NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

January 9, 2020

Factual Report

METEOROLOGY

ERA19FA188

Table Of Contents

A. ACCIDENT

Location: Castalia, North Carolina
Date: June 7, 2019
Time: 1333 eastern daylight time
1733 Coordinated Universal Time (UTC)
Aircraft: Piper PA-46-350P, Registration: N709CH

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 eastern daylight time (EDT) on June 7, 2019, and are based upon the 24-hour clock, where local time is -4 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 statute 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 and "P" for OCONUS airports.

The accident site was located at latitude 36.1372° N, longitude 77.9958° W, with an approximate elevation of 260 feet (ft).

D. WEATHER 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.[1]

[1] https://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/1030

1.1 Surface Analysis Chart

The mid-Atlantic section of the NWS Surface Analysis Chart for 1400 EDT is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart identified surface low pressure centers located over northeastern North Carolina and central Tennessee with surface pressures of 1010- and 1005-hectopascals (hPa), respectively. A frontal boundary was located from the western Atlantic Ocean across northern North Carolina and into Kentucky with the cold front section of the frontal boundary located over the accident site. A surface trough[2] was located east of the accident site from eastern North Carolina into the western Atlantic Ocean. Another frontal boundary, associated with the 1005-hPa surface low pressure system, was located from eastern South Carolina into Tennessee.

The station models around the accident site depicted air temperatures in the mid 70's to low 80's degrees Fahrenheit (°F), dew point temperatures in the upper 60's to low 70's °F with temperature-dew point spreads of 10 °F or less, variable surface winds of 5 knots or less, and overcast sky cover with light rain.

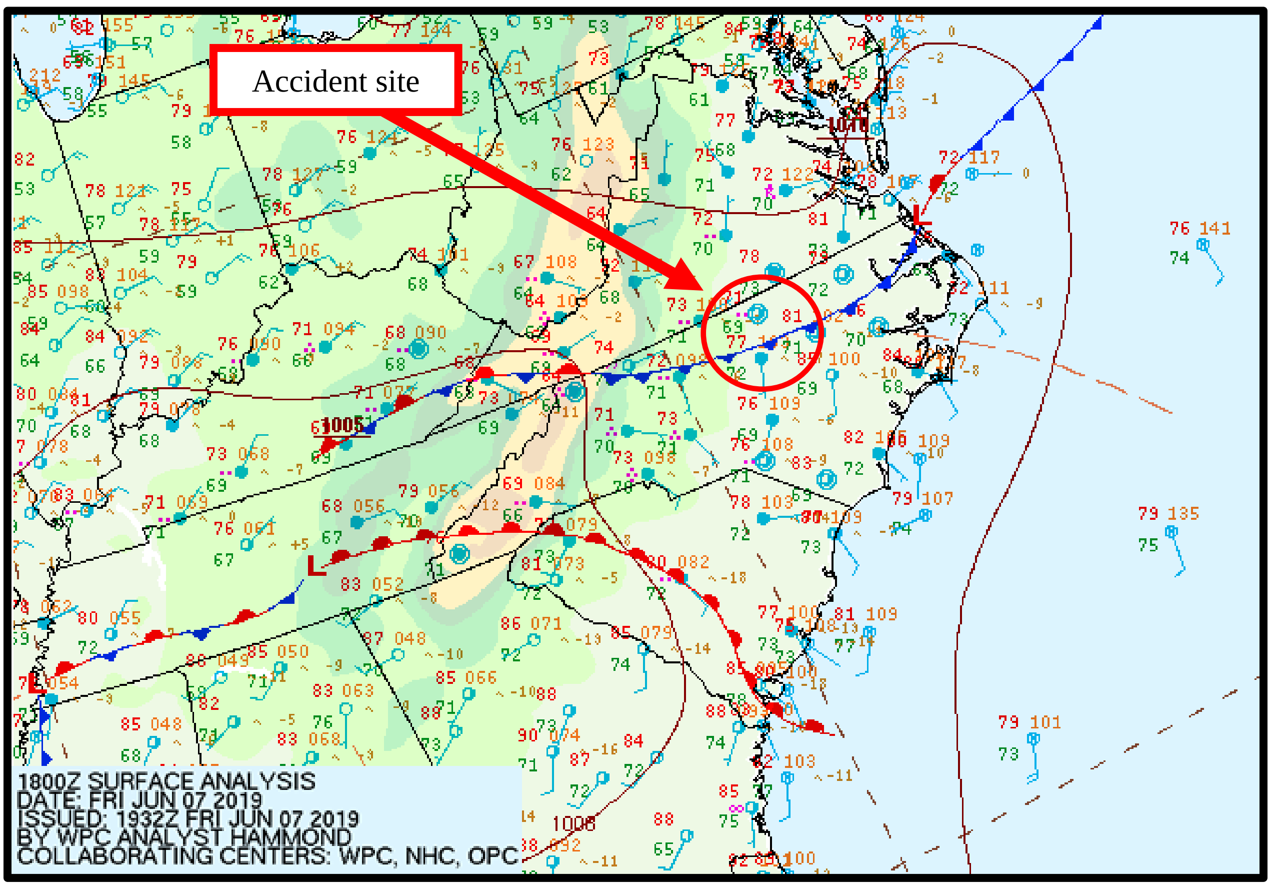

Figure 1 – NWS Surface Analysis Chart for 1400 EDT

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[2] Trough – An elongated area of relatively low atmospheric pressure or heights.

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 0800 EDT at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2 through 6. There were low- and mid-level troughs located above the accident site from 925- through 500-hPa. Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present. There was a southwest wind of 10 knots at 925-hPa above the accident site with the wind becoming southerly by 700-hPa (figure 4) with the wind speed at 15 knots. By 300-hPa, the wind above the accident site was from the west and the wind speed increased 30 knots (figure 6).

