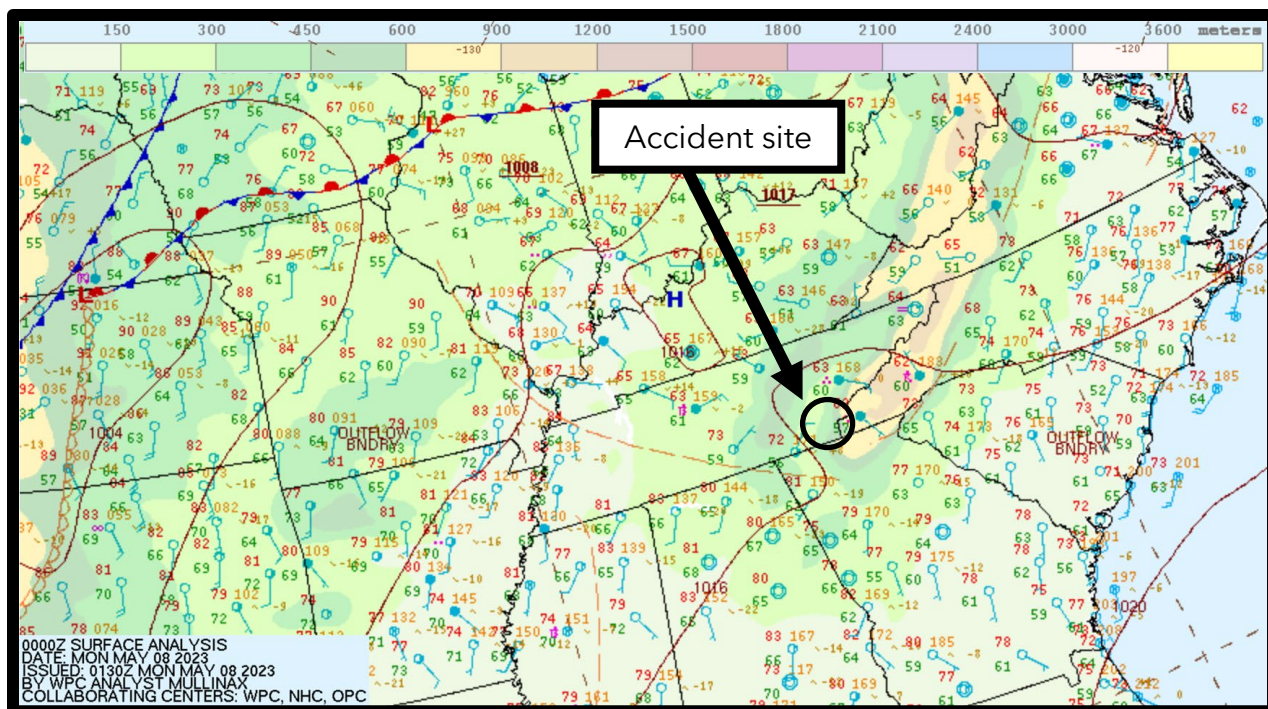


Figure 1. NWS Surface Analysis Chart for 2000 EDT.

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 2000 EDT at 925-, 850-, 700-, and 500-hPa are presented in figures 2 through 5. The charts depicted a trough³ to the west of the accident site stretching from the Midwest into the Tennessee River Valley. The 925-hPa constant pressure chart depicted a south wind around 15 knots above the accident site (figure 2) with the wind becoming westerly to 10 knots by 700-hPa (figure 4), and westerly 25 knots by 500-hPa (figure 5).

³ Trough - An elongated area of relatively low atmospheric pressure or heights.

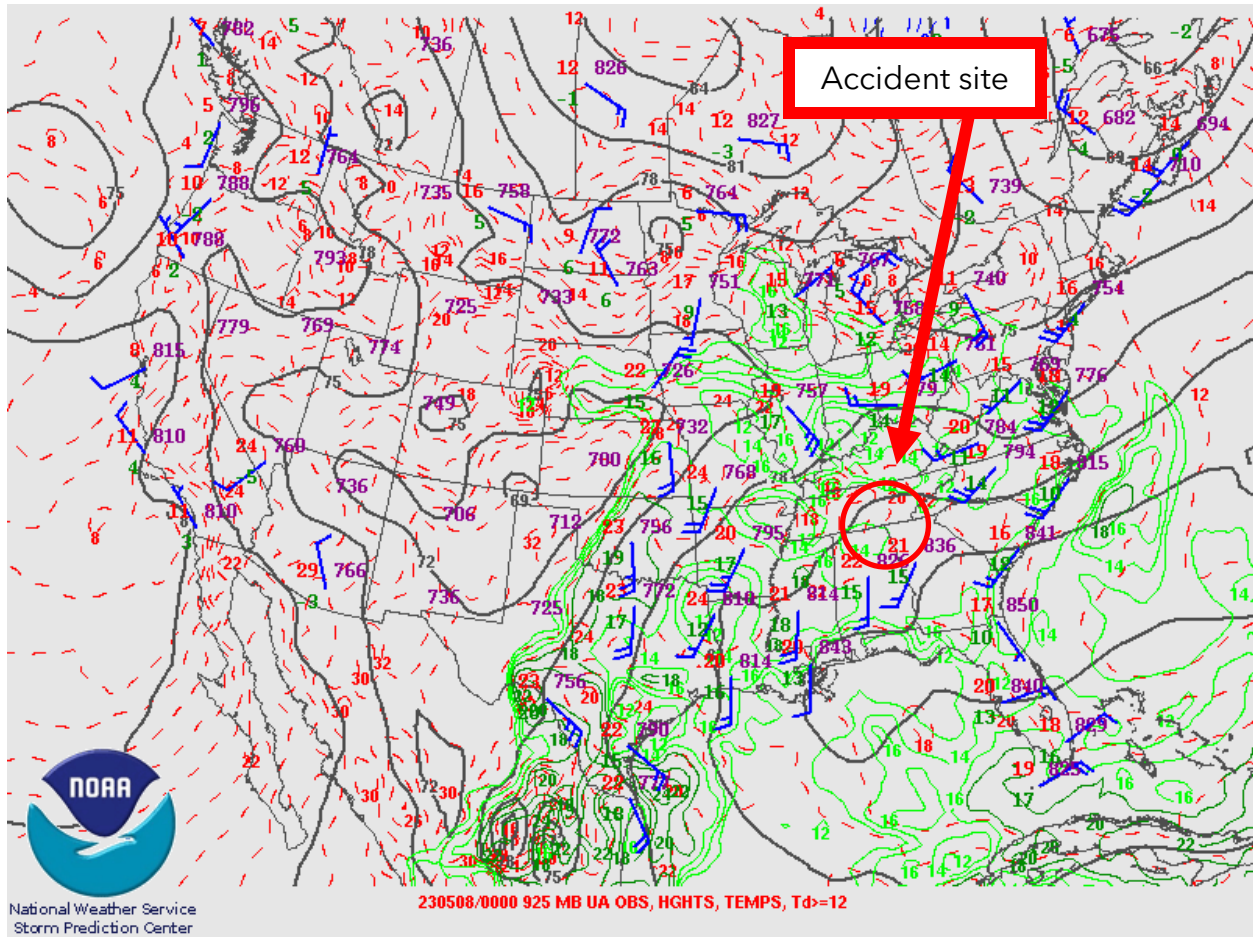


Figure 2. 925-hPa Constant Pressure Chart for 2000 EDT.

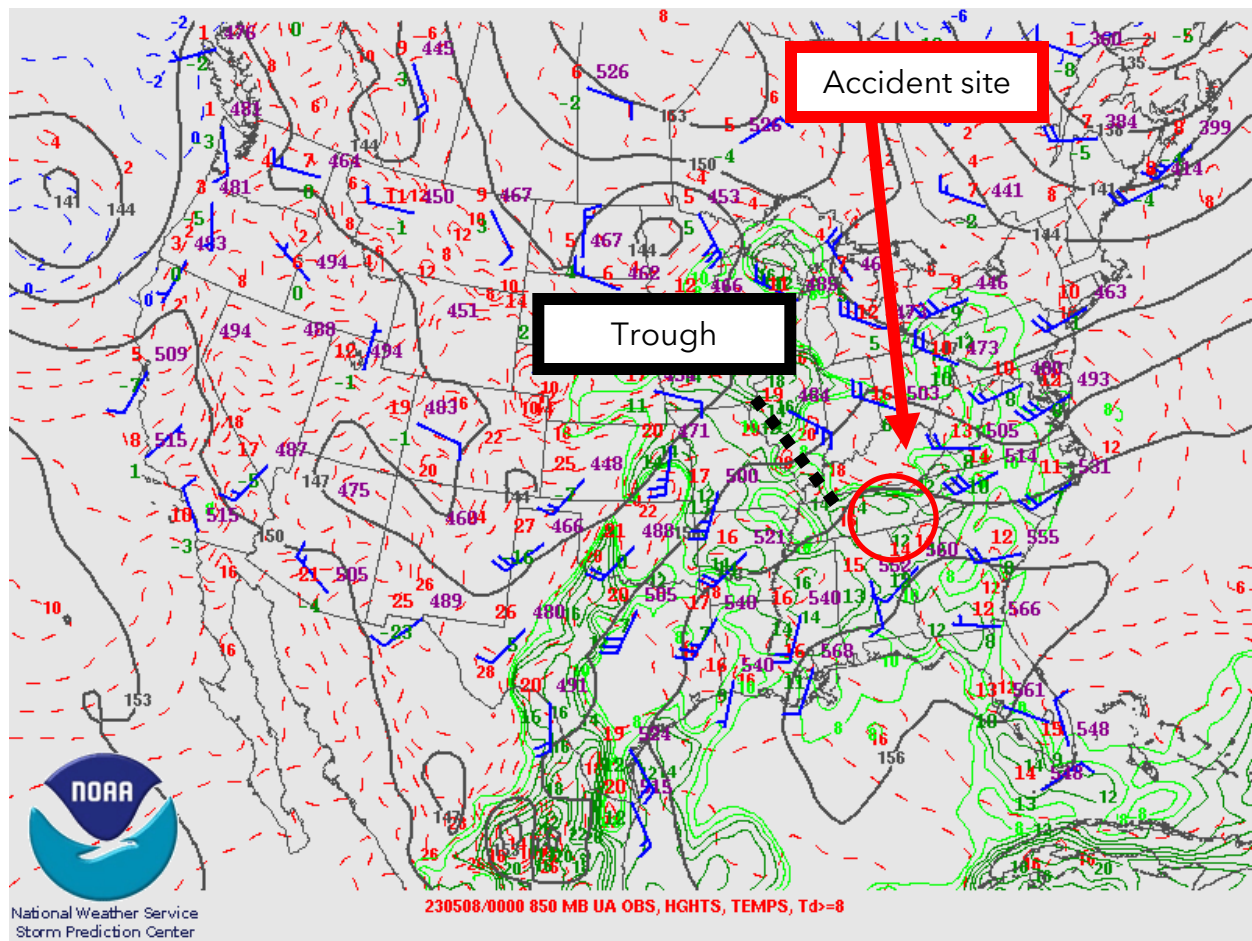


Figure 3. 850-hPa Constant Pressure Chart for 2000 EDT.

