



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

October 3, 2019

Weather Study

METEOROLOGY

DCA19CA091

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A. ACCIDENT

Near: Nashville, Tennessee
Date: February 17, 2019
Time: about 1805 central standard time
0005 Coordinated Universal Time (UTC) February 18, 2019
Aircraft: Delta Airlines flight 957, Boeing 737-800, Registration: N3730B

B. METEOROLOGIST

Paul Suffern
Senior Meteorologist
Operational Factors Division (AS-30)
National Transportation Safety Board

C. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's (NTSB) Meteorologist did not travel for this investigation and gathered the weather data for this investigation from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the National Centers for Environmental Information (NCEI). All times are central standard time (CST) on February 17, 2019, and are based upon the 24-hour clock, where local time is -6 hours from UTC, and UTC=Z (unless otherwise noted). Directions are referenced to true north and distances in nautical miles. Heights are above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of miles. NWS airport and 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 was located at latitude 35.9005° N, longitude 86.9564° W descending through an approximate altitude of FL330¹ or ~250-hectopascals (hPa).

¹ 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 average 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.

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 Weather Prediction Center, 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 joint NWS and Federal Aviation Administration (FAA) Advisory Circular “Aviation Weather Services”, AC 00-45H.²

1.1 Surface Analysis Chart

The Tennessee Valley section of the NWS Surface Analysis Chart for 1800 CST is provided as figure 1 with the location of the accident site marked within the red circle. The chart indicated a low pressure system at 1006-hectopascals (hPa) over southern Ohio associated with an occluded front, which stretching southwestward through Ohio, eastern Tennessee, through northwestern Georgia, to northeastern Alabama, where another low-pressure system at 1017-hPa was located at the triple point. A cold front continued southwestward from this triple point low across Alabama, into southern Mississippi, into Louisiana. A stationary front extended east-southeastward from the triple point low over Alabama across central Georgia. The accident site was located west of the occluded front on the cold air side of the frontal boundary.

The station models around the accident site depicted air temperatures in the mid 40’s degrees Fahrenheit (°F), dew point temperatures in the low 40’s °F with a temperature-dew point spread of 4° or less, a west wind to 5 knots, overcast cloud cover, and light rain.

²

https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1030235

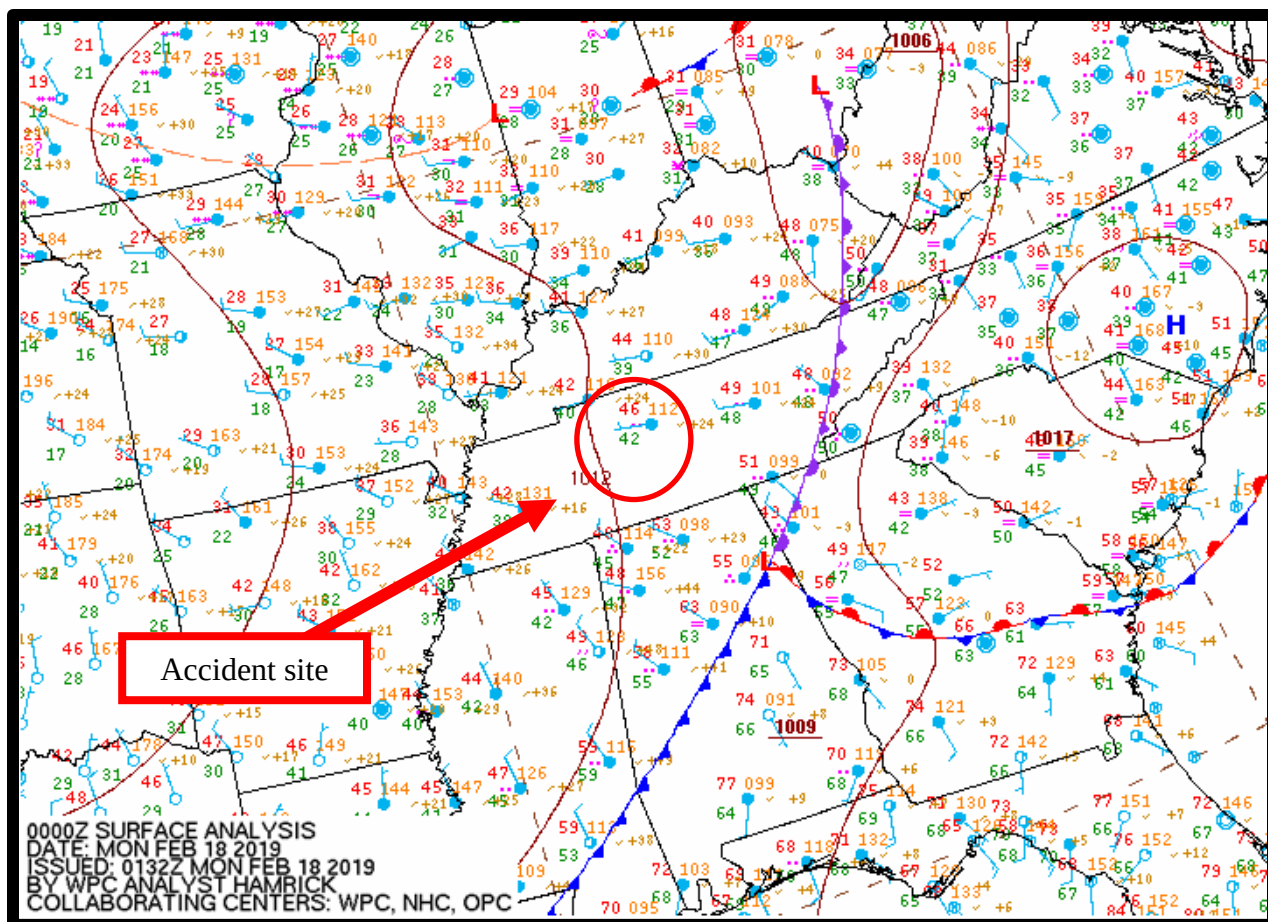


Figure 1 – NWS Surface Analysis Chart for 1800 CST

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 1800 CST at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2 through 6. There were low- and mid-level trough³ located above and around the accident site at 925- through 500-hPa (figures 2 through 5). Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present and there is upper level support from surface fronts. At 300-hPa, the accident site was located just southeast of the strongest jet stream wind speed with 180-knots observed in central Illinois (figure 6). The wind was from the west at 10 knots at 925-hPa with the wind becoming southwesterly at 80 knots by 700-hPa (figure 4). The wind speed continued to increase through 300-hPa with the 300-hPa wind was from the southwest at 135 knots (figure 6).