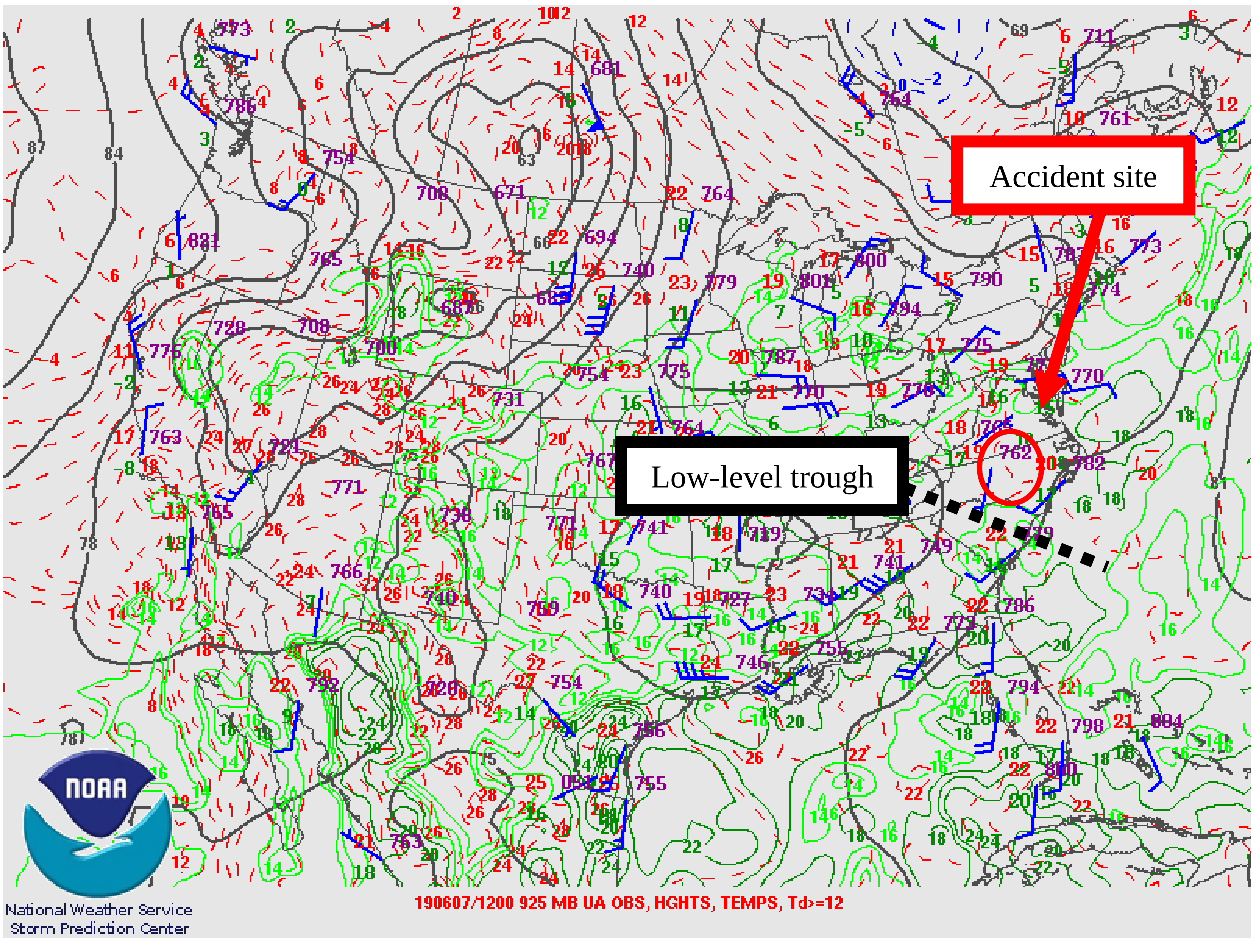

Figure 2 – 925-hPa Constant Pressure Chart for 0800 EDT

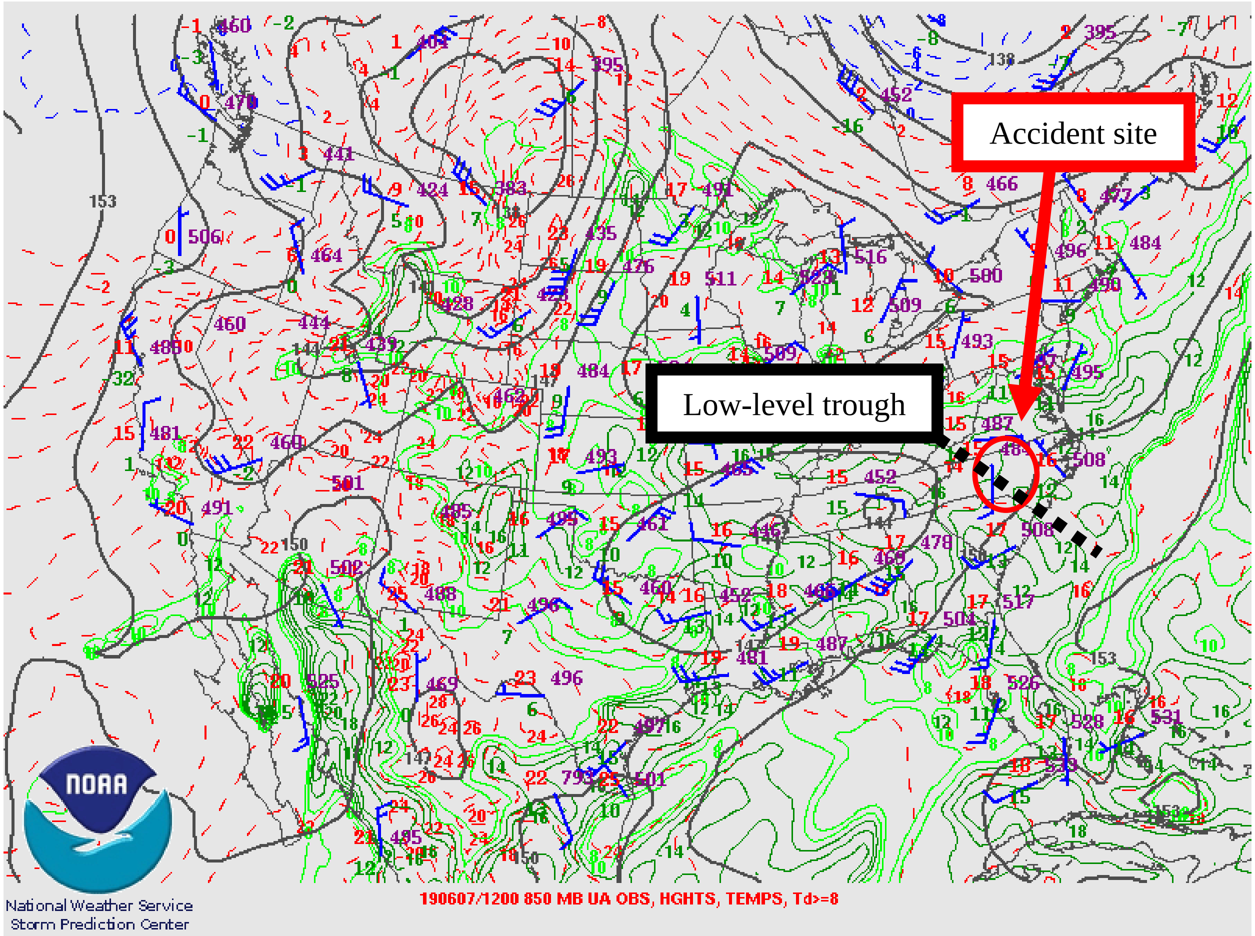

Figure 3 – 850-hPa Constant Pressure Chart for 0800 EDT

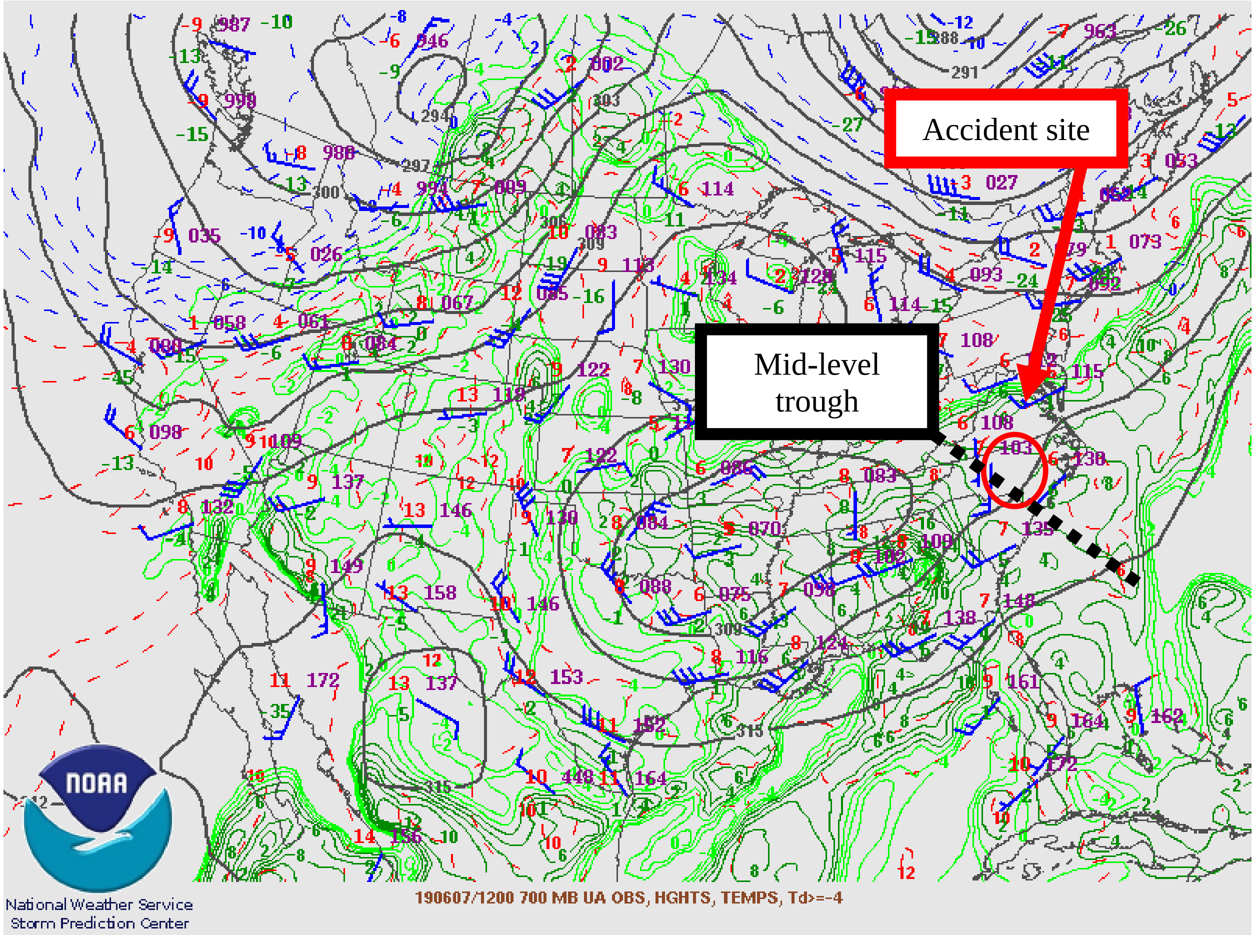

Figure 4 – 700-hPa Constant Pressure Chart for 0800 EDT

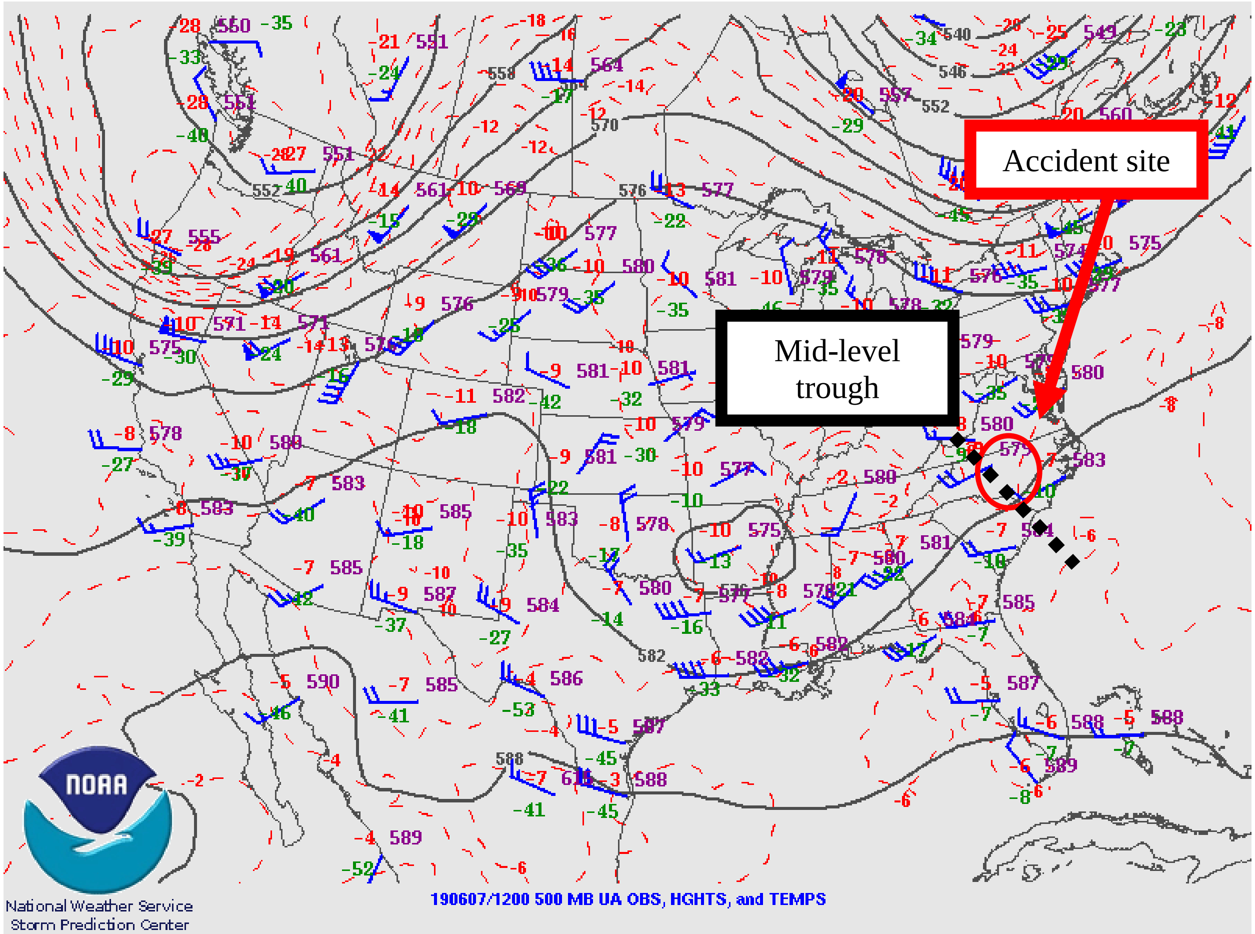

Figure 5 – 500-hPa Constant Pressure Chart for 0800 EDT

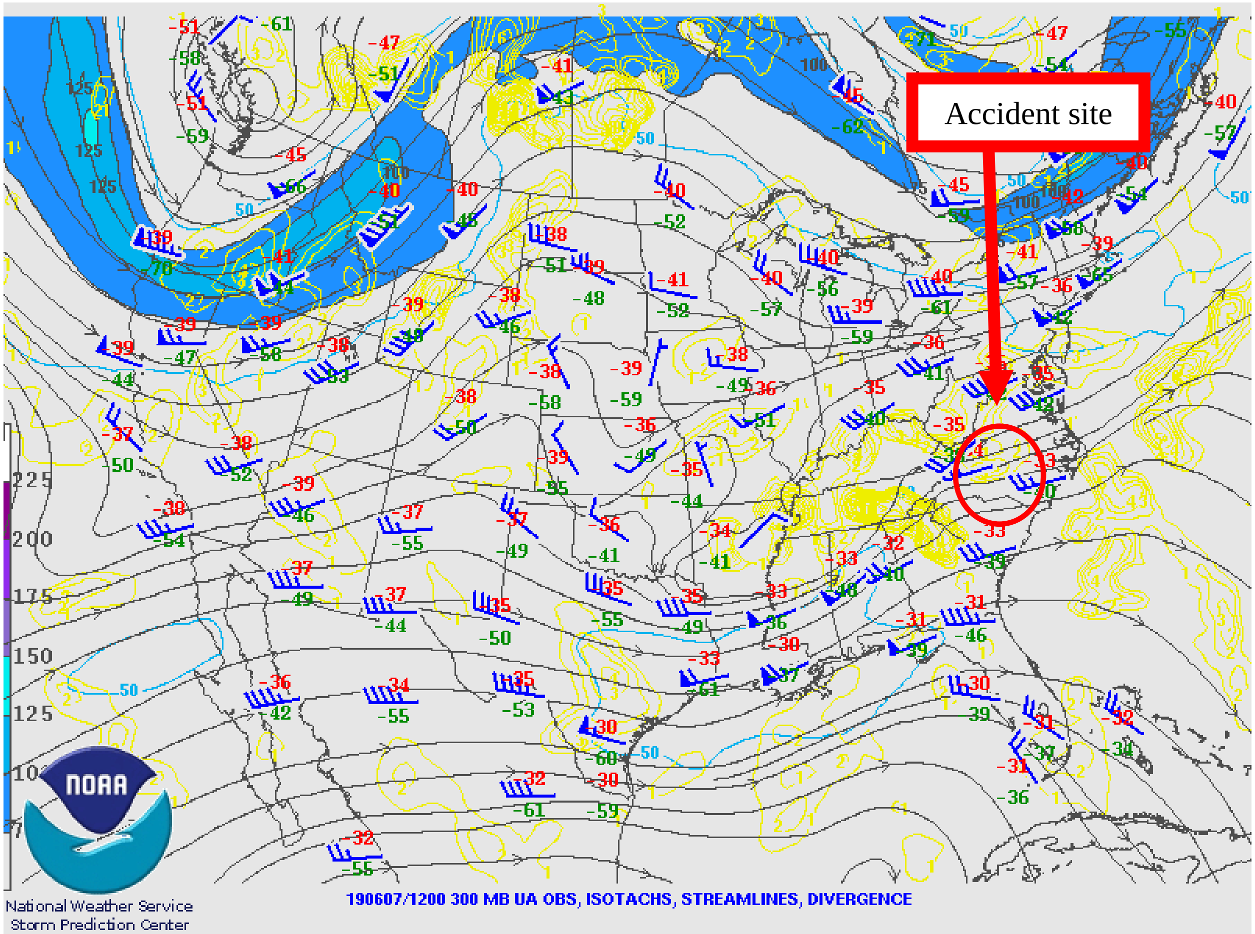

Figure 6 – 300-hPa Constant Pressure Chart for 0800 EDT

2.0 SPC Products

SPC issued the following Day 1 Convective Outlook at 1226 EDT (figure 7) with areas of general thunderstorms forecast for the accident site. 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 issued at 0848 EDT (valid before the accident flight departed) had a similar forecast for the accident site. The SPC Day 1 Convective Outlook text follows figure 7.

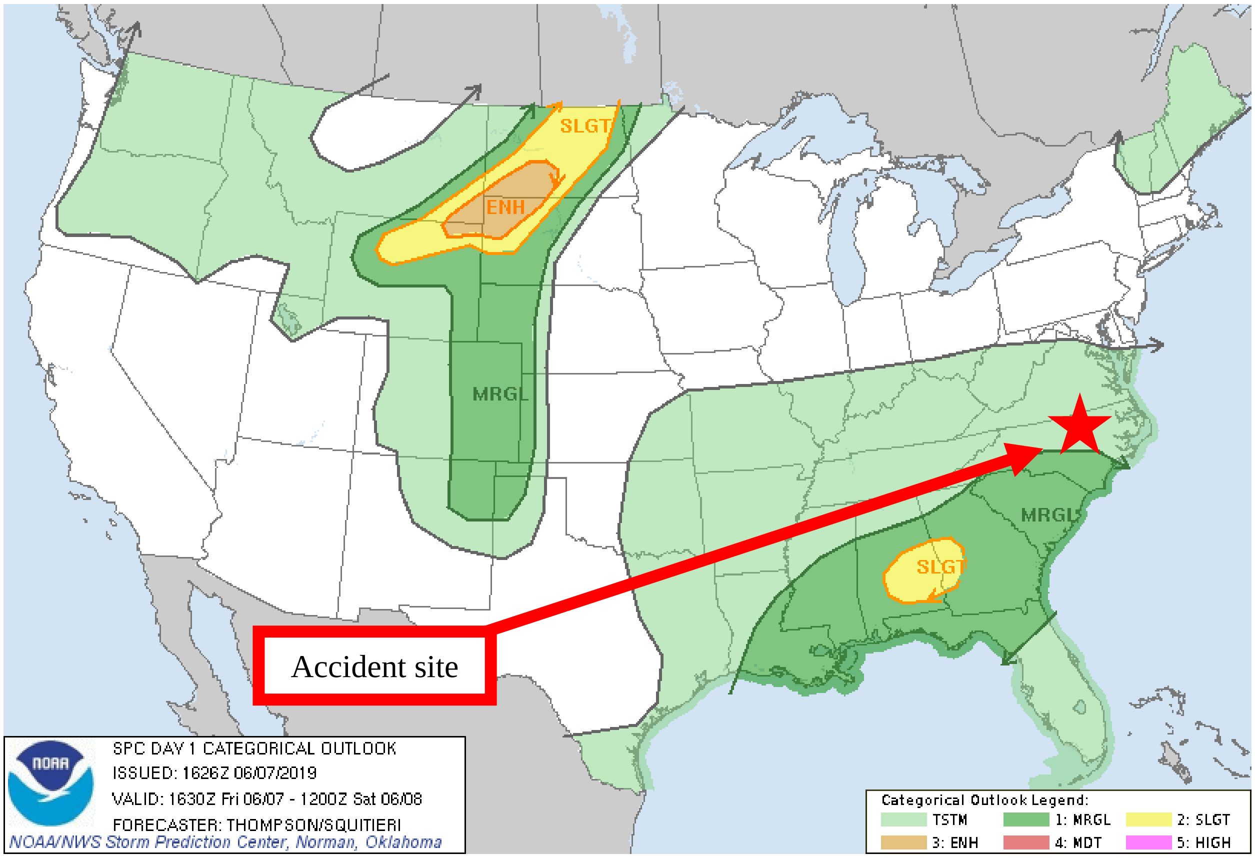

Figure 7 – SPC day 1 Convective Outlook valid at the time of the accident

SPC AC 071626

Day 1 Convective Outlook
NWS Storm Prediction Center Norman OK
1126 AM CDT Fri Jun 07 2019

Valid 071630Z - 081200Z

...THERE IS AN ENHANCED RISK OF SEVERE THUNDERSTORMS THIS AFTERNOON/EVENING ACROSS PARTS OF THE NORTHERN HIGH PLAINS...

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS THIS AFTERNOON FOR PARTS OF SOUTHERN AL AND WEST CENTRAL GA...

...SUMMARY...
Thunderstorms should produce severe hail and winds over a portion of the northern Plains this afternoon into evening, while storms this afternoon could produce a few damaging gusts across parts of Alabama and Georgia.

...Northern High Plains this afternoon into tonight...
A pronounced mid-upper trough over the interior Pacific Northwest and northern Rockies will move slowly eastward toward the northern High Plains through early Saturday. An associated surface cold front will likewise move slowly east-southeastward across WY, eastern MT, and western ND, though progress of the front will be

slowed some today by cyclogenesis in the lee of the Wind River Range
in WY. Low-level moisture is modest across the northern High Plains
this morning, with some increase possible across the Dakotas through
weak advection and local evapotranspiration. However, the primary
driver of buoyancy this afternoon will be surface heating/deep
mixing near the lee cyclone/trough and along the cold front closer
to the Big Horn Mountains.

High-based thunderstorm development is expected by early-mid
afternoon across northwest and north central WY as ascent downstream
from an embedded speed max over the northern Great Basin interacts
with the deepening boundary layer and at least weak surface-based
buoyancy. Deep-layer vertical shear will favor supercells
initially, with the potential to produce large hail and damaging
winds. Eventual upscale growth into organized/bowing clusters is
probable as convection spreads northeastward this evening along the
front into the Dakotas through early tonight. Weakening buoyancy
and increasing convective inhibition after about 05z should result
in a diminishing threat of severe storms.

...Southeast states this afternoon/evening...
A midlevel low and weak surface reflection over AR as of late
morning will only drift eastward through tonight. Surface heating
within a very moist low-level air mass is contributing to moderate
buoyancy in a corridor from southeast LA into AL/GA, in advance of
ongoing/loosely organized storm clusters. Continued destabilization
in conjunction with modest (roughly 30 kt) low-midlevel
southwesterly flow will support a threat for expansion of the
ongoing convection as a few multicell clusters capable of producing
a few marginally severe outflow gusts with resultant wind damage.

Along the northeast edge of the richer moisture and more unstable
warm sector, there will be a zone of somewhat enhanced low-level
shear/hodograph curvature across SC this afternoon. Here, weak
supercell structures will be possible with an attendant threat for a
brief tornado. However, the extent of the threat will be limited by
rather modest low-level flow/SRH (effective SRH generally 150 m2/s2
or less) and deep-layer shear (effective bulk shear of 30 kt or
less), in an environment with poor midlevel lapse rates.

..Thompson/Squitieri.. 06/07/2019

CLICK TO GET WUUS01 PTSDY1 PRODUCT

NOTE: THE NEXT DAY 1 OUTLOOK IS SCHEDULED BY 2000Z

3.0 Surface Observations

The area surrounding the accident site was documented using official Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). 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 locations marked.

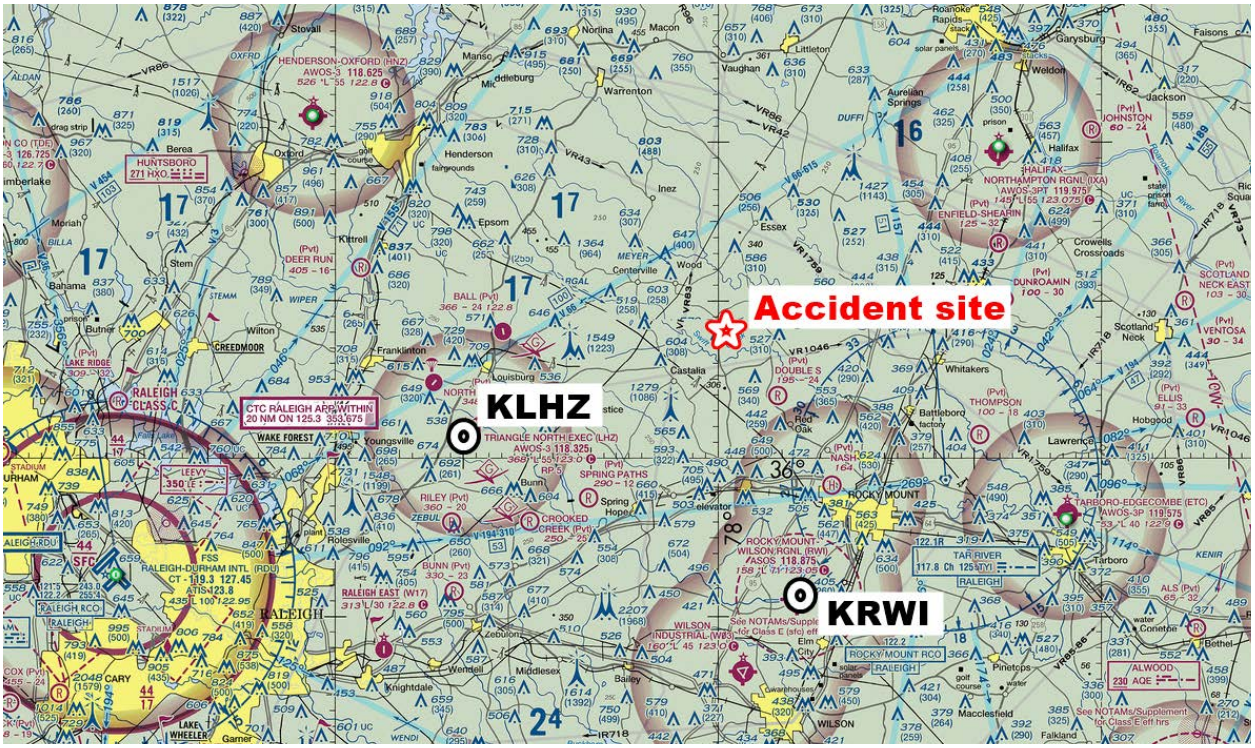

Figure 8 – Sectional map of the accident area with the location of the accident site and surface observation sites

Triangle North Executive Airport (KLHZ), had the closest official weather station to the accident site. KLHZ had an Automated Weather Observing System (AWOS[3]) whose reports were not supplemented. KLHZ was located 18 miles west-southwest of the accident site, at an elevation of 368 ft, and had a 9° westerly magnetic variation[4] (figure 8). The following observations were taken and disseminated during the times surrounding the accident:[5]

[1120 EDT] METAR KLHZ 071520Z AUTO 12003KT 7SM SCT012 BKN021 OVC090 25/22 A2989 RMK AO2=

[1140 EDT] METAR KLHZ 071540Z AUTO 06003KT 4SM RA SCT011 BKN025 OVC055 24/22 A2989 RMK AO2 P0002=

[1200 EDT] METAR KLHZ 071600Z AUTO 27006KT 5SM BR BKN012 BKN024 OVC035 23/22 A2990 RMK AO2=

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3 AWOS – Automated Weather Observing System is equipped with meteorological instruments to observe and report temperature, dewpoint, wind speed and direction, visibility, cloud coverage and ceiling up to twelve thousand feet, and altimeter setting.

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

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

[1220 EDT] METAR KLHZ 071620Z AUTO 31004KT 5SM -RA SCT012 BKN022 OVC036 22/22 A2989 RMK AO2 P0002=

[1240 EDT] METAR KLHZ 071640Z AUTO 00000KT 4SM +RA SCT006 OVC022 22/21 A2990 RMK AO2 P0003=

[1300 EDT] METAR KLHZ 071700Z AUTO 00000KT 7SM SCT009 SCT015 OVC022 22/21 A2990 RMK AO2=

[1320 EDT] METAR KLHZ 071720Z AUTO 04003KT 7SM SCT012 BKN047 OVC065 22/21 A2988 RMK AO2=

<u>ACCIDENT TIME 1333 EDT</u>

[1340 EDT] METAR KLHZ 071740Z AUTO 00000KT 3SM RA SCT004 BKN047 OVC065 22/21 A2988 RMK AO2 P0003=

[1400 EDT] METAR KLHZ 071800Z AUTO 32004KT 2 1/2SM RA SCT004 BKN011 OVC039 21/21 A2988 RMK AO2=

[1420 EDT] METAR KLHZ 071820Z AUTO 36003KT 5SM -RA SCT013 SCT023 OVC055 22/21 A2987 RMK AO2 P0002=

[1440 EDT] METAR KLHZ 071840Z AUTO 02003KT 10SM OVC055 22/21 A2987 RMK AO2 P0002=

KLHZ weather at 1320 EDT, automated, wind from 040° at 3 knots, 7 miles visibility, scattered clouds at 1,200 ft above ground level (agl), broken ceiling at 4,700 ft agl, overcast skies at 6,500 ft agl, temperature of 22°Celsius (C), dew point temperature of 21°C, and an altimeter setting of 29.88 inches of mercury. Remarks: automated station with a precipitation discriminator.

KLHZ weather at 1340 EDT, automated, wind calm, 3 miles visibility, moderate rain, scattered clouds at 400 ft agl, broken ceiling at 4,700 ft agl, overcast skies at 6,500 ft agl, temperature of 22°C, dew point temperature of 21°C, and an altimeter setting of 29.88 inches of mercury. Remarks: automated station with a precipitation discriminator, 0.03 inches of precipitation since 1300 EDT.

The observations from KLHZ surrounding the accident time indicated MVFR to IFR[6] conditions with moderate rain.

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[6] 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

4.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)[7] model sounding was created for the accident site for 1300 EDT with station elevation of 262 ft.[8] The 1300 EDT HRRR sounding was plotted on a standard Skew-T Log P diagram[9] 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 RAOB[10] software package. The sounding depicted the lifted condensation level (LCL)[11] at 1,729 ft agl, the level of free convection (LFC)[12] at 1,781 ft agl, and the convective condensation level (CCL)[13] at 2,448 ft agl. The sounding had a greater than 80% relative humidity from 1,000 ft through 24,000 ft msl. The freezing level was located at 14,382 ft msl. The precipitable water value was 2.11 inches. The mean storm motion was from 249° at 8 knots.

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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.

[7] 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.
[8] HRRR sounding was created using NOAA Air Resource Laboratory: https://ready.arl.noaa.gov/READYamet.php
[9] 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.
[10] RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.
[11] LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.
[12] 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.
[13] 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.