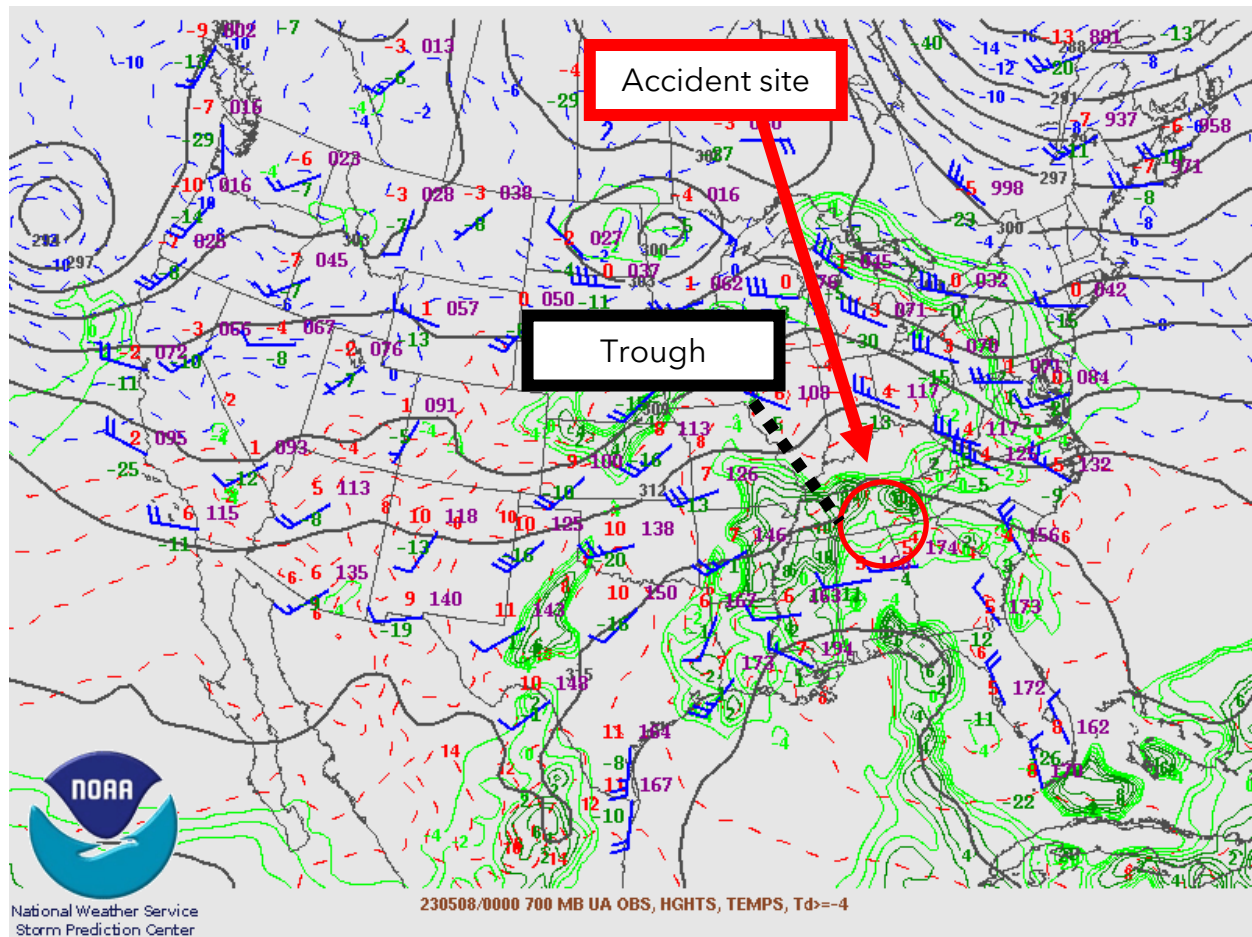


Figure 4. 700-hPa Constant Pressure Chart for 2000 EDT.

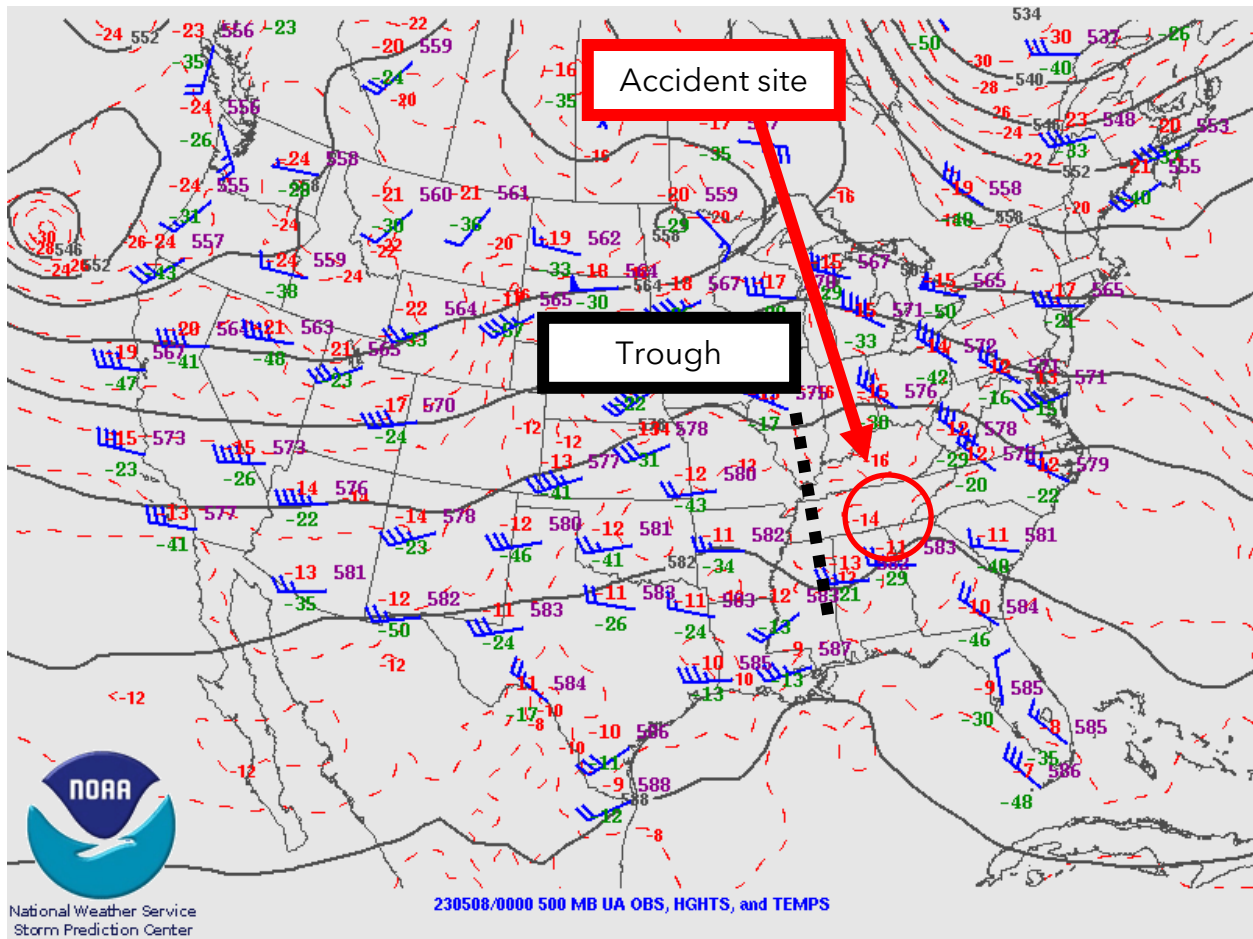


Figure 5. 500-hPa Constant Pressure Chart for 2000 EDT.

2.0 Storm Prediction Center Convective Outlook

SPC issued a Day 1 Convective Outlook at 1547 EDT (figure 6) with the accident site located in an area where a "marginal" risk for severe thunderstorms was expected (or a level 1 out of 5 risk). In addition, the accident location was located in 5% probability of damaging thunderstorms winds or wind gusts of 50 knots or higher within 25 miles of a point (figure 7). The text of the SPC Day 1 Convective Outlook follows figure 7.

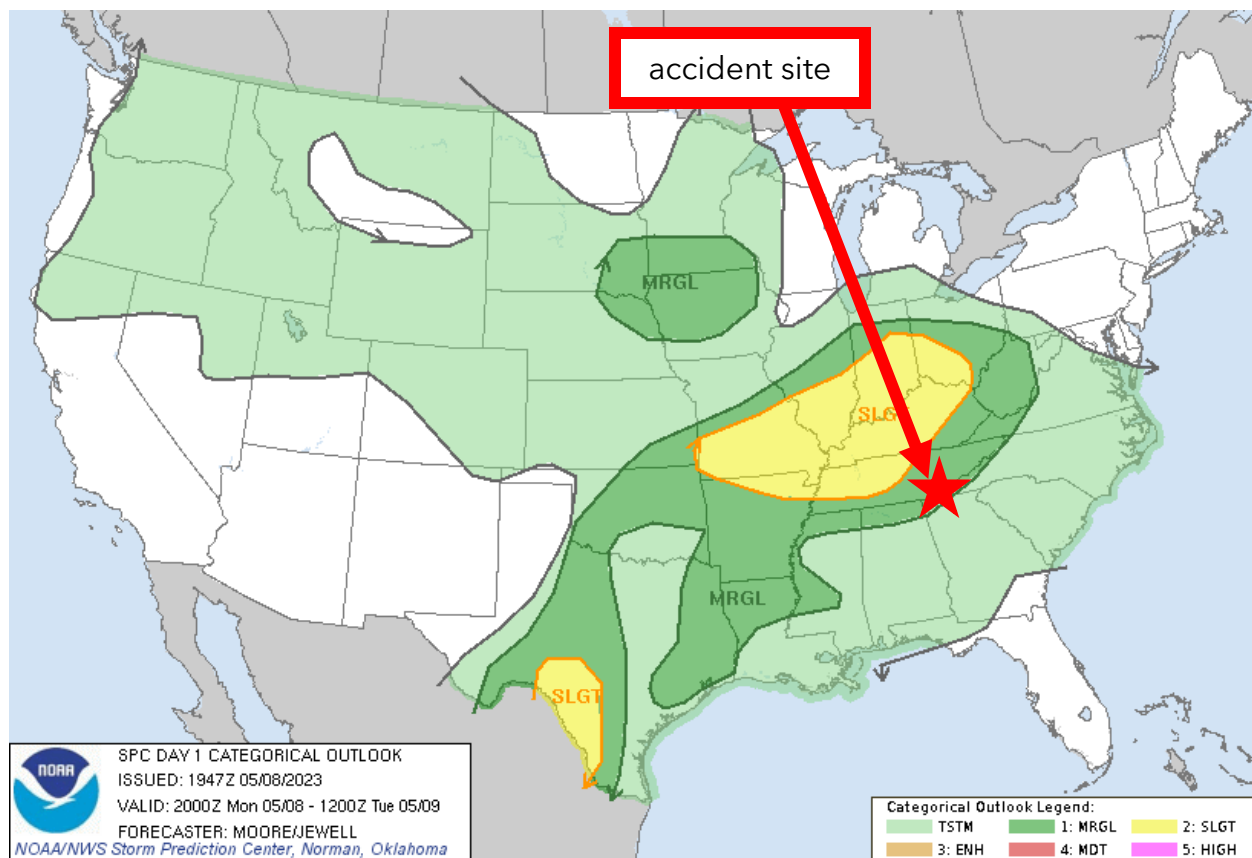


Figure 6. SPC day 1 Convective Outlook valid at the time of the accident.

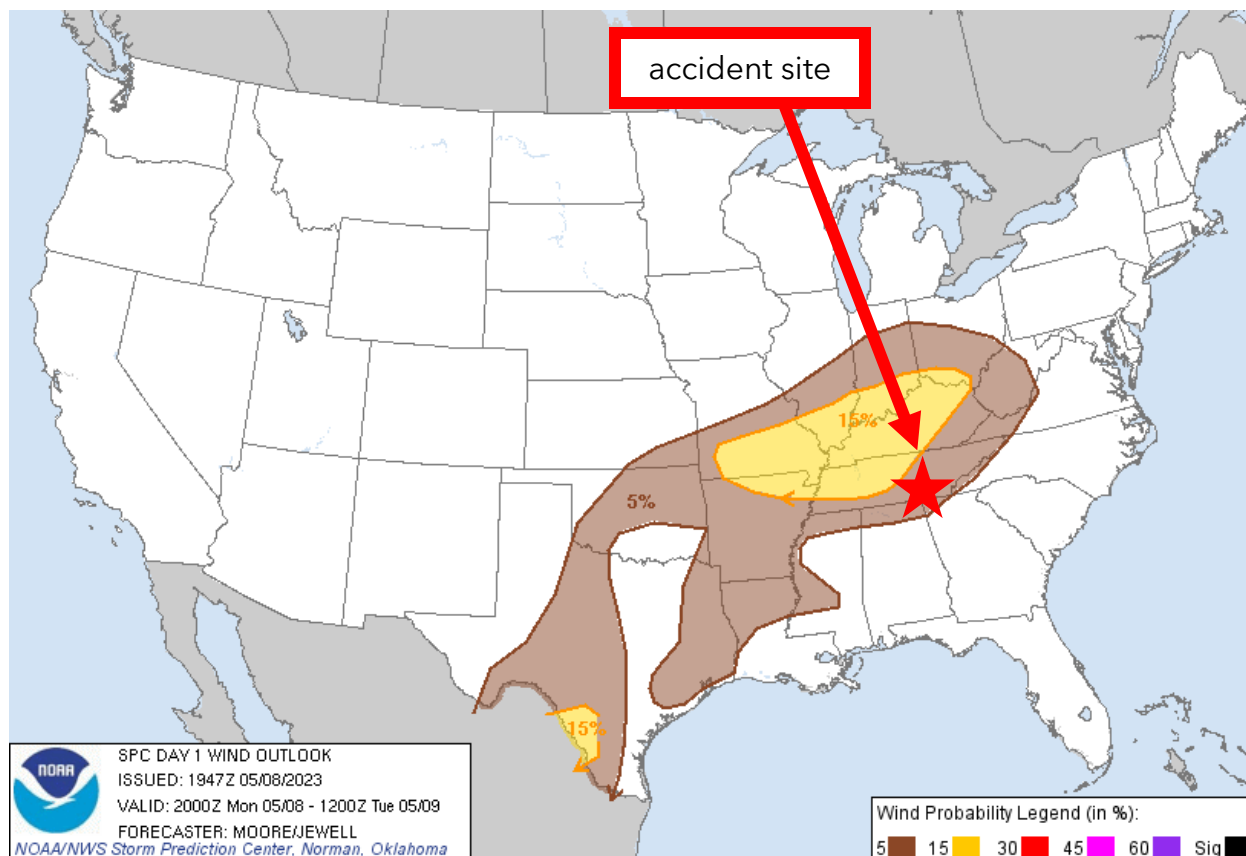


Figure 7. SPC day 1 Wind Outlook valid at the time of the accident.