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

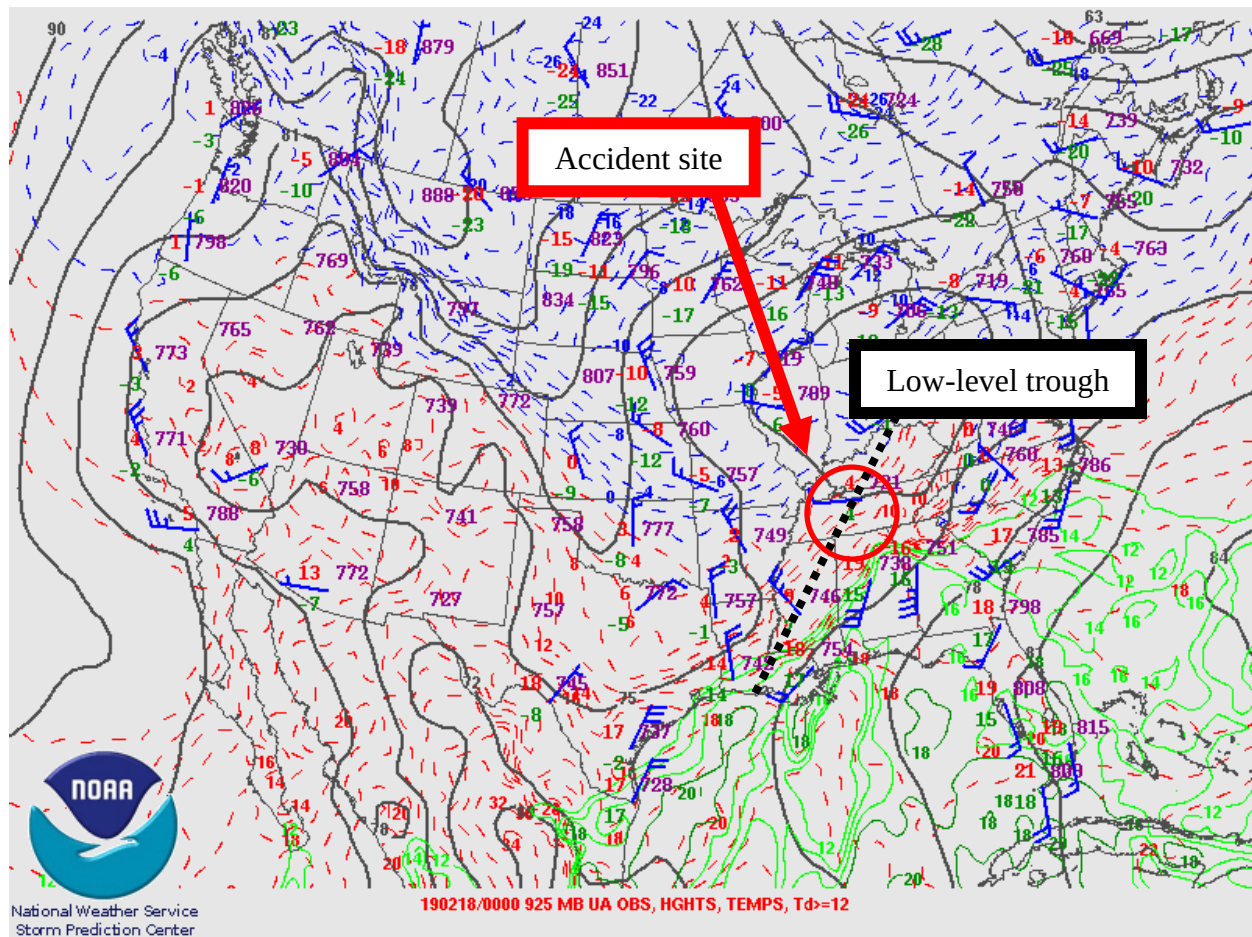


Figure 2 – 925-hPa Constant Pressure Chart for 1800 CST

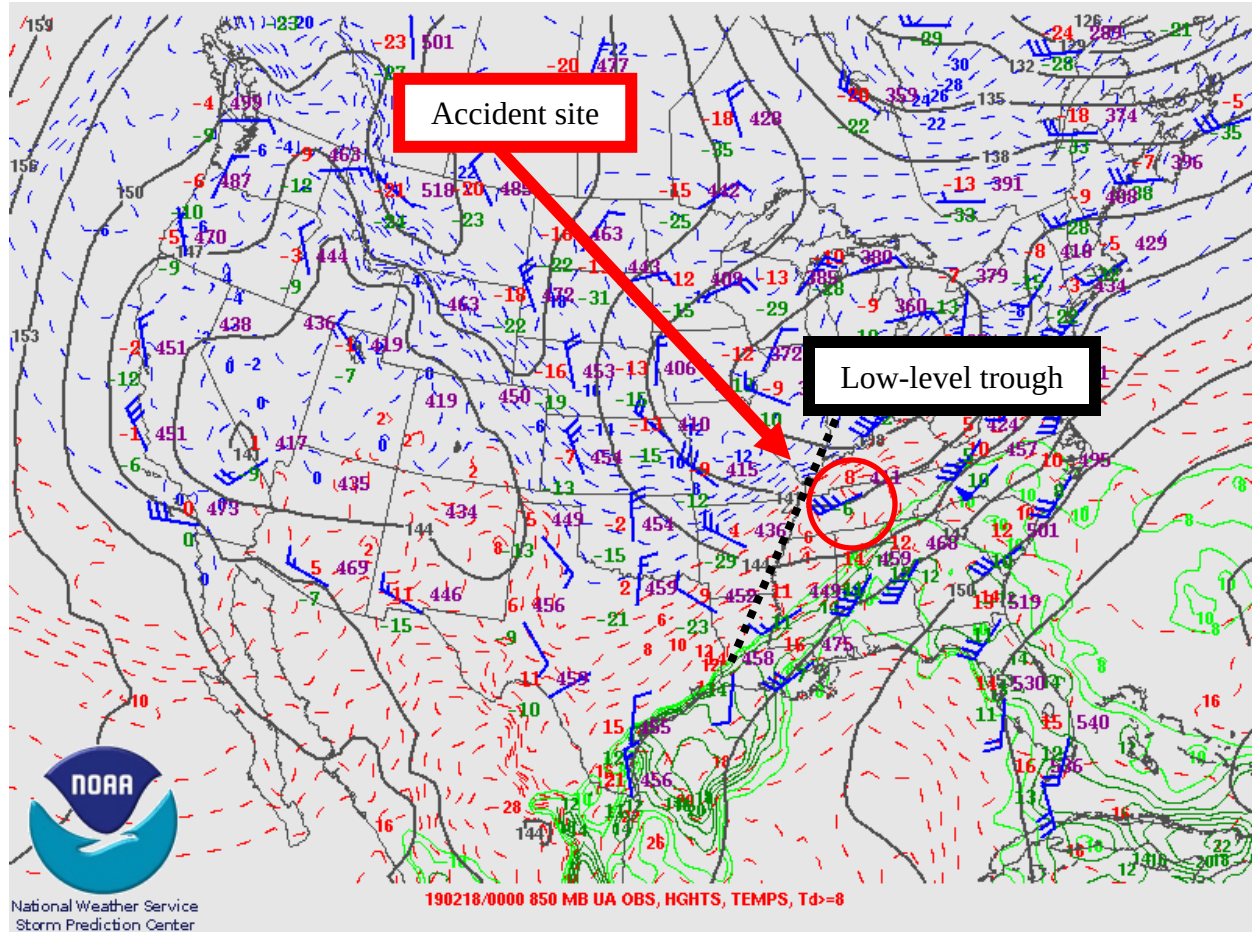


Figure 3 – 850-hPa Constant Pressure Chart for 1800 CST

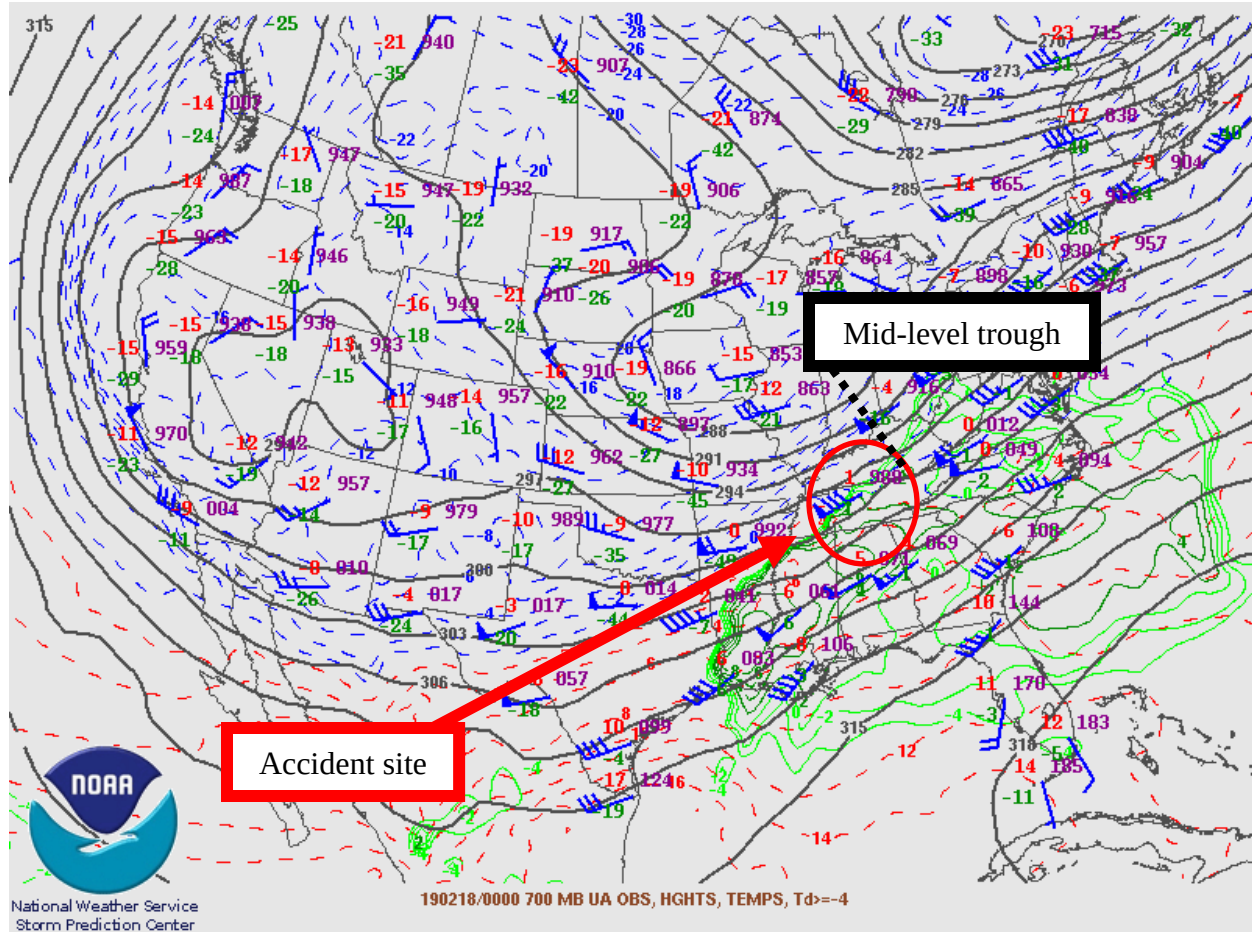


Figure 4 – 700-hPa Constant Pressure Chart for 1800 CST

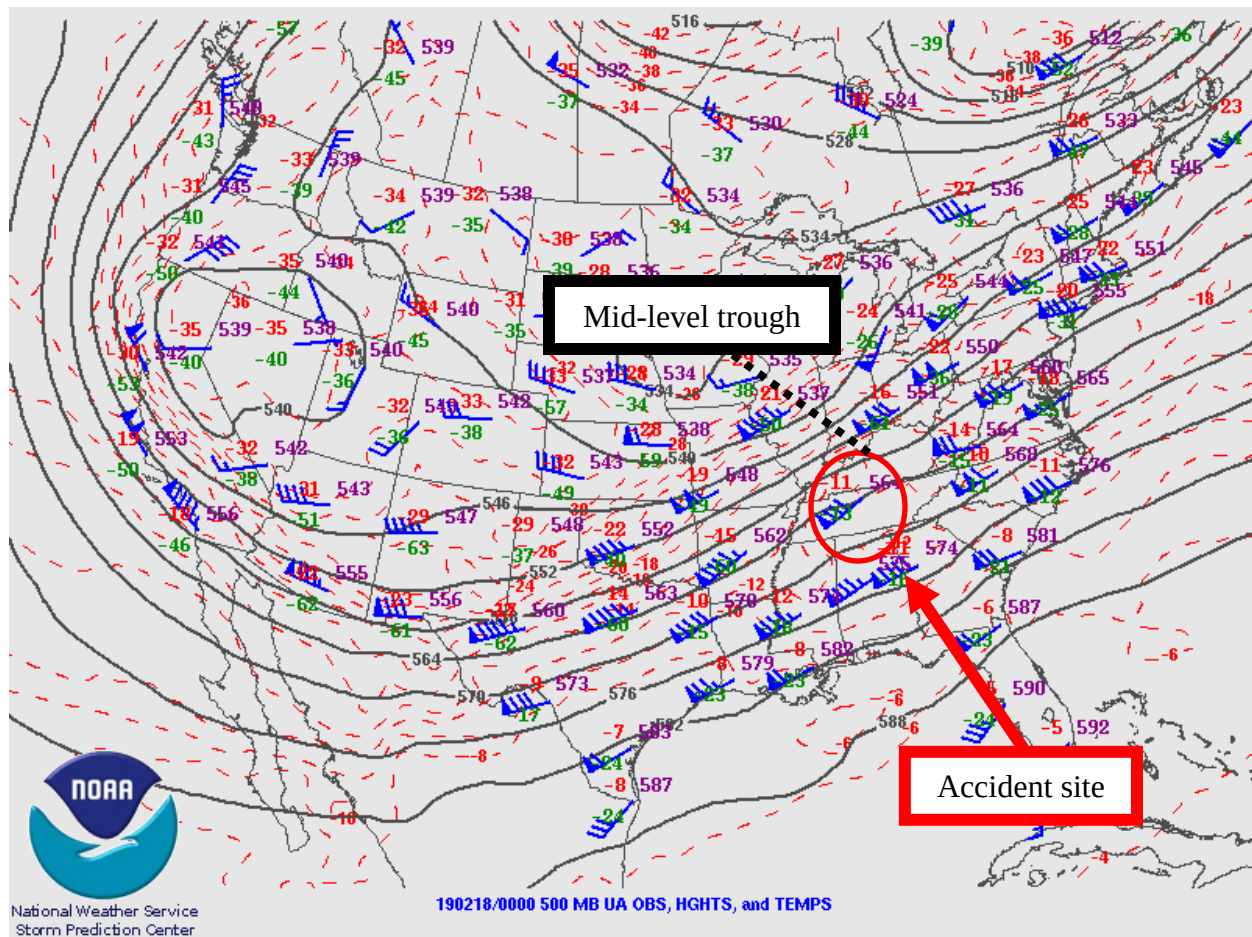


Figure 5 – 500-hPa Constant Pressure Chart for 1800 CST

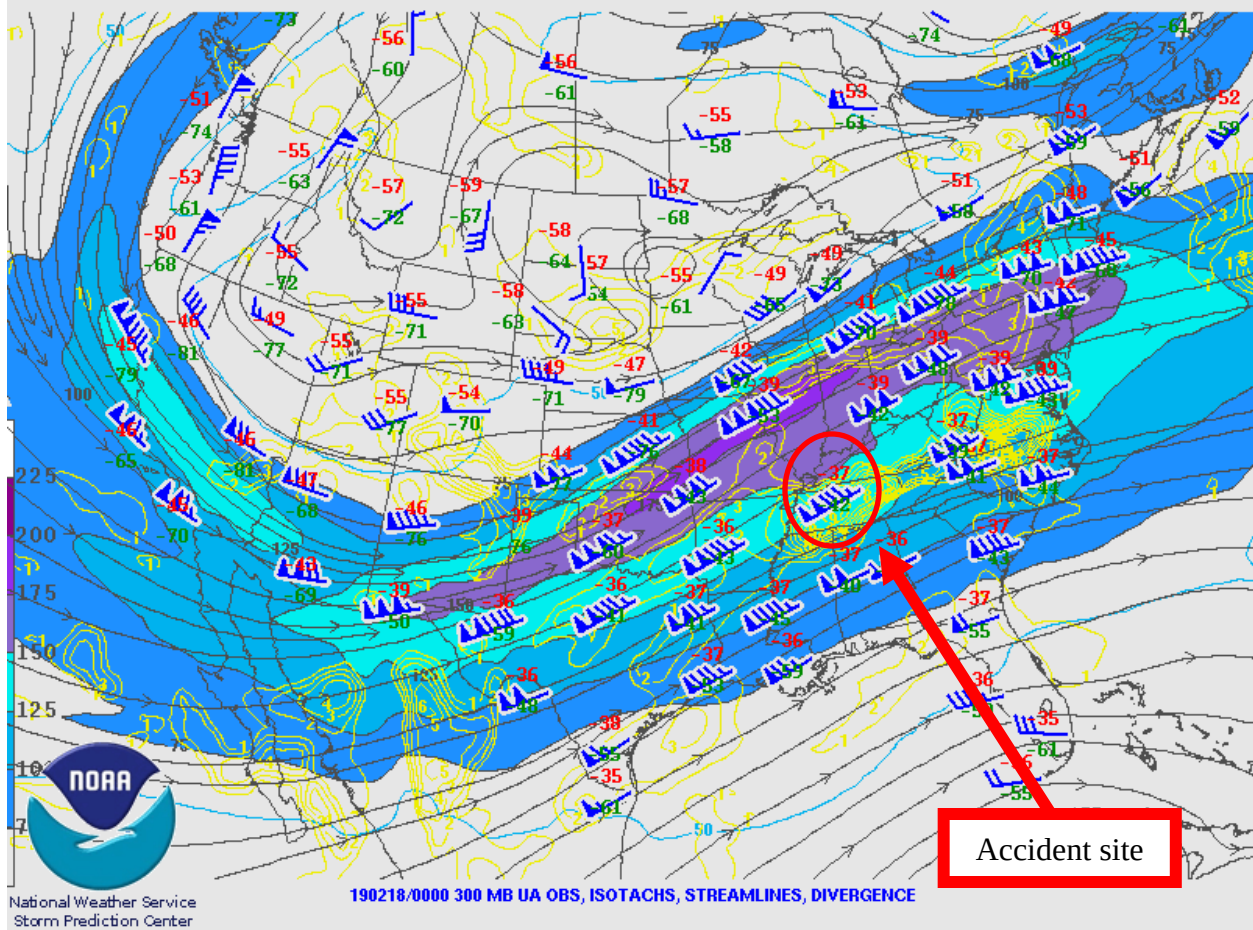


Figure 6 – 300-hPa Constant Pressure Chart for 1800 CST

2.0 SPC Products

SPC issued the following Day 1 Convective Outlook at 1338 CST (figure 7) with areas of general thunderstorms forecast for the accident site⁴. SPC defines the “TSTM” area as an area that encloses where a 10% or higher probability of thunderstorms is forecast during the valid period. The SPC Day 1 Convective Outlook text follows figure 7:

⁴ The 0900 and 0800 EDT SPC Day 1 Convective Outlook forecast similar conditions and had similar graphics.

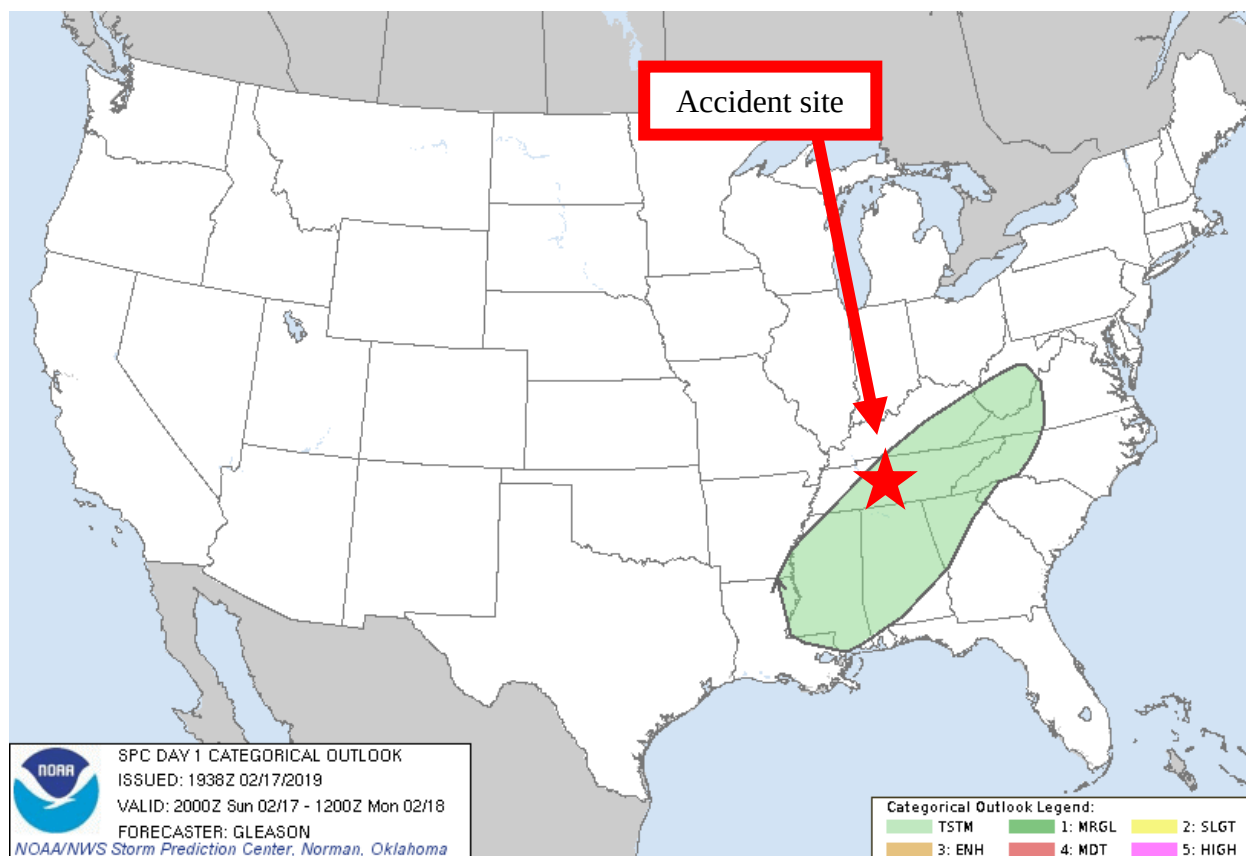


Figure 7 – SPC day 1 Convective Outlook valid at the time of the accident

SPC AC 171938

Day 1 Convective Outlook
NWS Storm Prediction Center Norman OK
0138 PM CST Sun Feb 17 2019

Valid 172000Z - 181200Z

...NO SEVERE THUNDERSTORM AREAS FORECAST...

...SUMMARY...

Isolated thunderstorms will continue over portions of the Southeast, Tennessee Valley, and Appalachians today.

...20Z Update...

Some adjustments have been made to the northern extent of the general thunderstorm area across MS/TN/KY into the central Appalachians to account for current convective trends. Across the Southeast, thunderstorms will likely remain confined to the cool side of surface front. With only weak elevated instability expected, severe potential continues to appear too low to include any probabilities across this region.

..Gleason.. 02/17/2019

.PREV DISCUSSION... /ISSUED 1030 AM CST Sun Feb 17 2019/

...Tennessee Valley/Southeast States...

Showers and occasional thunderstorms are expected today along an advancing cold front. Relatively warm mid-level temperatures and a displacement of the stronger lift to the north will result in poor lapse rates and minimal instability overall. While deep-layer/low-level shear will be strong, and semi-organized convection may evolve particularly across AL, severe potential is still expected to be considerably limited by the marginal thermodynamic environment.

...Northern/central California Coast...

In relation to a south/southeastward-digging shortwave trough, some shallow convection is likely but updrafts reaching temperatures needed for lightning production will be sparse. Thus, lightning coverage is expected to be less than 10 percent.

CLICK TO GET WUUS01 PTSDY1 PRODUCT

NOTE: THE NEXT DAY 1 OUTLOOK IS SCHEDULED BY 0100Z