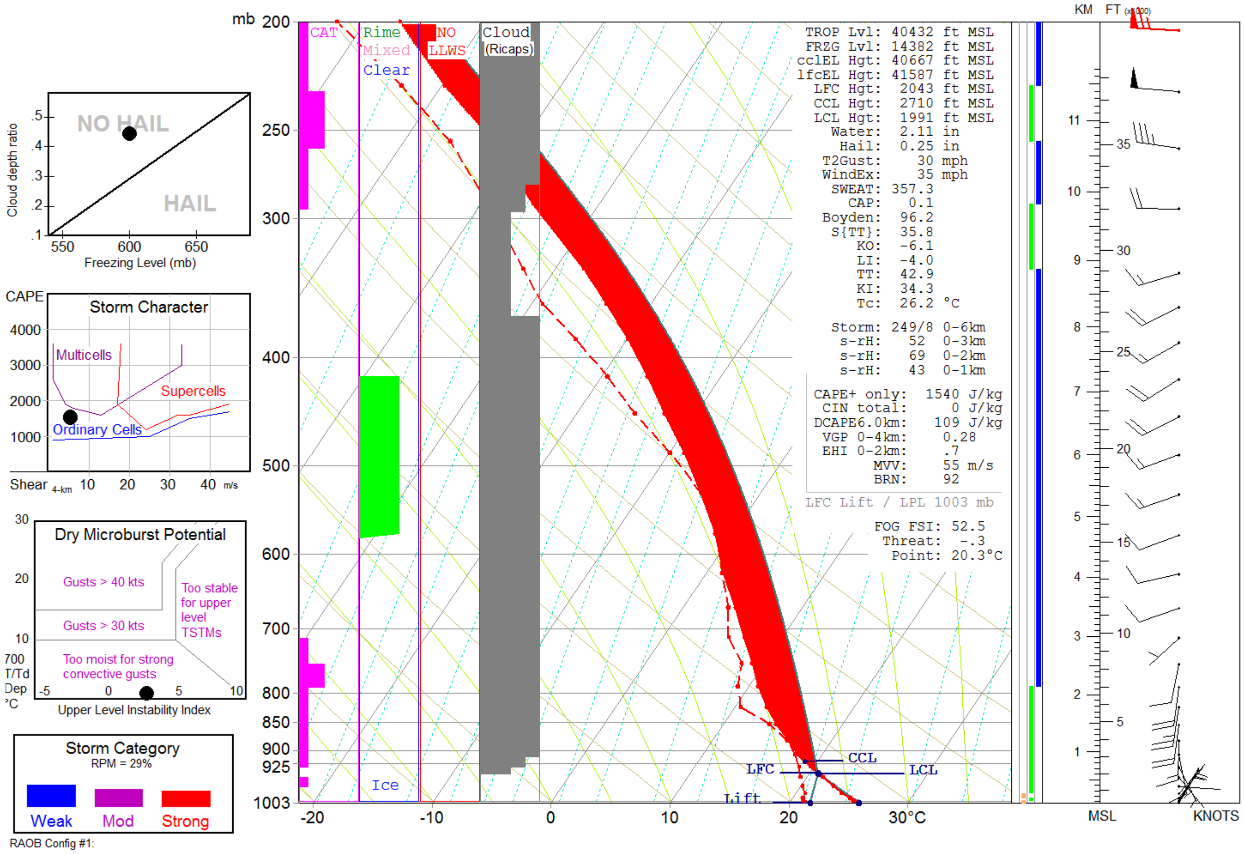


Figure 9 – 1300 EDT HRRR sounding

The 1300 EDT HRRR sounding for the accident site indicated alternating layers of a conditionally unstable environment and stable environment from the surface through 39,000 ft. RAOB identified the possibility of clouds from 2,000 ft agl through 39,000 ft msl. 1,540 Joules/kilogram (J/kg) of CAPE[14] were indicated on the sounding and the maximum vertical velocity (MVV) for this atmosphere was calculated as 55 meters/second (about 10,826 ft per minute).[15] Given the environment, RAOB indicated that ordinary thunderstorm development was possible with no hail or severe thunderstorm activity (wind, tornadoes, hail, etc…) at the surface. Downdraft CAPE (DCAPE; 6 kilometers agl)[16] was measured at 109 J/kg. If rain showers or thunderstorms formed in this environment, the 1300 EDT HRRR sounding indicated that the strongest wind speeds possible at the surface (due to, for example, a microburst, outflow boundary, or gust front) would have been 35 mph (30 knots) according to the WindEx parameter.

[14] 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.
[15] 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.
[16] 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.

The 1300 EDT HRRR sounding wind profile indicated a surface wind from 029° at 2 knots with the wind becoming southwesterly through 10,000 ft. The wind continued to veer[17] to the west by 32,000 ft. The wind speed remained between 5 and 20 knots between 10,000 and 33,000 ft. RAOB did not indicate the possibility of low-level wind shear (LLWS) outside of a rain shower or thunderstorm activity. RAOB indicated that a chance of light to moderate clear-air turbulence existed in several layers between 1,000 ft and 39,000 ft. At the accident airplane's altitude before descent (and accident time)[18] around 27,000 ft, the sounding indicated a southwest wind at 18 knots with a temperature of -23.7ºC and a relative humidity of 61%.

5.0 Satellite Data

The 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 1000 EDT through 1500 EDT and reviewed, and the closest images to the time of the accident were documented.

Figures 10 and 11 present the GOES-16 visible imagery at 1330 and 1340 EDT at 3X magnification with the accident site highlighted with a red square. The visible imagery indicated an extensive layer of cloud cover, which was cumuliform in nature, over the accident site. The cloud cover moving from southwest to northeast (attachment 1).

Figure 12 presents the GOES-16 infrared imagery from 1330 EDT at 6X magnification with the accident site highlighted with a red square. Inspection of the infrared imagery indicated cloud cover over the accident site. The lower brightness temperatures (blue and green colors; higher cloud tops) were located above and to the northeast and southwest of the accident site. The cloud cover was moving from southwest to northeast with the lower brightness temperatures becoming more abundant near the accident site and KLHZ between 1100 and 1400 EDT (attachment 2). Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 1300 EDT HRRR sounding, the approximate cloud-top heights over the accident site were 38,000 ft at 1330 EDT (223 Kelvin). It should be noted these figures have not been corrected for any parallax error.

[17] A clockwise turning of the wind with height in the northern hemisphere.
[18] For more information please see the NTSB ATC information in the docket for this accident.

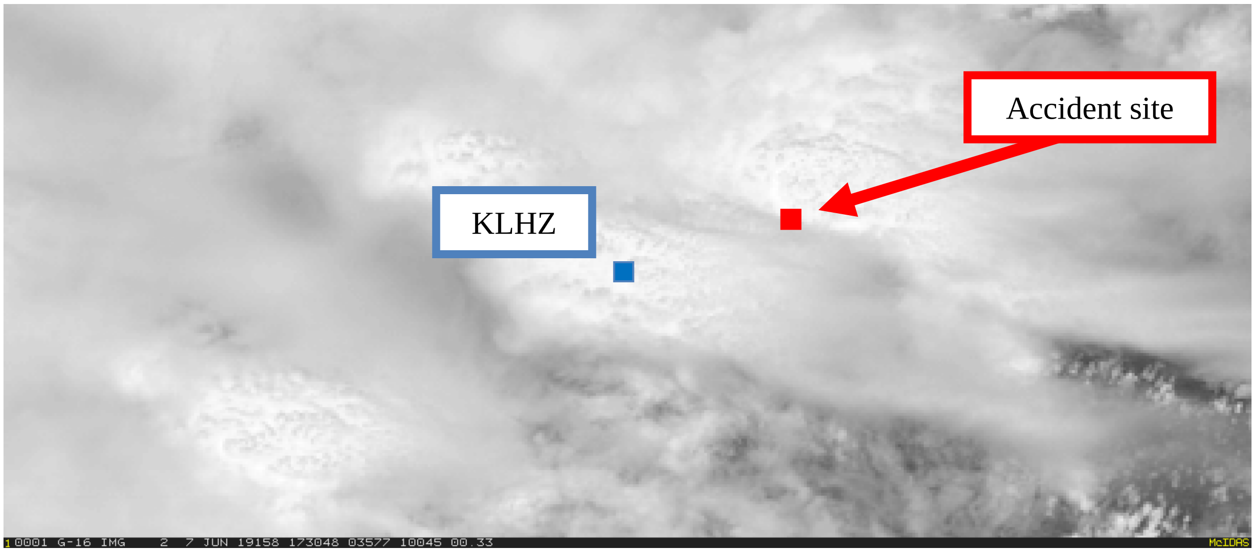


Figure 10 – GOES-16 visible image at 1330 EDT

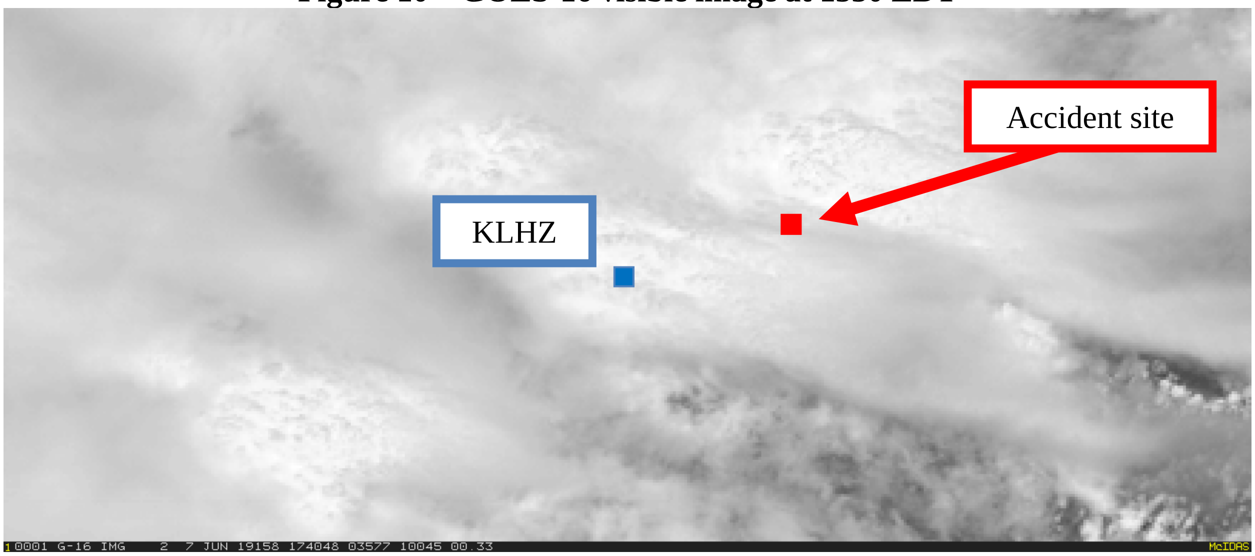


Figure 11 – GOES-16 visible image at 1340 EDT

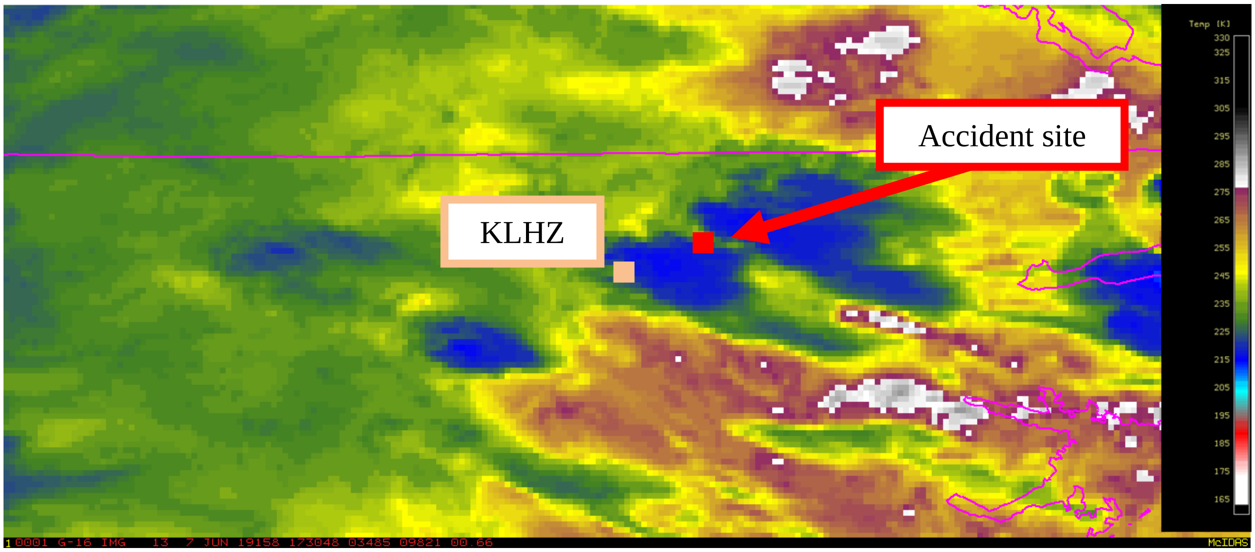


Figure 12 – GOES-16 infrared image at 1330 EDT

6.0 Regional Radar Imagery Information

A regional view of the NWS national composite radar mosaic is included as figure 13 for 1330 EDT with the approximate location of the accident site marked by a red circle. The image depicted echoes from 40 to 60 decibels (dBZ[19]) echoes in the immediate vicinity of the accident site.

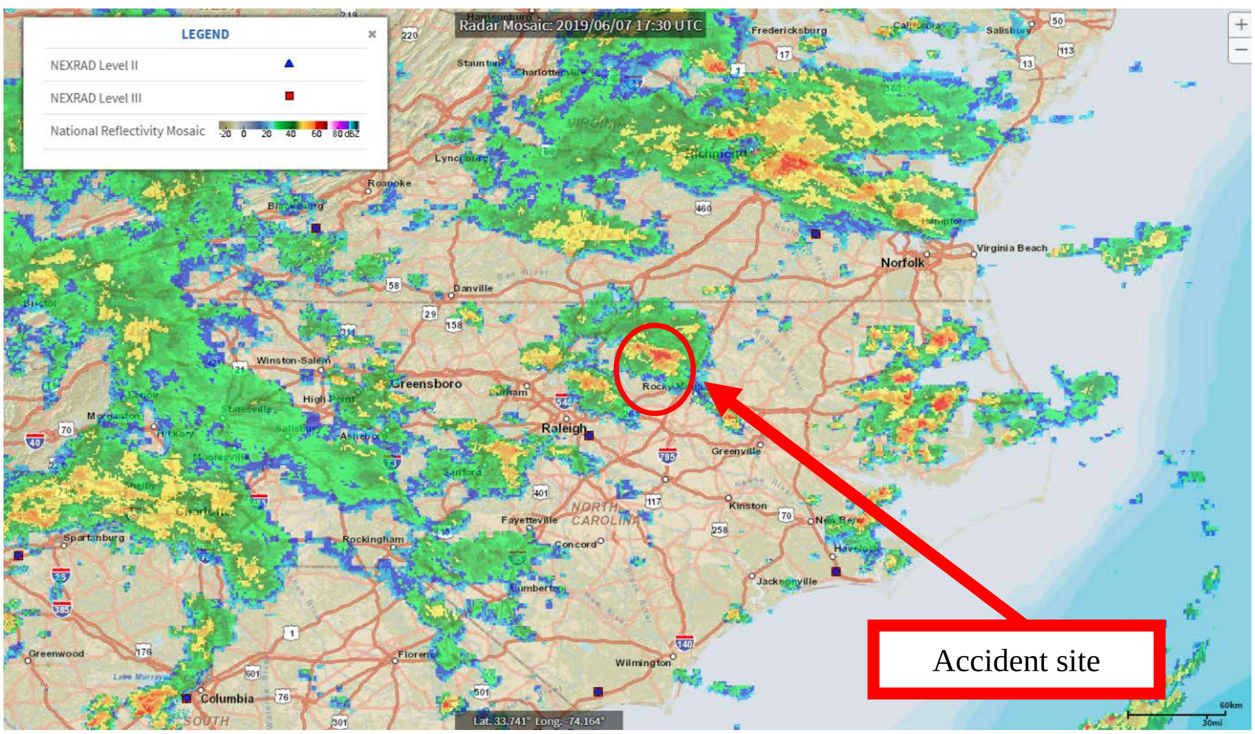


Figure 13 – Regional Composite Reflectivity image for 1330 EDT

[19] 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.

7.0 Radar Imagery Information

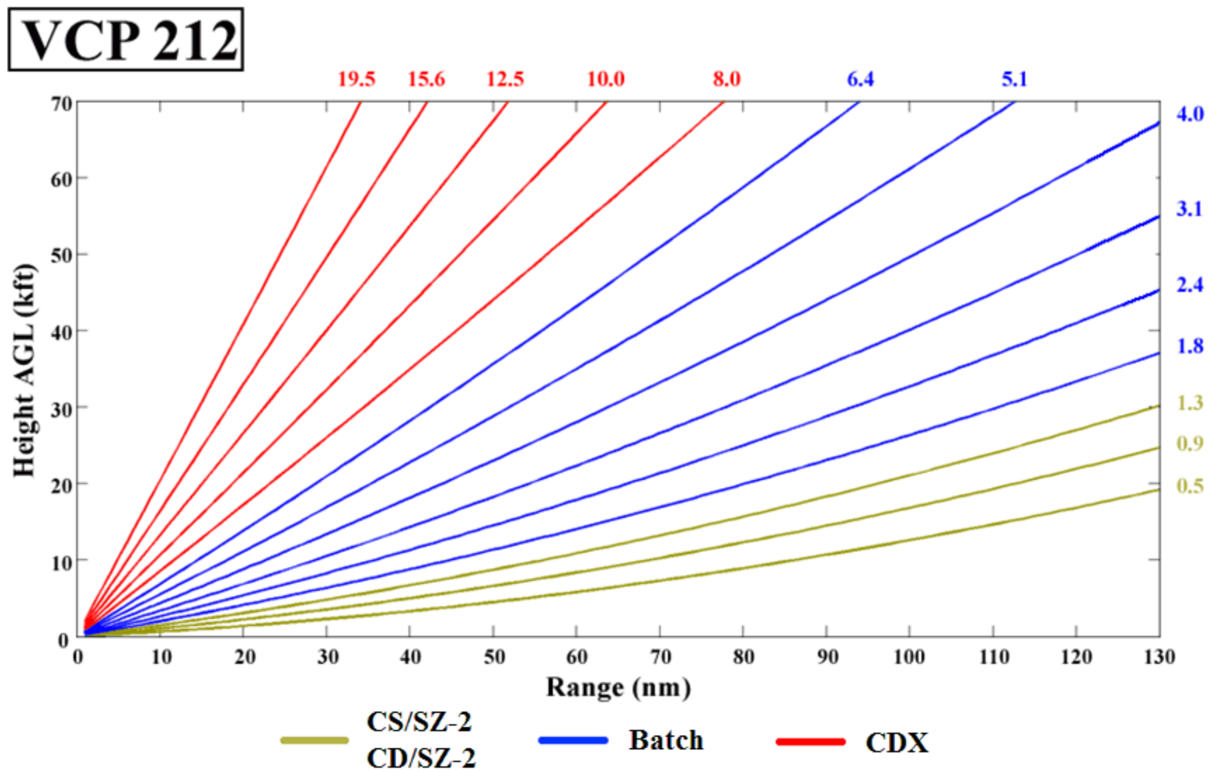
The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)[20] to the accident site was Raleigh/Durham, North Carolina, (KRAX), with antenna elevation of 461 ft, located 37 miles southwest of the accident site. Level II and level III archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

7.1 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 14 elevation scans from 0.5° to 19.5° every four and a half minutes. This particular scanning strategy is documented as volume coverage pattern 212 (VCP-212). 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 KRAX WSR-88D radar was operating in the precipitation mode VCP-212. 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.