Day 1 Convective Outlook
 NWS Storm Prediction Center Norman OK
 0247 PM CDT Mon May 08 2023

Valid 082000Z - 091200Z

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS THE OZARKS INTO THE OHIO RIVER VALLEY AND ACROSS PORTIONS OF SOUTH TEXAS...

...SUMMARY...

Scattered severe thunderstorms are most likely from the Ozark Plateau to the Lower Ohio Valley, centered on 4 to 11 PM CDT. Large hail and damaging winds should be the main severe risks. Severe thunderstorms are also possible across areas such as South Texas.

...Ozarks to Lower Ohio Valley...

Convective initiation appears likely within the next 1-2 hours across south-central MO per latest trends in visible imagery. A residual outflow boundary is noted extending from the southern MO cumulus field southeastward into southern Middle TN. This may be a preferential corridor for storm clusters and/or a more organized MCS to propagate into during the late evening hours. While most CAMs appear to be too low with CI based on noted trends, several solutions hint at the idea of convection maintaining intensity into middle TN. Wind probabilities were nudged slightly southward to

address this potential. See MCD #729 for more details on near-term trends.

...Texas Coastal Plains...

A cluster of strong thunderstorms has initiation northwest of the Houston metro area. While radar trends suggest this convection is slow to mature, GOES IR imagery has shown persistent cloud top cooling consistent with intensifying storms. Consequently, this activity may pose an isolated severe hail/damaging wind threat through the late afternoon given favorable environmental buoyancy and modest, but perhaps adequate, deep-layer shear. A storm or two is plausible to the southwest of this activity along the TX coast, but a diminishing cumulus field under approaching cirrus suggest additional CI is unlikely in the near-term.

..Moore/Jewell.. 05/08/2023

.PREV DISCUSSION... /ISSUED 1147 AM CDT Mon May 08 2023/

...Ozarks to Lower Ohio Valley...

A linear cluster of storms across western/central Kentucky has gradually trended downscale since early this morning but still otherwise continues to persist southeastward. To its west/northwest, the most confident scenario is for the front and lingering outflow boundary to focus later afternoon convective development from southern Missouri into southern Illinois, and eventually western Kentucky.

Regional WSR-88D VWP data continues to sample a core of relatively strong, potentially rear inflow/convectively enhanced, mid-level winds in the wake of the MCS across southeast Missouri/western Kentucky/southern Illinois vicinity. Resultant 40+ kt deep-layer shear will tend to largely persist regionally and support organized updrafts, including some supercells and sustained multicells as storms redevelop later this afternoon. This should particularly be the case within the greater instability reservoir across southern portions of Missouri/Illinois. Significant severe hail will be possible with initial supercells given the rather steep mid-level lapse rates emanating east from the Great Plains. However, convection should quickly tend to grow upscale into clusters where the deep-layer shear vector is oriented more parallel to the front from the Ozark Plateau to the Lower Ohio Valley. As such, a mix of large hail and damaging wind should be the primary threats as clusters/MCSs spread east-southeastward towards the Tennessee Valley and central Appalachians tonight.

...Texas Rio Grande vicinity/Edwards Plateau/Low Rolling Plains...

The dryline from the Big Country to the Edwards Plateau should support isolated thunderstorms from late afternoon to early evening. Unlike previous days, winds should be weak through much of the large buoyancy profile as stronger upper flow is displaced southeast of the dryline due to a low-amplitude upper trough. While isolated large hail/localized severe-caliber gusts are possible, the scenario

suggests that convection should tend to be rather disorganized across the Low Rolling Plains into parts of the Edwards Plateau.

A somewhat higher probability of severe storms (Slight Risk), nonetheless with a number of lingering uncertainties, appears to exist from the middle Rio Grande vicinity northward into southern parts of the Edwards Plateau, potentially aided by a weak mid-level disturbance currently over northern Mexico. Near-dryline convective development aside, this could also include the eastward propagation of storms across the Rio Grande this evening. The northwestward advection of a very moist air mass, as sampled by the 12z CRP sounding with 1.80 PW value and 15.4 g/kg mean mixing ratio, will support robust 4000+ J/kg MLCAPE across south-central Texas this afternoon. Very steep mid-level lapse rates (12z DRT observed sounding), ample buoyancy, and around 30 kt effective shear will support large hail/severe-caliber wind gusts where storms do develop later this afternoon into evening.

...South-Central Plains to ArkLaTex - Marginal Risk Areas...

Several mechanisms for sustaining deep convection are apparent this afternoon and evening, offering a threat for generally isolated large hail and severe wind gusts. The trailing portion of the weak quasi-stationary front near the Oklahoma/Kansas border may be a focus for later evening slow-moving thunderstorm development.

Additionally, a pair of MCVs, one drifting east from north-central Texas and the other drifting northeast near the Upper TX Coast should support downstream isolated to scattered thunderstorms, peaking in intensity this afternoon to early evening. Modest deep-layer shear coincident with the eastern fringe of the steep mid-level lapse rate plume should yield sporadic multicell clusters and foster a threat for lower-end intensities of severe hail/wind.

...Mid-Missouri Valley/Upper Midwest...

A belt of enhanced mid-level westerlies will be maintained to the south of a low near the Minnesota/Ontario border drifting northwest into southern Manitoba. Despite an ill-defined surface pattern, robust boundary-layer heating from Kansas towards the Middle Missouri Valley should overlap with the western periphery of a lingering plume of 50s F surface dew points over Iowa. This may aid in isolated late afternoon to early evening thunderstorms. With light low-level winds, speed shear through the cloud-bearing layer will foster a moderately elongated straight-line hodograph. This will favor splitting discrete cells with mid-level rotation and potential for isolated large hail, and perhaps even a brief tornado risk across far southeast Minnesota/northeast Iowa near a residual weak boundary.

3.0 Surface Observations

The area surrounding the accident site was documented using official Aviation Routine Weather Reports (METARs) and Special Reports (SPECIs)⁴. The following observations were taken from standard code and are provided in plain language. Figure 8 is a local sectional chart with the accident site and the closest weather reporting location marked. A magnetic variation⁵ of 5° west was indicated over the area.

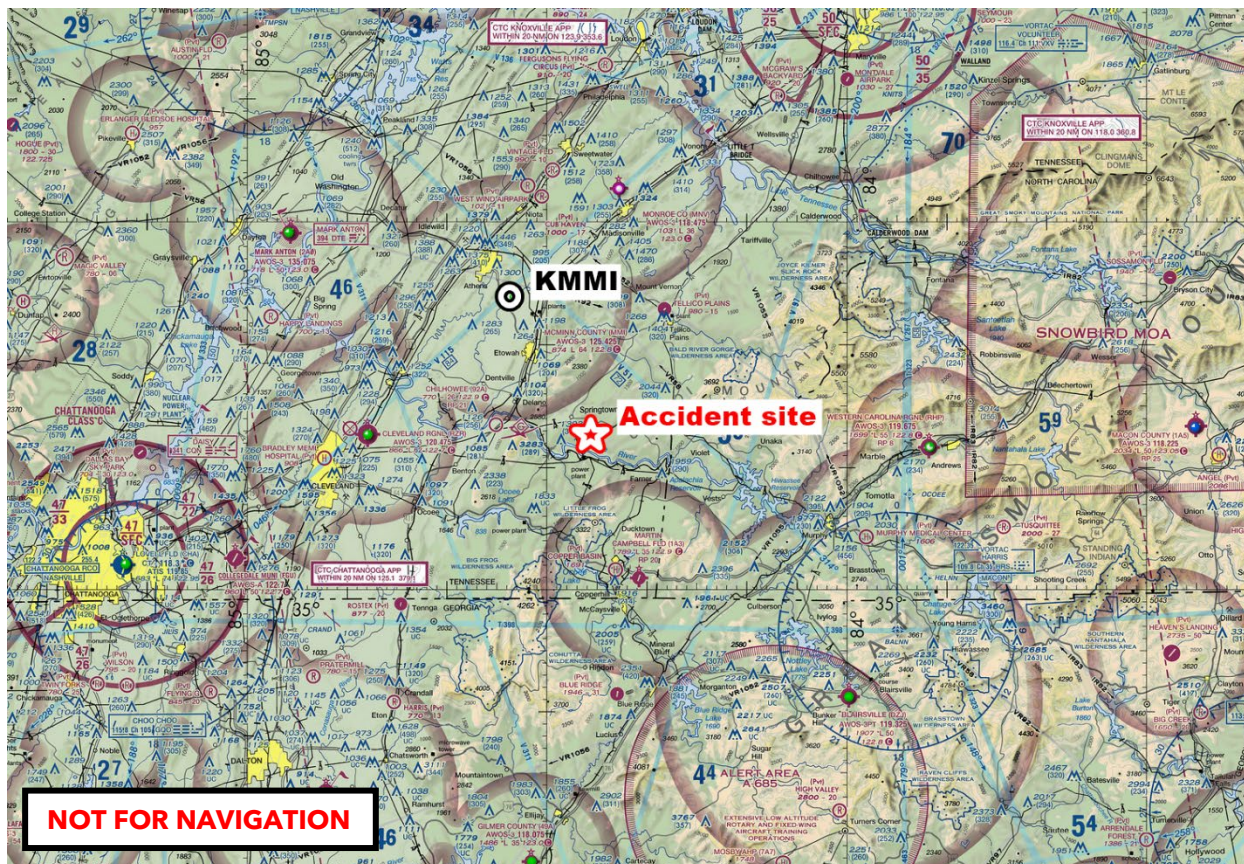


Figure 8. FAA sectional aeronautical chart of the accident area with the location of the accident site and surface observation site.

⁴ Latest criteria for SPECIs can be found in the Federal Meteorological Handbook: [Federal Meteorological Handbook Number 1, Surface Weather Observations and Reports \(icams-portal.gov\)](https://www.federalregister.gov/documents/2018/01/16/2018-01-16-federal-meteorological-handbook-number-1-surface-weather-observations-and-reports)

⁵ Magnetic variation - The angle (at a particular location) between magnetic north and true north. Latest measurement taken from <https://skyvector.com/>

McMinn County Airport (KMMI) had the closest official weather station to the accident site. KMMI had an Automated Weather Observing System (AWOS⁶) which issued observations every 20-minutes and its longline⁷ reports were not augmented. The KMMI AWOS was located 12 miles north-northwest of the accident site (figure 8), at an elevation of 874 ft, and issued the following observations surrounding the period of the accident:⁸

[1715 EDT] METAR KMMI 072115Z AUTO 21007G13KT 160V250 10SM
CLR 28/18 A3004 RMK A01

[1735 EDT] METAR KMMI 072135Z AUTO 20006KT 10SM CLR 28/18
A3003 RMK A01

[1755 EDT] METAR KMMI 072155Z AUTO VRB04G13KT 10SM CLR
28/18 A3004 RMK A01

[1815 EDT] METAR KMMI 072215Z AUTO 01016G29KT 340V040 10SM
FEW044 FEW055 SCT070 27/17 A3008 RMK A01

**[1835 EDT] METAR KMMI 072235Z AUTO 36010G29KT 10SM
SCT042 BKN049 OVC070 21/15 A3011 RMK A01**

ACCIDENT TIME 1849 EDT

**[1855 EDT] METAR KMMI 072255Z AUTO 05006G14KT 1 3/4SM BR
SCT008 BKN035 OVC055 18/17 A3012 RMK A01 P0009**

[1915 EDT] METAR KMMI 072315Z AUTO 07010G16KT 5SM BR
FEW035 SCT048 BKN070 18/17 A3010 RMK A01

The bold type observations decoded in plain language were as follows:

⁶ AWOS - Automated Weather Observing System is equipped with meteorological instruments to typically observe and report temperature, dewpoint, wind speed and direction, visibility, cloud coverage and ceiling up to 12,000 feet, and altimeter setting. AWOS are maintained by the FAA. Certain AWOS may have different reporting or observational equipment.

⁷ "Longline" refers to the dissemination of weather observations with the intent that they are available in near-real time to national databases and accessible to the general global public from a large number of vendors. This does not include public accessibility to observations from a reporting station's Very High Frequency (VHF; line-of-site) or telephone broadcast, where applicable. Longline dissemination of weather observations is the primary vehicle through which the weather observations are distributed.

⁸ The bold sections of products in this report are intended to highlight the text that directly reference the weather conditions that affected the accident region around the accident time. The local times in this section next to the METARs are provided for quick reference between UTC and local times.

KMMI weather at 1835 EDT, automated, wind from 360° at 10 knots with gusts to 29 knots, visibility 10 miles or greater, scattered clouds at 4,200 ft above ground level (agl), broken ceiling at 4,900 ft agl, overcast skies at 7,000 ft agl, temperature of 21° Celsius (C), dew point temperature 15°C, and an altimeter setting of 30.11 inches of mercury (inHg). Remarks, automated station without a precipitation discriminator.