3.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)⁵ model sounding was created for the accident site for 1800 CST with a station elevation of 745 feet (ft).⁶ The 1800 CST HRRR sounding was plotted on a standard Skew-T Log P diagram⁷ with the derived stability parameters included in figure 9 with data from the surface to 200-hPa (or approximately 39,000 ft msl). This data was analyzed using the RAOB⁸ software package. The sounding depicted the lifted condensation level (LCL)⁹ at 1,076 ft msl, the level of free convection (LFC)¹⁰ at 1,416 ft msl, and the convective condensation level (CCL)¹¹ at 10,209 ft msl. The freezing level was located at 9,294 ft msl. The precipitable water value was 0.99 inches. The tropopause was located at 42,536 ft msl and the maximum wind level was at ~42,000 ft with a wind of 144 knots from 259°.

⁵ 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.

⁶ HRRR sounding was created using NOAA Air Resource Laboratory: <https://ready.arl.noaa.gov/READYamet.php>

⁷ 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.

⁸ RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.

⁹ LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.

¹⁰ 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.

¹¹ 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.

4.0 Satellite Data

Data from the Geostationary Operational Environmental Satellite number 16 (GOES-16) data was 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 (band 2) and infrared (bands 13) imagery at wavelengths of 0.64 microns (μm) and 10.3 μm , respectively, were retrieved for the period. Satellite imagery surrounding the time of the accident, from 1500 CST through 2000 CST at approximately 5-minute intervals were reviewed, and the closest images to the time of the accident are documented here. Due to the time of day and sunset, the visible imagery does provide helpful imagery around the accident time.

Figures 10, 11, and 12 present the GOES-16 infrared imagery from 1800, 1802, and 1807 CST at 4X magnification and with a temperature enhancement curve applied with the accident site highlighted with a red square. Inspection of the infrared imagery indicated abundant cloud cover over the accident site at the accident time with the lowest brightness temperatures (green and blue colors, higher clouds) located above and to the southwest and northeast of the accident site. The cloud cover was moving generally from the southwest to northeast with wave or bandlike features indicated on the southwest through northwest side of the higher clouds tops near the accident site at the accident time (attachment 1). Based on the brightness temperatures above the accident site (220 Kelvin) and the vertical temperature profile provided by the 1800 CST HRRR sounding, the approximate cloud-top heights over the accident site were 37,000 ft at 1802 CST. It should be noted these figures have not been corrected for any parallax error.