[20] 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.



VCP-212 Precipitation Mode Scan Strategy[21]

7.2 Beam Height Calculation

Assuming standard refraction[22] of the KRAX WSR-88D radar beam with the antenna elevation at 461 ft, and considering a beamwidth[23] 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
KRAX 0.5°	3,410 ft	1,590 ft	5,230 ft
KRAX 6.4°	26,430 ft	24,620 ft	28,240 ft

[21] 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)

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

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

Based on the radar height calculations, the elevation scans from KRAX listed in the above table depicted the conditions between 1,590 ft and 5,230 ft and between 24,620 and 28,240 ft over the accident site and the 6.4° scans "saw" the closest altitudes to the accident aircraft's flight level before the descent in altitude from FL270.[24,25]

7.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors[26] 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 00-24C[27], "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:

- 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

[24] 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.

[25] For more information please see air traffic control (ATC) data located in the docket of this accident.

[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.

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

7.4 Base Reflectivity and Lightning Data

Figures 14, 15, 16, and 17 present the KRAX WSR-88D base reflectivity images for the 0.5° and 6.4° elevation scans initiated at 1331:37, 1322:35, 1327:37, and 1332:48 EDT, respectively, with a resolution of 0.5° X 250 m. Reflectivity values between 20 and 35 dBZ were located above the accident site at the accident time and along the accident aircraft's flight track[28] (pink line, figures 15 through 17) with reflectivity values of 30 to 50 dBZ closer to the surface (figure 14). The accident flight track went through an area of 20 to 40 dBZ values between 1322 and 1327 EDT (figures 15 and 16). The reflectivity bands were moving from southwest to northeast (attachments 3 and 4).

There were 39 lightning flashes[29] between 1315 and 1345 EDT and the lightning flashes are plotted as black dots on figures 14 through 17.[30]

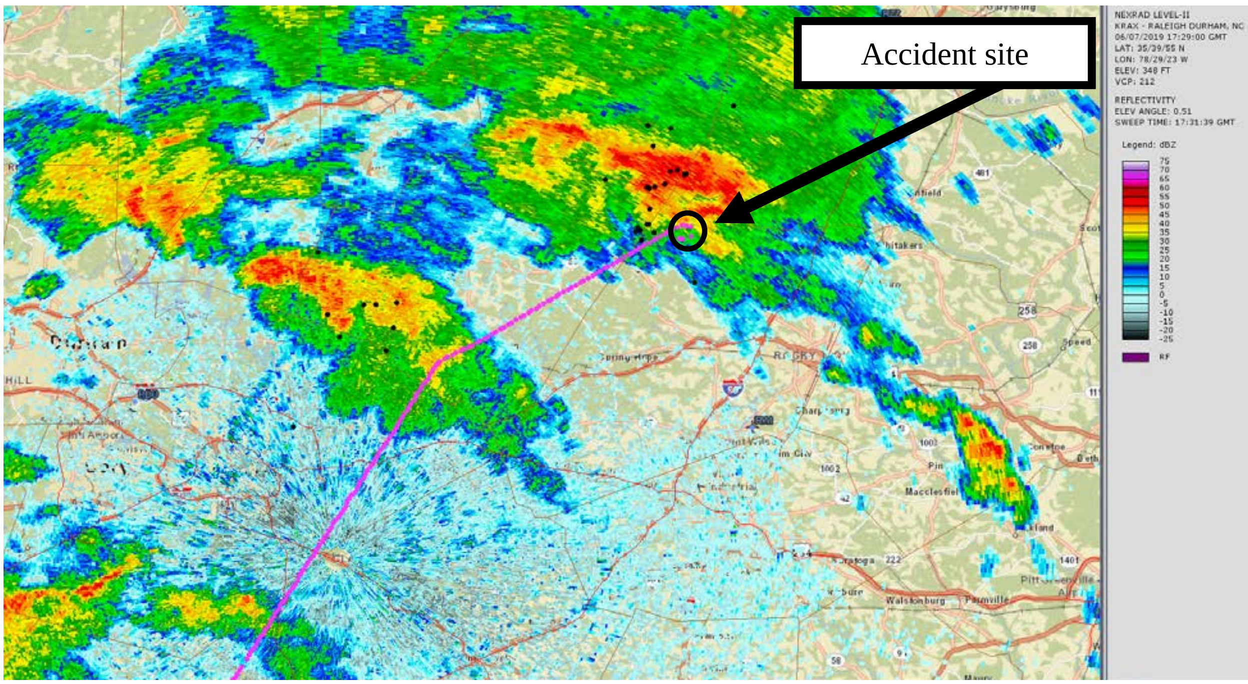


Figure 14 – KRAX WSR-88D reflectivity for the 0.5° elevation scan initiated at 1331:39 EDT with the accident site marked with black circle, the accident flight track in pink, lightning flashes marked as black dots

[28] More details on flight track found in the docket for this accident.

[29] 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.

[30] A review of Earth Networks Total Lightning network was done.

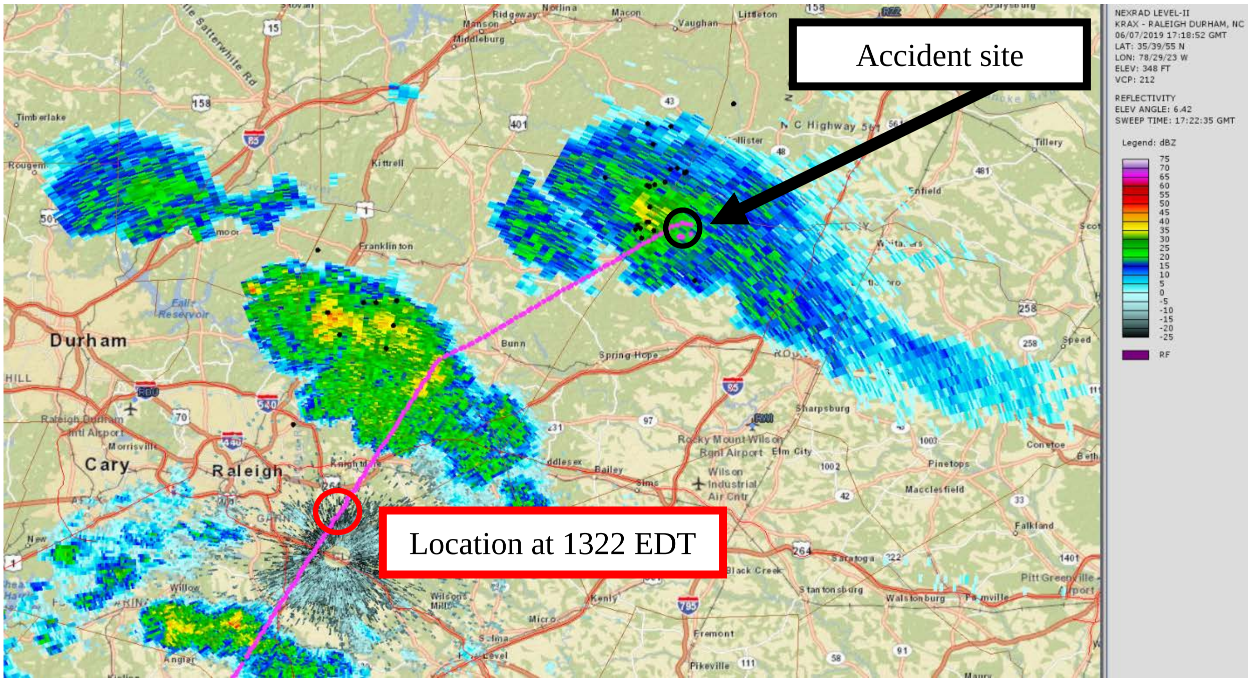


Figure 15 – KRAX WSR-88D reflectivity for the 6.4° elevation scan initiated at 1322:35 EDT with the accident site marked with black circle, the accident flight track in pink, lightning flashes marked as black dots

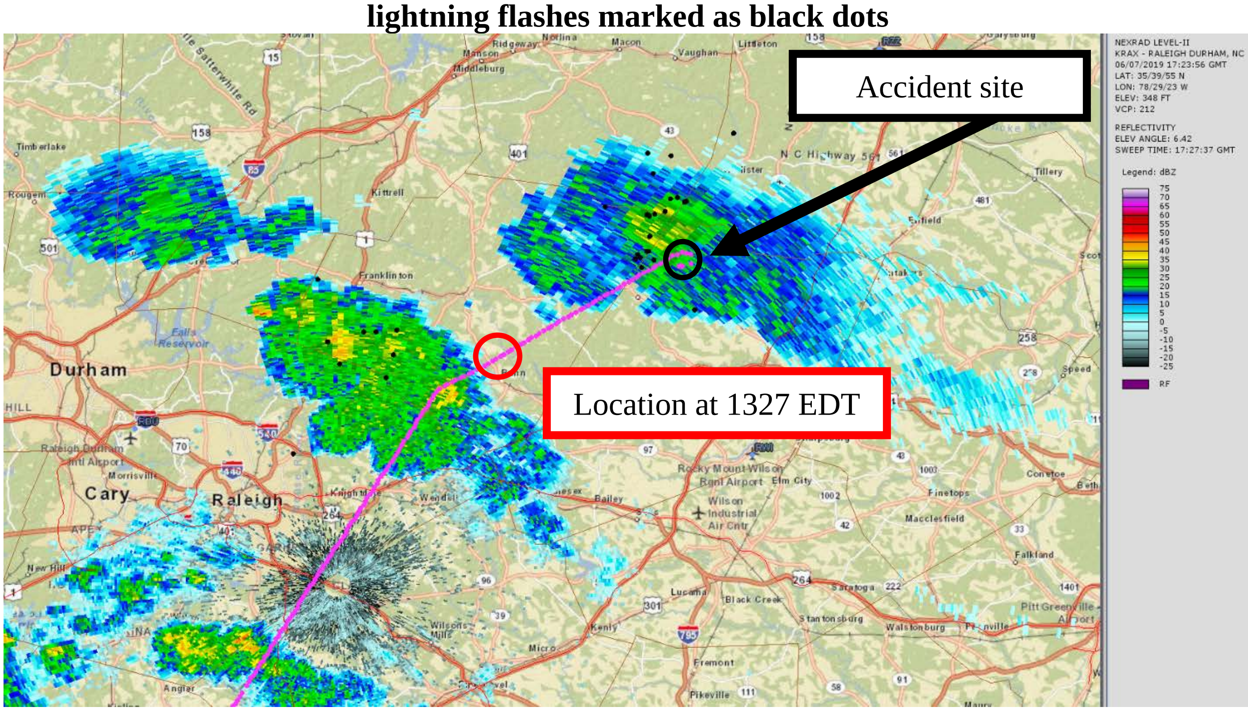


Figure 16 – KRAX WSR-88D reflectivity for the 6.4° elevation scan initiated at 1327:37 EDT with the accident site marked with black circle, the accident flight track in pink, lightning flashes marked as black dots

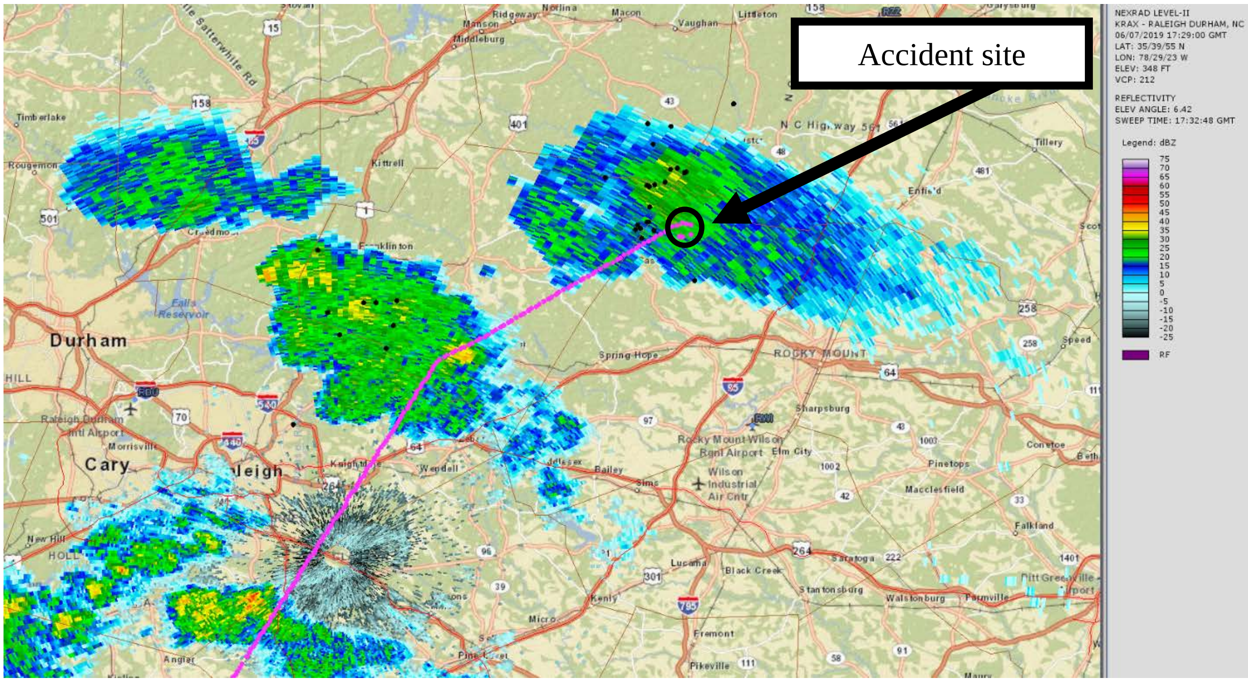


Figure 17 – KRAX WSR-88D reflectivity for the 6.4° elevation scan initiated at 1332:48 EDT with the accident site marked with black circle, the accident flight track in pink, lightning flashes marked as black dots

Before the accident flight departed from Naples Municipal Airport (KAPF) around 1054 EDT a convective cell had developed west of KAPF around 0931 EDT and moved over KAPF around 0953 EDT and then moved east of the airport by 1025 EDT (attachment 5).

8.0 Pilot Reports[31]

All pilot reports (PIREPs) within 100 miles of the accident site from about one hour prior to the accident time to about one hour after the accident time are provided below:

RIC UA /OV FINAL RWY34/TM 1630/FL005/TP EC45/SK SCT005/RM RWY IN SIGHT 005

ILM UA /OV ILM340030/TM 1634/FL370/TP B738/TB MOD CAT

RIC UA /OV 3NM FINAL RWY34/TM 1644/FL012/TP A319/SK SCT002/WX +RA/TB +10KTS 012

GSO UA /OV GSO050006/TM 1653/FL030/TP CRJ2/SK BKN013/WX RA/RM DURD FINAL RWY 23R

DPL UA /OV ILM360030/TM 1700/FL045/TP PA32/SK FEW035/OVC070

ETC UA /OV TYI/TM 1710/FL330/TP A319/TB MOD 330

RDU UA /OV RDU180020/TM 1711/FL330/TP A320/TB MOD 330

ARP UAL2206 3731N 07749W 1715 F370 TB LGT-MOD

[31] Only pilot reports with the World Meteorological Organization headers UBNC** and UBVA** were considered.

RIC UA /OV RIC/TM 1715/FL020/TP E135/SK BASES OVC003/TB LGT-MOD/RM LIGHTING 1 NM FINAL R34 CLOUD TO GROUN

GSO UA /OV GSO05008/TM 1717/FLDURD/TP MD88/SK BKN017-TOPUNKN/WX 5SM/RM DURD FINAL RWY 23R

RIC UA /OV HPW/TM 1727/FL290/TP A321/TB MOD 290/RM PILOT SAID STAY AWAY

RIC UA /OV RIC/TM 1802/FL020/TP CRJ2/SK BASES OVC003

RIC UA /OV RWY 2 FINAL/TM 1802/FL004/TP E175/SK SCT009/WX -RA BR/RM FIELD IN SIGHT AT MINS

RDU UA /OV RDU230015/TM 1805/FLDURGD/TP A320/WX HEAVY RAIN/TB SMOOTH

GSO UA /OV GSO050002/TM 1805/FLDURGD/TP A319/SK BKN006/WX RA/TB SMOOTH

RDU UA /OV RDU010008/TM 1825/FLDURGD/TP E170/SK BASES OVC050/TB LGT-MOD

The reports in plain language taken from standard code and abbreviations, with time converted to local were as follows:

Richmond International Airport, Virginia (RIC), routine pilot report (UA); Over – Final into runway 34; Time – 1230 EDT (1630Z); Altitude – 500 ft; Type aircraft – Airbus Helicopter EC-145; Sky – Scattered clouds at 500 ft; Remarks; - Runway in sight at 500 ft.

Wilmington International Airport, North Carolina (ILM), routine pilot report (UA); Over – 30 miles from ILM on the 340° radial; Time – 1234 EDT (1634Z); Altitude – FL370; Type aircraft – Boeing B737-800; Turbulence – Moderate clear-air turbulence.

RIC, routine pilot report (UA); Over – 3 miles final into runway 34; Time – 1244 EDT (1644Z); Altitude – 1,200 ft; Type aircraft – Airbus A319; Sky – Scattered clouds at 200 ft; Weather – Heavy rain; Turbulence – +10 knots at 1,200 ft.

Piedmont Triad International Airport, North Carolina (GSO), routine pilot report (UA); Over – 6 miles from GSO on the 050° radial; Time – 1253 EDT (1653Z); Altitude – 3,000 ft; Type aircraft – Bombardier CRJ200; Sky – Broken clouds at 1,300 ft; Weather – Moderate rain; Remarks – During descent final into runway 23R.

Duplin County Airport, North Carolina (DPL), routine pilot report (UA); Over – 30 miles from ILM on the 360° radial; Time – 1300 EDT (1700Z); Altitude – 4,500 ft; Type aircraft – Piper PA-32; Sky – Few clouds at 3,500 ft, overcast clouds at 7,000 ft.

Tarboro-Edgecombe Airport, North Carolina (ETC), routine pilot report (UA); Over – Tar River, North Carolina (TYI) VORTAC; Time – 1310 EDT (1710Z); Altitude – FL330; Type aircraft – Airbus A319; Turbulence – Moderate.

Raleigh-Durham International Airport, North Carolina (RDU), routine pilot report (UA); Over – 20 miles from RDU on the 180° radial; Time – 1311 EDT (1711Z); Altitude – FL330; Type aircraft – Airbus A320; Turbulence – Moderate at FL330.

Aircraft report (AIREP) from United 2206 located at 37° 31’ N and 77° 49’ W; Time – 1315 EDT (1715Z); Altitude – FL370; Turbulence – Light to moderate.

RIC, routine pilot report (UA); Over – RIC; Time – 1315 EDT (1715Z); Altitude – 2,000 ft; Type aircraft – Embraer ERJ-135; Sky – Bases overcast at 300 ft; Turbulence – Light to moderate; Remarks – Cloud to ground lightning at 1 mile final into runway 34.