KMMI weather at 1855 EDT, automated, wind from 050° at 6 knots with gusts to 14 knots, visibility 1 and ¾ miles, mist, scattered clouds at 800 ft agl, broken ceiling at 3,500 ft agl, overcast skies at 5,500 ft agl, temperature of 18°C, dew point temperature 17°C, and an altimeter setting of 30.12 inHg. Remarks, automated station without a precipitation discriminator, 0.09 inches of precipitation since 1755 EDT.

The observations from the KMMI AWOS around the accident time identified VFR conditions deteriorating to IFR⁹ conditions due to visibility and mist with gusting surface winds to 29 knots.

⁹ The NWS and the FAA Aeronautical Information Manual (AIM) section 7-1-7 defines the following general flight categories:

- Low Instrument Flight Rules (LIFR*) – ceiling below 500 ft above ground level (agl) and/or visibility less than 1 statute mile.
- Instrument Flight Rules (IFR) – ceiling between 500 to below 1,000 feet agl and/or visibility 1 to less than 3 miles.
- Marginal Visual Flight Rules (MVFR**) – ceiling from 1,000 to 3,000 ft agl and/or visibility 3 to 5 miles.
- Visual Flight Rules (VFR) – ceiling greater 3,000 ft agl and visibility greater than 5 miles.

* By definition, IFR is a ceiling less than 1,000 ft agl and/or visibility less than 3 miles while LIFR is a sub-category of IFR.

**By definition, VFR is a ceiling greater than or equal to 3,000 ft agl and visibility greater than 5 miles while MVFR is a sub-category of VFR.

4.0 Upper Air Sounding

A High-Resolution Rapid Refresh (HRRR)¹⁰ model sounding was created¹¹ for the approximate accident site coordinates for 1900 EDT. The HRRR sounding was plotted on a standard Skew-T Log P diagram¹² from the surface to 500-hPa (or approximately 18,000 ft) using the RAOB¹³ software package and is included as figure 9. The sounding depicted an elevation of 1,411 ft over the grid point. The sounding depicted the lifted condensation level (LCL)¹⁴ at 3,303 ft, the level of free convection (LFC)¹⁵ at 4,786 ft, and the convective condensation level (CCL)¹⁶ at 5,125 ft. The freezing level was located at 12,492 ft. The precipitable water value at 1.31 inches.

¹⁰ The HRRR is a NOAA real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three-kilometer grids with three-kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one-hour period.

¹¹ HRRR sounding was created using NOAA Air Resource Laboratory: [READY Archived Meteorology \(noaa.gov\)](https://ready.arl.noaa.gov/).

¹² Skew T log P diagram – is a standard meteorological plot using temperature and the logarithmic of pressure as coordinates, used to display winds, temperature, dew point, and various indices used to define the vertical structure of the atmosphere.

¹³ RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Esonde Research Services, The Villages, Florida.

¹⁴ LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.

¹⁵ LFC - The level at which a parcel of saturated air becomes warmer than the surrounding air and begins to rise freely. This occurs most readily in a conditionally unstable atmosphere.

¹⁶ CCL - The level in the atmosphere to which an air parcel, if heated from below, will rise dry adiabatically, without becoming colder than its environment just before the parcel becomes saturated.

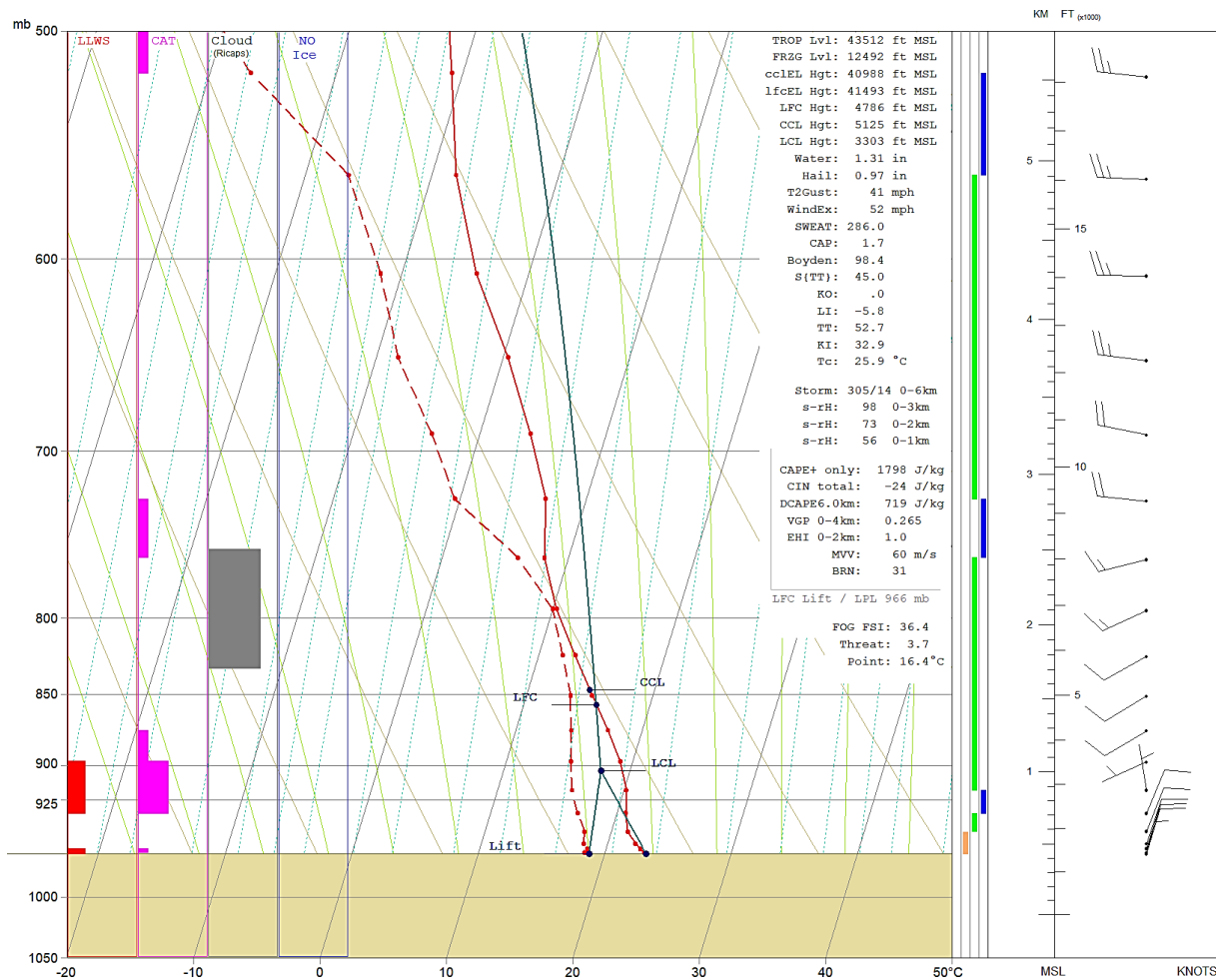


Figure 9. 1900 EDT HRRR sounding.

The 1900 EDT HRRR sounding indicated a conditionally unstable environment from the surface through 16,000 ft with a few shallow layers of stability around 2,500 ft, then again between 8,500 and 9,500 ft. Clouds were indicated outside of convective activity by RAOB between 6,000 and 9,000 ft. No icing was indicated by RAOB below 18,000 ft outside of convective activity. A positive CAPE¹⁷ value of 1,798 Joules/kilogram (J/kg) was indicated on the sounding and the maximum vertical velocity (MVV) for this atmosphere was calculated as 60 meters/second (about 11,811 ft per minute).¹⁸ Downdraft CAPE (DCAPE; 6 kilometers agl)¹⁹ was measured at 719 J/kg. If rain showers or thunderstorms formed in this environment, the sounding

¹⁷ Convective Available Potential Energy (CAPE) - CAPE is a measure of the amount of energy available for convection and is directly related to the maximum potential vertical speed within an updraft.

¹⁸ MVV is not usually considered a realistic estimate for maximum vertical velocity in a storm. Anecdotes suggest considering a value of MVV/2, however it is not well understood when or where such a half-value should be applied.

¹⁹ The DCAPE can be used to estimate the potential strength of rain-cooled downdrafts within thunderstorm convection, and is similar to CAPE. Larger DCAPE values are associated with stronger downdrafts.

indicated that the strongest wind speeds possible at the surface (due to, for example, an outflow boundary, or gust front) would have been 52 mph (45 knots) according to the WindEx parameter.

The 1900 EDT HRRR sounding wind profile indicated a near surface wind from 020° at 8 knots with the wind outside of rain showers and thunderstorms remaining northerly around 10 knots through 3,000 ft. Above 3,000 ft the wind became westerly through 18,000 ft. The wind speed increased to 15 knots by 7,000 ft and the wind speed was up to 25 knots by 18,000 ft. The RAOB analysis program indicated the possibility of light low-level wind shear (LLWS) outside of rain shower and thunderstorm activity, along with several layers of light clear air turbulence (CAT) from the surface through 18,000 ft. At the approximate airplane's altitude before descent²⁰ (around 8,500 ft), the wind was from 270° at 16 knots, with a temperature of 7.6°C, the dew point temperature was 3.1°C, the relative humidity was 73%.

5.0 Satellite Data

Geostationary Operational Environmental Satellite number 16 (GOES-16) visible and infrared data were obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System software. Visible and infrared imagery (GOES-16 bands 2 and 13) at wavelengths of 0.64 microns (μm) and 10.3 μm, respectively, were retrieved for the period from 1500 EDT through 2200 EDT and reviewed, and the closest images to the time of the accident were documented.

Figures 10 and 11 present the GOES-16 visible image at 1846 and 1851 EDT at 3X magnification with the accident site highlighted with a red square. The visible imagery indicated cloud cover above the accident site at the accident time with the cloud cover moving from north to south (attachment 1). Figure 12 presents the GOES-16 infrared image at 1851 EDT at 7X magnification with the accident site highlighted with a red square. The lower brightness temperatures (blue and green colors; higher cloud tops) were located northwest through northeast of the accident site at the accident time. The brightness temperature of 265 Kelvin above the accident site would have been near 19,000 ft based on the vertical temperature profile provided by the 1900 EDT HRRR sounding. It should be noted these figures have not been corrected for any parallax error.

²⁰ Please see track information located in the docket of this accident.

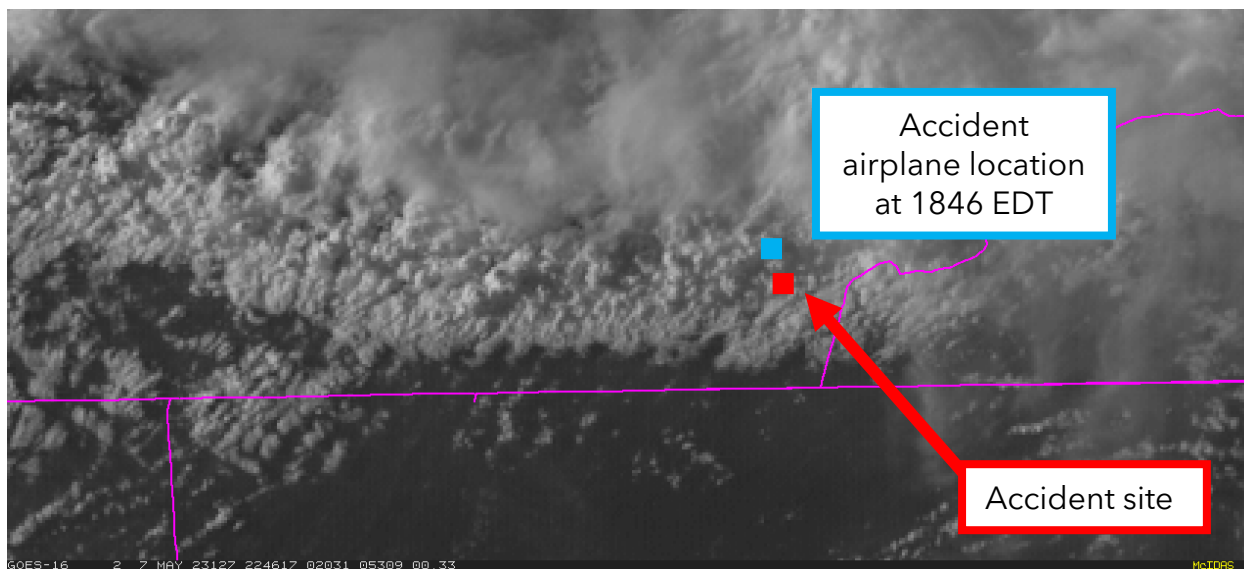


Figure 10. GOES-16 visible image at 1846 EDT with the accident airplane location at 1846 EDT marked.