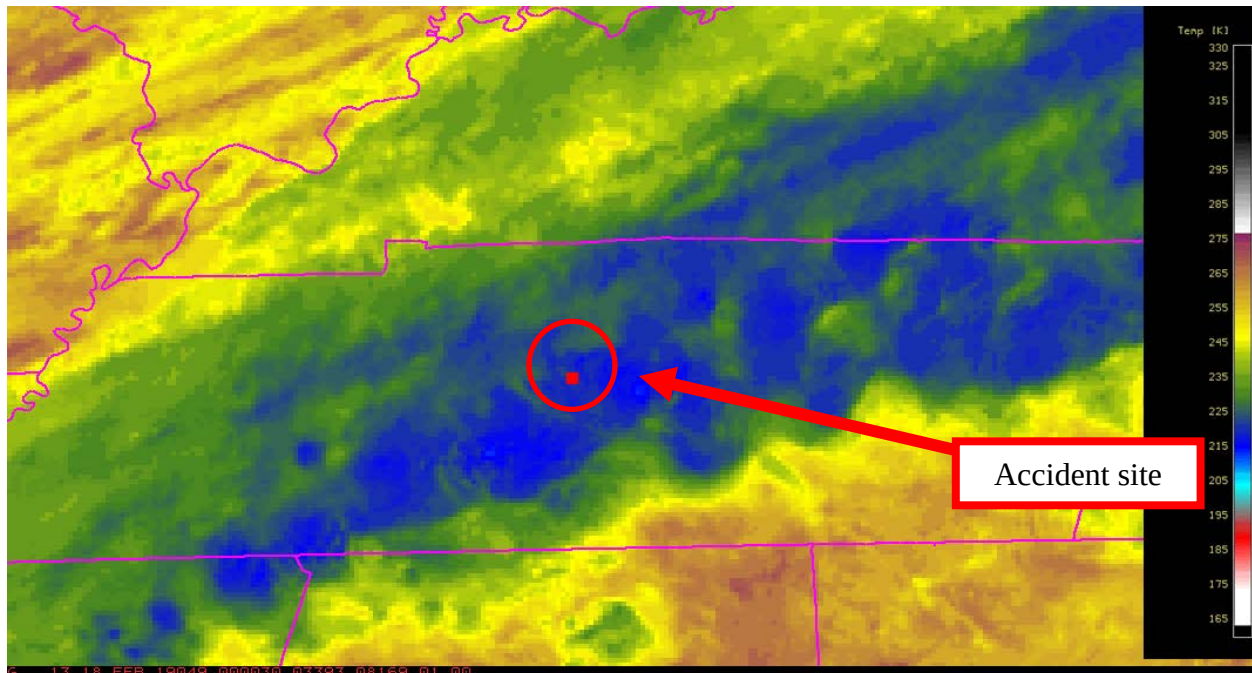


Figure 10 – GOES-16 infrared image at 1800 CST

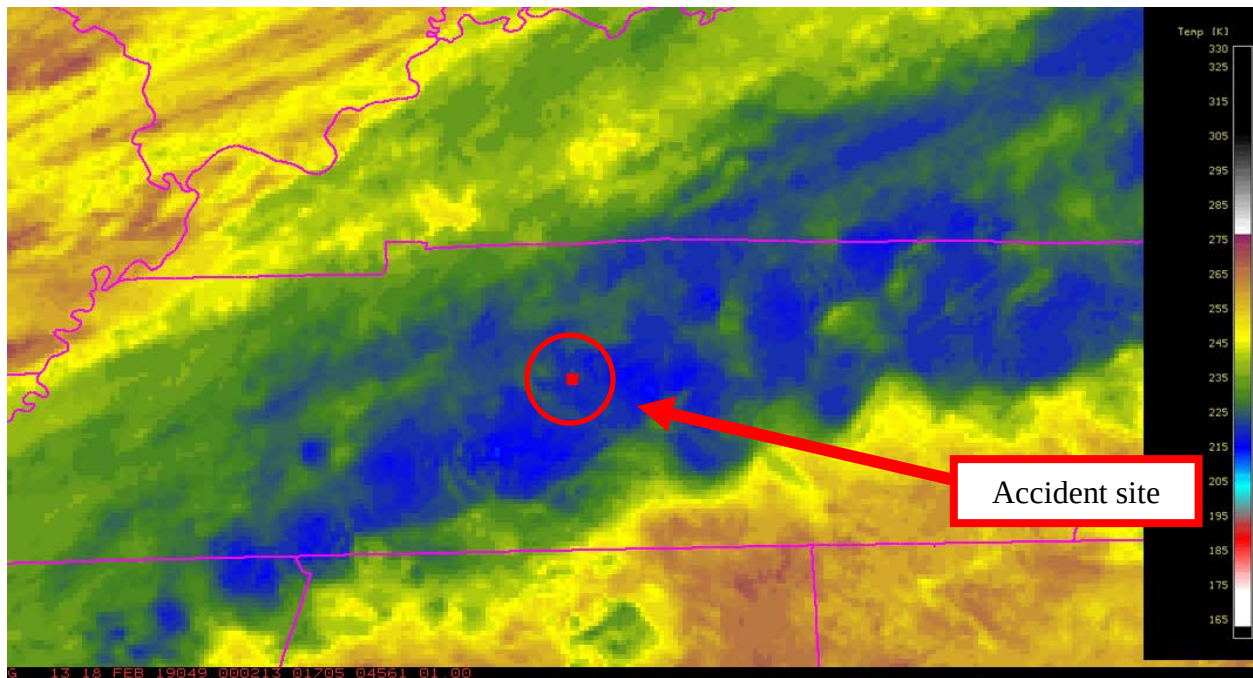


Figure 11 – GOES-16 infrared image at 1802 CST

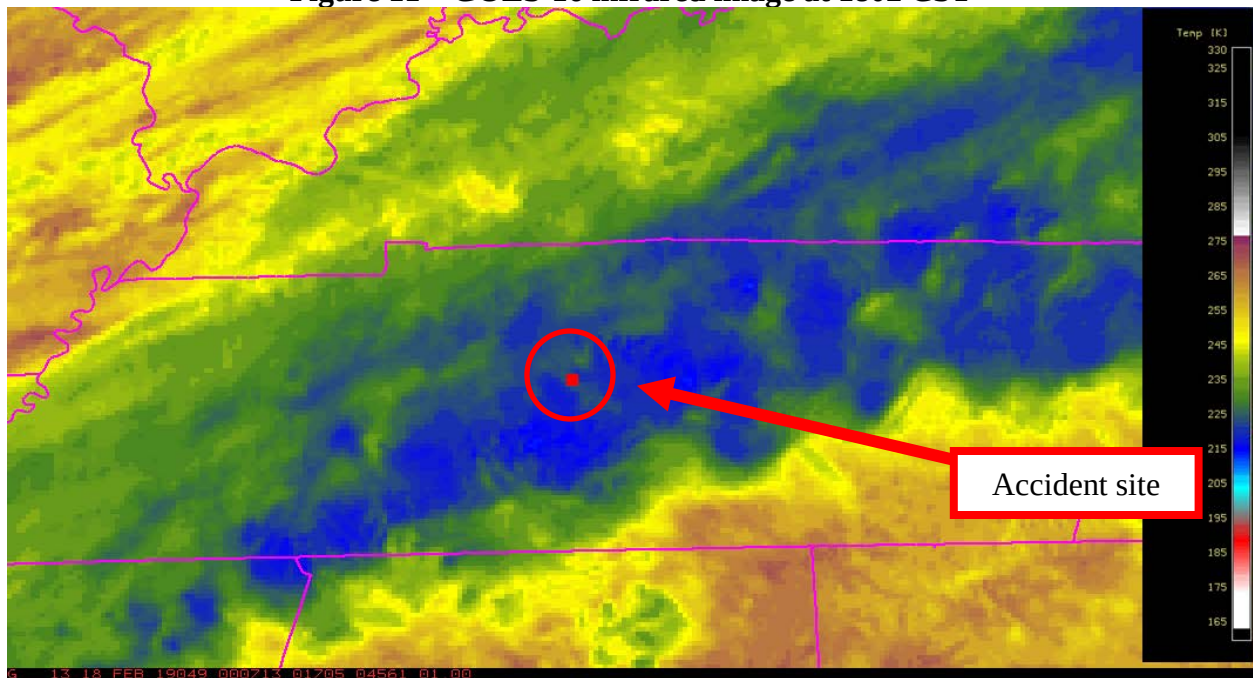


Figure 12 – GOES-16 infrared image at 1807 CST

5.0 Regional Radar Imagery Information

A regional view of the NWS National Composite Radar Mosaic is included as figure 13 for 1805 CST with the approximate location of the accident site marked by a red circle. The image depicted echoes from 30 to 55 decibels (dBZ¹²) echoes in the immediate vicinity of the accident site.

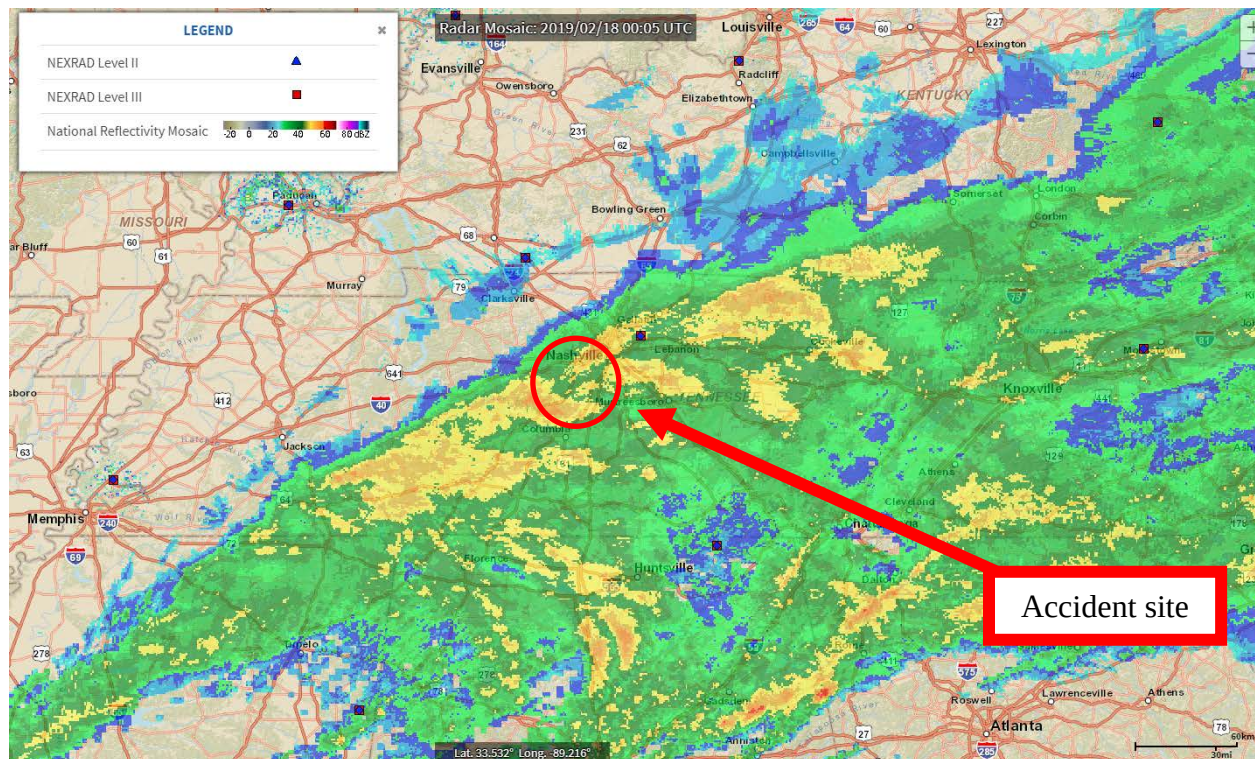


Figure 13 – Regional Composite Reflectivity image for 1805 CST

6.0 Radar Imagery Information

The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)¹³ to the accident site was Nashville, Tennessee, (KOHX), with antenna elevation of 676 ft, located 28 miles northeast of the accident site. Level II archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA’s Weather and Climate Toolkit software.