GSO, routine pilot report (UA); Over – 8 miles from GSO on the 050° radial; Time – 1317 EDT (1717Z); Altitude – During descent; Type aircraft – McDonnell Douglas MD-88; Sky – Broken clouds at 1,700 ft with tops unknown; Weather – 5 miles forward visibility; Remarks – During descent final into runway 23R.

RIC, routine pilot report (UA); Over – Hopewell, Virginia, VORTAC (HPW); Time – 1327 EDT (1727Z); Altitude – FL290; Type aircraft – Airbus A321; Turbulence – Moderate at FL290; Remarks – Pilot said stay away.

RIC, routine pilot report (UA); Over – RIC; Time – 1402 EDT (1802Z); Altitude – 2,000 ft; Type aircraft – Bombardier CRJ200; Sky – Bases overcast at 300 ft.

RIC, routine pilot report (UA); Over – Runway 2 final; Time – 1402 EDT (1802Z); Altitude – 400 ft; Type aircraft – Embraer ERJ-175; Sky – Scattered clouds at 900 ft; Weather – Light rain and mist; Remarks – Field in sight at minimums.

RDU, routine pilot report (UA); Over – 15 miles from RDU on the 230° radial; Time – 1405 EDT (1805Z); Altitude – During descent; Type aircraft – Airbus A320; Weather – Heavy rain; Turbulence – Smooth.

GSO, routine pilot report (UA); Over – 2 miles from GSO on the 050° radial; Time – 1405 EDT (1805Z); Altitude – During descent; Type aircraft – Airbus A319; Sky – Broken clouds at 600 ft; Weather – Moderate rain; Turbulence – Smooth.

RDU, routine pilot report (UA); Over – 8 miles from RDU on the 010° radial; Time – 1425 EDT (1825Z); Altitude – During descent; Type aircraft – Embraer ERJ-170; Sky – Bases overcast at 5,000 ft; Turbulence – Light to moderate.

9.0 SIGMET

There was convective Significant Meteorological Information (SIGMET) 65E valid for the accident site at the accident time. SIGMET 65E warned of an area of embedded thunderstorms with tops to FL410 between 1255 and 1455 EDT[32]. The convective SIGMET box was forecast to move from 230° at 10 knots (figures 18 through 20):

[32] SIGMET 65E was valid through 1455 EDT, unless another SIGMET issued at 1355 EDT superseded it.

WSUS31 KKCI 071655
SIGE
MKCE WST 071655

CONVECTIVE SIGMET 65E
VALID UNTIL 1855Z
NC
FROM 50NE RDU-60ESE RDU-20SSW RDU-30NNW RDU-50NE RDU
AREA EMBD TS MOV FROM 23010KT. TOPS TO FL410.

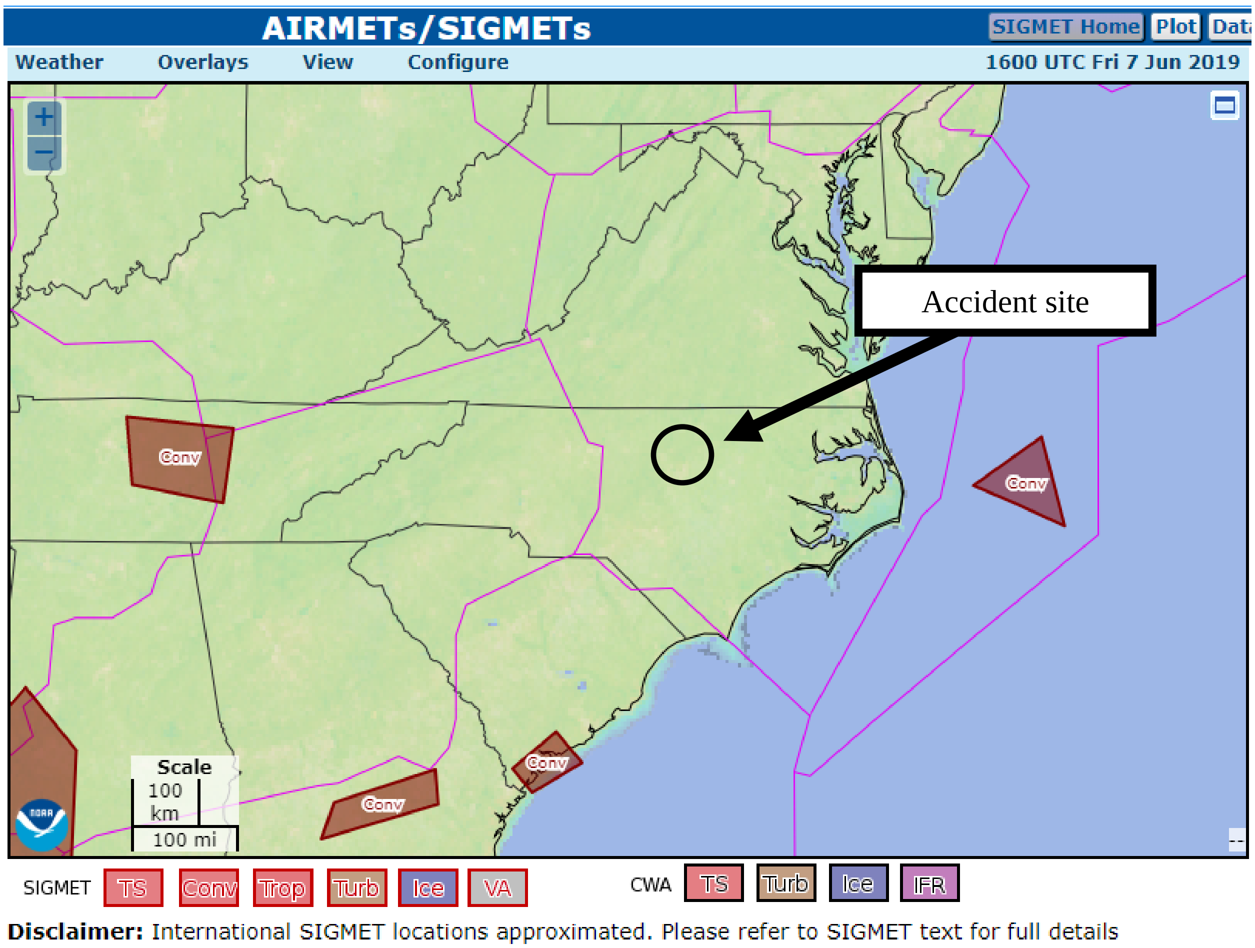


Figure 18 – SIGMETs and CWAs valid at 1200 EDT

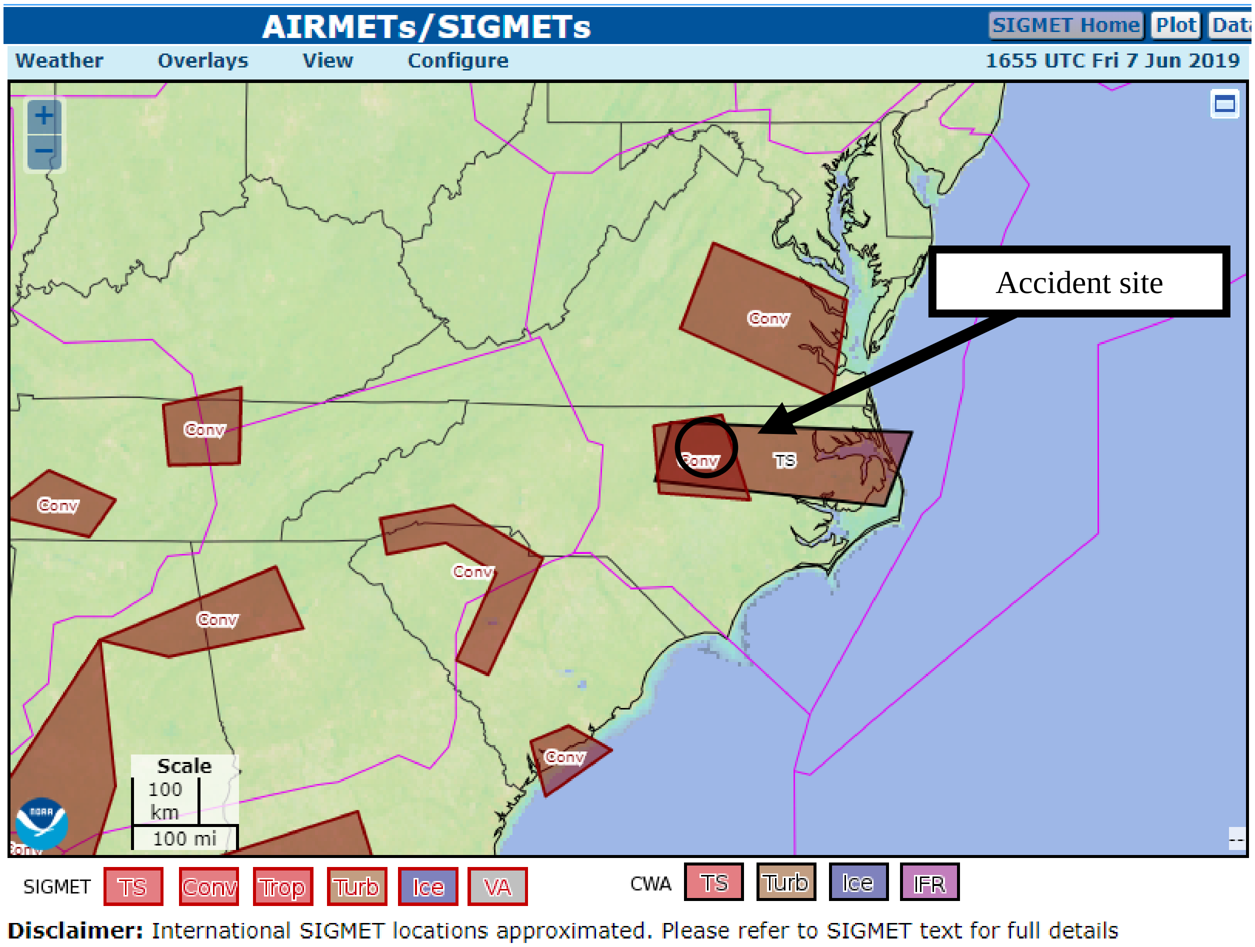


Figure 19 – SIGMETs and CWAs valid at 1255 EDT

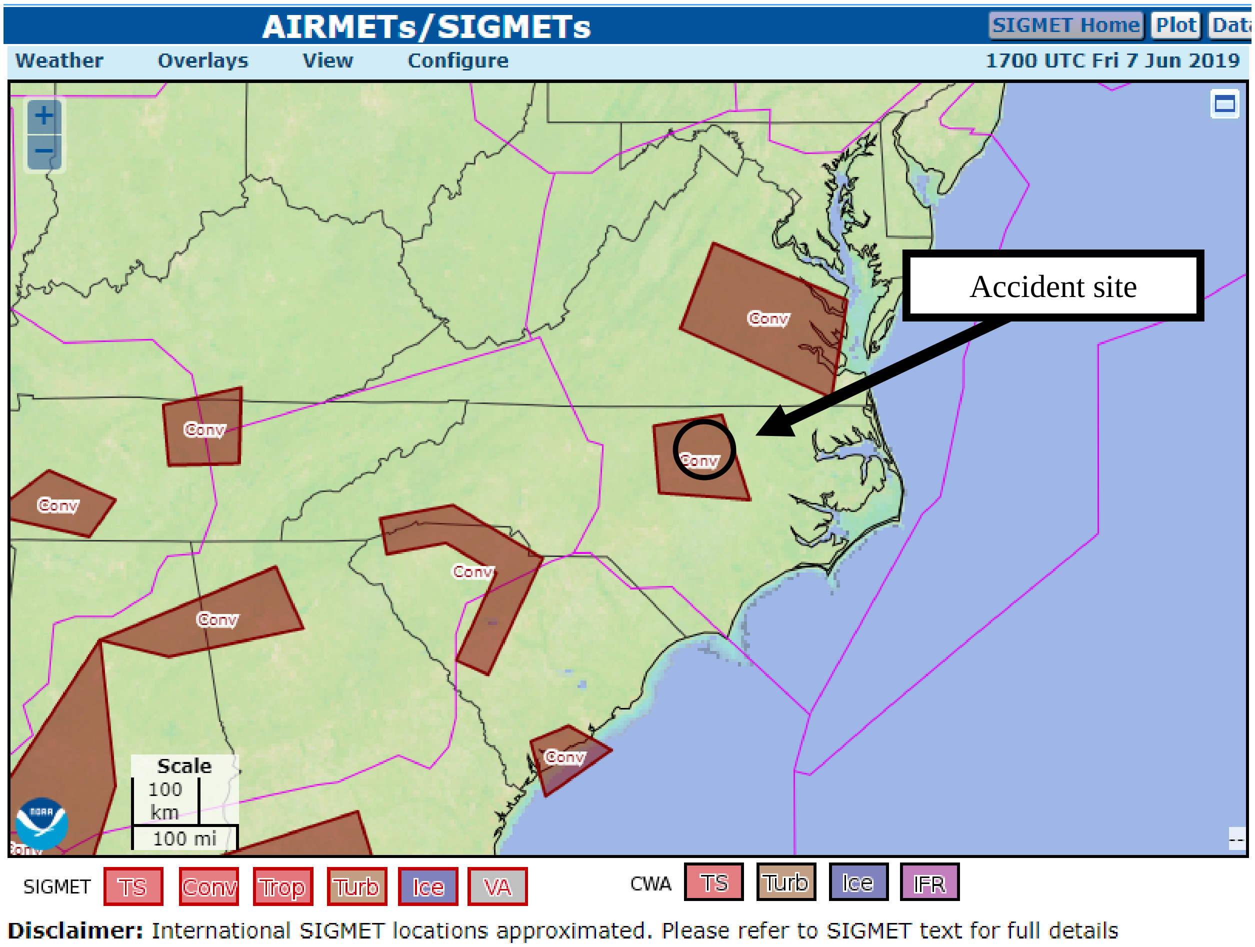


Figure 20 – SIGMETs and CWAs valid at 1300 EDT

10.0 CWSU Products

The Air Route Traffic Control Center Washington, DC, (ZDC) Center Weather Service Unit (CWSU) was responsible for the region. The ZDC CWSU issued no Meteorological Impact Statements (MIS) for the area prior to the accident. ZDC CWSU issued had Center Weather Advisory (CWA) 201 at 1232 EDT (with a correction sent at 1235 EDT) and was valid until 1300 EDT for the accident area (figure 19). The advisory warned of a developing area of thunderstorms moving northeast at 10 knots with tops around FL400. Impacts to J55, J121, and J174 routes. Additional development likely through 1300 EDT:

FAUS22 KZDC 071632
ZDC2 CWA 071630
ZDC CWA 201 VALID UNTIL 071700
FROM 30N RUD-40E ECG-55SSE ECG-15SW RDU-30N RDU
AREA OF DEVELOPING TSRA MOVG NE 10KT W/ TOPS AROUND FL400. IMPACTS TO J55 J121 J174. ADDITIONAL DEVELOPMENT LIKELY THROUGH 17Z.*
=

FAUS22 KZDC 071635
ZDC2 CWA 071630 COR
ZDC CWA 201 VALID UNTIL 071700
FROM 30N RDU-40E ECG-55SSE ECG-15SW RDU-30N RDU
AREA OF DEVELOPING TSRA MOVG NE 10KT W/ TOPS AROUND FL400. IMPACTS TO J55 J121 J174. ADDITIONAL DEVELOPMENT LIKELY THROUGH 17Z. COR COORDINATE.*
=

11.0 AIRMETs

Airmen's Meteorological Information (AIRMET) advisories Tango and Zulu were valid for the accident site at the accident time. The AIRMETs warned of moderate turbulence between FL210 and FL420 and moderate icing between 15,000 ft and FL250:

WAUS41 KKCI 071445
WA1T
-BOST WA 071445
AIRMET TANGO UPDT 2 FOR TURB VALID UNTIL 072100
.
AIRMET TURB...NY NJ PA OH WV MD DC DE VA NC SC GA FL AND CSTL WTRS
FROM 30W SLT TO 20SSE SAX TO 30SE JFK TO 160SE SIE TO 190ESE ECG TO 130SSE ILM TO 220SE CHS TO 20S AMG TO 40NW PZD TO GQO TO HMV TO HNN TO CVG TO 30W SLT
MOD TURB BTN FL210 AND FL420. CONDS CONTG BYD 21Z THRU 03Z.

WAUS41 KKCI 071445
WA1Z
-BOSZ WA 071445
AIRMET ZULU UPDT 2 FOR ICE AND FRZLVL VALID UNTIL 072100
.
AIRMET ICE...PA OH WV MD DC DE VA NC SC GA AND CSTL WTRS
FROM 20ESE APE TO AIR TO 20E DCA TO 20NW SBY TO 50ESE SBY TO 100SE ECG TO 130SSE ILM TO SAV TO 30NNW ODF TO 30W VXV TO HMV TO HNN TO CVG TO 50WSW ROD TO 20ESE APE
MOD ICE BTN 150 AND FL250. CONDS CONTG BYD 21Z THRU 03Z.

12.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products made available before the accident flight and valid at 1400 EDT are shown in attachment 6. The GFA surface forecast products indicated VFR to MVFR surface visibilities with numerous (between 60 and 100 percent chance) thunderstorm activity forecast and variable surface winds at or below 5 knots at the accident site. The GFA cloud forecast valid before departure for around the accident time indicated overcast skies around 14,000 ft with clouds top between FL310 and FL430. For more information please see attachment 6.

13.0 Terminal Aerodrome Forecast

Rocky Mount-Wilson Regional Airport (KWRI) was the closest airport to the accident site with a NWS Terminal Aerodrome Forecast (TAF). KRWI was located 18 miles south-southeast of the accident site with an elevation of 158 ft (figure 8). The KRWI TAF valid at the time of the accident was issued at 1017 EDT and was valid for a 22-hour period beginning at 1000 EDT. The TAF for KRWI was as follows:

KRWI 071417Z 0714/0812 **23005KT P6SM VCSH SCT015 BKN050 BKN080**
TEMPO 0715/0719 BKN015
FM071900 05004KT 4SM -TSRA BR OVC025CB
TEMPO 0721/0801 1SM TSRA OVC025CB
FM080400 07004KT 2SM -SHRA BR OVC007=

Between 1000 and 1500 EDT, the forecast expected a wind from 230° at 5 knots, greater than 6 miles visibility, vicinity[33] showers, scattered clouds at 1,500 ft agl, a broken ceiling at 5,000 ft agl, and broken clouds at 8,000 ft agl. Temporary conditions of a broken ceiling at 1,500 ft agl were forecast between 1100 and 1500 EDT.

14.0 NWS Area Forecast Discussion

The NWS office in Raleigh, North Carolina, issued the following Area Forecast Discussion (AFD) at 1243 EDT (closest AFD to the accident time). The aviation section of the AFD discussed numerous to widespread thunderstorm activity during the afternoon and evening hours:

FXUS62 KRAH 071643
AFDRAH

AREA FORECAST DISCUSSION
National Weather Service Raleigh NC
1243 PM EDT Fri Jun 7 2019

.SYNOPSIS...
A pair of surface fronts will converge upon central NC through tonight; and the merged front will then waver over the Carolinas through the weekend. A series of disturbances in southwesterly flow aloft will overspread the frontal zone and act upon deep, tropical moisture residing over the southeastern US.

&&

.NEAR TERM /THROUGH TONIGHT/...
As of 1235 PM Friday...