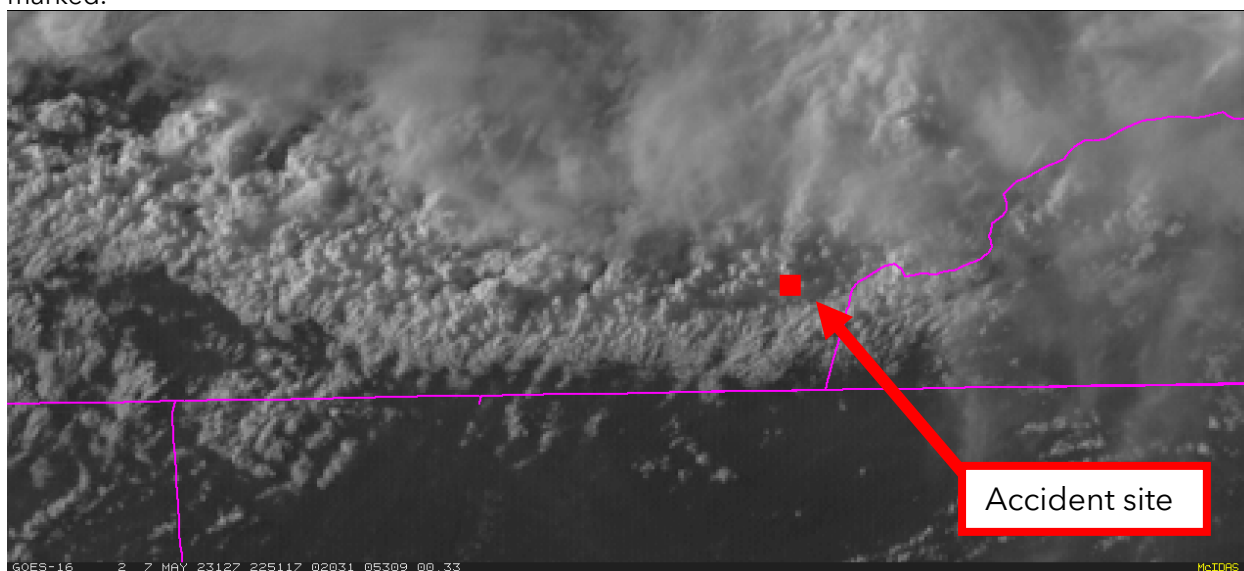


Figure 11. GOES-16 visible image at 1851 EDT.

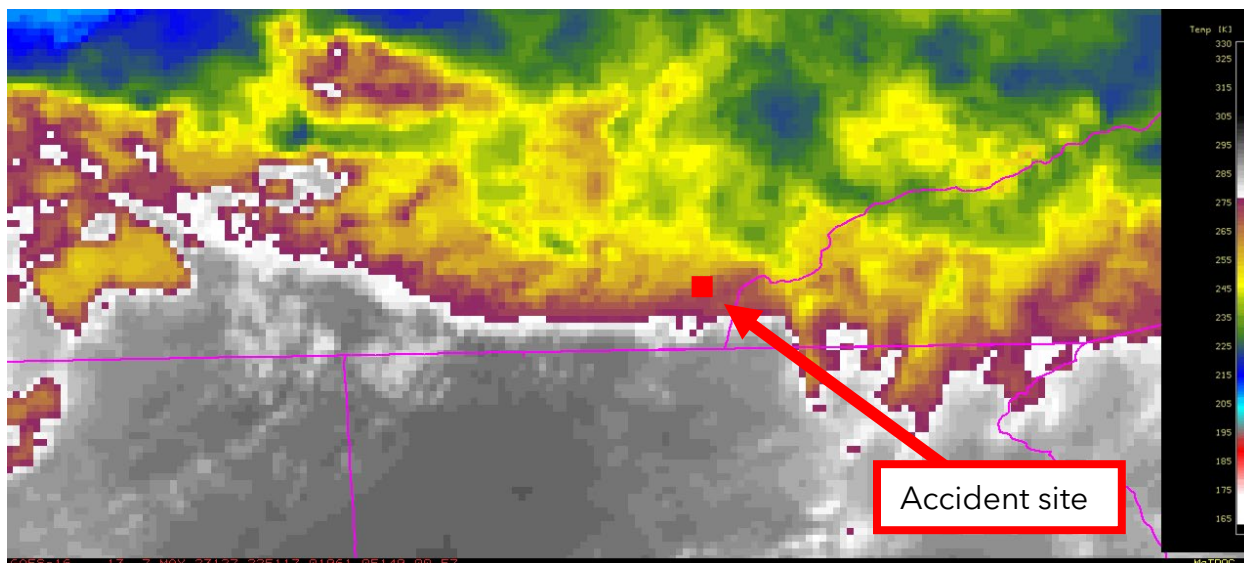


Figure 12. GOES-16 infrared image at 1851 EDT.

6.0 National Radar Imagery

A regional view of the NWS National Reflectivity Mosaic is included as figure 13 for 1850 EDT with the approximate location of the accident site marked by a black circle. The image depicted 20 to 50 dBZ²¹ echoes near the accident site.

²¹ dBZ - A non-dimensional "unit" of radar reflectivity which represents a logarithmic power ratio (in decibels or dB) with respect to radar reflectivity factor, Z.

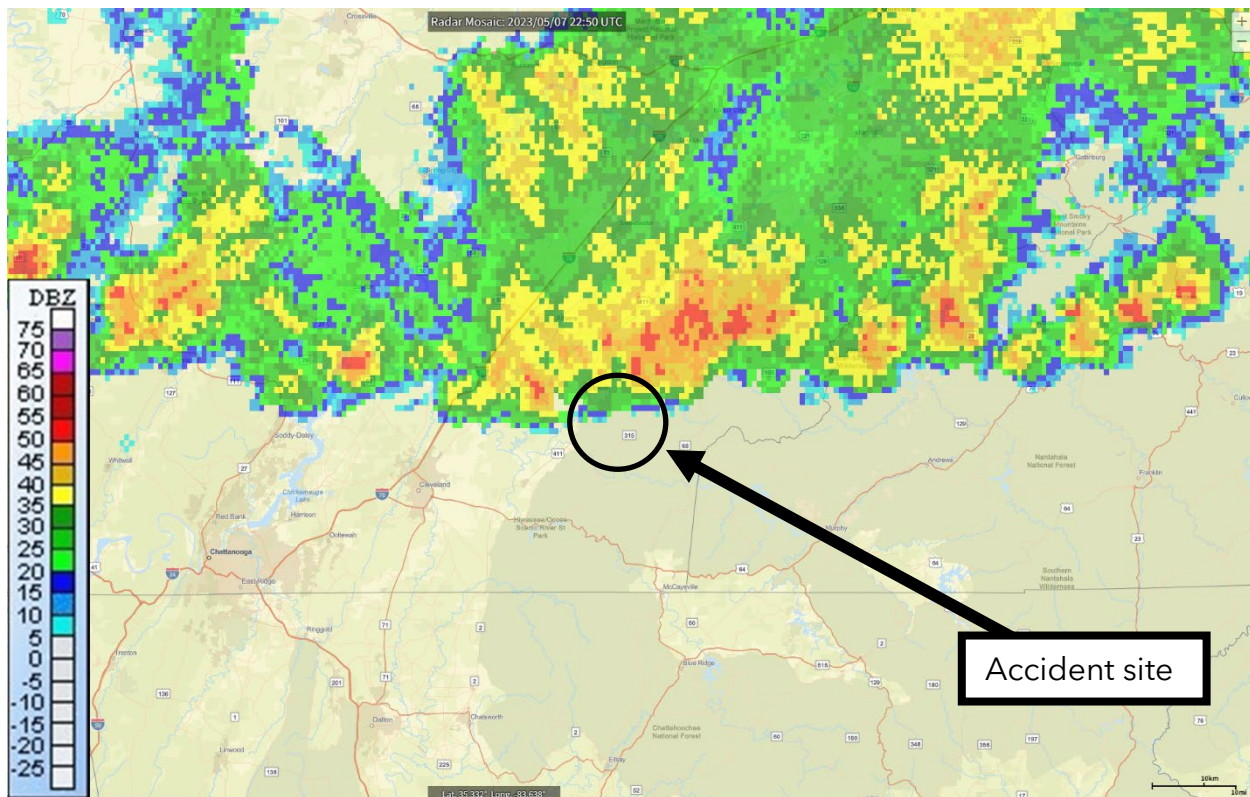


Figure 13. National Reflectivity Mosaic for 1850 EDT.

7.0 Weather Surveillance Radar Imagery

The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)²² to the accident site was Knoxville, Tennessee, WSR-88D, (KMRX) located 75 miles northeast of the accident site. The Level II archive radar data were obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

²² The WSR-88D is an S-band 10-centimeter wavelength radar with a power output of 750,000 watts, and with a 28-foot parabolic antenna that concentrates the energy between a 0.87° and 0.96° beam width. The radar produces three basic types of products: base reflectivity, base radial velocity, and base spectral width.

7.1 Volume Scan Strategy

During the period surrounding the accident, the KMRX WSR-88D radar was operating in the precipitation mode VCP-215²³ (figure 14). The following figure provides an indication of the different elevation angles in this VCP, and the approximate height and width of the radar beam with distance from the radar site.

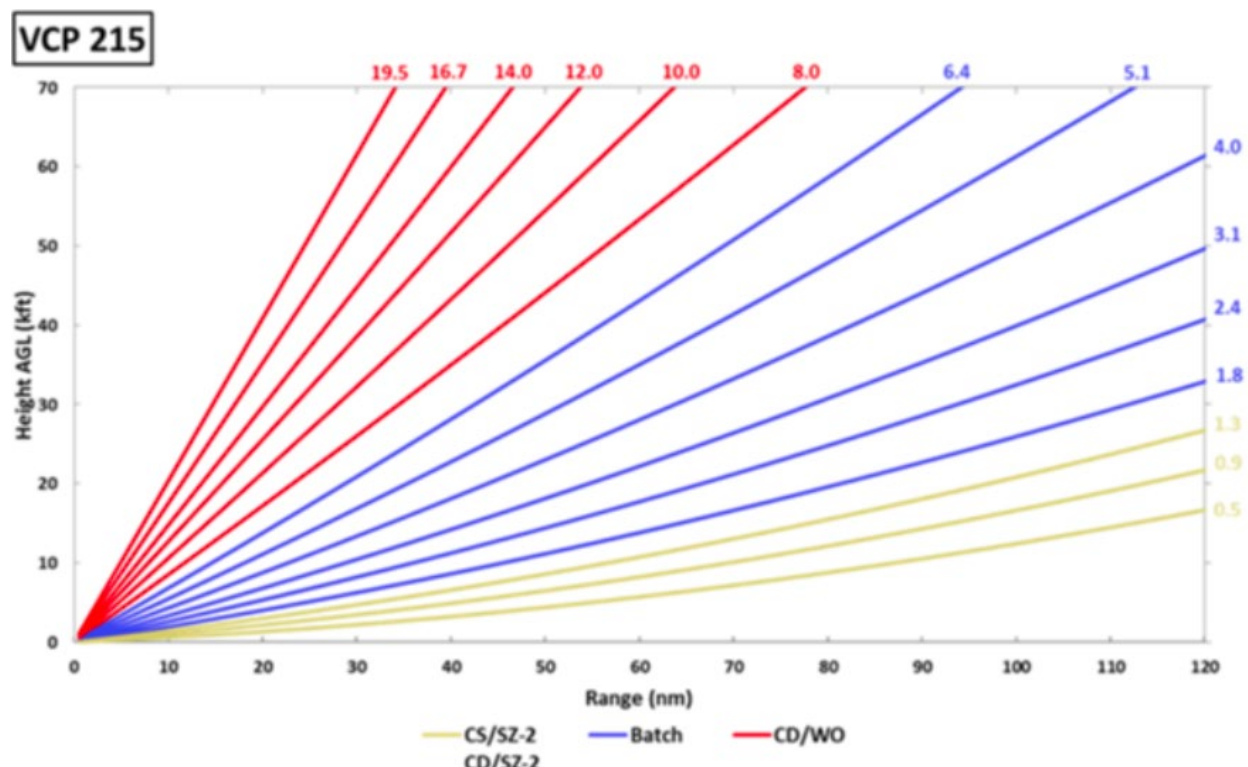


Figure 14. VCP-215 precipitation Mode Scan Strategy.

²³ Contiguous Surveillance (CS)--The low Pulse Repetition Frequency (PRF) scan of the split cut. Gives a high R_{max} value to determine proper target location and intensity, but a low V_{max} value limits the velocities that can be measured.

Contiguous Doppler (CD)--The high PRF scan of the split cut. Gives a low R_{max} value causing more range folded (multiple trip) echoes, but a high V_{max} value to get higher, more accurate velocity values. Batch Mode - Uses alternating low and high PRFs on each radial for one full rotation at each elevation angle. The two resulting data sets (low PRF and high PRF) are combined to resolve range ambiguity.

Used in the middle elevation angles.

W - With range unfolding (W)

WO - Without range unfolding (WO)

7.2 Beam Height Calculation

Assuming standard refraction²⁴ of the KMRX WSR-88D radar beam with the antenna elevation at 1,434 ft, and considering a beamwidth²⁵ of 0.95°, the following table shows the approximate heights for the 0.53° radar beams' center, top and base for certain antenna elevations over the accident site. These heights have been rounded to the nearest 10 ft.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP
KMRX 0.53°	9,380 ft	5,600 ft	13,160 ft

Based on the radar height calculations, the 0.53° elevation scan reviewed from KMRX listed in the above table combined to depict conditions between 5,600 ft and 13,160 ft over the accident site.