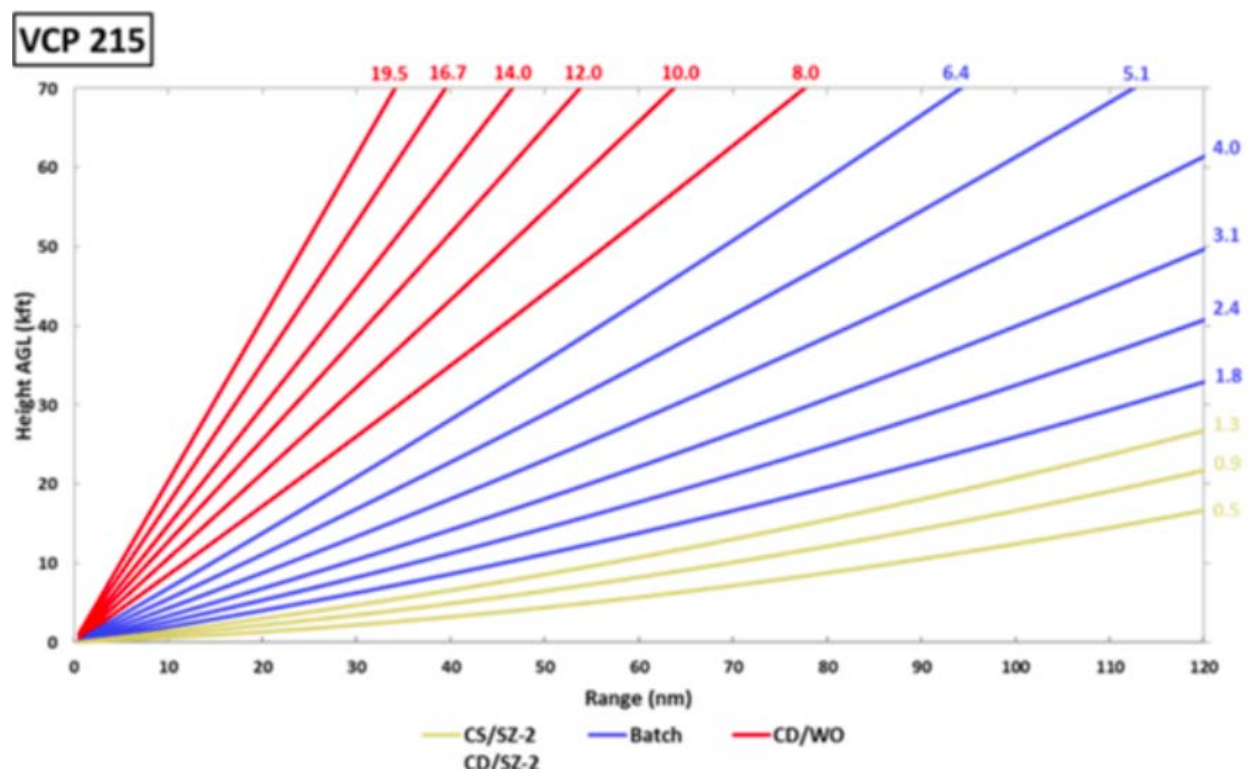
¹² dBZ – A non-dimensional “unit” of radar reflectivity which represents a logarithmic power ratio (in decibels , or dB) with respect to radar reflectivity factor, Z.

¹³ 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.

6.1 Volume Scan Strategy

The WSR-88D is a computer-controlled radar system, which automatically creates a complete series of specific scans in a specific sequence known as a volume scan. Individual elevation scans are immediately available. Products that require data from multiple elevation scans are not available until the end of the five to ten-minute volume scan.

The WSR-88D operates in several different scanning modes, identified as Mode A and Mode B. Mode A is the precipitation scan and has three common scanning strategies. The most common is where the radar makes 15 elevation scans from 0.5° to 19.5° every six minutes. This particular scanning strategy is documented as volume coverage pattern 215 (VCP-215). Mode B is the clear-air mode, where the radar makes 5 elevation scans during a ten-minute period. During the period surrounding the accident, the KOHX WSR-88D radar was operating in the precipitation mode VCP-215. The following chart 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.



VCP-215 Precipitation Mode Scan Strategy¹⁴

¹⁴ 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)

6.2 Beam Height Calculation

Assuming standard refraction¹⁵ of the WSR-88D radar beam with the antenna elevation at 676 ft (KOHX), and considering a beamwidth¹⁶ of 0.95°, the following table shows the approximate heights for the radar beam center, top and base for antenna elevations over the accident site. These heights have been rounded to the nearest 10 ft.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP
KOHX 0.5°	2,730 ft	1,350 ft	4,110 ft
KOHX 10.0°	30,700 ft	29,340 ft	32,060 ft

Based on the radar height calculations, the elevation scan from KOHX listed in the above table depicted the conditions between 1,350 ft and 4,110 ft, and 29,340 ft and 32,060 ft over the accident site and the KOHX 10.0° elevation scans “saw” the closest altitudes to the accident aircraft’s flight level before the accident.¹⁷

6.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors¹⁸ 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. FAA Advisory Circular AC 00-24C¹⁹, “Thunderstorms,” dated February 19, 2013, 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 but less than 50 dBZ, inclusive. Finally, any dBZ values above 50 dBZ shall be described as “extreme.” From the NWS, precipitation conditions at the surface can be inferred from VIP Levels described in the chart below:

¹⁵ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

¹⁶ Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

¹⁷ For more information on accident aircraft’s track please see the docket for this accident.

¹⁸ 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.

¹⁹

https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1020774

- VIP 1 (Level 1, 18-30 dBZ) - Light precipitation
- VIP 2 (Level 2, 30-38 dBZ) - Light to moderate rain
- VIP 3 (Level 3, 38-44 dBZ) - Moderate to heavy rain
- VIP 4 (Level 4, 44-50 dBZ) - Heavy rain
- VIP 5 (Level 5, 50-57 dBZ) - Very heavy rain; hail possible
- VIP 6 (Level 6, >57 dBZ) - Very heavy rain and hail; large hail possible

6.4 Base Reflectivity and Lightning Data

Figures 14 through 17 present the KOHX WSR-88D base reflectivity images for the 0.5° and 10.0° elevation scans initiated at 1803:33, 1809:29, 1802:09, and 1808:04 CST, respectively, with a resolution of 0.5° X 250 m. Reflectivity values between 0 and 40 dBZ were located above the accident site at the accident time. The reflectivity bands were moving from southwest to northeast (attachments 2 and 3).

There were no lightning flashes²⁰ around the accident site at the accident time.²¹

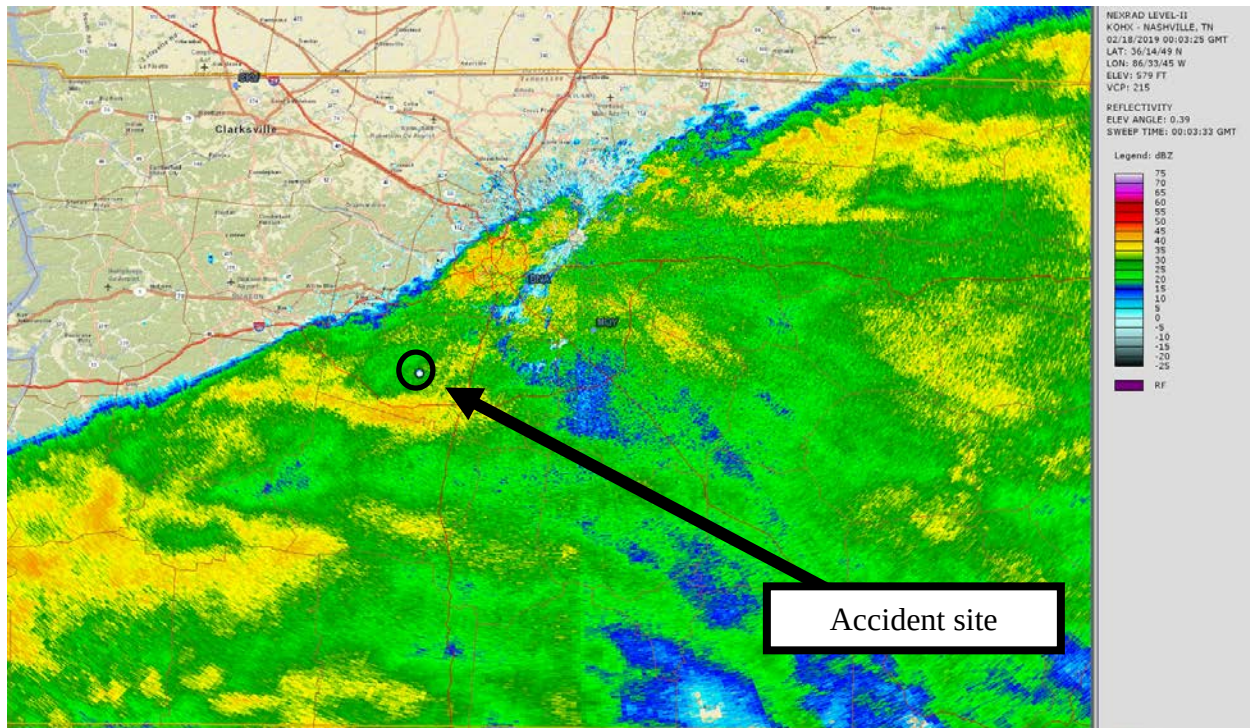


Figure 14 – KOHX WSR-88D reflectivity for the 0.5° elevation scan initiated at 1803:33 CST with the accident site marked with a black circle

²⁰ 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.

²¹ A review of Earth Networks Total Lightning network was done.

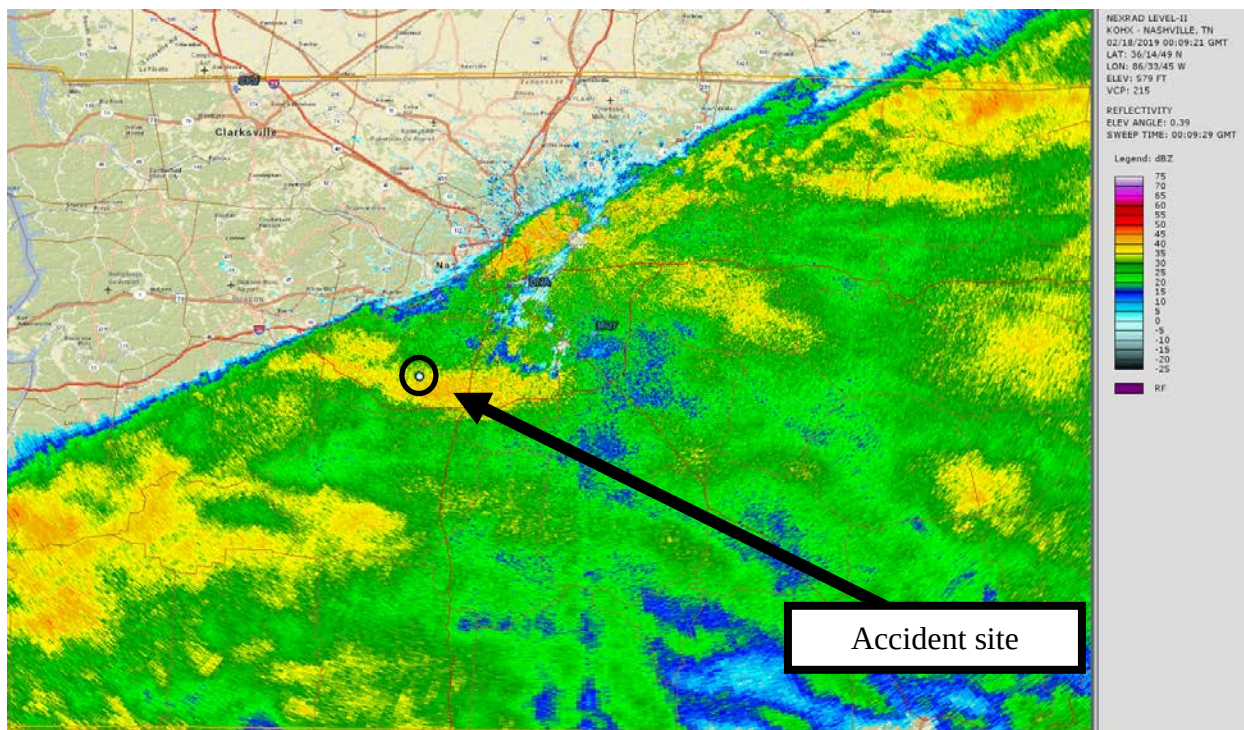


Figure 15 – KOHX WSR-88D reflectivity for the 0.5° elevation scan initiated at 1809:29 CST with the accident site marked with a black circle