A mid to upr-lvl low will over ern AR will move slowly newd into the Mid-South and middle/wrn TN by 12Z Sat, at the base of a strengthening ridge building across the top from the cntl Plains to the Great Lakes. To the east and ne of the low center, WV satellite and regional radar imagery depict a quartet of vorticity maxima over nrn MS, e-cntl TN, s-cntl VA, and the Upstate of SC, respectively,

[33] In the vicinity of the airport is defined as a weather phenomenon within 5-10 statute miles of the airfield.

along the nwrn fringe of deep, tropical moisture characterized by precipitable water values between 1.8 and 2.2 inches (around 2 sigma above normal) over the sern US. The most important of these smaller scale vorticity maxima/disturbances for cntl NC will be the one approaching from the Upstate of SC, as that feature will continue to lift newd across cntl NC this afternoon.

At the surface, a cold front was analyzed at 16Z very near the VA/NC state line, wswwd as a stationary front, to a 1006 mb low near MEM. This front will continue to drift/develop swd into cntl NC through this evening. And this synoptic frontal zone extends through most of the lwr troposphere, as it is evident in both 12Z RAOB data and regional VWP data at 925 and 850 mb, with related deep convergence and weak Fgen favorable for vertical motion over cntl NC through tonight. A separate differential diabatic heating warm front was analyzed roughly along the back edge of the convection related to the disturbance over the Upstate of SC, in an arc from n-cntl GA sewd across cntl and coastal SC. This front will develop newd into nrn SC, and possibly into the srn NC Piedmont and wrn Sandhills from near VUJ and AFP to MEB.

Preceding these showers now affecting the wrn/srn Piedmont, breaks in the overcast over the ne Piedmont, ern NC, and sern VA, have allowed temperatures to warm into the lwr to mid 80s, with resultant MLCAPE around 1000 J/kg, and highest probability of thunder during the next few hrs. Indeed, a couple of the deeper cells over Wake and Franklin Co. have just produced a few cloud-to-ground strikes in the past hour. Showers will become increasingly numerous to widespread, with embedded thunder in the relatively deeper cells initially over the ne Piedmont, and then late this afternoon over the srn Piedmont owing to the retreat of the foregoing warm front there. While an isolated tornado would be possible in the latter regime from near CLT to MEB this afternoon, heavy downpours and mainly urban flooding will pose the primary hazard otherwise and elsewhere.

Showers and storms will continue overnight, with the relative greatest concentration over the nw Piedmont, where a weak low to mid-lvl circulation may stall, and also ewd along the sfc to 850 mb convergence axis/front that is forecast to roughly bisect cntl NC from north to south. One to two inches of rain will likely result through tonight, with the lowest amounts likely over the sern half of the cwfa. Muggy, with persistence lows again in the upr 60s to lwr 70s, and with the development of widespread low overcast.

&&

.SHORT TERM /SATURDAY AND SATURDAY NIGHT/...
As of 430 AM Friday...

The upper low over the TN Valley will sit and spin, and will under go slow de-amplification, devolving into an open wave trough as it awaits the northern stream kicker trough to exit from the Northern Plains on Monday. The main forecast challenge hasn't changed; Where will the quasi-stationary frontal zone lie? Given that the eventual location of the front will be highly tied to the evolution of convection elements across central NC over the 24 hours this will remain of great uncertainty, while proving to be very pivotal WRT to where the axis of heaviest rainfall will occur into the day on Saturday.

With expectations of the stalled front lying somewhere across central NC, shortwave impulses emanating from the weakening closed cyclonic vortex will lead to episodic DPVA and enhanced lift within the continued anomalously moist PWATs of 2-2.2 in place. Convective coverage will most likely be maximized during peak heating/instability during the afternoon and evening but should persist through the overnight hours across portions of the area. An additional 1 to 2 inches is possible, with steady upslope/orographic enhancement across western portions of the state supporting the highest amounts. If a second consecutive day of heavy rain materializes across portions of the forecast area, a flash flood watch will likely be needed with any additional Sunday and into Monday. Severe threat appears given relatively meager shear and questionable instability.

Highs ranging from lower 70s NW to lower 80s SE, potentially cooler if rain/showers are more widespread. Lows 65 to 70.

&&

.LONG TERM /SUNDAY THROUGH THURSDAY/...
As of 415 AM Friday...

...Heavy rainfall possible across North Carolina this weekend and into early next week...

Global ensembles continue to advertise mid-level low pressure slowly heading east this weekend with mid-level ridging across the Northeast helping to block the progression of the low. By Tuesday an upper level low will dive south out of Manitoba helping to sweep up most of the remnant low pressure. By the end of the extended a much stronger upper low will approach from the west. This type of pattern will support multiple rounds of precipitation for central North Carolina through the extended.

On Sunday morning a vertically stacked low pressure will be located near western TN, with a mid-level ridge located near New York City. There will also be a stalled front just south of the triad at this time extending across central North Carolina. Forcing for ascent will come in two forms. The first from central North Carolina being on the divergent side of the trough axis (located to the west). The second will be from multiple rounds of PV sweeping across the area as the low slowly looses cohesion. PWATs, or moisture values, will be above 2.00" (or near daily max values). ML Cape values will also be on the rise as the stationary front retreats north as a warm front Sunday afternoon. Multiple rounds of precipitation are forecast for Sunday given the above with warm cloud depth layers at or above 10kft for most of the day (supporting warm rain processes).

Monday a potent upper level disturbance over Manitoba will head east which will begin to pick up some of the energy from the stalled low over the Southeastern United States. PWATs at this time still remain above 2.00" with deep southerly flow helping to keep moisture rich air flowing north. Have continued high end likely PoPs Monday, with the threat for flash flooding continuing.

Tuesday into Wednesday the upper level low that dove south out of Manitoba will be moving east across the Great Lakes and eventually northeast back into Canada. Global models have come into better agreement showing that this will only partially pickup some of the remnant low across the southeastern United States. This will likely bring another cold front in from the northwest before it stalls. Late Tuesday into early Wednesday a much stronger piece of energy will dive south out of Canada across the Midwest helping to amplify the long wave trough axis. Surface cyclogenesis will occur over Georgia Wednesday with the low tracking northeast along the stalled baroclinic zone. Late Thursday the cold front from the stronger upper level disturbance will finally clear the zones ushering in drier weather. Before this though, Tuesday and Wednesday continue to look wet with multiple rounds of precipitation forecast. In fact, the approaching trough axis on Tuesday has allowed for likely PoPs to continue.

&&

.AVIATION /12Z FRIDAY THROUGH TUESDAY/...
As of 740 AM Friday...

Strong moisture advection into the region ahead of the slow moving upper level low moving east into the Tn Valley will fuel scattered showers and sub-VFR to low-end VFR ceilings into the area from the SW during the early to mid morning hours. **Aided by daytime heating/instability and the merger of a cold front moving into the area from the north and the warm moist air from the south, shower coverage will become numerous to widespread with thunderstorms developing through the afternoon and evening. With the front becoming stationary across the area and copious moisture in place, scattered to numerous showers will linger overnight with widespread LIFR to IFR ceilings.**

Outlook: An unsettled pattern will continue to evolve across the Carolinas through early next week, as a frontal zone wavers over the region and is overrun by deep moisture and lift downstream of a slowly-approaching mid to upr-level low/trough. Widespread IFR-MVFR conditions will result during the overnight-early morning hours, transitioning through early afternoon to MVFR or VFR ones, with generally numerous showers and storms that will be maximized with diurnal heating each day.

&&

.RAH WATCHES/WARNINGS/ADVISORIES...
None.

&&

$$

15.0 Winds and Temperature Aloft Forecast

The NWS 1000 EDT Winds and Temperature Aloft forecast valid for the closest point to the accident site is included below:

```
FBUS31 KWNO 071400
FD1US1
DATA BASED ON 071200Z
VALID 071800Z   FOR USE 1400-2100Z. TEMPS NEG ABV 24000

FT  3000    6000    9000   12000   18000   24000  30000  34000  39000

RDU 2214 2312+14 2514+09 2615+04 2514-07 2514-18 252232 262843 274257
```

The accident site was located closest to the Raleigh, North Carolina, (RDU) forecast point. The 1000 EDT RDU forecast for use between 1000 EDT and 1700 EDT indicated a wind at 18,000 ft from 250° at 14 knots with a temperature of -7° C, a wind at 24,000 ft from 250° at 14 knots with a temperature of -18° C, and a wind at 30,000 ft from 250° at 22 knots with a temperature of -32° C.

16.0 Pilot Weather Briefing

The accident pilot did not request a weather briefing from Leidos.

A search of archived ForeFlight information indicated that the accident pilot did request weather information via ForeFlight Mobile (attachments 7 and 8) at 0935 EDT with a planned departure of 0945 EDT and an actual departure time around 1054 EDT. A convective cell developed west of KAPF around 0931 EDT and moved over KAPF around 0953 EDT and then moved east of the airport by 1025 EDT (section 7.4). The 0935 EDT weather briefing information contained all the standard weather information valid at 0935 EDT, including a convective SIGMET "outlook" area valid along the route of flight, AIRMETs, a CWA valid for the departure airport and surrounding area (for an area of thunderstorms with tops to FL320, etc…) from 0815 to 1015 EDT, a surface analysis chart, current METARs valid along the route of flight, PIREPs, a GFA forecast, TAFs, and the winds aloft information. The accident pilot did not access any weather imagery via ForeFlight mobile prior to the accident flight on the accident day but could have accessed text information. For more information please see attachments 7 and 8. There is no record of the accident pilot receiving or retrieving any other weather information before or during the accident flight.

17.0 ZDC CWSU Information

ZDC CWSU provided a pre-duty weather briefing the morning of the accident for ATC working at ZDC, but that data was not archived in time for this accident. The ZDC CWSU weather briefing sheet was archived and is available as attachment 9. In addition, the CWSU personnel on duty at and after the accident time were interviewed and that information is contained in attachments 10 and 11.

18.0 XM Weather images

The airplane was equipped with a Garmin[34], which could be optionally fitted to be able to display XM Weather information with a subscription.[35] If the accident pilot had XM Weather composite radar information up during the accident flight he would have seen something similar to figures 21 and 22 (time in figures in CDT), which is XM Weather composite radar information available around and before the accident time. The scale used in the XM Weather composite radar information is located in figure 23. There was an unknown time delay of the XM weather composite images made available in the cockpit.[36] The XM Weather composite radar images from 1327 and 1332 EDT displayed 40 to 50 dBZ values above the accident site. For additional information regarding the XM Weather composite radar data please see attachment 12.

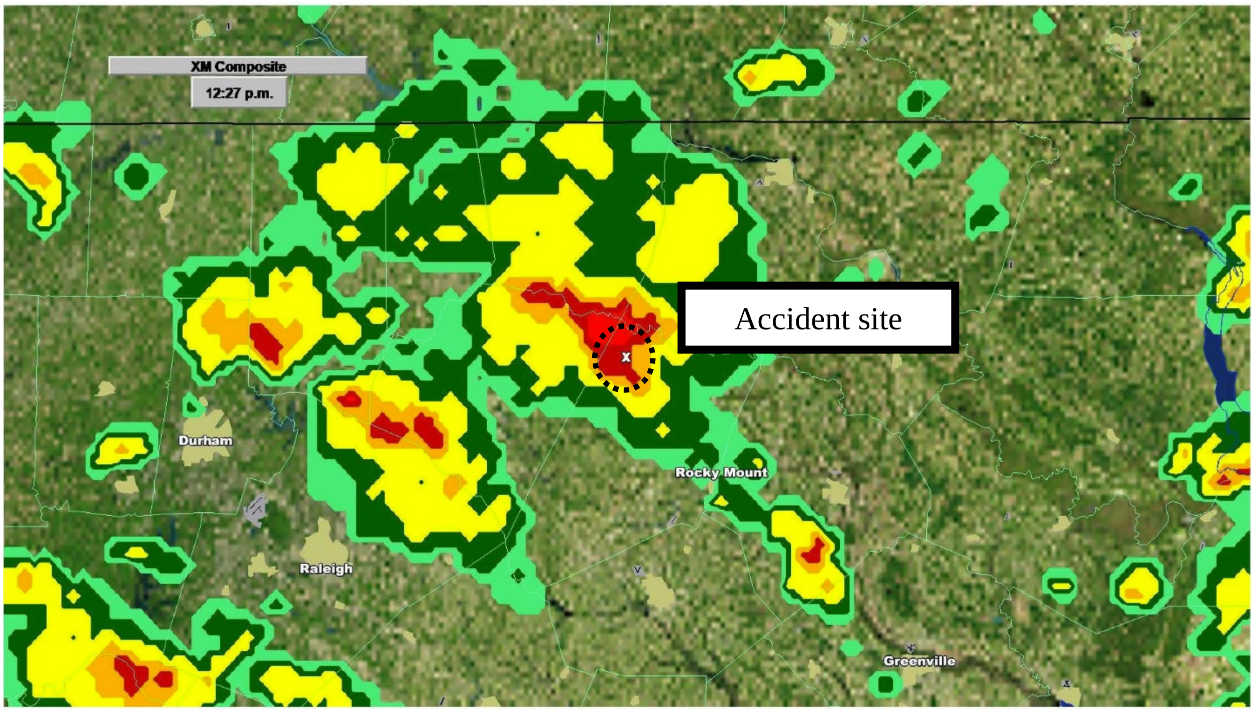


Figure 21 –XM Weather Radar from 1327 EDT

[34] For more information on the electronic equipment located on the accident aircraft please see the docket information for this accident.
[35] It is unknown if the pilot had a subscription to display XM Weather information.
[36] See: https://ntsb.gov/safety/safety-alerts/Documents/SA_017.pdf

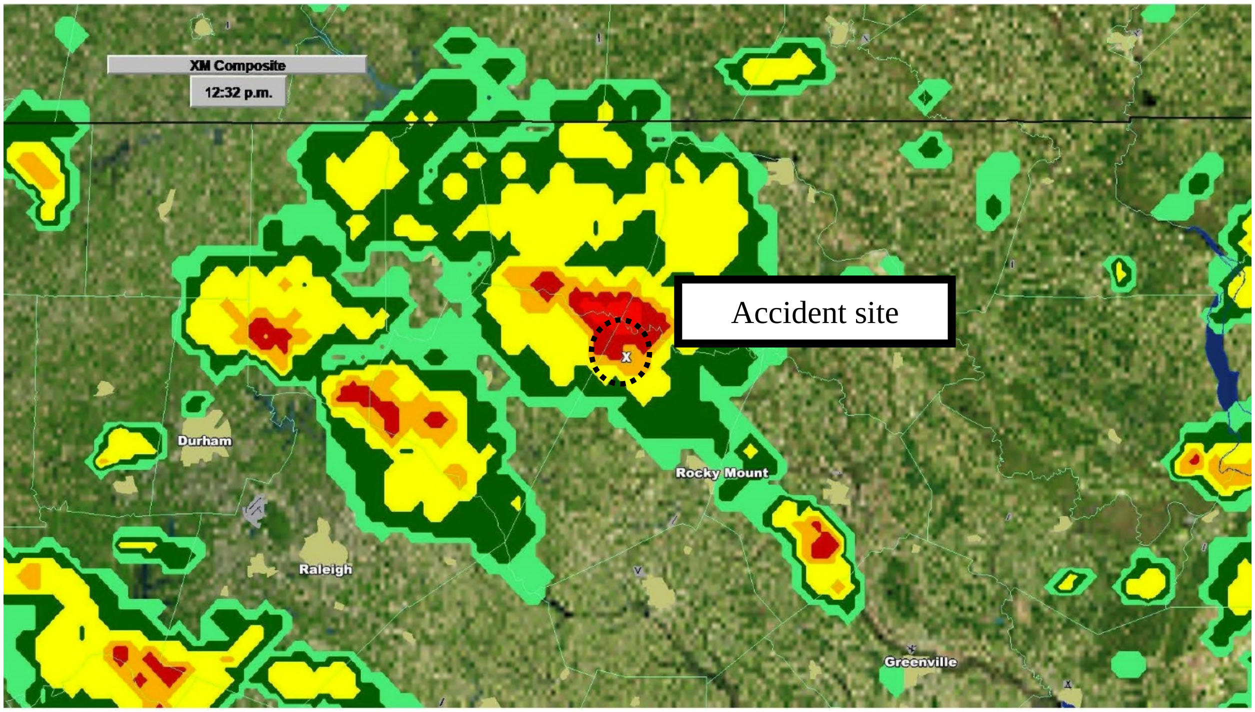


Figure 22 – XM Weather Radar from 1332 EDT

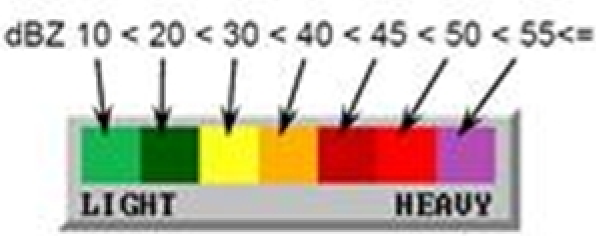


Figure 23 – XM Weather Radar scale for figures 21 and 22

19.0 FIS-B Regional NEXRAD with Flight Path

Flight Information Services–Broadcast (FIS-B) data was retrieved for this accident. If the accident pilot had the regional NEXRAD weather radar screen selected on their electronic equipment[37] then the FIS-B regional NEXRAD weather radar data provided in attachment 13 would have been the imagery being viewed. The FIS-B regional NEXRAD data is updated once every 5 minutes and is based upon composite NEXRAD reflectivity data. For more information please see attachment 13.

[37] For more information on the electronic equipment located on the accident aircraft please see the docket information for this accident.

20.0 Consolidated Storm Prediction for Aviation Data

The Consolidated Storm Prediction for Aviation (CoSPA)[38] images were retrieved for 1325, 1330, and 1335 EDT and provided in figures 24 through 26 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). The thunderstorm and rain shower activity was moving from southwest to northeast around 15 knots with the accident site located in an area of VIP level values of 3 to 4 (section 7.3) and CoSPA cloud top values indicated to FL430.