7.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors²⁶ it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in dBZ and is a general measure of echo intensity. The FAA Aviation Weather Handbook also defines the echo intensity levels and weather radar echo intensity terminology associated with those levels. For dBZ values less than 30 the weather radar echo intensity terminology should be "light." For dBZ values between 30 and 40, the terminology should be "moderate." "Heavy" terminology is used for dBZ values greater than 40 dBZ to 50 dBZ, inclusive. Finally, any dBZ values above 50 dBZ shall be described as "extreme."

²⁴ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

²⁵ Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

²⁶ Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth's surface; also, any water particles blown by the wind from the earth's surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist, or fog. (b) Liquid precipitation: drizzle and rain. (c) Freezing precipitation: freezing drizzle and freezing rain. (d) Solid (frozen) precipitation: ice pellets, hail, snow, snow pellets, and ice crystals. (e) Falling particles that evaporate before reaching the ground: virga. (f) Liquid or solid water particles lifted by the wind from the earth's surface: drifting snow, blowing snow, blowing spray. (g) Liquid or solid deposits on exposed objects: dew, frost, rime, and glazed ice.

7.4 Base Reflectivity and Lightning Data

Figures 15, 16, 17, 18, and 19 present the KMRX WSR-88D base reflectivity images for the 0.53° elevation scan initiated at 1834:35, 1841:17, 1847:54, 1847:54, and 1851:22 EDT with resolutions of 0.5° X 250 m. These images depicted reflectivity values between 30 and 50 dBZ moving from north to south towards the accident site at the time of the accident (attachment 2). The accident airplane passed through areas of 20 to 45 dBZ between 1834 and 1848 EDT.

There were 98 lightning flashes²⁷ reported within 40 miles of the accident site within 15 minutes before and after the accident time.²⁸ The lightning flashes are indicated by black dots overlaid on the radar images. Select air traffic control (ATC) transmissions with the accident flight are overlaid on figures 15 through 18, times in EDT. For more ATC information please see the docket in this accident.

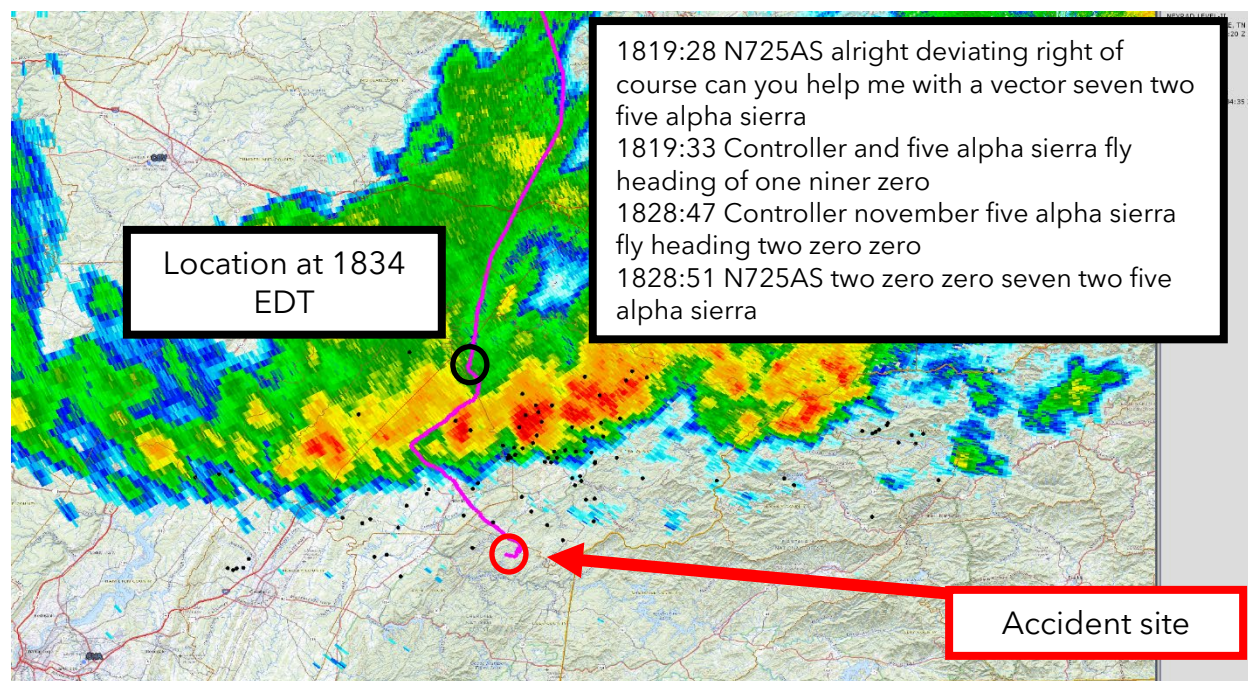


Figure 15. KMRX WSR-88D reflectivity for the 0.53° elevation scan initiated at 1834:35 EDT with the accident site marked with the red circle and the location of the accident aircraft in the black circle. Lightning flashes are marked with black dots and pink line is the airplane flight track.

²⁷ Lightning Flash – This is one contiguous conducting channel and all the current strokes/pulses that flow through it. There are two types of flashes: ground flashes and cloud flashes.

²⁸ A review of Earth Networks Total Lightning network and GOES Geostationary Lightning Mapper was done.

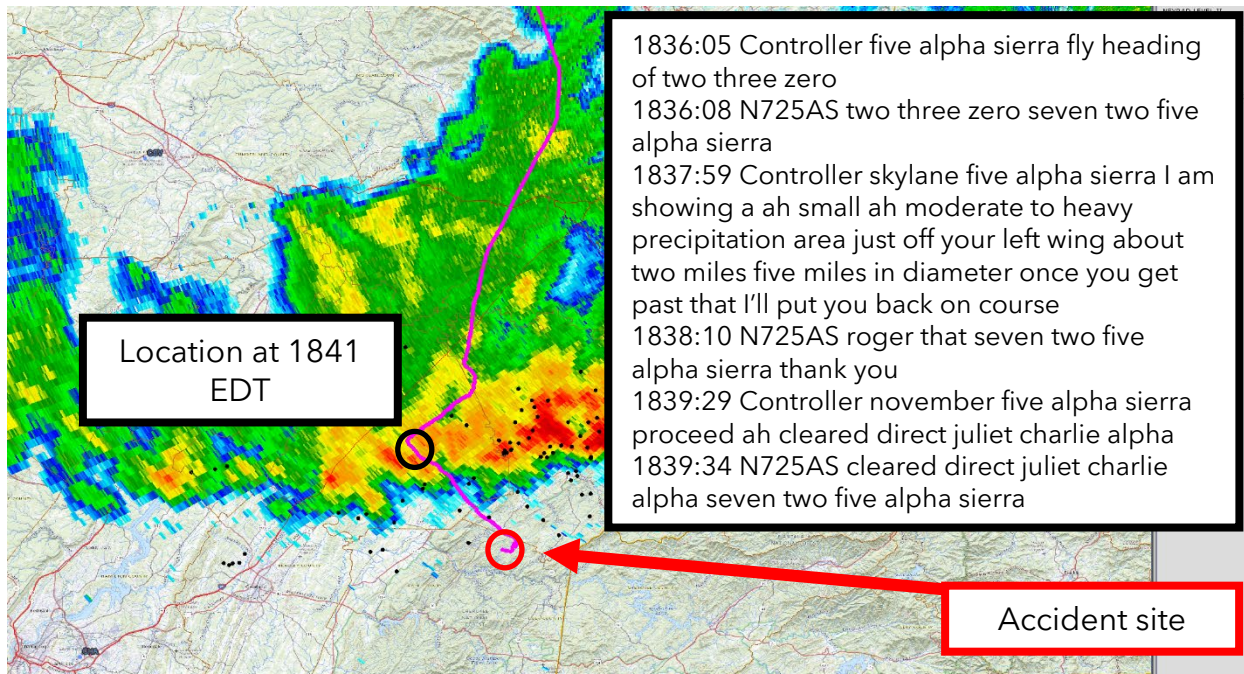


Figure 16. KMRX WSR-88D reflectivity for the 0.53° elevation scan initiated at 1841:17 EDT with the accident site marked with the red circle and the location of the accident aircraft in the black circle. Lightning flashes are marked with black dots and pink line is the airplane flight track.

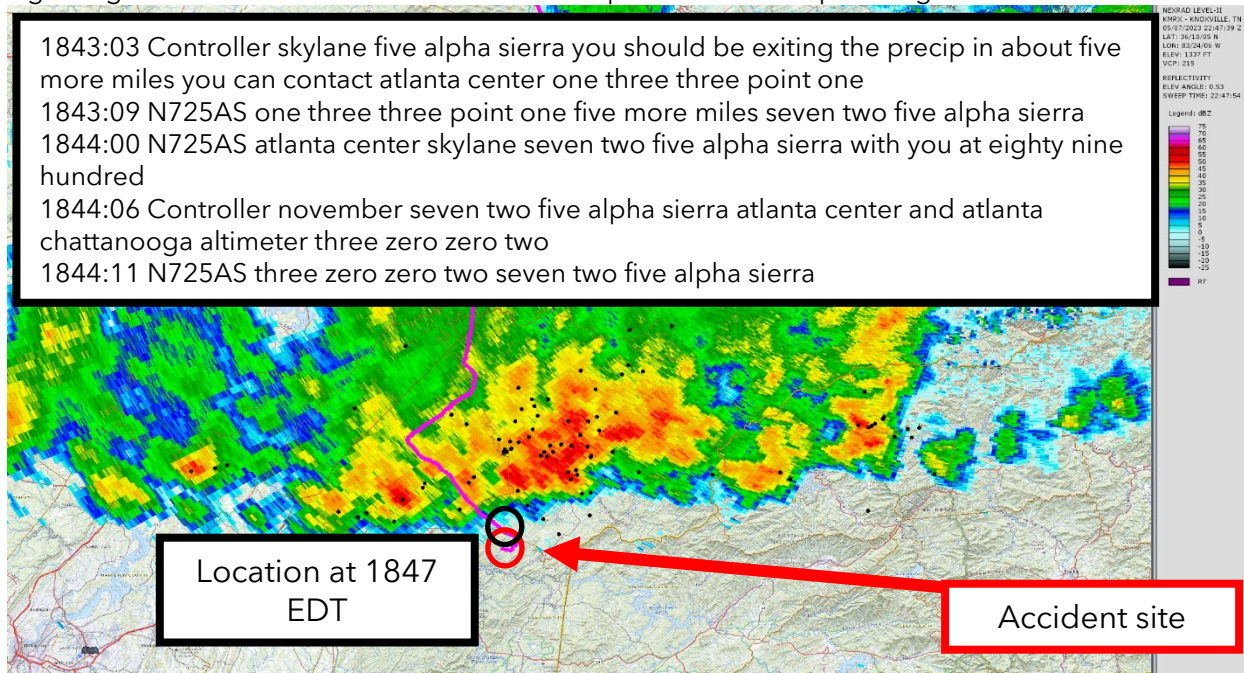


Figure 17. KMRX WSR-88D reflectivity for the 0.53° elevation scan initiated at 1847:54 EDT with the accident site marked with the red circle and the location of the accident aircraft in the black circle. Lightning flashes are marked with black dots and pink line is the airplane flight track.