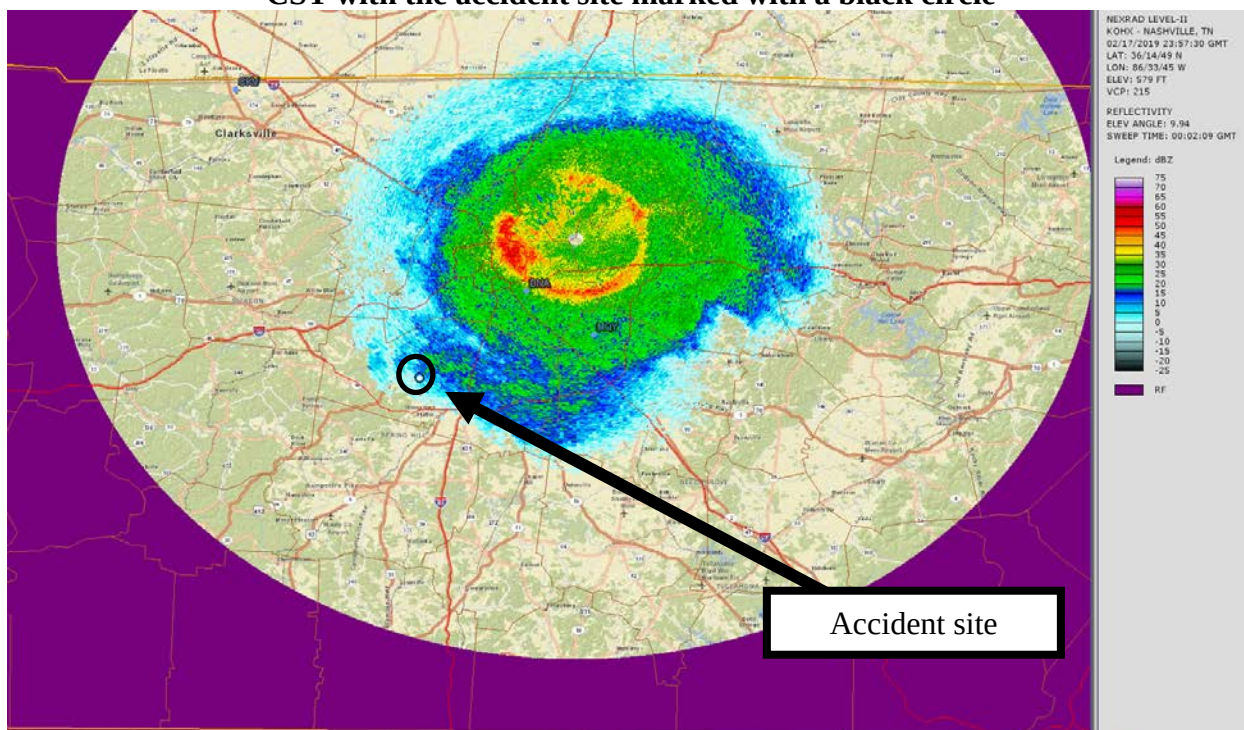


Figure 16 – KOHX WSR-88D reflectivity for the 10.0° elevation scan initiated at 1802:09 CST with the accident site marked with a black circle

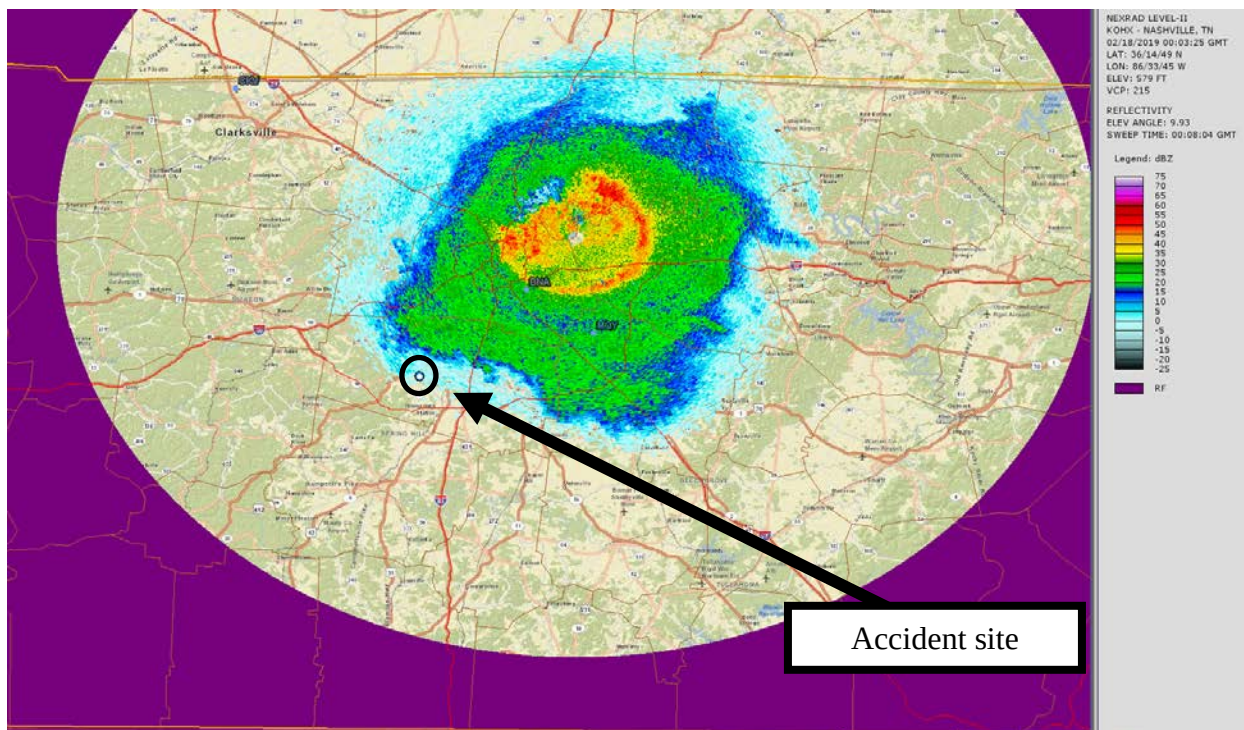


Figure 17 – KOHX WSR-88D reflectivity for the 10.0° elevation scan initiated at 1808:04 CST with the accident site marked with a black circle

7.0 Pilot Reports²²

All pilot reports (PIREPs) within 75 miles of the accident site from about 90 minutes prior to the accident time to about 90 minutes after the accident time for above FL200 are provided below:

BNA UA /OV BNA180030/TM 2248/FL330/TP B738/TB CONT MOD/RM ZME =

BNA UA /OV BNA090025/TM 2251/FL320/TP B739/TB OCNL MOD/RM ZME =

BNA UA /OV BNA270010/TM 2304/FLDURC/TP B738/TB MOD 060 - 095=

MEM UA /OV MEM090065/TM 2354/FL350/TP B753/TB CONT MOD/RM ZME =

BNA UA /OV BNA135025/TM 0010/FL370/TP NMRS/TB MOD CHOP/RM RPTD BY
NMRS ACFT. ZME=

BNA UA /OV BNA225045/TM 0020/FL350/TP E75/TB MOD CHOP/RM ZME=

BNA UA /OV BNA090040/TM 0034/FL370/TP A319/TB MOD/RM ZME =

BNA UA /OV BNA220035/TM 0045/FLDURD/TP B737/TB MOD =

The reports in plain language taken from standard code and abbreviations, with cloud heights in msl:

²² Only pilot reports with the World Meteorological Organization (WMO) header UBTN** identifier were considered.

Nashville International Airport, Tennessee, (BNA) routine pilot report (UA); Over – 30 miles from BNA VORTAC on the 180° radial; Time – 1648 CST (2248Z); Altitude – FL330; Type aircraft – Boeing B737-800; Turbulence – Continuous moderate; Remarks – entered by the Memphis Air Route Traffic Control Center (ZME).

BNA, routine pilot report (UA); Over – 25 miles from BNA VORTAC on the 090° radial; Time – 1651 CST (2251Z); Altitude – FL320; Type aircraft – Boeing B737-900; Turbulence – Occasional moderate; Remarks – ZME.

BNA, routine pilot report (UA); Over – 10 miles from BNA VORTAC on the 270° radial; Time – 1704 CST (2304Z); Altitude – During climb; Type aircraft – Boeing B737-800; Turbulence – Moderate between 6,000 and 9,500 ft.

Memphis International Airport, Tennessee, (MEM) routine pilot report (UA); Over – 65 miles from MEM VORTAC on the 090° radial; Time – 1754 CST (2354Z); Altitude – FL350; Type aircraft – Boeing B757-300; Turbulence – Continuous moderate; Remarks – ZME.

BNA, routine pilot report (UA); Over – 25 miles from BNA VORTAC on the 135° radial; Time – 1810 CST (0010Z); Altitude – FL370; Type aircraft – Numerous; Turbulence – Moderate chop; Remarks – Reported by numerous aircraft, ZME.

BNA, routine pilot report (UA); Over – 45 miles from BNA VORTAC on the 225° radial; Time – 1820 CST (0020Z); Altitude – FL350; Type aircraft – Embraer ERJ-175; Turbulence – Moderate chop; Remarks – ZME.

BNA, routine pilot report (UA); Over – 40 miles from BNA VORTAC on the 090° radial; Time – 1834 CST (0034Z); Altitude – FL370; Type aircraft – Airbus A319; Turbulence – Moderate; Remarks – ZME.

BNA, routine pilot report (UA); Over – 35 miles from BNA VORTAC on the 220° radial; Time – 1845 CST (0045Z); Altitude – During descent; Type aircraft – Boeing B737-700; Turbulence – Moderate.

8.0 SIGMET

There were no convective or non-convective Significant Meteorological Information (SIGMET) advisories valid for the accident site at the accident time.

9.0 CWSU Advisories

There were no Center Weather Service Unit (CWSU) Center Weather Advisories (CWA) or Meteorological Impact Statement (MIS) valid for the accident site at the accident time.

10.0 AIRMETs

There was only Airmen's Meteorological Information (AIRMET) advisory Tango valid for the accident site at the accident time for up to FL380. AIRMET Tango warned of moderate turbulence between 16,000 ft and FL380:

WAUS44 KPCI 172058 CCA

WA4T

-DFWT WA 172058 COR

AIRMET TANGO UPDT 3 FOR TURB AND LLWS VALID UNTIL 180300

.
**AIRMET TURB...OK TX AR TN MS AL NE KS MN IA MO WI LM MI LH IL IN
KY**

**FROM 50WNW SSM TO 20E YVV TO DXO TO FWA TO CVG TO HNN TO HMV TO
20SE VXV TO 20SE ARG TO 60SSW MRF TO ELP TO INK TO 30ESE TBE TO
50W LBL TO GLD TO 40SSE SNY TO 50WNW SSM
MOD TURB BTN 160 AND FL380. CONDS CONTG BYD 03Z THRU 09Z.**

.
AIRMET TURB...TN AL KY...UPDT

FROM CVG TO HNN TO HMV TO GQO TO LGC TO VUZ TO 30WNW MSL TO CVG
MOD TURB BLW 160. CONDS CONTG BYD 03Z THRU 09Z.