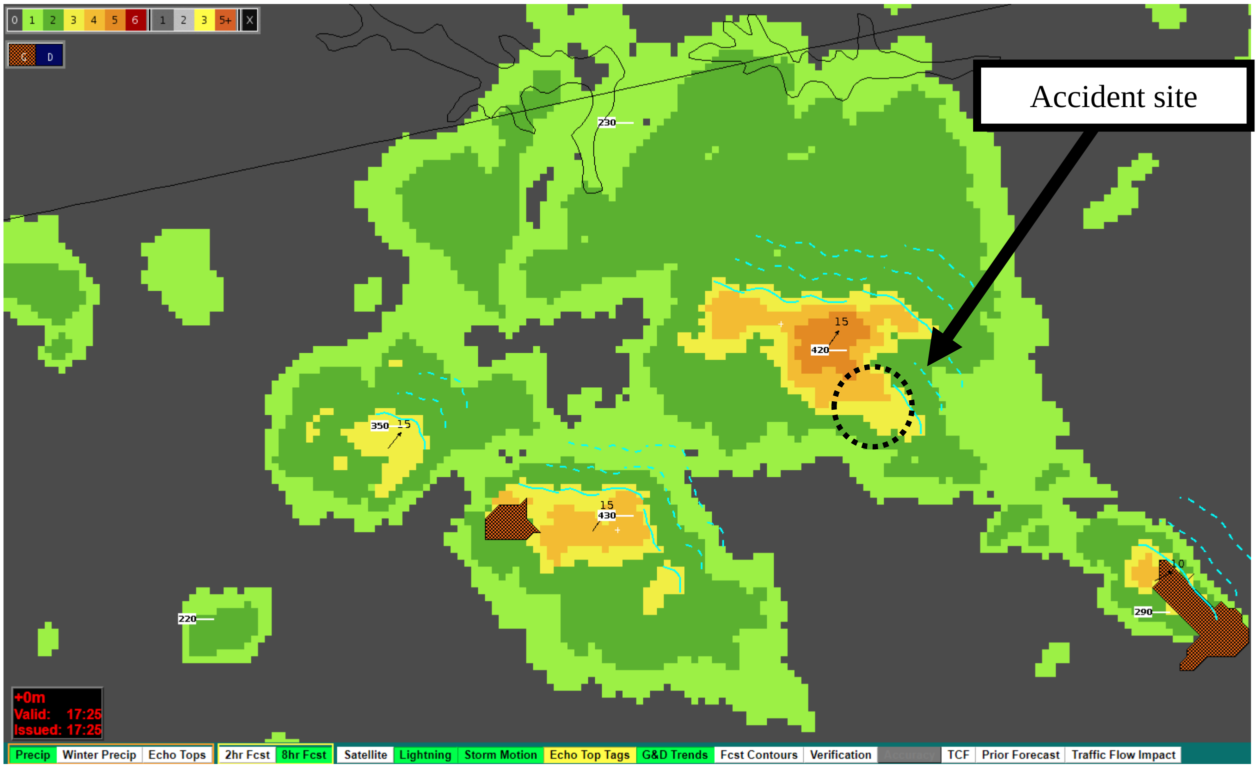


Figure 24 – CoSPA image from 1325 EDT with the accident site marked

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[38] https://cospa.wx.ll.mit.edu/
https://ral.ucar.edu/projects/CoSPA/index.php
https://ral.ucar.edu/solutions/products/consolidated-storm-prediction-aviation-cospa

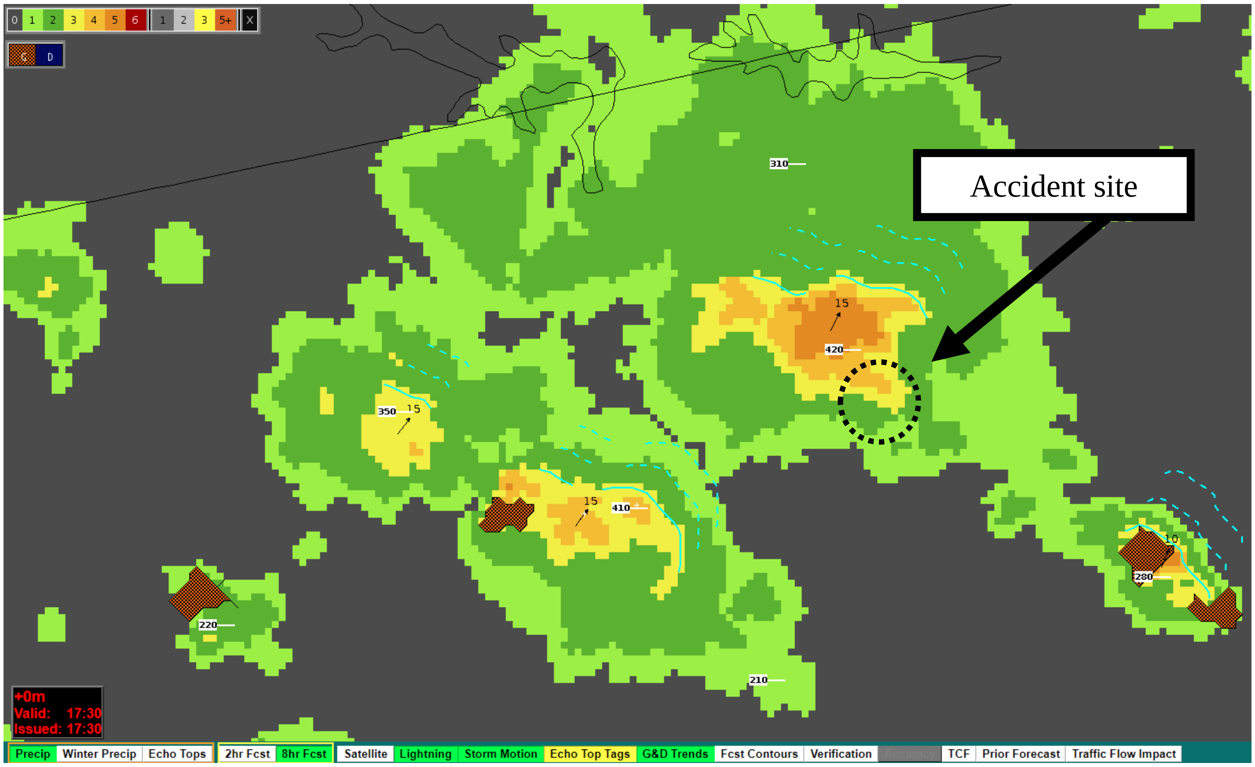

Figure 25 – CoSPA image from 1330 EDT with the accident site marked

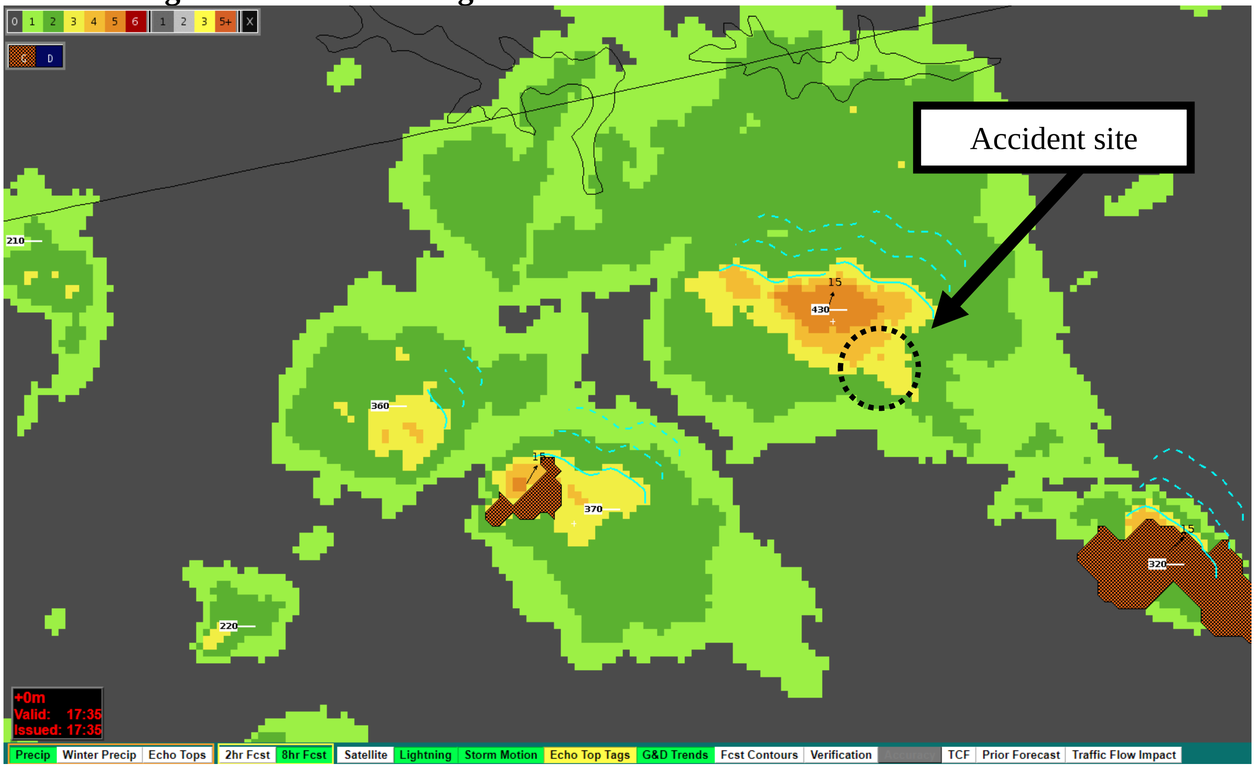

Figure 26 – CoSPA image from 1335 EDT with the accident site marked

21.0 Radar Display of WARP Derived Imagery

The ZDC ATC's radar display of Weather and Radar Processor (WARP)[39] weather derived imagery, weather radar representation, settings, and aircraft movement of the accident aircraft is provided in figures 28 through 33 with images from 1323, 1325, 1327, 1329, 1331, and 1333 EDT, respectively. Screen captures of the WARP weather imagery every minute is displayed in attachment 14. An exemplar image of WARP weather derived imagery precipitation levels is provided as figure 27. The ZDC radar display of WARP weather derived imagery indicated the accident aircraft was in an area of moderate precipitation at 1325 EDT (figure 29). The accident aircraft entered an area of heavy precipitation between 1329 and 1331 EDT (figures 31 and 32) and remained in the heavy precipitation through the accident time (figures 33). For more WARP imagery please see attachment 14.

[39] http://www.tc.faa.gov/its/cmd/visitors/data/ACT-300/warp.pdf

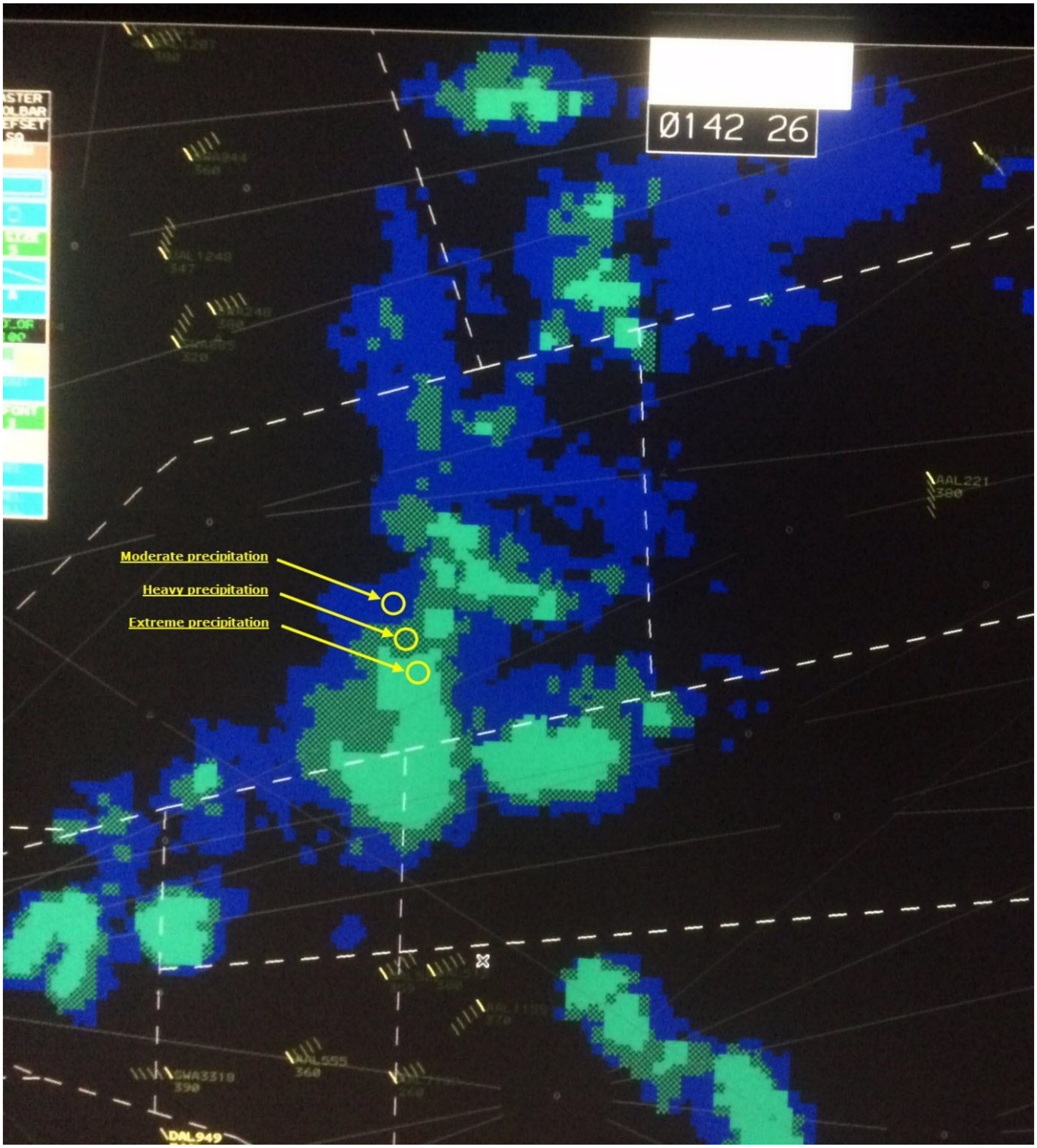

Figure 27 – Exemplar display of WARP derived precipitation levels

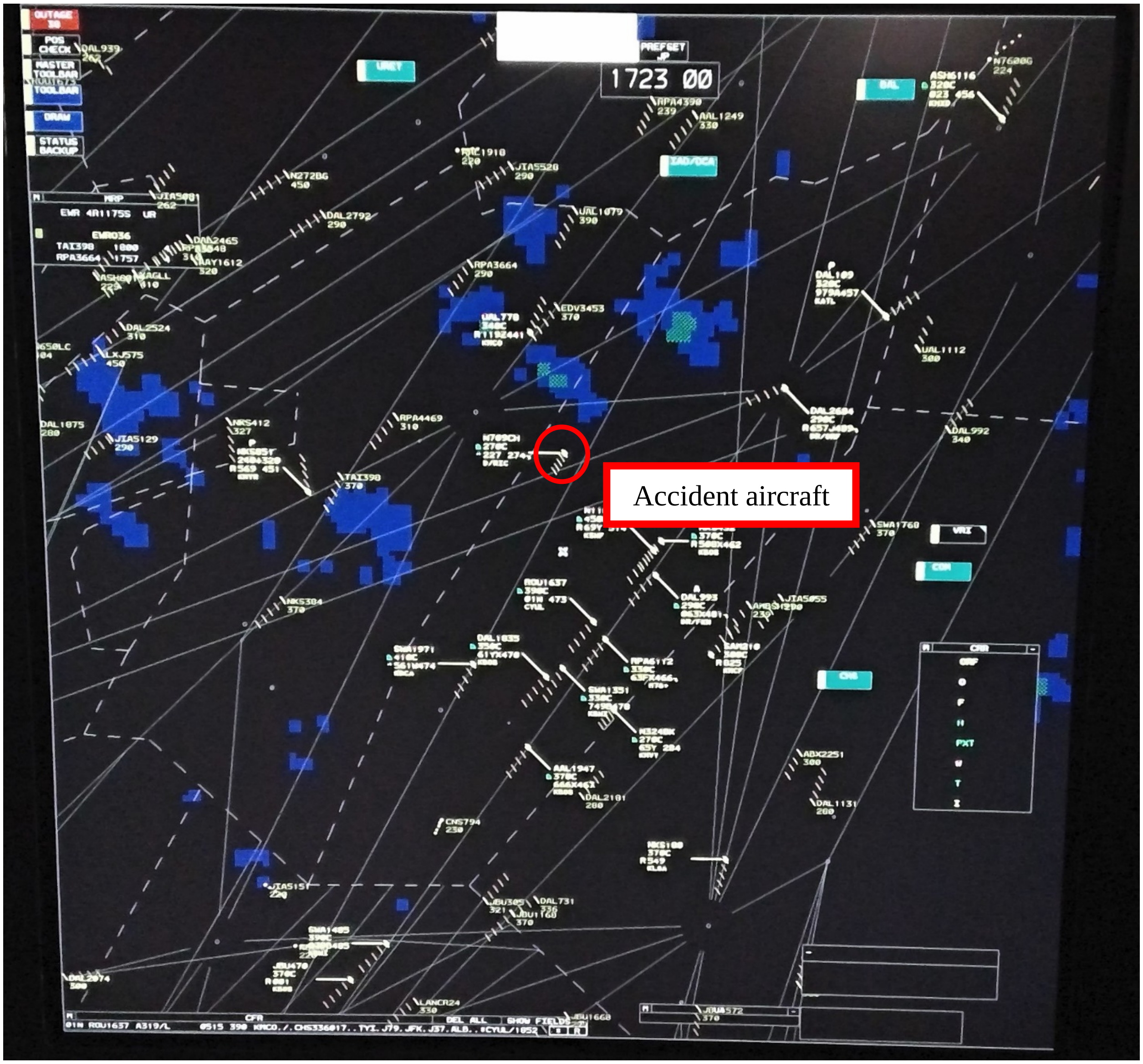

Figure 28 – Screenshot of the ZDC air traffic controller's radar display at 1323 EDT with WARP derived weather displayed

Figure 29 – Screenshot of the ZDC air traffic controller's radar display at 1325 EDT with WARP derived weather displayed

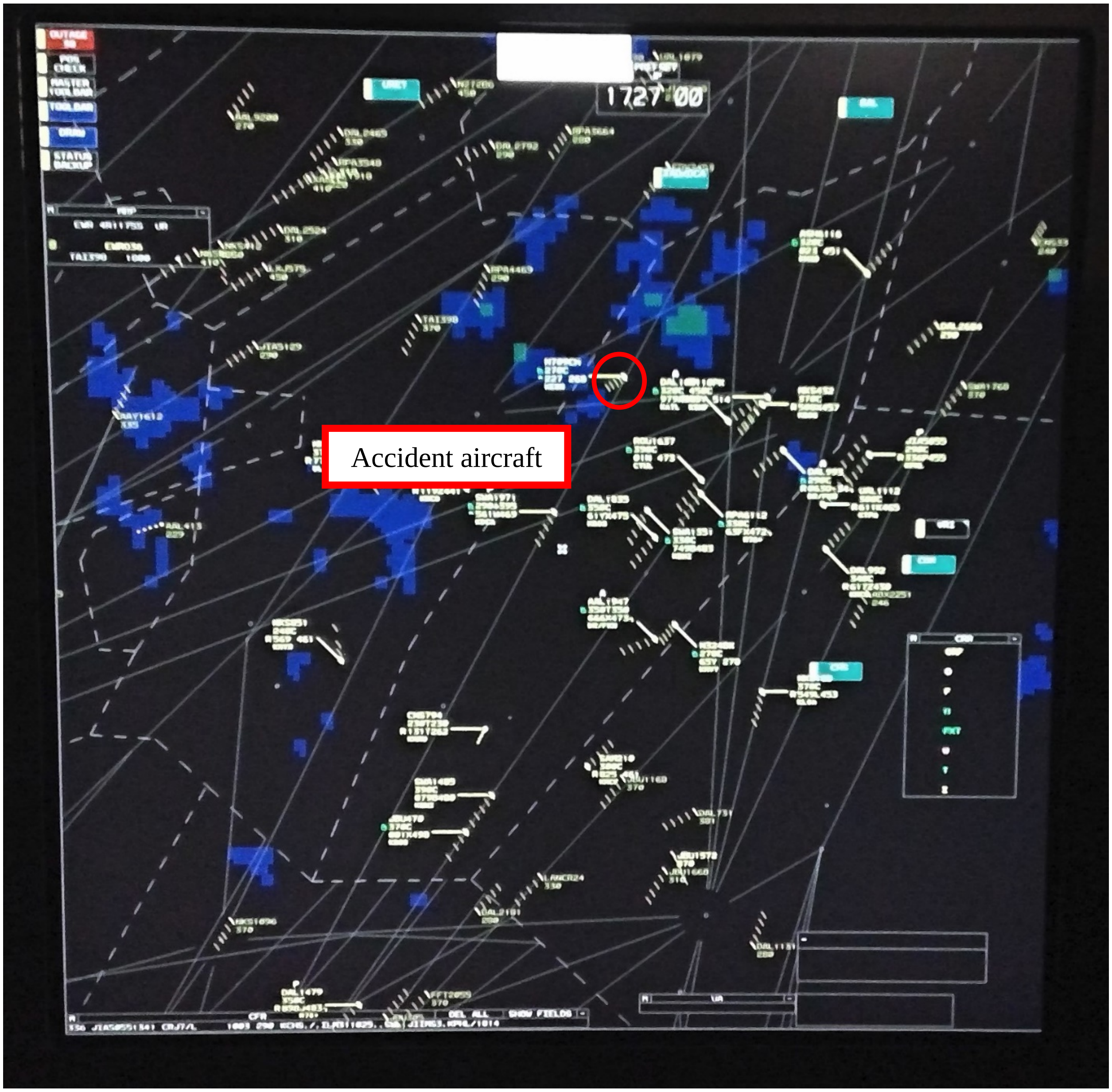

Figure 30 – Screenshot of the ZDC air traffic controller's radar display at 1327 EDT with WARP derived weather displayed