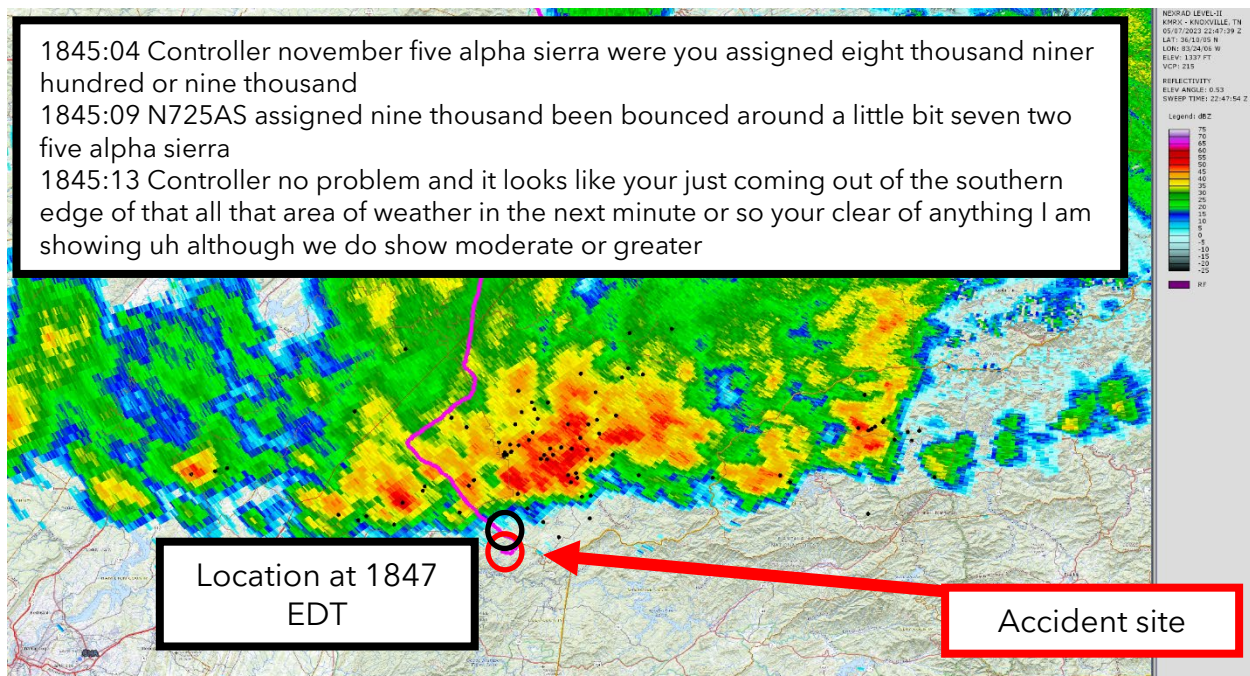


Figure 18. KMRX WSR-88D reflectivity for the 0.53° elevation scan initiated at 1847:54 EDT with the accident site marked with the red circle and the location of the accident aircraft in the black circle. Lightning flashes are marked with black dots and pink line is the airplane flight track. Additional ATC information inlaid on the top of figure 18 and different text from the inlay on figure 17.

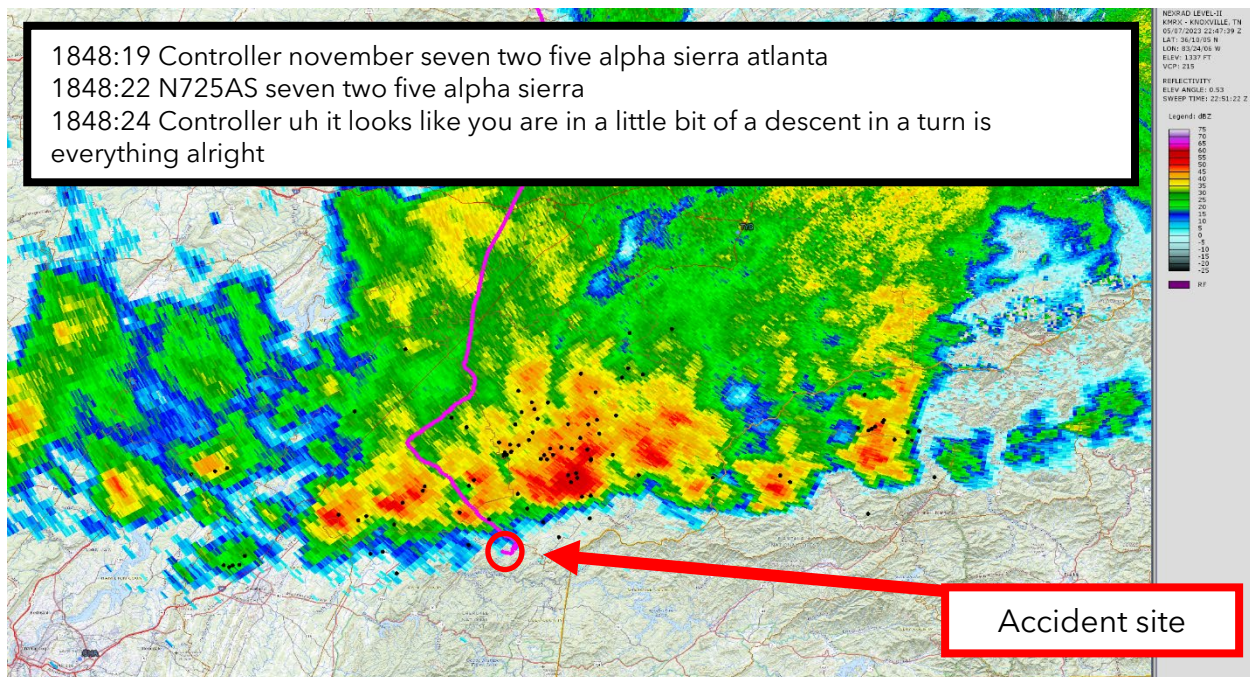


Figure 19. KMRX WSR-88D reflectivity for the 0.53° elevation scan initiated at 1851:22 EDT with the accident site marked with the red circle. Lightning flashes are marked with black dots and pink line is the airplane flight track.

8.0 Pilot Reports

The longline-disseminated pilot reports²⁹ (PIREPs) distributed into the national airspace system (NAS) within 2 hours before and after the accident time and within 150 miles of the accident site at altitudes below 20,000 ft are shown here:

BNA UUA /OV BNA135030/TM 2050/FL150/TP E170/TB SEV 150 NO INJURIES OR DAMAGE/RM ZME

BNA UA /OV BNA200080/TM 2055/FL030/TP B737/TB MOD

BNA UA /OV BNA270010/TM 2118/FLMULT/TP MULT/TB SEV

BNA UA /OV BNA150025/TM 2120/FL060/TP B737/TB MOD CHOP

TYS UA /OV TYS135010/TM 2121/FL040/TP A320/TB LIGHT TURB BLO 40/MOD TURB 50-80/LIGHT TURB ABOVE 80

GAD UA /OV GAD/TM 2125/FL180/TP B712/TB NEG CHOP/RM ZTLFD

TYS UUA /OV 5 MILE FINAL 05 TYS/TM 2133/FL40/TP B752/TB MOD TURB /RM SEVERE WIND SHEAR

ATL UUA /OV ATL045010/TM 2136/FL045/TP B737/SK TOPS AT 080/WX CONVECTIVE WX / 045-050/TB SEV

BNA UUA /OV BNA270035/TM 2140/FL100/TP P46T/G/TB EXTRM 100-110 NO INJURY OR DAMAGE/RM ZME

BNA UA /OV BNA090020/TM 2151/FL030/TP SR22/TB SEV

BNA UA /OV BNA130020/TM 2151/FL100/TP SR22/TB SEV

TOC UA /OV ODF085020/TM 2219/FL100/TP C210/SK SKC/TB NEG/RM SMOOTH ZTLFD

LOZ UA /OV AZQ330030/TM 2244/FL140/TP PC12/TB MOD

TRI UA /OV HVM220020/TM 2247/FL155/TP E75L/SK IMC/WX RA/TA M10/TB LGT CHOP/IC NEG/RM ZTLFD

BNA UUA /OV BNA230030/TM 2315/FLDURGD/TP B350/TB SEV 060-030

BNA UUA /OV BNA225020/TM 2320/FL050/TP B350/G/TB SEV 050 +/-500FT-NO DAMAGE OR INJURIES/RM ZME

LUG UA /OV LUG360010/TM 2322/FL030/TP B350/TB MOD-SEV 030-060/RM ZME

BNA UA /OV BNA090015/TM 2327/FLDURGC/TP B737/TB MOD SFC-090

CHA UA /OV GQO094030/TM 2330/FL090/TP PA30/TB CONS MOD 055-090/RM ZTLFD

LOZ UA /OV LVT050015/TM 2336/FL155/TP B58T/TA M04/TB MOD CHOP/IC LGT RIME DURGC 150-150

²⁹ Only PIREPs with the World Meteorological Organization headers UBTN**, UBAL**, UBGA**, UBSC**, UBKY**, UBVA**, UBMS**, and UBNC** were considered. These do not include pilot reports only broadcast via radio.

AND UA /OV ELW275010/TM 2338/FL070/TP P28A/TB NEG/RM ZTLFD
LOZ UA /OV LOZ200020/TM 2340/FL160/TP B58T/TA NOT REPORTED/IC LGT RIME
160-180
BNA UUA /OV BNA225040/TM 2343/FL030/TP H25B/TB CONS SEV 030/RM ZME
BNA UUA /OV BNA270020/TM 2353/FL150/TP E135/TB SEV-MOD ABV 150170-
170/RM ZME
BNA UUA /OV BNA300025/TM 2353/FL150/TP E135/TB SEV
BNA UA /OV BNA225020/TM 0013/FL120/TP B737/TB CONS MOD 120-260/RM ZME
CPF UA /OV CPF/TM 0037/FL200/TP AT43/TB CONS MOD CHOP
RHP UA /OV HRS/TM 0039/FL190/TP B712/TA M19/IC LGT RIME 220/RM ZTLFD

9.0 Significant Meteorological Information

Convective Significant Meteorological Information (SIGMET) advisory 26E was issued at 1755 EDT and was valid for the area immediately north of the accident site at the time (figure 19). The advisory warned of an area of severe thunderstorms with cloud tops to FL410³⁰, hail to 1 inch, and wind gusts to 50 knots were possible with the Convective SIGMET box movement from 320° at 35 knots. This implied that with time the accident site was included in that advisory and could expect impact from the area of thunderstorms.

The Convective SIGMET issued immediately after the accident at 1855 EDT is contained in figure 20 and included the accident site:

WSUS31 KPCI 072155
SIGE
CONVECTIVE SIGMET 26E
VALID UNTIL 2355Z
VA NC TN KY
FROM 40NW HNV-20W GSO-20ESE CLT-40SSE BNA-30ENE BNA-40NW HNV
AREA SEV TS MOV FROM 32035KT. TOPS TO FL410.
HAIL TO 1 IN...WIND GUSTS TO 50KT POSS.

³⁰ Flight Level - A Flight Level (FL) is a standard nominal altitude of an aircraft, in hundreds of ft. This altitude is calculated from the International standard pressure datum of 1013.25 hPa (29.92 inHg), the standard sea-level pressure, and therefore is not necessarily the same as the aircraft's true altitude either above mean sea level or above ground level.

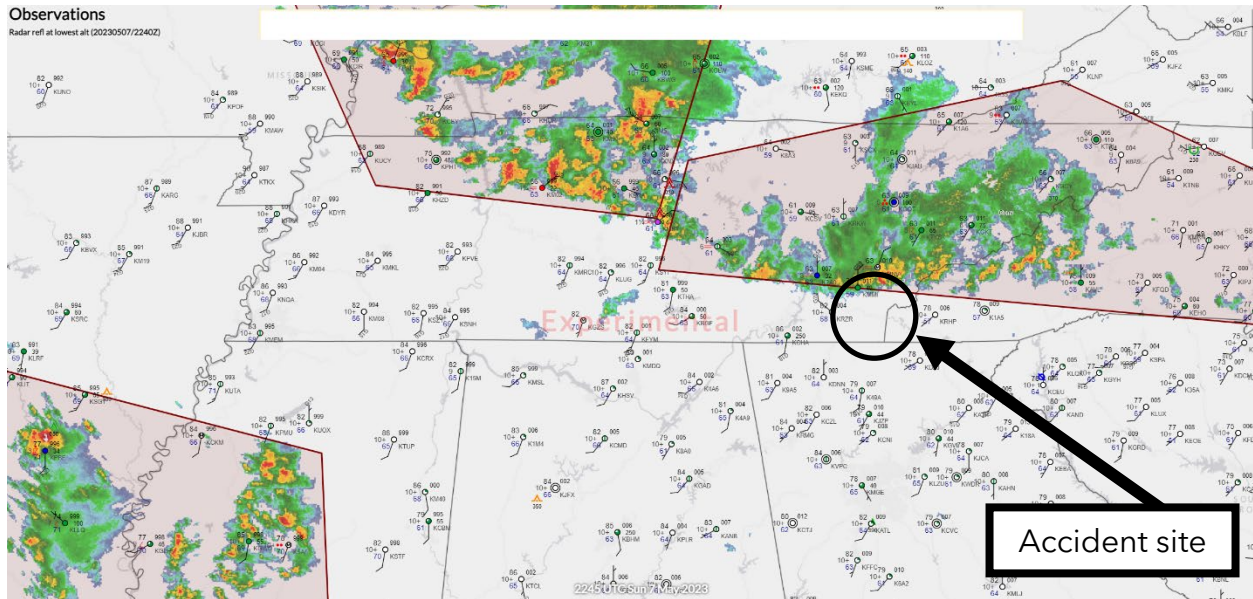


Figure 19. Convective SIGMET valid at the accident time with National Reflectivity Mosaic for 1840 EDT.