...CORRECTED AIRMET...

.
LLWS POTENTIAL...TN AL IN KY

BOUNDED BY CVG-HNN-HMV-GQO-60S LGC-MGM-40SE IGB-50W LOZ-CVG

LLWS EXP. CONDS CONTG BYD 03Z THRU 09Z.

....

11.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products made available before the accident flight are shown in attachment 4. The GFA surface forecast products indicated surface MVFR²³ to IFR conditions would prevail, with likely of rain shower activity (greater than 60 percent chance), and a surface wind from the west at 5 knots. The GFA cloud forecast products indicated an overcast cloud ceiling at 1,500 to 1,900 ft msl with cloud tops between FL390 and FL420. For more information please see attachment 4.

²³ As defined by 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.

12.0 Winds and Temperature Aloft Forecast

The NWS 1359 CST Winds and Temperature Aloft forecast valid for 1800 CST for the closest point to the accident site is included below:

```
FBUS31 KWN0 171959
FD1US1
DATA BASED ON 171800Z
VALID 180000Z   FOR USE 2000-0300Z. TEMPS NEG ABV 24000

FT  3000    6000    9000   12000   18000   24000   30000   34000   39000
BNA 2730 2735+01 2663+01 2153-03 2298-10 7408-21 761738 762548 763160
```

The accident site was closest to the BNA forecast point. The BNA forecast for use between 1400 CST and 2100 CST indicated a wind at 30,000 ft from 260° at 117 knots with a temperature of -38°C, a wind at 34,000 ft from 260° at 125 knots with a temperature of -48°C, and a wind at 39,000 ft from 260° at 131 knots with a temperature of -60°C.

13.0 Pilot Weather Briefing

The accident pre-flight weather information is further discussed in the Operations Report located in the docket for this accident.

14.0 Delta Meteorology Weather Package

Delta meteorology produced a weather package for this accident and those details can be found in attachment 5.

15.0 GTG information

The NWS Aviation Weather Center (AWC) provided Graphical Turbulence Guidance (GTG) plots that indicated turbulence at the accident time and at the flight level. For more information please see attachment 6.²⁴

16.0 Consolidated Storm Prediction for Aviation Data

The Consolidated Storm Prediction for Aviation (CoSPA)²⁵ images were retrieved from 1745 through 1810 CST at 5-minute intervals and provided in figures 18 through 23 with the accident site marked. The CoSPA, along with depicting NWS weather radar VIP levels, lightning data, weather satellite, and storm motion, forecast areas of likely rain shower or thunderstorm growth (orange hatched areas) and areas of likely rain shower or thunderstorm dissipation (blue hatched areas). During the time surrounding the accident CoSPA indicated VIP levels of 2 to 3 over the accident site with echo tops of FL310 to FL350 and areas of rain shower or thunderstorm growth (orange hatched areas, figures 18, 22, and 23).

²⁴ For more information on GTG please see: <https://aviationweather.gov/turbulence>

²⁵ For more information please see <https://ral.ucar.edu/solutions/products/consolidated-storm-prediction-aviation-cospa> and <https://cospa.wx.ll.mit.edu/login.jsf>