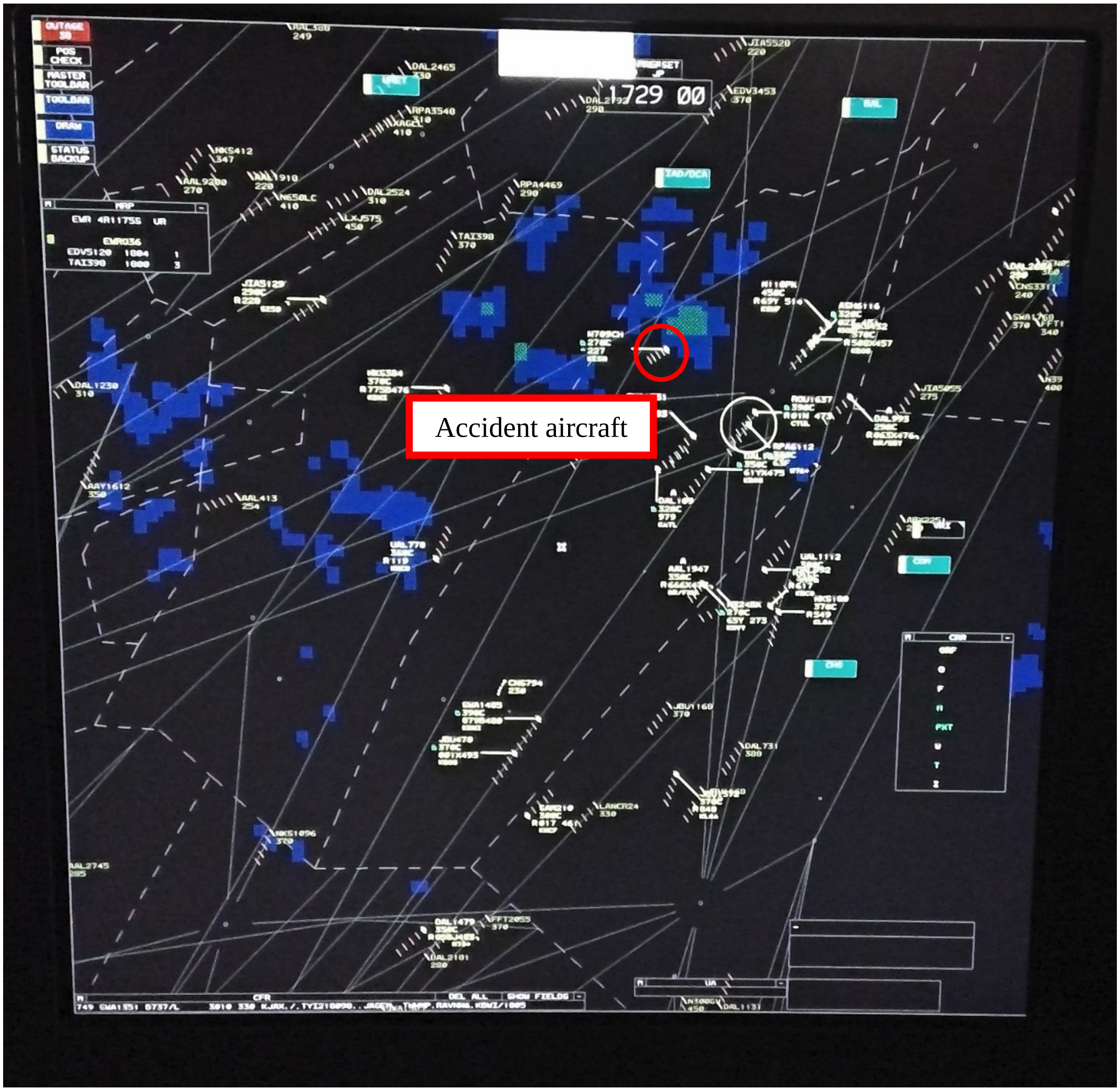

Figure 31 – Screenshot of the ZDC air traffic controller's radar display at 1329 EDT with WARP derived weather displayed

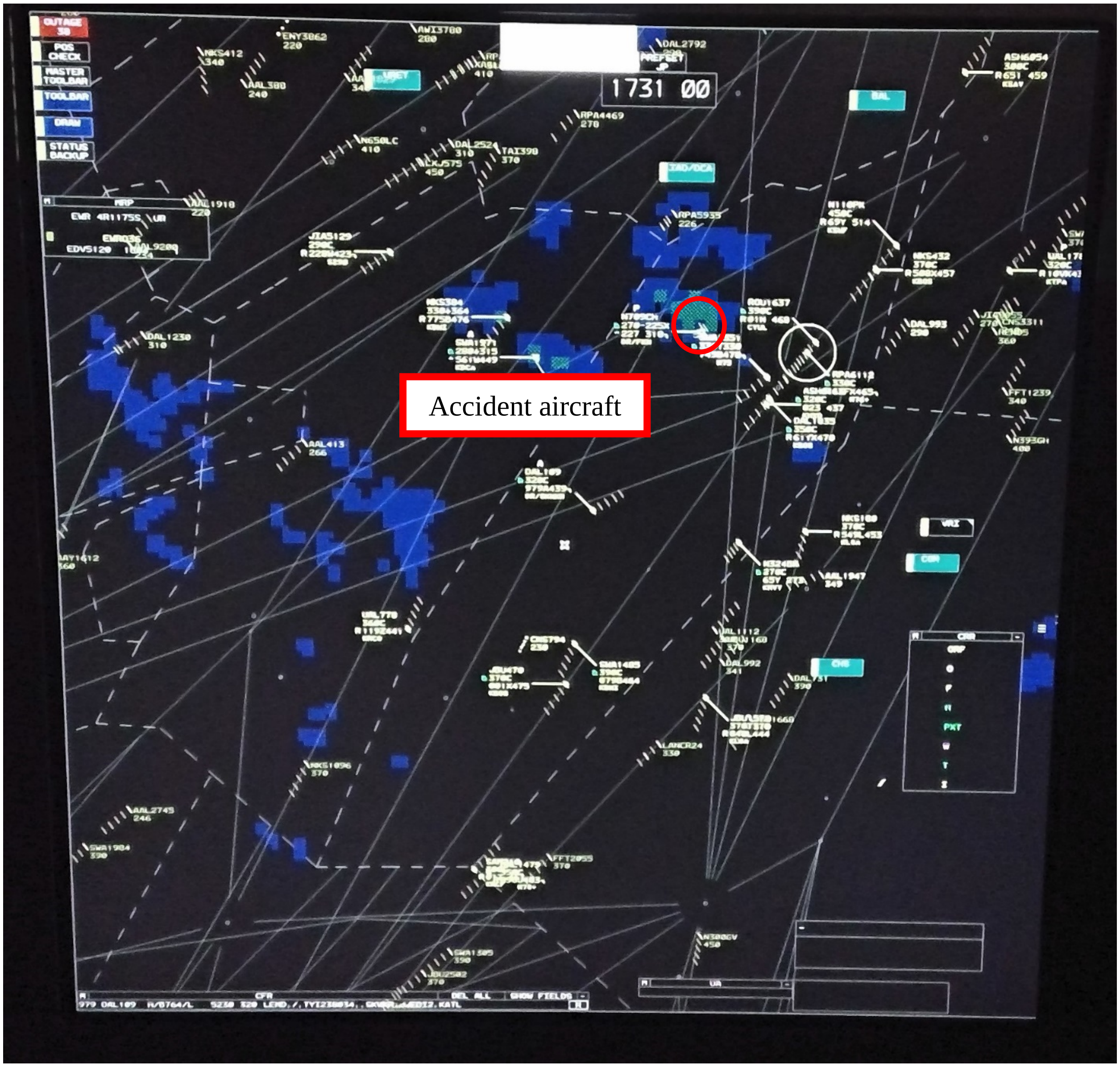

Figure 32 – Screenshot of the ZDC air traffic controller's radar display at 1331 EDT with WARP derived weather displayed

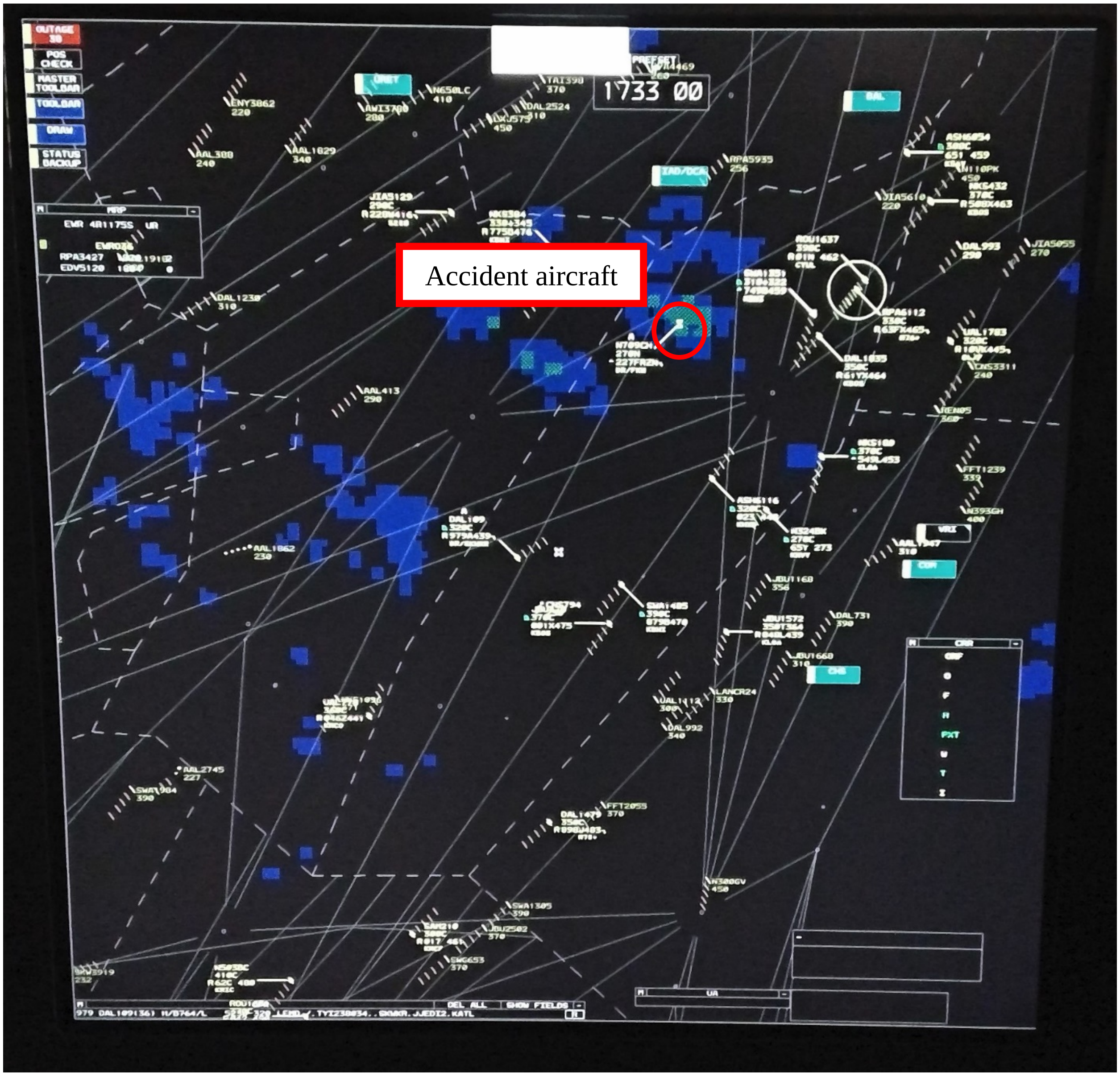

Figure 33 – Screenshot of the ZDC air traffic controller's radar display at 1333 EDT with WARP derived weather displayed

22.0 Astronomical Data

The astronomical data obtained for the accident site on June 7, 2019, indicated the following:

SUN	
Begin civil twilight	0524 EDT
Sunrise	0554 EDT
Sun transit	1310 EDT
Accident time	**1333 EDT**[40]
Sunset	2027 EDT
End civil twilight	2057 EDT

23.0 Thunderstorm Training Information

The Federal Aviation Administration's (FAA) Advisory Circular AC 00-24C titled "Thunderstorms" issued in February 2013 is a basic training guide on thunderstorm hazards used for flight training guidance. As a result of the hazardous nature of thunderstorms the FAA has published several common practices or do's and don'ts on thunderstorm flying, which are published in AC 00-24C and the Aeronautical Information Manual (AIM) under Chapter 7 Safety of Flight, section 7-1-29. The following avoidance rules are published:

DOS AND DON'TS OF THUNDERSTORM AVOIDANCE.

a. Thunderstorm Avoidance. Never regard any thunderstorm lightly, even when radar observers report the echoes are of light intensity. Avoiding thunderstorms is the best policy. Following are some dos and don'ts of thunderstorm avoidance:

(1) Don't land or takeoff in the face of an approaching thunderstorm. A sudden gust front of low-level turbulence could cause loss of control.

(2) Don't attempt to fly under a thunderstorm even if you can see through to the other side. Turbulence and wind shear under the storm could be hazardous.

(3) Don't attempt to fly under the anvil of a thunderstorm. There is a potential for severe and extreme clear air turbulence.

(4) Don't fly without airborne radar into a cloud mass containing scattered embedded thunderstorms. Scattered thunderstorms not embedded usually can be visually circumnavigated.

(5) Don't trust the visual appearance to be a reliable indicator of the turbulence inside a thunderstorm.

(6) Don't assume that ATC will offer radar navigation guidance or deviations around thunderstorms.

(7) Don't use data-linked weather next generation weather radar (NEXRAD) mosaic imagery as the sole means for negotiating a path through a thunderstorm area (tactical maneuvering).

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[40] Inserted accident time for reference and context.

(8) Do remember that the data-linked NEXRAD mosaic imagery shows where the weather *was*, not where the weather *is*. The weather conditions may be 15 to 20 minutes older than the age indicated on the display.

(9) Do listen to chatter on the ATC frequency for Pilot Weather Reports (PIREP) and other aircraft requesting to deviate or divert.

(10) Do ask ATC for radar navigation guidance or to approve deviations around thunderstorms, if needed.

(11) .Do use data-linked weather NEXRAD mosaic imagery (e.g., Flight Information Service-Broadcast (FIS-B)) for route selection to avoid thunderstorms entirely (strategic maneuvering).

(12) Do advise ATC, when switched to another controller, that you are deviating for thunderstorms before accepting to rejoin the original route.

(13) Do ensure that after an authorized weather deviation, before accepting to rejoin the original route, that the route of flight is clear of thunderstorms.

(14) Do avoid by at least 20 miles any thunderstorm identified as severe or giving an intense radar echo. This is especially true under the anvil of a large cumulonimbus.

(15) Do circumnavigate the entire area if the area has 6/10 thunderstorm coverage.

(16) Do remember that vivid and frequent lightning indicates the probability of a severe thunderstorm.

(17) Do regard as extremely hazardous any thunderstorm with tops 35,000 ft or higher whether the top is visually sighted or determined by radar.

(18) Do give a PIREP for the flight conditions.

(19) Do divert and wait out the thunderstorms on the ground if unable to navigate around an area of thunderstorms.

b. Dos Before Entering a Storm. If unable to avoid penetrating a thunderstorm, the following are some dos *before* entering the storm:

(1) Tighten the safety belt, put on the shoulder harness (if installed), and secure all loose objects.

(2) Plan and hold the course to take the aircraft through the storm in a minimum time.

(3) To avoid the most critical icing, establish a penetration altitude below the freezing level or above the level of -15ºC.

(4) Verify that pitot heat is on and turn on carburetor heat or jet engine anti-ice. Icing can be rapid at any altitude and cause almost instantaneous power failure and/or loss of airspeed indication.

(5) Establish power settings for turbulence penetration airspeed recommended in the aircraft manual.

(6) Turn up cockpit lights to highest intensity to lessen temporary blindness from lightning.

(7) If using automatic pilot, disengage Altitude Hold Mode and Speed Hold Mode. The automatic altitude and speed controls will increase maneuvers of the aircraft thus increasing structural stress.

(8) If using airborne radar, tilt the antenna up and down occasionally. This will permit the detection of other thunderstorm activity at altitudes other than the one being flown.

c. Dos and Don'ts for Thunderstorm Penetration. Following are some dos and don'ts during the thunderstorm penetration:

(1) Do keep your eyes on the flight instruments. Looking outside the cockpit can increase danger of temporary blindness from lightning.

(2) Don't change power settings; maintain settings for the recommended turbulence penetration airspeed.

(3) Do maintain constant attitude. Allow the altitude and airspeed to fluctuate.

(4) Don't turn back once in the thunderstorm. A straight course through the storm most likely will get the aircraft out of the hazards most quickly. In addition, turning maneuvers increase stress on the aircraft.

E. LIST OF ATTACHMENTS

Attachment 1 – GOES-16 Visible animation from 1111 to 1411 EDT

Attachment 2 – GOES-16 Infrared animation from 1111 to 1411 EDT

Attachment 3 – KRAX WSR-88D level 2 base reflectivity animation for the 0.5° elevation scans from 1318 to 1349 EDT

Attachment 4 – KRAX WSR-88D level 2 base reflectivity animation for the 6.4° elevation scans from 1318 to 1349 EDT

Attachment 5 – KAMX (Miami, Florida) WSR-88D level 2 base reflectivity animation for the 0.5° elevation scans from 0931 to 1057 EDT

Attachment 6 – GFA products valid for the accident flight

Attachment 7 – ForeFlight weather briefing information requested by accident pilot at 0935 EDT

Attachment 8 – Additional ForeFlight correspondence

Attachment 9 – ZDC CWSU weather briefing sheet

Attachment 10 – ZDC CWSU interview 1

Attachment 11 – ZDC CWSU interview 2

Attachment 12 – XM weather composite weather radar imagery from around accident time

Attachment 13 – FIS-B accident data imagery and package

Attachment 14 – ZDC WARP derived imagery from accident flight

Submitted by:

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Paul Suffern
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