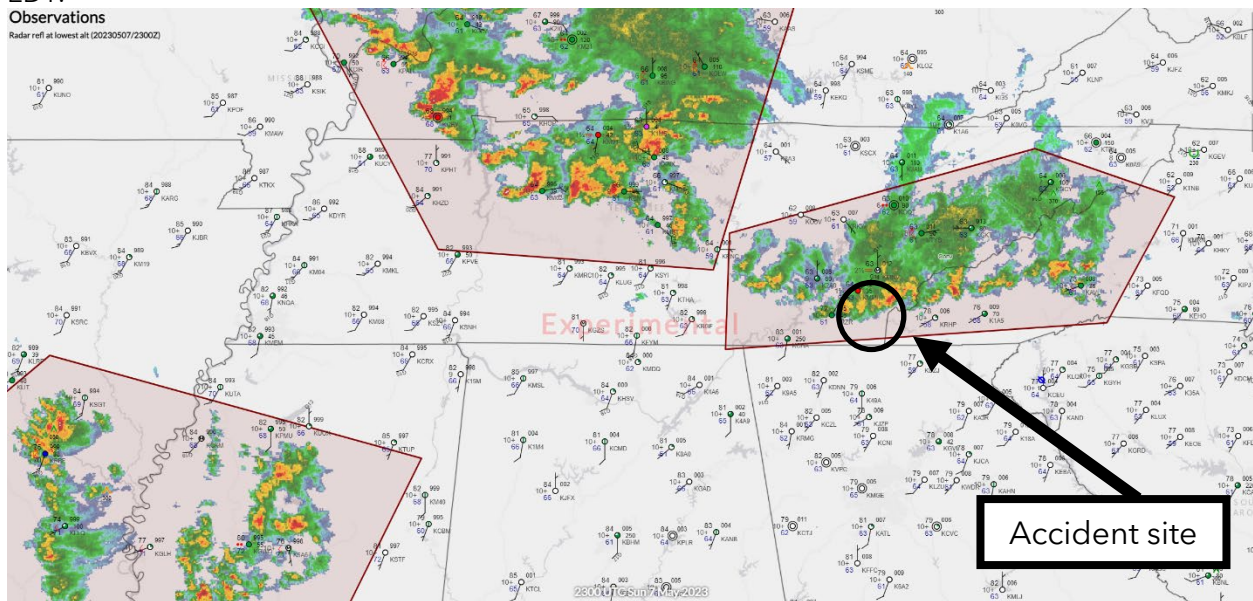


Figure 20. Convective SIGMET valid at 1900 EDT and National Reflectivity Mosaic for 1900 EDT.

10.0 Center Weather Service Advisories

The Atlanta (ZTL) Air Route Traffic Control Center (ARTCC) Center Weather Service Unit (CWSU) was responsible for the accident region. There was no Center Weather Advisory (CWA) valid for the accident site at the accident time. The ZTL CWSU issued pre-duty weather briefings (PDWB) on the day of the accident and they can be found in attachment 3.

11.0 Airmen's Meteorological Information

The NWS Aviation Weather Center (AWC) had text Airmen's Meteorological Information (AIRMET) advisory Sierra valid for the accident site at the accident time. The text AIRMET Sierra was issued at 1645 EDT and forecast mountain obscuration due to clouds and precipitation:

```
WAUS42 KPCI 072045
WA2S
-MIAS WA 072045
AIRMET SIERRA UPDT 4 FOR IFR AND MTN OBSCN VALID UNTIL 080300
.
NO SGFNT IFR EXP OUTSIDE OF CNVTV ACT.
.
AIRMET MTN OBSCN...NC SC GA WV VA
FROM 20NE BKW TO LYH TO CLT TO 40SE ODF TO GGO TO HNV TO 40WSW
BKW TO 20NE BKW
MTNS OBSC BY CLDS/PCPN. CONDS CONTG BYD 03Z THRU 09Z.
.
OTLK VALID 0300-0900Z...IFR FL AND CSTL WTRS
BOUNDED BY 40W CEW-60E CEW-50SE CEW-60SSW CEW-40W CEW
CIG BLW 010/VIS BLW 3SM BR. CONDS DVLPG 06-09Z. CONDS CONTG THRU
09Z.
....
```

12.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products issued by the AWC before the accident flight and valid at 1700 and 2000 EDT are shown in attachment 4. The GFA surface forecasts applicable to the accident site that were valid before the accident flight's departure indicated VFR conditions with a southwest wind of 5 to 10 knots. In addition, isolated to scattered (between 10 and 50 percent) thunderstorm activity was expected at 1700 and 2000 EDT. The GFA cloud forecast applicable to the accident site issued at 1502 EDT and valid at 1700 and 2000 EDT indicated just cirrus clouds at the accident site. The 1802 EDT GFA cloud forecast valid at 2000 EDT indicated broken cloud coverage with cloud tops to FL410. The Graphical AIRMET³¹ (G-AIRMET) Sierra were overlaid on the GFA cloud forecast products. The only human-generated information reflected in the two GFA products were the G-AIRMETs.

³¹ Graphical AIRMETs (G-AIRMETs), found on the Aviation Weather Center webpage at <http://aviationweather.gov>, are graphical forecasts of en-route weather hazards valid at discrete times no more than 3 hours apart for a period of up to 12 hours into the future (for example, 00, 03, 06, 09, and 12 hours). G-AIRMETs are snap shots at discrete time intervals as defined above. The text AIRMET is the result of the production of the G-AIRMET but provided in a time smear for a 6hr valid period.

13.0 Terminal Aerodrome Forecast

There were no NWS Terminal Aerodrome Forecast³² (TAF) locations within 30 miles of the accident site.

14.0 National Weather Service Area Forecast Discussion

The NWS weather forecast office in Morristown, Tennessee, (WFO MRX) was responsible for the public and surface aviation forecast in the region of the accident site. WFO MRX issued the following Area Forecast Discussion (AFD) at 1515 EDT, the closest AFD to the accident time with an aviation section:

FXUS64 KMRX 071915
AFDMRX

Area Forecast Discussion
National Weather Service Morristown TN
315 PM EDT Sun May 7 2023

...New SHORT TERM, LONG TERM...

.SHORT TERM...
(This evening through Monday)
Issued at 251 PM EDT Sun May 7 2023

Key Messages:

1. Line of showers and thunderstorms this evening may produce strong and gusty winds of 40-50 mph and hail up to 1/2 inch size. Mainly along and north of interstate 40.
2. Another cluster of showers and storms overnight mainly along and south of interstate 40. These storms may also produce winds up to 40 mph and locally heavy rain.

Discussion:

Through this evening, a line of showers and storms will move slowly southeast across southwest VA/northern half of east Tennessee. Main forcing for this complex of storms is a wave/jet streak riding the top of the ridge over Kentucky/northern Tennessee valley.

Airmass along and ahead of this line will be marginally unstable

³² According to NWS Instruction 10-813: "An NWS TAF consists of the expected meteorological conditions significant to aviation at an airport for a specified time period. For the U.S., this is the area within five (5) statute miles (SM) of the center of an airport's runway complex."
www.nws.noaa.gov/directives/sym/pd01008013curr.pdf

with MLCAPES of 500 (northeast) to 1,500 (Plateau) with mid-level lapses of 6.5 to 6.8 degrees. Main concern is the area of mid-level and sub-cloud layer initial dry air that produces DCAPE values of 800 to 1000. This level of Downdraft CAPE may produce isolated strong and gusty winds of 40-50 mph with main impact being isolated down trees and localized power outages. Due to the low Wet Bulb Zero around 9kft and decent mid-level lapse rates, the strongest storms could produce small hail.

Latest HREF and HRRR shows this line of convection weakening once it moves south of interstate 40.

For tonight, high-resolution CAMS shows another cluster of convection moving southeast from middle Tennessee into the southern half of east Tennessee and southwest North Carolina for early Monday morning. Strongest storms will be along and south of the outflow boundary from this evening's convection (southeast Tennessee). This complex of storms will move southeast of the region soon after daybreak Monday.

For Monday, deterministic models and ensembles vary greatly on the convective coverage and timing of next storm development. Trending toward the latest HRRR model which only produces scattered storms. This seems reasonable given the outflow boundary from the series of convective will be well west and south of the region.

&&

.LONG TERM...

(Monday night through next Sunday)

Issued at 251 PM EDT Sun May 7 2023

Key Messages:

1. Additional showers/storms expected Monday night into Tuesday. Dry mid week with low rain chances making a return Friday into the weekend.
2. Above normal temperatures expected throughout the long-term period.

Discussion:

The omega block pattern remains in place to start off the long term portion of this forecast package. Ridging will gradually amplify into the mid-week in response to shortwave activity deepening troughing across the PNW. Monday night into Tuesday a surface boundary will slowly shift southward through the forecast area and act as a forcing point for additional showers and storms. NAM soundings continue to show MLCAPES at or in excess of 1000J/kg and mid-level lapse rates in the 6.5-7.5C/km range. There will also be a brief increase in amplitude of nwly flow aloft, leading to enhanced but mostly unidirectional shear. For this reason, a few strong or

isolated severe storms will remain possible. Primary threat will be damaging wind gusts with perhaps some hail as well. One thing working against storm activity will be increasing subsidence aloft. Additionally, PWATs hovering around 1.3 inches(which is between the 75th and 90th percentile according to SPC sounding climatology out of BNA) could result in some isolated flooding concerns dependent on antecedent rainfall over these next two days and whether or not areas see repeated moderate/heavy downpours.

The increased ridging influence into the mid-week should keep the forecast area mostly dry with continued above normal temperatures expected. By the late week and into the weekend, surface high pressure will transition east of the area with some extent of ridge suppression that takes place due to increased troughing over the northeastern CONUS and into Canada. Weaker subsidence will favor a return of PoP chances. However, it looks to follow a more diurnal trend at this time, with best chances in the afternoon/evening.

&&

.AVIATION...

(18Z TAFS)

Issued at 1247 PM EDT Sun May 7 2023

Main concern is timing of line of showers and storms moving across the TAF sites. First line will move across TRI around 19-20Z and TYS around 21-22Z. Do not expect this line of convection to make it to CHA before dissipating.

However, another cluster of convection will move from middle Tennessee across CHA between 05-08Z possibly reaching north into TYS/TRI with some showers early Monday morning.

Due to the expected rain cooled airmass, some low cloud development is possible at all TAF early Monday morning before lifting.

&&

.PRELIMINARY POINT TEMPS/POPS...

Chattanooga Airport, TN	64	82	65	86	/	70	50	40	50
Knoxville McGhee Tyson Airport, TN	62	79	64	81	/	60	50	50	60
Oak Ridge, TN	62	79	63	83	/	60	50	50	50
Tri Cities Airport, TN	60	76	61	77	/	40	30	60	60

&&

.MRX WATCHES/WARNINGS/ADVISORIES...

NC...NONE.

TN...NONE.

VA...NONE.

&&

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15.0 Winds and Temperature Aloft Forecast

The NWS 1559 EDT, Winds and Temperature Aloft forecast valid for the closest station to the accident site is included below:

FBUS31 KWN0 071959

FD1US1

DATA BASED ON 071800Z

VALID 080000Z FOR USE 2000-0300Z. TEMPS NEG ABV 24000

FT 3000 6000 9000 12000 18000 24000 30000 34000 39000

TYS 2421 2621+13 2923+08 2826+02 2927-12 2933-22 274438 274949 286460

The closest forecast point to the accident site was Knoxville, Tennessee, (TYS). The forecast was for use between 1600 and 2300 EDT.

16.0 Pilot Weather Information

Title 14 CFR 91.103 states that "Each pilot in command shall, before beginning a flight, become familiar with all available information concerning that flight." FAA AC 91-92 "Pilot's Guide to a Preflight Planning" (dated March 15, 2021) provided pilot guidance on preflight self-briefings, including planning, weather interpretation, and risk identification/mitigation skills. The AC further stated in part:

Pilots adopting these guidelines will be better prepared to interpret and utilize real-time weather information before departure and en route, in the cockpit, via technology like Automatic Dependent Surveillance-Broadcast (ADS-B) and via third-party providers.³³

A search of archived information indicated that the accident pilot did not request weather information from Leidos Flight Service. The accident pilot did request and receive a weather briefing package from ForeFlight at 1544 EDT on May 6 and the weather briefing package contained all the standard weather forecast information valid at that time. The accident pilot did not request a weather briefing package on May 7. The accident pilot did view airport information at 4 separate airports at 1301, 1313, 1429, and 1624 EDT on May 7. For more information please see attachments 5 and 6. Prior to the flight the accident pilot had not viewed any weather imagery information on the ForeFlight App. It is unknown what additional weather information, if any, the accident pilot checked or received during the accident flight.

³³ https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC_91-92.pdf. The AC also listed multiple online FAA resources for aviation flight planning services for adverse weather.

17.0 Astronomical Data

The astronomical data obtained for the accident site on May 7, 2023, indicated the following:

SUN

Begin civil twilight 0613 EDT

Sunrise 0640 EDT

Sun transit 1334 EDT

Accident time 1849 EDT³⁴

Sunset 2029 EDT

End civil twilight 2056 EDT

At the time of the accident, the Sun was at an altitude of 18.79° and azimuth of 277.89°.

E. LIST OF ATTACHMENTS

Attachment 1 - GOES-18 Visible imagery animation from 0801 to 1001 EDT

Attachment 2 - KMRX WSR-88D base reflectivity animation from 1814 to 1901 EDT

Attachment 3 - ZTL CWSU PDWB

Attachment 4 - GFA information valid at the accident time

Attachment 5 - ForeFlight information

Attachment 6 - ForeFlight weather information

Submitted by:

Paul Suffern
Senior Meteorologist

³⁴ Inserted accident time for reference and context.