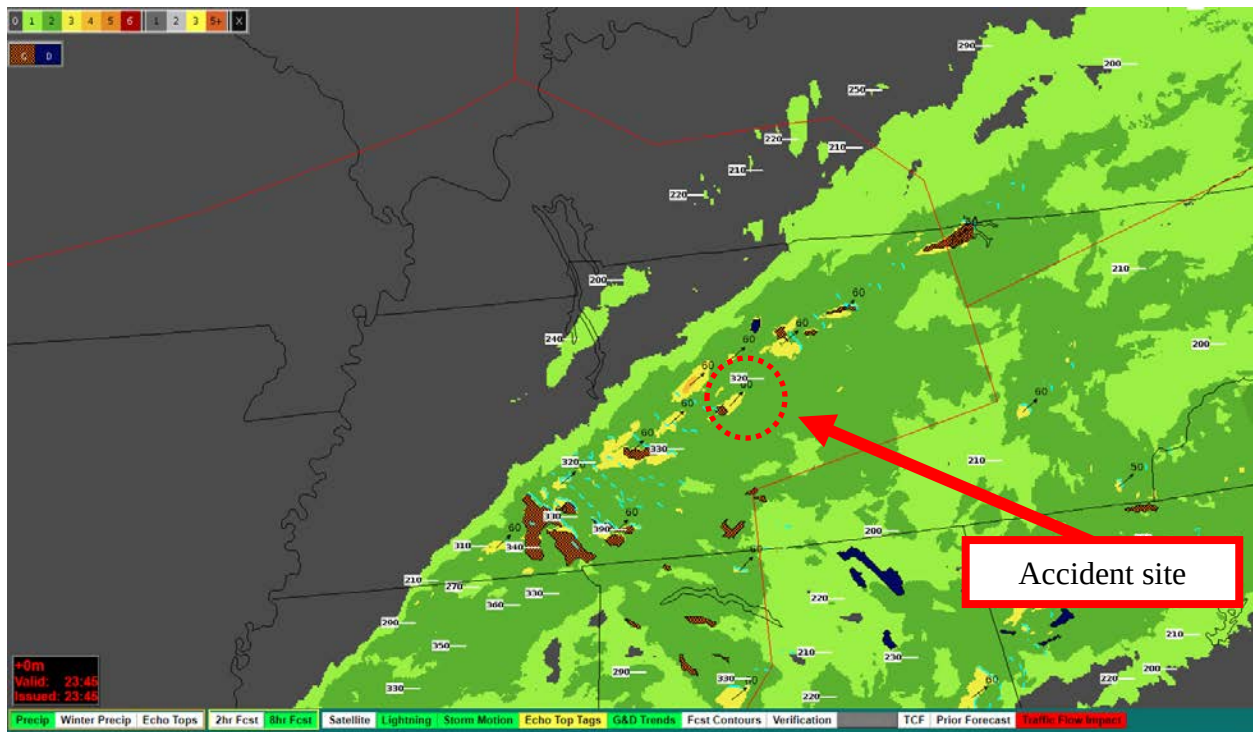


Figure 18 – CoSPA image from 1745 CST with the accident site marked

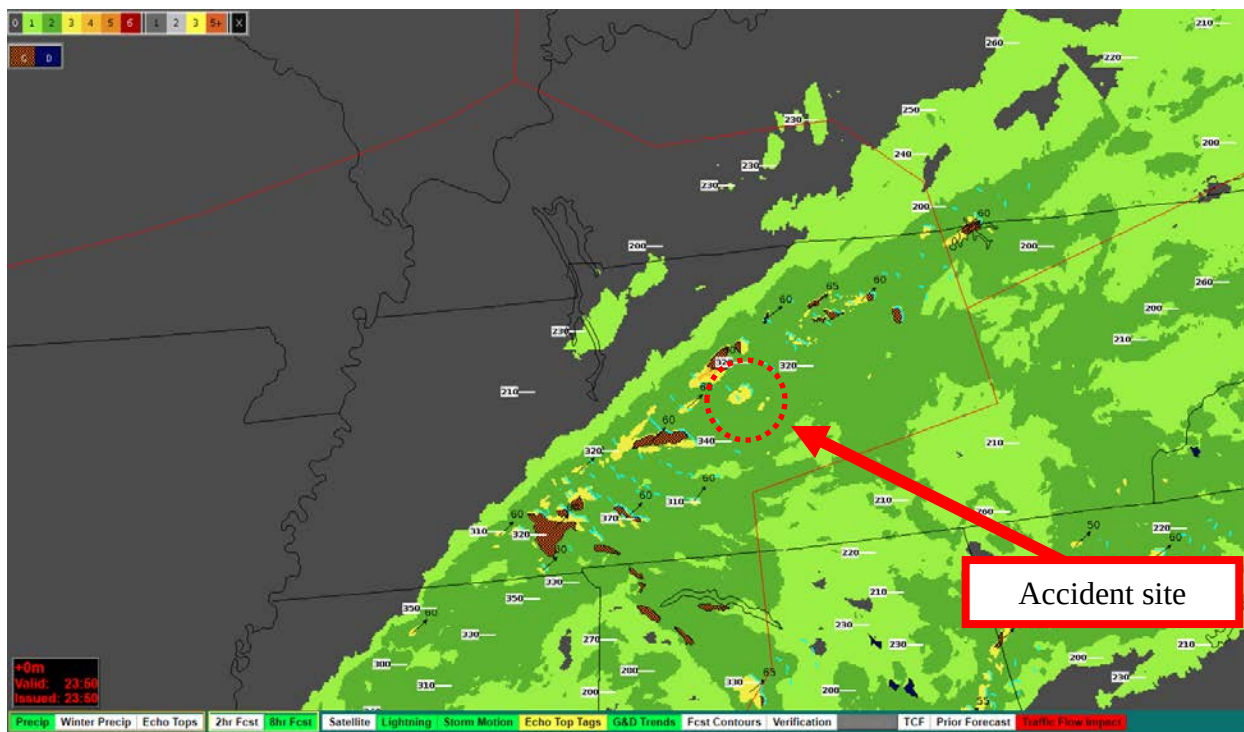


Figure 19 – CoSPA image from 1750 CST with the accident site marked

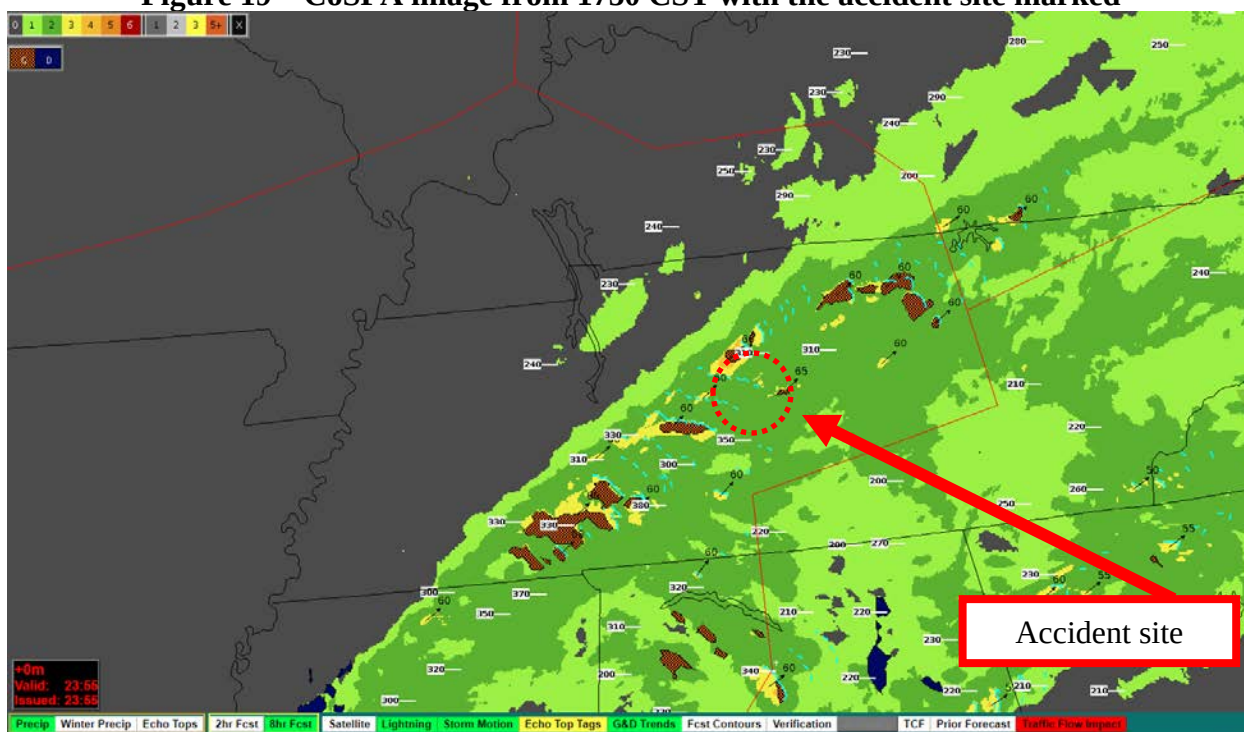


Figure 20 – CoSPA image from 1755 CST with the accident site marked

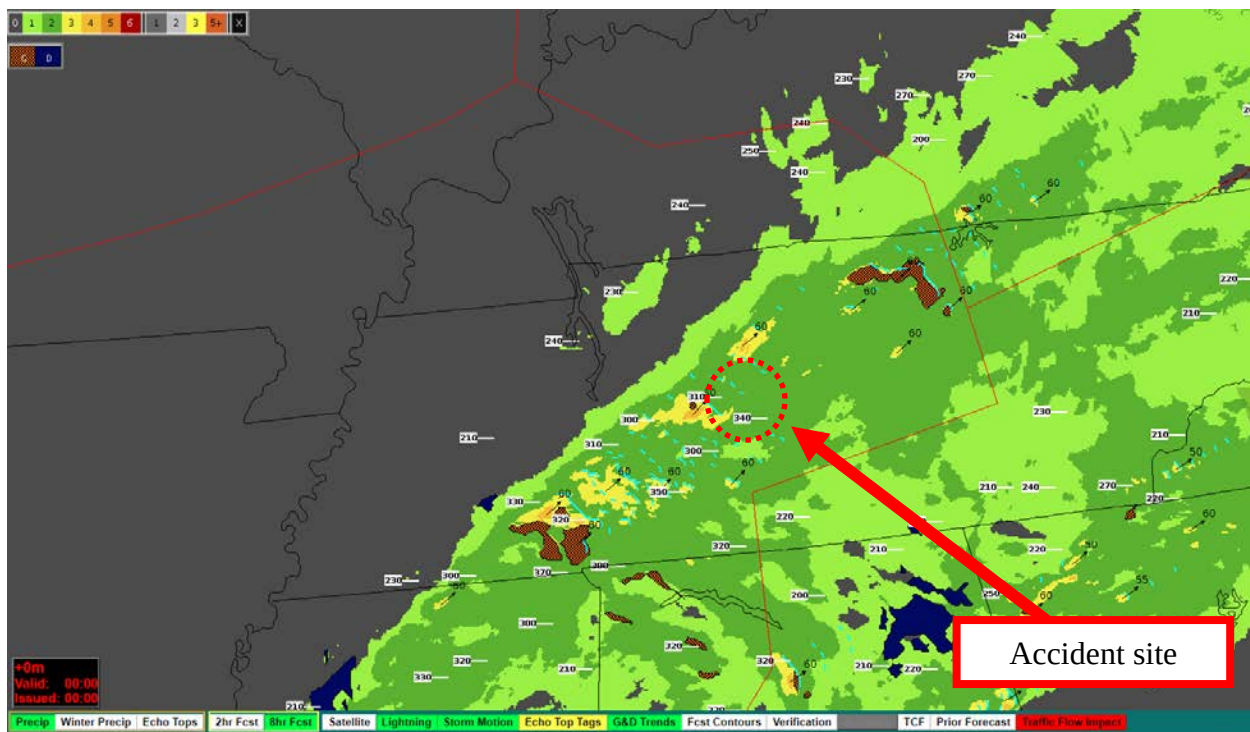


Figure 21 – CoSPA image from 1800 CST with the accident site marked

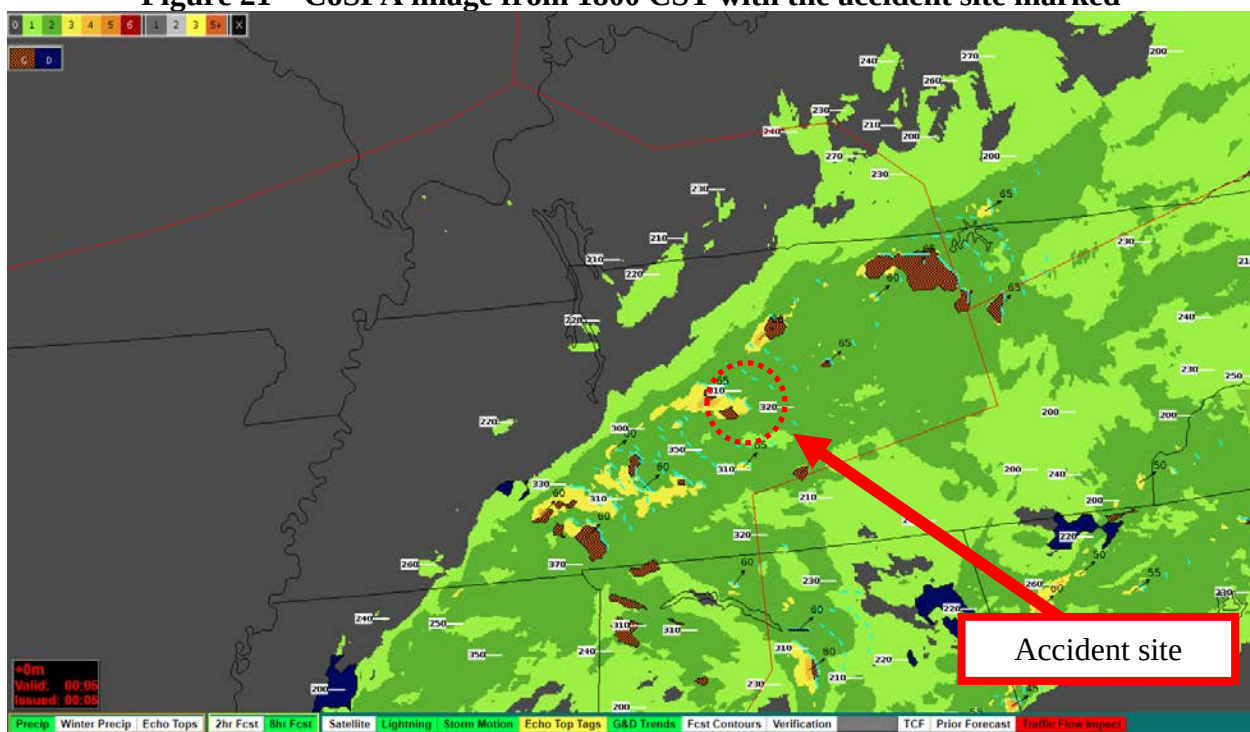


Figure 22 – CoSPA image from 1805 CST with the accident site marked

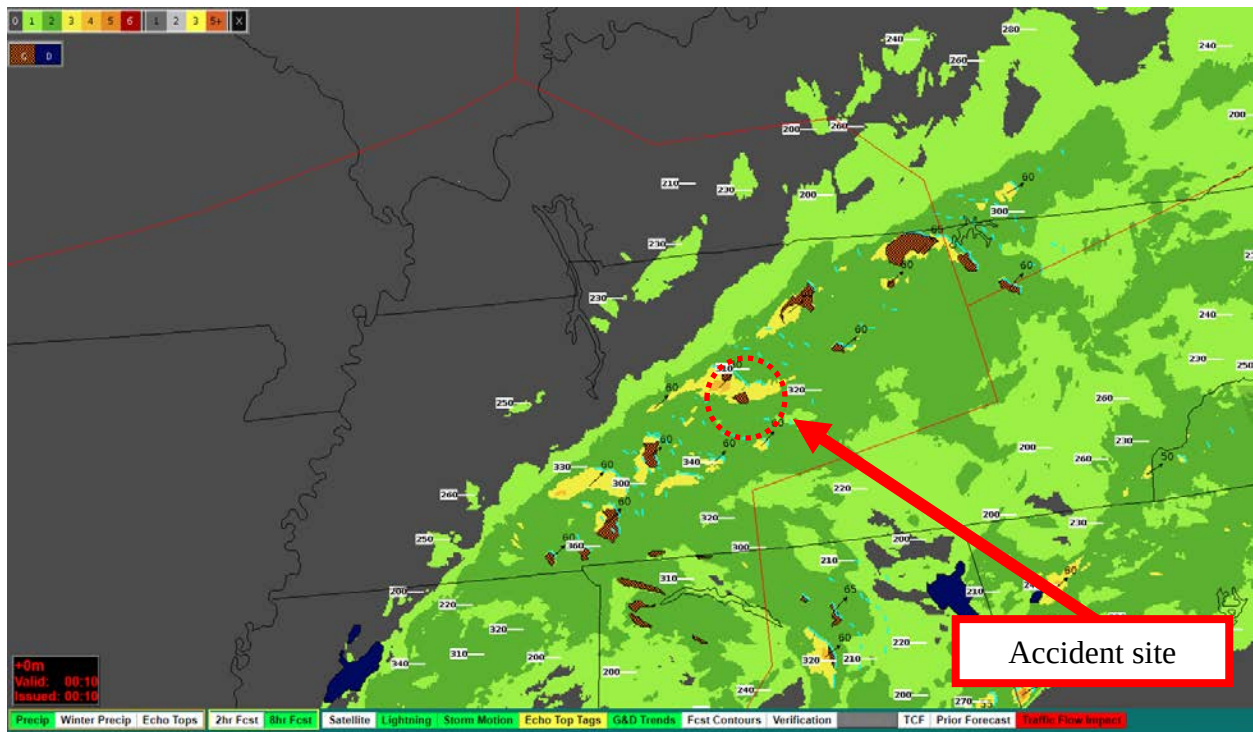


Figure 23 – CoSPA image from 1810 CST with the accident site marked

17.0 Astronomical Data

The astronomical data obtained for the accident site on February 17, 2019, indicated the following:

SUN

Begin civil twilight	0606 CST
Sunrise	0632 CST
Sun transit	1201 CST
Sunset	1731 CST
End civil twilight	1757 CST
Accident	1804 CST²⁶

MOON

Moonrise	1522 CST
Accident	1804 CST²⁷
Moon transit	2241 CST
Moonset	0500 CST on February 18, 2019

At the time of the accident the Moon was at an altitude of 29.41° with azimuth of 86.60° with the Moon phase a Waxing Gibbous and 95.8% illumination. The Moon would have been visible above the tops of the clouds.

²⁶ Inserted accident time for reference and context.

²⁷ Inserted accident time for reference and context.

E. LIST OF ATTACHMENTS

Attachment 1 – GOES-16 infrared animation from 1730 to 1830 CST

Attachment 2 – KOHX WSR-88D base reflectivity images for the 0.5° elevation scans animation from 1727 to 1827 CST

Attachment 3 – KOHX WSR-88D base reflectivity images for the 10.0° elevation scans animation from 1727 to 1827 CST

Attachment 4 – GFA products available before the accident flight for around the accident time

Attachment 5 – Delta meteorology weather package for the accident flight

Attachment 6 – AWC GTG forecast and imagery

Submitted by:

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